

Received: 2006.08.23
Accepted: 2006.11.16
Published: 2007.01.30

The effect of whole body vibration on lower extremity skin blood flow in normal subjects

Authors' Contribution:

- A** Study Design
- B** Data Collection
- C** Statistical Analysis
- D** Data Interpretation
- E** Manuscript Preparation
- F** Literature Search
- G** Funds Collection

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Source of support: Departmental sources

Summary

Background:

Circulation plays a vital role in tissue healing. Increases in muscle flexibility and strength, secretion of hormones important in the regeneration and repair process, blood flow, and strength of bone tissues has been attributed to whole body vibration (WBV) combined with exercise. The purpose of the study was to determine the effects of short-duration, high-intensity, isometric weight bearing exercise (vibration exercise [VE]) and vibration only on skin blood flow (SBF).

Material/Methods:

Forty-five subjects 18–43 years of age were randomly divided into three groups: Group 1 – VE, Group 2 – exercise only, and Group 3 – vibration only. SBF was measured using a laser Doppler imager at three time intervals: 1) initial base line, 2) immediately following intervention, and 3) 10-minutes following intervention.

Results:

There was no significant difference between the three groups' SBF prior to intervention. Immediately following the intervention a difference among groups was found. Post hoc testing revealed that Group 3 subjects' mean SBF was significantly increased at both post-intervention time intervals.

Conclusions:

The study findings suggest that short duration vibration alone significantly increases SBF; doubling mean SBF for a minimum of 10 minutes following intervention. The emerging therapeutic modality of WBV as a passive intervention appears to increase SBF in individuals with healthy microcirculation.

key words:

whole body vibration • skin blood flow • vibration exercise

Full-text PDF:

<http://www.medscimonit.com/fulltxt.php?IDMAN=9612>

Word count:

2756

Tables:

2

Figures:

1

References:

33

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BACKGROUND

Circulation plays a vital role in tissue healing. One local factor in wound healing is the vascular supply. Richly vascularized areas such as the face heal faster than poorly vascularized areas such as the feet [1]. In the elderly, a delay in healing is often attributed to impaired circulation. Both autonomic and endothelial function are adversely influenced by aging and disease processes such as diabetes mellitus [1]. As a result, ulcerations and impaired healing of the lower limb may occur due to altered peripheral microcirculation [2].

Peripheral circulation can be divided into blood flow to: 1) contractile tissue (muscle blood flow) and 2) the integumentary system (skin blood flow). Peripheral circulation is regulated by two mechanisms: 1) Central control from the nervous system and 2) local control by the tissues (metabolic state) in the immediate vicinity of the blood vessels [3]. Central and local control mechanisms of blood flow varies in function depending on the tissue type [3]. For example, skin blood flow is predominately regulated by neural regulation [3], whereas vasomotion (the contraction and relaxation of the precapillary sphincter) as seen in skeletal muscle, is heavily dependent upon the metabolic state of the tissue [4]. During exercise, capillaries will open several-fold (up to 100 fold) to increase blood flow to the muscle [3,5,6]. Muscular blood flow, activated by somatic nerves, is exercise intensity dependent [7,8]. The muscular vascular bed vasoconstriction as regulated by sympathetic nervous system restricts blood flow to skeletal muscles to maintain arterial blood pressure [7-9]. Thus, skeletal muscle blood flow in response to exercise is regulated by concomitant somatic and sympathetic pathways [7,9].

Whole body vibration (WBV) has been shown to induce improvements in muscular strength and performance, as well as effect changes in peripheral circulation [10-17]. "Rhythmic muscle contractions" evoked by imposed vibration on the body can induce changes in peripheral circulation, although heart rate or blood pressure are unaltered [12]. Despite these acknowledged benefits from WBV, the majority of research has focused on the negative effects of high frequency occupational vibration such as decreased digital blood flow as in 'vibration white finger' and 'vibration-induced Raynaud's phenomenon' [18,19]. This adverse high frequency occupational vibration is associated with industrial tools that resonate at 80 to 100 Hz [20].

