ORIGINAL ARTICLE

Benefits of whole-body vibration training on arterial function and muscle strength in young overweight/ obese women

Stacey Alvarez-Alvarado[1], Salvador J Jaime[1], Michael J Ormsbee[1,2], Jeremiah C Campbell[1], Joy Post[1], Jacob Pacilio[1] and Arturo Figueroa[1]

The early arterial dysfunction linked with obesity and a sedentary lifestyle heightens the likelihood of suffering from future cardiovascular events. Whole-body vibration training (WBVT) may improve systemic arterial stiffness (brachial-ankle pulse wave velocity (baPWV)) and muscle strength in pre- and post-menopausal women. However, the effectiveness of WBVT to impact the arterial segments included in baPWV is unknown. The aim of this study was to investigate the effects of WBVT on aortic and leg arterial stiffness in young sedentary overweight/obese women. Thirty-eight young (21 years) overweight/obese women were randomized to WBVT ($n = 25$) or a nonexercising control (CON, $n = 13$) groups for 6 weeks. PWV, brachial and aortic blood pressures (BP), wave reflection (augmentation index (AIx)) and leg muscle strength measurements were acquired before and after 6 weeks. WBVT significantly reduced carotid-femoral PWV (aortic stiffness, $P < 0.05$), femoral-ankle (leg arterial stiffness, $P < 0.01$) and baPWV (systemic arterial stiffness, $P < 0.01$) compared with CON. The reduction in brachial systolic BP (SBP), heart rate, aortic SBP, aortic diastolic BP, AIx normalized to a heart rate of 75 beats per min (AIx@75; $P < 0.01$) and AIx ($P < 0.05$) following WBVT was significant compared with CON ($P < 0.05$). WBVT increased leg muscle strength compared with CON ($P < 0.001$). There was a significant negative correlation between changes in relative muscle strength and aortic stiffness ($r = -0.41$, $P < 0.05$). WBVT led to reductions in arterial stiffness, central BP and wave reflection in young obese women. WBVT may be an effective intervention toward vascular health promotion and prevention in young overweight/obese women (ClinicalTrials.gov identifier: NCT02679898).

INTRODUCTION

The impact of excessive adiposity on hypertension is increased with aging, especially in women.[1] Peripheral (brachial and femoral) arterial stiffness (pulse wave velocity (PWV)) increases with higher levels of obesity at an early age in both sexes.[2] Interestingly, adults with obesity aged 20–30 years have higher aortic PWV when compared with individuals in lean and overweight categories.[3] Although increased aortic PWV is a characteristic of arterial aging,[4] obesity has a greater adverse impact on aortic PWV in middle-aged and older women than men.[2] Unlike older adults, recent data suggest that elevated systolic blood pressure (BP) precedes increases in aortic PWV in young adults.[5] Furthermore, individuals with obesity also have elevated pressure wave reflection (augmentation index (AIx))[6] and aortic BP[7] that more accurately reflect loading conditions of the left ventricle and, thereby, relate better to adverse cardiovascular events than brachial BP.[8] Accordingly, effective interventions targeting for improvements on arterial function in women with obesity are critical for prevention of hypertension and cardiovascular disease at a young age.

Low muscle strength and mass are negatively related to the incidence of hypertension[9] and increased PWV.[10] It is well recognized that exercise training is an essential component in the prevention, treatment and management of obesity.[7,11–13] Abundant evidence supports that resistance training (RT) at high intensity is the preferred exercise modality to improve muscle strength and mass.[14] Nevertheless, the effects of whole-body high-intensity RT on arterial function seem to be adverse, although controversial,[7,15] in young healthy adults as shown by increases in AIx and aortic but not leg PWV in women.[16] Therefore, an effective strength training modality that results in concurrent improvements in BP and arterial function (AIx and PWV) would be of great clinical importance in young women with obesity.

Whole-body vibration training (WBVT) is an exercise mode that involves static or dynamic movements on a vibrating platform.

