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A comparison of whole body vibration and moist heat on lower extremity skin temperature and skin blood flow in healthy older individuals

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A Study Design
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Summary

Background: Tissue healing is an intricate process that is regulated by circulation. Heat modalities have been shown to improve skin circulation. Recent research supports that passive vibration increases circulation without risk of burns. Study purpose is to compare and determine effects of short duration vibration, moist heat, and a combination of the two on skin blood flow (SBF) and skin temperature (ST) in elderly, non-diabetic individuals following short-term exposure.

Material/Methods: Ten subjects, 3 female and 7 male (55–73 years of age), received two interventions over three days: 1 – Active vibration, 2 – passive vibration, 3 – moist heat, 4 – moist heat combined with passive vibration (MHPV), 5 – a commercial massaging heating pad, and 6 – no intervention. SBF and ST were measured using a MOOR Laser Doppler before and after the intervention and the third measurement were taken 10 minutes following.

Results: Mean SBF following a ten-minute intervention were significantly different in the combination of moist heat and passive vibration from the control, active vibration, and the commercial massaging heating pad. Compared to baseline measurements, this resulted in mean SBF elevation to 450% (at conclusion of 10 minutes of intervention) and 379% (10 minutes post). MHPV (p=0.02) showed significant changes in ST from the commercial massaging heating pad, passive vibration, and active vibration interventions.

Conclusions: SBF in the lower legs showed greatest increase with MHPV. Interventions should be selected that are low risk while increasing lower extremity skin blood flow.

key words: **Laser Doppler • circulation • aging**

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Background

One of the most common and costly age-associated pathological changes in the geriatric population is impaired healing of chronic wounds which includes leg ulcers, pressure ulcers and diabetic foot ulcers and this represents a major area of unmet clinical need [1]. Impaired circulation is often associated with delayed wound healing in the elderly. Due to altered endothelial function [2,3], ageing is associated with a weakening of skin vasodilator responses to various stimuli [4]. Integumentary function and healing are strongly influenced by a healthy circulatory system in order to provide the tissues with adequate nutrients, maintain thermoregulation, decrease susceptibility to infection and promote tissue repair [5–8].

Traditional therapies such as skin heating with a moist heat pack increases blood circulation that may help to delivering healing nutrients and waste removal to promote tissue healing. Although moist heat and warm water immersion have been shown to elevate skin circulation; these passive-heating modalities are not without risks since they can cause burns especially in older individuals [9,10]. Active therapies such as therapeutic exercise have also been shown to improve blood flow by stimulating the cardiovascular system in elderly individuals. Exercise training in the elderly is beneficial even in individuals with coronary artery disease and CAD and peripheral artery disease; however, not everyone is motivated or healthy enough to perform regular exercise training [11]. Although cardiovascular fitness in the elderly population helps reduce the age-related decline in skin microcirculation [12], not all elderly individuals are healthy enough to engage in aerobic exercise.

Whole Body Vibration (WBV) refers to mechanical energy oscillations which are transferred to the whole body as opposed to specific body regions through a supporting system such as a seat or platform. The effects produced by the vibration are used in sports, fitness, aesthetics, rehabilitation and medical therapies and are influenced by the type of platform used [13,14]. Whole Body Vibration is receiving attention in regards to altering the peripheral circulation without significantly stressing the cardiovascular system [1,8,15–17].

Lohman, et al. (2007) documented that the use of short duration (3 minutes), high-amplitude (5–6 mm), high-frequency vibration (30 Hz) applied to the posterior calf muscles significantly increased skin blood flow. In a follow up study, the subjects had passive vibration delivered to their forearm muscles which significantly increased the skin blood flow as well; the findings revealed that 50 Hz was more efficient compared to the 30 Hz application [17]. The researchers demonstrated that there was a peak in the blood flow found after 5 minutes and that an additional 5 minutes of vibration application did not produce added benefits [17]. Hazell, et al. (2008) reported that exercising for 12 minutes with the subjects standing on a vibration platform was found to increase skin blood flow and temperature. These changes remained elevated during a recovery period of 10 minutes [15]. The identification of a safe, passive therapy to improve lower limb circulation would be beneficial. We suggest combining whole body vibration therapy with traditional therapies as an original therapy to improve skin blood flow in the elderly population.