A modest amount of research has been published on low-frequency vibration (frequencies below 80 Hz) and its effect on peripheral circulation [12]. One such study examines WBV and exercise relating to muscle blood volume and concludes that short term exposure to low-frequency (26 Hz) vibration does not have the negative effects associated with high frequency vibration.¹² Following nine minutes of standing on a low-frequency vibrating platform, subject's relative moving quadriceps and gastrocnemius muscles blood volume and popliteal artery mean blood flow increased as the flow resistive index decreased [12].

No research has specifically assessed the effect of exercise combined with WBV on SBF as a primary study outcome. When exercise is performed on a vibration platform; this

form of exercise is termed 'vibration exercise (VE)'. In one study SBF, as a secondary measurement, was assessed using Doppler imaging following VE [17]. The results of the study demonstrated an increase in laser Doppler flow signal after VE without noticeable erythema [17]. This suggests "...differential effects on cutaneous superficial and deeper arteries" [17]. In contrast, two studies have reported erythema on the foot and calf of many subjects as a result of exercise while standing on a vibrating platform [12,17]. Ritweger et al. [17] discovered "itching erythema" over the skin of activated muscles and stated that this phenomenon warranted further study. The purpose of our study was to determine the effects of low frequency weight bearing VE on lower extremity SBF following short-term exposure. For some individuals even minimal amounts of exercise can be difficult or contraindicated, so an additional purpose of our study was to determine if vibration alone can increase SBF in the lower extremities. Our hypothesis is that SBF will increase following short-term low frequency vibration to the lower extremities with and without exercise.

MATERIAL AND METHODS

Subjects

The subjects were 45 healthy adult volunteers aged 18-43 years (mean =23.93 years) from Loma Linda University and surrounding communities with no history of diabetes or other circulatory disorders. Subjects were recruited through fliers and word of mouth. All subjects were free of conditions that would limit their participation in the study such as neurological, orthopaedic, or circulatory disorders (e.g., deep vein thrombophlebitis, bleeding disorders) as determined through a subjective interview and brief physical examination. Twenty-two females and 23 males participated in the study. The subjects were randomly assigned to one of three groups: Group 1 = vibration exercise (VE), Group 2 = exercise only, and Group 3 = vibration only. Each group contained fifteen subjects. The Institutional Review Board of Loma Linda University approved all procedures and all subjects signed an informed consent document.

Laser Doppler

Skin blood flow was measured by a Doppler imager produced by Moor Instruments, Inc. (LDV 304, Oxford, England). This device is a completely non-invasive device and has no physical contact with the body. Subjects were positioned in prone with pillows under their abdomen and ankles for support while the feet hung freely from the end of the plinth. The device was securely anchored to a stand 35 cm above the right distal lower leg of the subject. The device scanned the body and produced a picture of blood flow to the skin. The scanned area was 117x149 pixels and the scan rate was 4 ms/pixel. The laser was warmed for 30 minutes prior to flow measurements to increase stability. An area of 25 cm² was scanned over a 2-minute period. An area of 10 cm² was chosen from the center of the scanned area for analysis. Markers were placed on the skin, just outside of the scan parameters, to allow repeat measurements in this same area of interest under different experimental conditions. The units of blood flow stated in the results are in "flux" units, the measure of flow generated by Doppler imaging. The error on repeated measurements is less than 5% from day to day [21].

Table 1. Therapeutic procedure parameters by group.