488

Previous studies have shown that WBVT evokes similar muscle strength adaptations as RT progressed from low to high intensity in postmenopausal women.[17] However, strength gains with these two training modalities cannot be generalized to other populations, particularly in healthy adults involved in intense RT. Improvements in muscle strength have been observed in young[11] and postmenopausal[18] sedentary women with overweight/obesity after 6 to 12 weeks of WBVT. We reported improvements in AIx and systemic PWV (brachial-ankle PWV (baPWV)) following 6 weeks of WBVT in young overweight/obese women.[11]

Because static and dynamic exercises were performed and only baPWV was examined, it was unclear which muscle contraction (static or dynamic) and arterial segment in baPWV (leg or aortic PWV) were responsible for the improvements in arterial function and muscle strength. Recently, Bush *et al.*[19] indicated that dynamic whole-body vibration exercise produces greater muscle strength benefits when compared with static exercise in young nonresistance trained men and women. Moreover, dynamic squats during whole-body vibration exercise might attenuate the exaggerated BP responses to static squats reported in obese women.[20] Importantly, because dynamic muscle contractions characterize conventional resistance training and could consequently translate into functional improvements (for example, activities of daily living), the vascular effects of dynamic exercises need to be investigated.

The purpose of this study was to examine the effects of dynamic WBVT on arterial function (BP, AIx and PWV) and muscle strength in young overweight/obese women. We hypothesized that WBVT would improve arterial function and leg muscle strength compared with a nonexercising control group (CON).

METHODS

Participants

Thirty-eight healthy young (aged 18–25 years) overweight/obese women (body mass index: 27–40 kg m^{-2}) were enrolled in this study. Women were free of chronic diseases (verified through medical history questionnaires), nonsmokers and sedentary (defined as <120 min per week of light–moderate intensity exercise for the past 6 months). Exclusion criteria included body mass index <25 and >40 kg m^{-2}, hypertension, epilepsy, gallstones, kidney stones, arthritis, intense migraines, hernias, cardiovascular and metabolic diseases, nonconsolidated fractures, recent operative wounds, herniated disks or metal implants. Additional exclusion criteria were pregnancy, amenorrhea or irregular bleeding and/or taking any medications that affected the outcome variables. Because of the short duration of the study, only women with stable ovulatory cycle duration over at least the past 2 months were eligible for participation.[21] In addition, none of the participants had previous experience with WBVT. Women were recruited from around the community through announcements and direct communication. The study protocol was approved by the Institutional Human Subject Committee and all participants provided written informed consent to participate in the study.

Study protocol

We used a parallel experimental design. Following an initial screening and familiarization session, eligible women were randomly assigned (2:1) to one of the following groups: WBVT or CON for 6 weeks (Figure 1). Randomization was stratified by body mass index (< or >30 kg/m^2). Researchers were blinded to group assignment. Participants reported to the laboratory for assessments before and after the 6 weeks. Measurements were conducted in the morning after an overnight fast (at least 8 h), at the same time of the day (±1 h in order to avoid diurnal variations), at least 48 h after the last training session (to avoid the acute effects of exercise) and during the placebo phase of oral contraceptives or late luteal/early follicular phase of the ovarian cycle (to avoid the vasoprotective effects of estrogens).[21] Participants were requested to refrain from nonsteroidal anti-inflammatory drugs, caffeine, alcohol
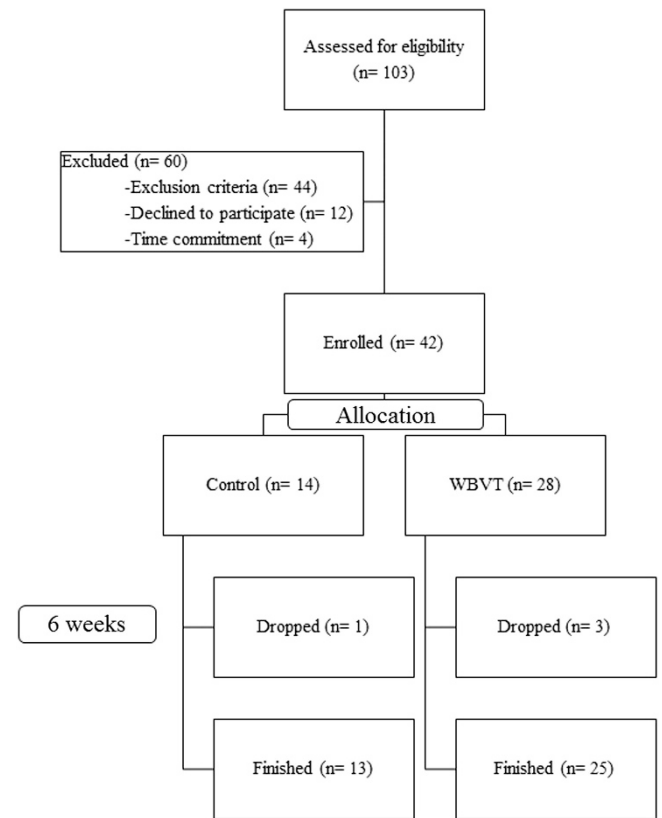