The purpose of this study is to determine the effects of short-term exposures to vibration on lower extremity skin blood flow and temperature compared to moist heat or a massaging heating pad in elderly, non-diabetic subjects. Our hypothesis is that short-duration, low frequency vibration will increase local skin blood flow while decreasing skin temperature with the combination of passive vibration and moist heat as compared to moist heat alone due to increased circulation and decreased skin impedance. We predict that the rank order of skin blood flow (most to least) will be as follows: 1) combination of passive vibration and heat, 2) moist heat alone, 3) passive vibration alone, 4) a commercial massaging heating pad, and 5) active vibration.

Material and Methods

Subjects

Ten adult volunteers aged between 55 to 73 years (mean =65.7 years) from a Southern California community participated in this study. Three females (age =67.0±2 years; weight =66.5±6.1 kg.; height =170.2±8.8 cm) and seven males (age =64.5±7 years; weight =90.9±15.5 kg; height =176.7±8.7 cm) were included. Subjects with diseases such as diabetes, orthopedic conditions (e.g., recent fractures, inability to sit for 10 minutes, and Charcot joint), documented cardiovascular diseases, bleeding disorders, or a history of deep vein thrombophlebitis were excluded from the study. Subjects who were pregnant, had leg ulcers, had pacemakers or were chronically exposed to vibration stimuli (e.g. jackhammer, train conductor) were excluded from the study. These exclusion parameters were determined through a subjective interview and a brief physical examination. The procedures were explained to all of the subjects before signing the informed consent form in order to participate in the study. The Institutional Review Board at Loma Linda University approved all of the procedures and all subjects signed a statement of informed consent.

Instrumentation

Laser Doppler flowmetry

Prior to the subjects entering the laboratory, the Laser Doppler was warmed up for 30 minutes for stability of blood flow measurements. Skin blood flow was measured by a non-invasive Laser Doppler flowmetry produced by MOOR Instruments, Inc. (MOOR FLPI V 2.1, Oxford, England) (Figure 1). The Laser Doppler was securely anchored to a stand and the scanner (sensor) was placed perpendicular to the posterior aspect of the calf. The machine provides blood perfusion images at a rate of as high as 25 images per second. The MOOR Laser Doppler uses a red laser beam to capture the reflected energy of blood flow from a single spot of 3×3cm area in the posterior part of the calf for 25 seconds. Anthropometric measurements were used to determine the appropriate captured area since the amount of tissue varies from subject to subject. Previous studies showed that skin blood flow was greatest at the points where the tissue directly contacted the vibration platform. This also ensures that the vibration effect is measured rather than its response that is travelled through the tissue [17]. There are no major veins contained in the calf capture area. The instrument captures skin blood flow and produces pictures at a

Figure 1. MOOR Laser Doppler.

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rate of 4 ms/pixels. The flow is stated in "flux" unit which is the measure of the flow generated by the Doppler imaging.

Skin temperature

A thermoster is attached to a BioPac SKT 100 C unit (BioPac, Inc, Goleta, California). This thermoster was placed on the medial muscle belly of the calf (gastrocnemius muscle) to record skin temperature for about 20 seconds.

Whole body Vibration

The Physio Plate® vibration platform (Physio Plate®, Domino S.R.L, San Vendemiano, Italy) with frequency settings ranges from 15–70 Hz was used to deliver mechanical vibration. The Physio Plate® can deliver low amplitude (2–3 mm) or high amplitude (5–6 mm) plate oscillations. A frequency of 40–50 Hz with low or high amplitude is recommended for massage and non-weight bearing activities [19]. In this study, vibration frequency of 50 Hz at high amplitude (5–6 mm displacement) was delivered for bouts of 60 seconds working time with a rest period of 2 seconds for a total number of 10 cycles. One cycle includes working time and rest time. A two centimeter (2 cm) rubber pad was used to reduce friction to the skin during massage related vibration techniques. This also reduces the amplitude by approximately 1–2 mm; however, frequency is unchanged. This slightly reduced the overall gravitational force applied to the lower extremity.