Group	Exercise	Exercise parameters	Description	WBV/VE
Group 1	Partial squat	Isometric hold for 60"	Feet in the middle of the plate (15–20 cm apart), slightly apart. Knees bent at 80°, back straight, head up, and stomach held in. Do not allow knees to proceed beyond the toes.	VE: 30 HZ, high amplitude oscillations
	Deep calves	Isometric hold for 60"	Feet slightly apart (20 cm), stand on your toes. Knees bent at 100°, back straight, head up, and stomach held in.	VE: 30 HZ, high amplitude oscillations
	Calves	Isometric hold for 60"	Feet in the middle of the plate (15–20 cm apart), stand on your toes. Knees slightly bent (25°), back straight, head up, and stomach held in.	VE: 30 HZ, high amplitude oscillations
Group 2	Partial squat	Isometric hold for 60"	Feet in the middle of the plate (15–20 cm apart), slightly apart. Knees bent at 80°, back straight, head up, and stomach held in. Do not allow knees to proceed beyond the toes.	No
	Deep calves	Isometric hold for 60"	Feet slightly apart (20 cm), stand on your toes. Knees bent at 100°, back straight, head up, and stomach held in.	No
	Calves	Isometric hold for 60"	Feet in the middle of the plate (15–20 cm apart), stand on your toes. Knees slightly bent (25°), back straight, head up, and stomach held in.	No
Group 3	Calves massage	The subjects relaxes for three bouts of 60", with 10 second rest between bouts	Subject supine on floor with calves resting on the plate. Relaxed. Head rested on single pillow.	WBV: 30 HZ, high amplitude oscillations

Whole body vibration

The mechanical stimulation of WBV was provided by the Power Plate®. The Power Plate® is a vibration platform (Power Plate® North America, LLC, Culver City, California, USA) with frequency settings ranging from 30–50 Hz. The Power Plate® has an option for either low amplitude (2–3 mm) or high amplitude (5–6 mm) plate oscillations [11]. For this study the vibration parameters were set at a frequency of 30 Hz, an amplitude of $\alpha_0=5-6$ mm (high amplitude), and therefore a peak acceleration of approximately 7 g.

Procedures

The subjects were led into an environmental room where room temperature was regulated between 22–24°C and the humidity was between 35 and 40%. The room was pre-warmed to 22–24°C for at least 30 minutes so that all tables and wall temperatures were constant. The subject was placed in the prone position on a horizontally positioned plinth. The skin was marked with skin-safe ink on the muscle belly of the right gastrocnemius muscle to insure that the Doppler flow readings were measured at the same location for both the pre and post test recordings. The subjects rested comfortably for a ten-minute period prior to the SBF Doppler imaging baseline scan to stabilize SBF.

Without repositioning the subject, a Homan's sign test was performed to help rule out a possible deep vein thrombosis. The subject's ankle was passive dorsiflexed, assessing for pain in the posterior aspect of the calf. Pallor, swelling,

or tenderness or warmth to palpation of the posterior lower limb was also assessed bilaterally. These signs and symptoms are indicative of a possible deep vein thrombophlebitis, which is a contraindication to WBV. Subjects with a positive finding of any of the above procedures were excluded from the study.

Immediately following the measurement of baseline SBF, the subject performed either an active isometric therapeutic exercise regimen with or without WBV or received vibration only (passive calf massage on the Power Plate®) depending on the group assignment. Refer to Table 1 for a description of the therapeutic procedures for the three groups.

Once the therapeutic intervention was complete, the subject returned to the plinth for an immediate post-test Doppler scan. A third Doppler scan began 10 minutes following the end of the therapeutic intervention. The markers placed on the skin afford accuracy of skin surface location for these repeated measurements.

Data analysis

Data was analyzed using SPSS, version 10.0 software. Data reported in the results are means (\pm SD). A repeated measures ANOVA for time was used to analyze the effects of treatment group and time on skin blood flow. Upon finding a significant interaction between time and treatment group, one-ANOVAs with and without repeated measures were run to test for separate effects of time and group, respectively, on blood flow. The lower-bound test for with-

Table 2. Comparison of skin blood flow (flux) over time for the three groups.

	Vibration only (n=15)		Exercise (n=15)		Vibration exercise (n=15)		p*
	Mean	(SD)	Mean	(SD)	Mean	(SD)	
Pre	112.13	(37.01)	140.44	(44.15)	139.19	(41.28)	0.11
Post	277.53	(179.74)	134.94	(41.49)	133.77	(37.57)	0.001
10 min Post	215.71	(166.00)	132.92	(43.93)	130.98	(24.88)	0.04
p**	.008		.37		.53		

* One-way ANOVA; ** One-way ANOVA with repeated measures.