Figure 1 Diagram for the experimental study. WBVT, whole-body vibration training.

consumption or any unaccustomed physical activity 24 h before each visit. Cardiovascular measurements were collected in a quiet temperature-controlled room (22–24 °C) following at least 10 min of rest in the supine position. Following the resting vascular measurements, body composition and leg muscle strength were assessed. Participants were asked to maintain their usual diet and lifestyle during the study period (verified through food/physical activity logs).

Anthropometry and body composition

Height was measured using a stadiometer to the nearest 0.01 m, and body weight was measured using a Seca Scale (Sunbeam Products, Boca Raton, FL, USA) to the nearest 0.1 kg. Body mass index was calculated as weight (kg)/height (m^2). Waist circumference was measured to the nearest 0.1 cm using a tape measure at the level of the iliac crest after a normal expiration. Arm and leg lean mass as well as total body fat (%) were evaluated by a whole-body DEXA scan (Lunar TM DPX-IQ, Madison, WI, USA).

Arterial stiffness

BaPWV, carotid-femoral PWV (cfPWV), and femoral-ankle PWV (faPWV) were acquired using an automatic device (VP-2000; Omron Healthcare, Vernon Hills, IL, USA). BP cuffs were wrapped around both arms (brachial artery) and ankles (posterior tibial artery) and two tonometers were placed over the right carotid and femoral arteries in order to obtain PWV measurements of the three arterial segments. The distance from the carotid to the femoral artery was measured using a segmometer and introduced into the device before acquiring the measurements, whereas the distance between sampling points of baPWV and faPWV was automatically calculated according to the participant's height.[22,23] The carotid, femoral, brachial and tibial arterial waveforms were recorded simultaneously by the tonometers and cuff sensors, and the transient time was calculated automatically by relating the foot of each waveform to the R-wave of the electrocardiogram. Two measurements were collected at each time point and averaged for data analysis.

Brachial and aortic hemodynamics

Brachial systolic BP (SBP) and brachial diastolic BP were measured using a validated automatic device (Omron HEM-907XL Pro Healthcare, Vernon Hills, IL, USA) and used to calibrate the radial waveforms obtained from a 10 s epoch using a noninvasive pencil-like high-fidelity transducer (SPT- 301B; Millar Instruments, Houston, TX, USA). The arterial pulse waveforms were obtained from the radial artery of the left arm using applanation tonometry. Aortic pressure waveforms were synthesized from the radial pressure waveform using a validated generalized transfer function (SphygmoCor; AtCor Medical, Sydney, Australia). Aortic SBP (aSBP) and aortic diastolic BP were obtained from the synthesized aortic wave. The aortic wave is composed of a forward wave (resulting from the ejection of the stroke volume) and a reflected wave (returns to the aorta from peripheral sites when it hits points of reflection). Augmented pressure was calculated as the difference between the reflected wave and the forward wave amplitudes. Tr (reflection time) denotes the travel time of the forward wave to the peripheral reflecting sites and back to the aorta.[24] AIx and Tr were previously used as markers of wave reflection and aortic stiffness, respectively.[25] Because of the negative association between heart rate and AIx, AIx was normalized to a heart rate of 75 beats per min (AIx@75). In addition, only high-quality (operator index ⩾ 80%) aortic hemodynamics and the average of two measurements were used in the analysis. For all measurements derived from pulse wave analysis, the intraclass correlation coefficient in our laboratory calculated on two separate days in a subsample was > 0.92. All measurements were acquired by the same experienced technician.