Moist heat

Moist heat was supplied by a commercial hydrocollator heat pack from an approximately 71°C water tank with a heating unit. The hydrocollator pack is a canvas-covered pouch, filled with hydrophilic substances such as petroleum distillate or bentonite that provides superficial therapeutic moist heat up to 1 cm below the skin [19]. It takes approximately 10 minutes for the maximum depth of 1 cm tissue heating to occur [19]. According to Prentice (2002), the therapeutic temperature range is approximately 30 to 40°C. The canvas cover is used with 6–8 layers of dry towels between the subject's skin and the hydrocollator pack to avoid skin burns [19]. Commercial terry cloth covers provide approximately 4 layers of thickness [20]. Chattanooga™ Hydrocollator® hot packs and covers were used in this study.

Although subjects do not typically lay on the hydrocollator pack, since the weight of the leg is relatively low, the patient's calf was placed on top of the hydrocollator pack. As further detail, a 90 kg-male-subject's lower leg will produce approximately 5.44 kg of force over a surface area of approximately 24 cm^2 or 0.23 kg/cm^2.

Sunbeam® Health at Home® Massaging Heating Pad

This commercial heating pad product provides a "massaging heat" with either a dry or moist heat option. To create the moist heat option for this study, the product sponge was saturated in warm water and then gently wrung out before attaching the sponge under the cloth heating pad cover. Both the heat and massage settings were set to "high" for this study. The temperature at the surface of this product ranged from 32.6 to 34.2°C after 10 minutes of use at the high settings of both massage and heat. This temperature range is at the lower half of the therapeutic temperature range of 30 to 40°C [19].

Procedures

Screening

Subjects who met the inclusion/exclusion criteria were invited for the study and led into a room that is pre-warmed to 71.6–75.2°F for approximately 30 minutes to maintain a constant temperature including the tables and walls throughout the experiment. The subject's age, weight, and height were recorded. A subjective examination was carried out to identify any history of neurological, orthopaedic, and cardiovascular disorders that would exclude the subject's ability to participate. Although it is relatively rare, there is a 0.08% annual incidence of deep vein thrombosis in non-diabetic individuals [20].

Subjects were assessed for possible deep vein thrombophlebitis prior to receiving the vibration intervention. Homan's sign test was performed to help rule out the possibility of a deep vein thrombosis. The subject's ankles were passively dorsiflexed while assessing for pain in the posterior aspect of the calf bilaterally. Pallor, swelling, tenderness, and warmth to palpation of the posterior lower limb were also assessed bilaterally. These signs and symptoms are indicative of a possible deep vein thrombosis, thromboembolism, or superficial thrombophlebitis and are contraindications for WBV. A positive finding of any of the above procedures served as exclusion from this study.

Testing

Subjects were positioned in prone on the plinth and a square shaped scan area of 3×3cm marked on the posterior aspect

Figure 2. Active vibration.

on the muscle belly of the gastrocnemius muscle with a skin safe ink marker to ensure that the skin blood flow and temperature were measured at the same location on all three test days. Markers were placed at the four points on the corners of the square outside the scan area for consistent repeated measurement. The baseline skin blood flow and skin temperature were recorded and then subjects received either vibration or no vibration depending on the group assignment immediately after the baseline measurement. The order of the interventions was randomly selected for each subject at the start of the study.