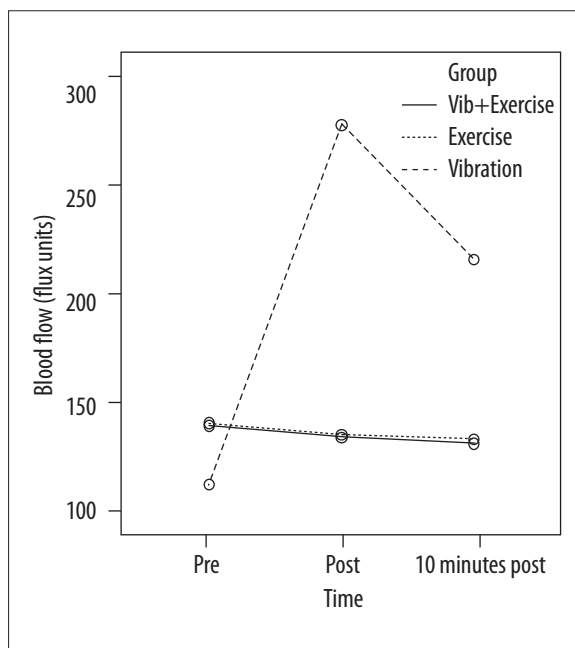


Figure 1. Changes in SBF between groups over time.

in-subjects effects was used to determine overall significant changes within each group over time. Bonferroni post hoc tests were used to identify significant differences between groups at each point in time. An alpha of 0.05 was selected for all statistical tests.

RESULTS

Mean SBF for each group at each point in time is presented in Table 1. At baseline, skin blood flow was similar for the three groups ($F_{2,42}=2.29, p=0.11$). Analysis of treatment effects showed a significant interaction between treatment groups and time following treatment. Significant differences in SBF between groups were apparent immediately ($F_{2,42}=8.68, p=0.001$) and 10 minutes following the intervention ($F_{2,42}=3.50, p=0.04$). For the group that received local vibration to the right gastrocnemius, SBF was more than twice that of the VE group ($p=0.002$) and Exercise group ($p=0.003$) immediately following the intervention. Blood flow over the following 10 minutes decreased fairly rapidly for the vibration only group but remained higher than either comparison group ($p=0.08$ and 0.09 for VE and exercise, respectively) (Table 2).

Analysis of the change in SBF over time by group revealed that only the group receiving local vibration increased significantly ($F_{1,14}=13.5, p=0.003$) following treatment and remained significantly elevated at 10 minutes post intervention ($F_{1,14}=6.6, p=0.02$).

DISCUSSION

One of our two hypotheses was supported; SBF was increased with vibration. Contrary to our expectations, exercise of the lower extremities, with and without WBV, did not increase SBF; rather SBF was actually decreased slightly. This suggests that the blood flow requirements of active muscles superseded the increased cutaneous vascular changes as a result of vibration [3].

All three groups were homogeneous at the initial Doppler SBF scan (Table 2). Immediately following the interventions; however, SBF were significantly different among the groups. The difference was between Group 3 (vibration only) and the two exercise groups. Groups 1 and 2 mean SBF did not change significantly either immediately following intervention or 10-minutes following the intervention; however, there was a slight downward trend for SBF (Table 2). Group 3 realized a significant mean increase in SBF of approximately 250% immediately following intervention. This mean increase in SBF remained significantly elevated for 10 minutes following the intervention (200%), though SBF did reduce over time (see Figure 1). If the SBF decline trend was to have continued in a similar manner, SBF would have approached the baseline flow value at approximately 15 to 20 minutes post intervention. The subjects with and without pathology in Sackner & Adams' study returned to their initial baseline dirotic wave and notch values within 5-minutes following vibration [22].