Muscle strength testing

The one-repetition maximum (1RM) was obtained by finding the maximum load that the participant could move through a full range of motion for the leg press exercise (MedX, Ocala, FL, USA). At least 72 h later, participants repeated the 1RM test. The highest measurement was considered as the 1RM in the analysis. The 1RM test was supervised and recorded by the same trained researcher before and after the 6 weeks.

Whole-body vibration training

Both WBVT groups performed three supervised training sessions per week. Participants performed the following four dynamic leg exercises on a vertical vibration platform (pro5 or pro6 AIRdaptive; Health Performance International, Northbrook, IL, USA): (1) squats at a 90° knee angle (180° considered as full knee extension), (2) semi-squats at 120° knee angle, (3) wide-squat at 90° knee angle and (4) calf-raises (maximal heel elevation). Dynamic exercises were performed with controlled movements (through the use of a metronome (60 beats per min)) at a rate of 3 s for both eccentric and concentric contractions. The training volume progressively increased over the 6-week training period by increasing the intensity of the vibration (frequency: 30 to 35 Hz; amplitude: low–high), the duration of the exercise set (30–60 s), the number of sets per each exercise (2–8) and total duration of the training session (11–30 min). Rest periods (60 to 45 s) were progressively decreased between sets. All training sessions were performed under careful supervision from certified personal trainers and researchers. The selected training protocol (intensity progression) (Table 1) was based on that previously used in young and postmenopausal women with obesity.[11,18,26] All the participants performed the exercises barefoot to avoid any variations and/or alterations in the propagation of the vibration to the upper body because of fabric (for example, sock thickness).

Table 1 Whole-body vibration training protocol

Week	Frequency (Hz)	Amplitude	Sets	Time (s)	Rest time (s)
1	30	Low	2	30	60
2	30	Low	4	30	60
3	30	High	4	45	60
4	35	High	6	45	60
5	35	High	6	60	45
6	35	High	8	60	45

Statistical analysis

Normal distribution of the data was confirmed by the Shapiro–Wilk test. Unpaired *t*-test was used to detect possible differences in parameters between groups at baseline. Between- and within-group comparisons were performed with a two-way analysis of variance with repeated measurements (groups (WBVT *vs.* CON) × time (0 weeks *vs.* 6 weeks)) with Bonferroni adjustments. If a significant time effect and/or group-by-time interaction was detected, appropriate *post hoc* tests were used. Pearson's correlations were performed to examine the relationships among changes in muscle strength and PWV as well as central hemodynamics. Statistical analyses were performed using SPSS, version 21.0 (SPSS, Chicago, IL, USA). Statistical significance was set *a priori* at $P < 0.05$. Data are presented as mean ± s.e.m.

RESULTS

Thirty-eight participants were included in the statistical analysis as four participants decided to discontinue their participation in the study because of time commitment (Figure 1). Compliance to the WBVT sessions was 98%. Importantly, none of the women in the WBVT group reported any unfavorable symptoms/signs or adverse side effects resulting from the vibration stimulus.

Participant characteristics, body composition and muscle strength

Participant characteristics, body composition and muscle strength at baseline and following the 6-week period are presented in Table 2. Groups did not differ in any of the variables at baseline. There were no significant changes in any characteristic, except for muscle strength. Leg muscle strength increased in the WBVT group when compared with the CON group ($P < 0.001$).

Hemodynamics and arterial function

Table 3 displays PWV, BP, heart rate and wave reflection at baseline and 6 weeks. Women did not differ in any of the arterial parameters at baseline. Following WBVT, significant time and group-by-time interactions were observed for baPWV, faPWV, brachial SBP, heart rate, aSBP, aortic diastolic BP, AIx@75 ($P < 0.01$), cfPWV (Figure 2) and AIx ($P < 0.05$) as compared with CON. There was a significant reduction in Tr following WBVT ($P < 0.05$). There were no significant changes in brachial diastolic BP in any of the groups. Reductions in cfPWV ($r = -0.41$, $P < 0.05$) were correlated with relative increases in leg muscle strength. Moreover, reductions in baPWV were correlated with decreases in faPWV ($r = 0.53$ $P < 0.001$), aSBP ($r = 0.46$, $P < 0.001$) (Figure 3a), augmented pressure ($r = 0.28$ $P < 0.05$) and AIx@75 ($r = 0.37$ $P < 0.01$) (Figure 3b).