Interventions

The subjects received two of the following interventions for 10 minutes each, per day, over a three day period: 1) Stand on the GLOBUS Physio Plate® (active vibration) (Figure 2), 2) A passive calf massage with the calf resting on the GLOBUS Physio Plate® (passive vibration) (Figure 3), 3) Moist heat, 4) A combination of passive vibration and moist heat (Figure 4), 5) Sunbeam® massaging heating pad (Figure 5), and 6) No intervention (resting in supine – control). An intervention was applied to the right and left posterior calf each day (at approximately the same time of day) to allow for all six interventions to be tested in a three day period without retesting the same extremity on any one day. Refer to Table 1 for a description of the six interventions. During the heat interventions, if the subject's calf became intolerable to the heat at anytime during the 10 minute intervention, or if the skin became excessively blotchy at the 5 minute inspection, an additional layer of toweling was added in order to order to prevent a skin burn.

Figure 3. Passive vibration.

Figure 4. Passive vibration with moist heat.

Figure 5. Massaging heating pad.

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Table 1. Therapeutic procedure parameters description by intervention.

	Intervention	Position & Parameters	Hydrocollator Hot Pack	Vibration
Intervention 1	Vibration – active	Subject stands supported with one foot on the vibration platform for 10 minutes (Figure 2)	None	50 HZ, 5–6 mm amplitude oscillations, 10 exposures of 60 seconds
Intervention 2	Vibration – passive	Subject in supine with lower leg elevated 10 cm with calf resting on the vibration platform for 10 minutes (Figure 3)	None	50 HZ, 5–6 mm amplitude oscillations, 10 exposures of 60 seconds
Intervention 3	Moist heat	Subject in supine with lower leg elevated 10 cm with calf resting on a firm platform for 10 minutes	The subject's posterior calf was placed on the hydro-collator with the equivalent to 6 layers of toweling	None
Intervention 4	Vibration – passive & moist heat	Subject in supine with lower leg elevated 10 cm with calf resting on the vibration platform for 10 minutes (Figure 4)	The subject's posterior calf was rested on the hydro-collator with the equivalent to 6 layers of toweling. 50 HZ, 5–6 mm amplitude oscillations, 10 exposures of 60 seconds	50 HZ, 5–6 mm amplitude oscillations, 10 exposures of 60 seconds
Intervention 5	Commercial massaging heating pad	Subject in supine with lower leg elevated 10 cm with calf resting on a firm platform for 10 minutes (Figure 5)	The subject's posterior calf rested on the Sunbeam® massaging heating pad with the manufacture's recommended toweling	Vibration setting: High Temperature setting: High Duration: 10 minutes
Intervention 6	Control	Subject resting in supine with lower leg elevated 12 cm on a firm, stationary platform for 20 minutes	None	None

Once the therapeutic intervention was completed, the subjects returned to the plinth immediately for post-test blood flow and temperature measurement. The Subjects then rested for ten minutes following the post intervention measurement. After 10 minutes of rest, a third blood flow and skin temperature measurements were recorded.

Data analysis

Descriptive statistics were used for baseline characteristics and demographics. Friedman's ANOVA was used to compare skin blood flow and skin temperature between the different interventions. The significance level was $p<0.05$. Wilcoxon Signed Ranks Test was used for further evaluation.

Results

Skin blood flow

Tables 2–4 shows the mean skin blood flow across time for each intervention and between interventions at the end and 10 minutes post. Out of the six different interventions used, there was a significant increase in mean skin blood flow across time for passive vibration, moist heat, and moist heat plus passive vibration combination. For passive vibration, the mean blood flow from the start to 10 minutes post intervention was 57.4±7.3 Flux *vs.* 78.4±9.8 Flux; (p=0.01). Moist heat showed a significant increase from the start to 10 minutes post intervention of 73.3±13.1 Flux *vs.* 193.4±19.3

Table 2. Mean skin blood flow (Flux) ± (SD) across time for each intervention.