Decreased microcirculation of the lower extremity integumentary system and peripheral nerves has been reported as a complication of the aging process and as a consequence of disease processes such as diabetes mellitus. Therefore, any intervention that increases microcirculation may be clinically relevant [1]. The passive intervention of vibration to the posterior calf musculature significantly increased skin blood flow in a healthy, youthful population without directly taxing the cardiovascular or musculoskeletal systems. Sackner & Adams [22] found similar findings with whole body, periodic acceleration resulting in increased vasodilation and a fall in the dirotic notch in both healthy adults and adults with inflammatory diseases when compared to

a sham acceleration intervention ($\pm 0.5 \text{ m/s}^2$ at 120–140 cycles per minute). Our study's instrumentation differed from Sackner & Adams [22] in that they used repetitive head-to-toe (parallel to body axis) whole body "acceleration" at $\pm 2.2 \text{ m/s}^2$ (0.224 g) and a frequency of 140 cycles per minute (2.33 Hz), while we used mechanical vibration forces perpendicular (Group 3) or vertical (Groups 1&2) to the long axis of the tibia at an amplitude of 7 g and a frequency of 30 Hz. Sackner & Adams [22] used a 45-minute intervention, while we used a 3-minute intervention. Despite the differences in study design, our findings did support the findings of Sackner & Adams [22] in that vibration alone did increase blood flow for a short duration.

Despite the short term reduction in SBF following isometric exercise, the benefits of an exercise program to the cardiovascular system are well documented including [23,24]: 1) endothelium-dependent vasodilation [25], 2) bone density [26], 3) physical fitness [26], and 4) muscle hypertrophy [27]. During active exercise blood flow is directed away from areas where it is not immediately needed and redirected to areas where it is needed. When short duration, high intensity demands are placed on the human musculoskeletal system; blood is shunted away from organs, including the integumentary system, and redirected to the musculature. This physiological response may explain why SBF was reduced, short term, in the two exercise groups.

Although passive motion does not increase hemodynamics [28–30], vibration is not the only passive procedure that has been shown to increase SBF. Massage of the lower limb has been reported to increase SBF without an increase in blood flow in the femoral artery or skeletal muscle [31]. This may help support the findings of this study in regards to increased SBF with passive motion; however, it does not explain the underlying mechanism responsible for the significant increase in SBF with 3 minutes of 30 Hz vibration. A logical explanation might be that the mechanical vibration forces on the endothelial cells have their effect due to friction at a cellular level. Another vibration study concluded that the increased blood flow was due to significant increases in nitric oxide (NO). Increased NO produced by an increase in endothelial NO synthase (eNOS) due to increased eNOS messenger RNA expression and eNOS promoter as a direct function of pulsatile sheer mechanical forces to the endothelium [22,32]. Sackner & Adams [22] reported a descent in the diastolic notch, similar to the effects of active exercise, from periodic acceleration. This cardiovascular change may be due to a significant increase in circulating NO concentrations resulting in vasodilation of resistant blood vessels. The underlying mechanism for the significant increase in SBF following vibration may be due to pulsatile endothelial stress resulting in increased circulating NO concentration as a result of increased eNOS activity. Hutcherson & Griffith [33] reported that the peak response of endothelium derived NO was 250–360 cycles per minute (4.17–6.00 Hz); however, a good response was provided at 180–210 cycles per minute (3.00–3.60 Hz).

Our findings in a youthful healthy population combined with the findings of Sackner & Adams [22] in an older population with circulatory pathology provides evidence of the efficacy of clinical application of vibration as an intervention in populations where aerobic exercise is contra-

indicated or is not feasible. Further studies should be performed on subjects with reduced microcirculation such as in the diabetic population. Another study could be conducted to determine if vibration might reduce the healing time of skin ulcers caused from impaired microcirculation. Follow up studies could be conducted to see if the increased SBF is dosage specific. Simply put, is there an optimal duration and frequency of vibration to increase SBF (therapeutic dosage)?

CONCLUSIONS

The study findings suggest that short duration vibration alone can significantly increase skin blood flow for a minimum of 10 minutes following intervention. Despite the fact that passive motion does not increase hemodynamics, the findings of this study support that vasodilation is increased in endothelial tissues with vibration. Short duration, high intensity, weight bearing superincumbent isometric lower extremity exercise, with and without 30 Hz WBV, resulted in a slight reduction in SBF immediately following and 10-minutes following the intervention. Vibration appears to be an alternative intervention in individuals with reduced SBF in the lower limbs especially in populations, such as those with insensitive feet, vulnerable to burns from thermal modalities. It appears that the emerging therapeutic modality of WBV significant increases SBF.

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