Modality (M)	Start (S)	End (E)	10 min post (P)	p value	p value (S-E)*	p value (S-P)*	p value (E-P)*	% change (S-E)	% change (S-P)
Active vibration	60.0 (5.3)	60.3 (10.4)	54.3 (4.3)	0.20				0.50	−9.52
Passive vibration	57.4 (7.3)	95.9 (6.7)	78.4 (9.8)	**0.01**	**0.02**	**0.03**	0.44	67.24	36.62
Moist heat	73.3 (13.1)	214.5 (10.6)	193.4 (19.3)	**0.001**	**0.01**	**0.01**	0.24	192.85	163.98
Moist heat & passive vibration	47.2 (6.6)	259.4 (19.6)	226.0 (19.1)	**0.001**	**0.01**	**0.01**	0.24	449.95	379.05
Sunbeam	61.6 (5.3)	56.2 (6.4)	76.7 (21.4)	0.17				−8.77	24.50
Control	54.8 (4.0)	53.9 (12.2)	56.6 (7.9)	0.50				−1.59	3.29

* p value was calculated using Friedman's ANOVA, when significant ($p<0.05$), p value is further expressed using Wilcoxon Signed Ranked test.

Table 3. Mean blood flow (Flux) ± (SD) comparisons between interventions at end modality.

Modality	Active vib 60.3 (10.4)	Passive vib 96.0 (6.7)	Moist heat 214.5 (10.6)	Passive & moist heat 259.4 (19.6)	Sunbeam 56.2 (6.4)	Control 53.9 (12.2)
Active vib 60.3 (10.4)						
Passive vib 96.0 (6.7)	**0.04**					
Moist heat 214.5 (10.6)	**0.01**	**0.01**				
Passive & moist heat 259.4 (19.6)	**0.01**	**0.01**	**0.04**			
Sunbeam 56.2 (6.4)	0.60	0.07	**0.01**	**0.01**		
Control 53.9 (12.2)	0.14	0.06	**0.01**	**0.01**	0.60	

Wilcoxon Signed Ranks Test $p<0.05$

Table 4. Mean blood flow (Flux) ± (SD) comparisons between interventions at 10 minutes post modality.

Modality	Active vib 54.3 (4.3)	Passive vib 78.4(9.8)	Moist heat 193.4 (19.3)	Passive & moist heat 226.0 (19.1)	Sunbeam 76.7 (21.4)	Control 56.6 (7.9)
Active vib 54.3 (4.3)						
Passive vib 78.4(9.8)	**0.01**					
Moist heat 193.4 (19.3)	**0.01**	**0.01**				
Passive & moist heat 226.0 (19.1)	**0.01**	**0.01**	**0.01**			
Sunbeam 76.7 (21.4)	0.17	0.72	**0.01**	**0.01**		
Control 56.6 (7.9)	0.80	**0.05**	**0.01**	**0.01**	0.11	

Wilcoxon Signed Ranks Test $p<0.05$.

Table 5. Mean skin temperature (°F) ± (SD) across time for each intervention.

Modality (M)	Start (S)	End (E)	10 min post (P)	p value	p value (S-E)*	p value (S-P)*	p value (E-P)*	% change (S-E)	% change (S-P)
Active vibration	85.6 (0.6)	85.3 (0.8)	84.9 (0.9)	0.8				–0.31	–0.78
Passive vibration	85.2 (0.7)	86.8 (1.0)	85.4 (1.0)	0.1				1.84	0.15
Moist heat	87.5 (0.5)	88.8 (1.5)	87.4 (1.1)	0.2				1.40	–0.12
Moist heat & passive vibration	87.3 (0.5)	89.1 (1.5)	87.3 (1.1)	**0.02**	**0.02**	0.72	0.06	2.06	0.00
Sunbeam	88.2 (0.5)	86.1 (1.0)	85.0 (0.9)	**0.001**	**0.01**	**0.01**	**0.02**	–2.38	–3.59
Control	85.9 (0.7)	85.8 (1.0)	85.7 (0.9)	0.7				–0.13	–0.15

* p value was calculated using Friedman's ANOVA, when significant ($p<0.05$), p value is further expressed using Wilcoxon Signed Ranked test.

Table 6. Mean skin temperature (°F) ± (SD) comparisons between interventions at end modality.

Modality	Active vib 85.3 (0.8)	Passive vib 86.8 (1.0)	Moist heat 88.8 (1.5)	Passive & moist heat 89.1 (1.5)	Sunbeam 86.1 (1.0)	Control 85.8 (1.0)
Active vib 85.3 (0.8)						
Passive vib 86.8 (1.0)	0.05					
Moist heat 88.8 (1.5)	**0.01**	**0.03**				
Passive & moist heat 89.1 (1.5)	**0.01**	0.05	0.51			
Sunbeam 86.1 (1.0)	0.45	0.33	**0.01**	**0.02**		
Control 85.8 (1.0)	0.33	0.39	0.05	0.01	0.80	

Wilcoxon Signed Ranks Test $p<0.05$.

Table 7. Mean skin temperature(°F) ± (SD) comparisons between interventions at 10 minutes post modality.

Modality	Active vib 84.9 (0.9)	Passive vib 85.4 (1.0)	Moist heat 87.4 (1.1)	Passive & moist heat 87.3 (1.1)	Sunbeam 85.0 (0.8)	Control 85.7 (0.9)
Active vib 84.9 (0.9)						
Passive vib 85.4 (1.0)	0.72					
Moist heat 87.4 (1.1)	**0.02**	**0.04**				
Passive & moist heat 87.3 (1.1)	**0.02**	0.07	0.96			
Sunbeam 85.0(0.8)	0.88	0.96	**0.01**	**0.04**		
Control 85.7 (0.9)	0.58	0.20	0.05	0.20	0.14	

Wilcoxon Signed Ranks Test $p<0.05$.

Flux; (p=0.001). This increase was also significant for the moist heat plus passive vibration combination with mean blood flow going from 47.2±6.6 Flux *vs.* 226.0±19.1 Flux; (p=0.001). In addition, from the start of the intervention to the end of the intervention, there were also significant increases for passive vibration, moist heat, and moist heat plus passive vibration combination (p=0.02; p=0.01, and p=0.01 respectively). The greatest percent increase of mean skin blood flow from start to end of the intervention was for the moist heat plus passive vibration combination (449.95%) and for moist heat (192.85%). The percent increase in comparing the moist heat plus passive vibration combination to the Sunbeam intervention from the start to 10 minutes post was 379.05% to 24.50% respectively.

Skin temperature

Tables 5–7 shows mean skin temperature across time for each intervention and between interventions (at the end and 10 minutes post). For the moist heat plus passive vibration combination and Sunbeam, there was a significant relationship in skin temperature from the start of the intervention to the end. The significance in skin temperature was 87.3±0.5°F *vs.* 89.1±1.5°F (p=0.02) for the moist heat plus passive vibration combination and 88.2±0.5°F *vs.* 86.1±1.0°F (p=0.01) for Sunbeam. The mean skin temperature from the start to 10 minutes post for the moist heat plus passive vibration combination and Sunbeam was 87.3±0.5°F (p=0.02) *vs.* 87.3±1.1°F (p=0.001) respectively. The percent change of the mean skin temperature from the start to 10 minutes post decreased for all interventions except for passive vibration and moist heat plus passive vibration combination. For passive vibration, the percent increase was 0.15%. More importantly, the percent change for the moist heat plus passive vibration combination was 0.00%.

Discussion

Thermal homeostasis in humans is controlled by the regulation of the level of blood flow in the skin [21]. Consequently, skin blood flow continuously adjusts to the skin temperature [22]. Hence, skin blood flow changes skin temperature and heat loss rate. In this way, fluctuations in skin blood flow are subject to thermoregulation [23]. Skin blood flow in the forearm and calf is increased by vibration [8]. Pulsatile sheer mechanical forces on the endothelium increase eNOS messenger RNA expression and eNOS promoter. This leads to an increase in endothelial NO synthase (eNOS) and produces Nitric Oxide. Circulating NO produces vasodilation and increases skin blood flow [24,25]. Lohman, et al. (2007) reports that skin blood flow might also increase due to friction forces applied by the mechanical vibration on the endothelial cells at the cellular level [8]. As discussed previously, the purpose of the study was to determine the most desirable intervention or combination of interventions that would significantly increase skin blood flow (SBF) without increasing skin temperature to the point that could cause a burn in the elderly population.

Skin blood flow parameters

In the healthy elderly population, skin blood flow was greatest during the combination of passive vibration and moist heat. This combination resulted in mean skin blood flow elevation to 450% (at the conclusion of the 10 minutes of intervention) and 379% (10 minutes post intervention) as compared to baseline measurements. These changes were significant at both time intervals. However, the change between the conclusion of the combination of passive vibration and moist heat and 10 minutes post were not significant suggesting that the SBF benefit lasted considerably longer than just 10 minutes. These findings were quite dissimilar to earlier findings reported by Lohman, et al. (2011) in healthy young adults (mean age =25.7 years) with mean SBF increases following a 10 minute bout of passive vibration and moist heat combination was 138% and 113% respectively, using the same procedure but a single point Doppler rather than the scanning Doppler used in this study. Although a direct comparison can only be generalized due to different instrumentation, the mean SBF changes from the combination intervention in the older population were much greater as compared to the young adults [16].

Although moist heat and passive vibration offered in isolation did result in significant gains in SBF immediately after each intervention and 10 minutes following, these changes were modest in comparison and significantly different than when combined (Table 2). The SBF changes with the combination of passive vibration and moist heat were significantly higher than compared to all the other interventions (Tables 2–4). Moist heat alone had a similar SBF curve. The other three interventions (i.e., Sunbeam massaging heating pad, active vibration, and control) did not show a significant change from the baseline SBF measurements for either of the post intervention measurements. These findings in the elderly population were similar to young adults in prior studies [8,16].

In an early study by Lohman, et al. (2007), passive vibration was applied to the same posterior calf region of healthy young adults for 10 minutes using the same instrumentation. The baseline SBF and both post-intervention SBF measurements were higher as compared to the elderly population in this study suggesting that reduced skin blood flow may be a consequence of aging [8]. This is supported by previous studies that reported that aging and certain diseases (e.g., diabetes) adversely affect circulation, the autonomic nervous system, and endothelial function and decreases the blood circulation [3,8,26]. This suggests that passive vibration alone is an intervention that can increase skin blood flow without increasing skin temperature.

Skin temperature parameters

Since burns are a potential adverse complication of utilizing thermal modalities to increase blood flow in elders, skin temperature (ST) and the time of the heat exposure are important study variables to consider. The mean ST was significantly increased with the combination of passive vibration and moist heat; however, the mean ST change of 1.8°F after the 10-minute intervention is not typically considered practically important. This modest change in ST is short lived with the mean ST following the 10-minute rest period being exactly the same as the base line reading (Table 5). Moist heat alone increased ST by 1.3°F and passive vibration alone increased ST by 1.6°F immediately following the intervention. None of the other interventions significantly increased ST. In fact, a few of the interventions actually slightly decreased ST including active vibration, the

Sunbeam massaging heating pad, and the control group (Table 5). The change in ST between the combination of passive vibration and moist heat as compared to moist heat alone was not significantly different (Tables 6, 7). Although relatively small (mean =2.3°F), the combination of passive vibration and moist heat was significantly higher as compared to vibration alone but only immediately following the intervention (Tables 6, 7). In patients vulnerable to burns, this small difference may be clinically important. However, in the healthy integumentary system, skin burns typically do not occur with short duration heat application until approximately 111°F [27,28]. Our hypothesis was not supported in that the ST following the 10 minute application of passive vibration and moist heat combined was higher than moist heat alone despite the fact that SBF was significantly greater. This finding suggests that the rate of tissue temperature slightly exceeded the ability of the circulation (although increased) to dissipate the heat.

The amount of skin destruction from heat is based on temperature and duration of the tissue exposure [27,29,30]. This type of insult will also affect the amount of tissue destruction (i.e., electrical, chemical, heat, friction, radiation, and light). A tremendous amount of heat is not required to cause damage. At temperatures below 111°F, local tissue damage will not occur unless the exposure is for prolonged periods. Bjerke (2010) reported that for temperatures of less than 111°F, an exposure time of six hours is needed to cause transepidermal necrosis in areas of adequate circulation [31]. In the temperature range between 111°F and 124°F, the rate of cellular death doubles with each degree rise in temperature, and short exposures will lead to cell destruction [27,28]. At temperatures in excess of 124°F, exposure time needed to damage tissue is extremely brief [32]. The American Burn Association (ABA) (2003) reported that hot water at 124°F can cause third degree burns with a 3 minute period [33]. The ABA recommends bathing at a water temperature of 100°F as safest warm water temperature (2003). Since all of the ST readings for interventions in this study were below 90°F that is well below the burn threshold. This finding does not have practical importance. Skin temperature standard deviations were small for this study, varying ≤1.5°F. Also, the heat exposure in this study was administered for a relatively short period of time. None of the subjects in the study experienced skin damage or a burn.

It is unclear why moist heat alone and passive vibration alone did not significantly increase ST but were significant when combined. We hypothesize that this is due to the mechanical properties of vibration releasing the steam vapor within the moist heat device at a more rapid rate. Additional towel layers (protective clothes) were added between the heating devices and the subject's skin during the experiment if the elderly subject reported the sensation of excessive heat during the application of any of the thermal heating modalities as recommended [34]. Since steam can burn and diabetic individuals frequently lose sensation in their lower extremities, moist heat with or without vibration may not be indicated in this region.

It is of the upmost importance to keep the room temperature consistent during the study. Petrofsky, et al. (2005) reported that skin blood flow doubled in a hot environment as compared to a cold environment [35]. Although the room temperature was set within the parameters of 71.6–75.2°F each day and subjects had a 10 minute acclimation period, readings did occur on subsequent days and the researchers could not control for all extrinsic factors such as the temperature of the environment from which the study came from prior to each session, activity level prior to arriving each day, and other factors that might affect the day-to-day skin temperature and blood flow variability. When possible, the examiners did attempt to control the time of day that the subsequent readings were taken. Performing these multiple interventions required the subjects to return on three consecutive days, although this provided the researchers with ample information on several interventions and allowed each subject to serve as their own control. It did allow for a small degree of day-to-day variability in human physiology which could be perceived to be a study limitation.

Maloney, et al. (2008) reported no additional benefit from applying passive vibration to the forearm beyond the duration of 5 minutes so the 10 minutes of passive vibration to the calf region should have been more than adequate [17]. Moist heat to the calf was only applied for 10-minutes in this study. For the superficial heating agents used in this study (Sunbeam and moist heat), the greatest degree of tissue temperature occurred within the first 0.5 cm of the skin and subcutaneous tissue [36]. This tissue temperature reaches the tissue maximum within 6 to 8 minutes while deeper tissues such as muscle requires up to 15 to 30 minutes [36]. Since our goal was to affect the skin blood flow, the duration of 10 minutes meets or exceeds this duration. For these reasons, the authors of the study do not feel that the short duration interventions were study limitations. Populations more vulnerable to skin burns, such as diabetics due to compromised circulatory systems should be studied in the future. The mean age in this study was in the mid to late 60's. Future studies should focus on an older population and elders with diabetes. In addition, it should focus on the effects of passive vibration in the feet which is the most vulnerable areas for skin ulcers in diabetics.

Conclusions

The combination of moist heat and passive vibration is a novel way to significantly increase SBF while only modestly increasing ST in the lower legs of healthy elders. In populations vulnerable to burns, passive vibration alone may be safer than moist heat or the combination of moist heat and vibration. Although the SBF is significantly increased by vibration alone, it is not as effective as the prior mentioned interventions. The range order of the top three interventions in this study to significantly increase SBF are the combination of passive vibration and moist heat, moist heat alone, and passive vibration alone, respectively. In patient populations that would benefit from increased lower extremity skin blood flow, the clinician should select an intervention or combination of interventions that best matches the integrity of the circulatory and afferent nervous system in order to avoid possible skin burns.

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