DISCUSSION

This study evaluated the effects of WBVT on arterial function and muscle strength in sedentary, young overweight/obese women. We found that 6 weeks of WBVT significantly improved arterial stiffness (aortic, leg and systemic), central blood pressures and wave reflection accompanied by significant increases in leg muscle strength. To our knowledge, this is the first study to evaluate the effects of solely dynamic WBVT on arterial function.

BaPWV, an accurate measure of systemic arterial stiffness with a clinical validity similar to cfPWV, is mainly composed of cfPWV and faPWV corresponding to central and peripheral arterial stiffness, respectively.[22] Increased baPWV and cfPWV have been associated with prehypertension in normotensive adults without obesity.[27] Recent evidence indicates that obesity does not increase cfPWV;[28] yet, there are increases in peripheral brachial[29] and leg PWV (faPWV).[30] Decreases in baPWV have been previously shown by our group and others following 6 to 12 weeks of WBVT consisting of both static and

Table 2 Participant characteristics, body composition and muscle strength before and after 6 weeks

Variable	CON (n = 13)		WBVT (n = 25)	
	0 Weeks	6 Weeks	0 Weeks	6 Weeks
Age	21 ± 1	—	20 ± 1	—
Height (m)	1.62 ± 0.02	—	1.64 ± 0.01	—
Weight (kg)	82.1 ± 2.8	82.0 ± 3.0	82.1 ± 2.0	82.2 ± 1.8
BMI (kg m^{-2})	31.3 ± 1.1	31.3 ± 1.1	30.7 ± 0.7	30.7 ± 0.6
WC (cm)	102.2 ± 1.5	102.4 ± 1.4	100.7 ± 1.4	100.3 ± 1.3
Body fat (%)	44.8 ± 1.6	44.4 ± 1.8	43.6 ± 0.8	43.4 ± 0.7
Arm LM (kg)	4.6 ± 0.2	4.7 ± 0.2	4.7 ± 0.2	4.7 ± 0.2
Leg LM (kg)	15.8 ± 0.7	15.8 ± 0.7	15.9 ± 0.5	16.2 ± 0.4
Leg 1RM (kg)	369 ± 27	367 ± 27	364 ± 13	425 ± 11[a,b]

Abbreviations: BMI, body mass index; CON, overweight/obese control; LM, lean mass; 1RM, one-repetition maximum; WBVT, whole-body vibration training; WC, waist circumference. Data are mean ± s.e.m.
[a]P < 0.001 different than baseline.
[b]P < 0.001 different than CON.

Table 3 Hemodynamics and arterial function measurements before and after 6 weeks

Variable	CON (n = 13)		WBVT (n = 25)	
	0 Weeks	6 Weeks	0 Weeks	6 Weeks
baPWV (m s^{-1})	10.6 ± 0.1	10.5 ± 0.1	10.9 ± 0.2	10.3 ± 0.1[‡b]
cfPWV (m s^{-1})	7.7 ± 0.1	7.8 ± 0.1	7.8 ± 0.2	7.6 ± 0.1[*a]
faPWV (m s^{-1})	8.6 ± 0.1	8.6 ± 0.1	8.9 ± 0.1	8.6 ± 0.1[†b]
bSBP (mm Hg)	108 ± 3	109 ± 3	108 ± 1	104 ± 1[†b]
bDBP (mm Hg)	69 ± 2	70 ± 2	70 ± 1	69 ± 1
HR (b.p.m.)	63 ± 2	67 ± 2	69 ± 2	66 ± 2[*b]
aSBP (mm Hg)	100 ± 2	100 ± 2	100 ± 1	95 ± 1[‡b]
aDBP (mm Hg)	72 ± 1	73 ± 2	72 ± 1	69 ± 1[†b]
AIx (%)	15.0 ± 2.7	15.0 ± 2.4	15.8 ± 1.0	12.3 ± 1.0[†a]
AIx@75 (%)	9.5 ± 2.7	11.2 ± 3.2	12.7 ± 1.0	7.8 ± 1.0[‡b]
Tr (ms)	144 ± 3	153 ± 6	146.3 ± 3	152.0 ± 3[*]

Abbreviations: aDBP, aortic diastolic blood pressure; AIx, augmentation index; AIx@75, AIx adjusted at a heart rate of 75 beats per min; aSBP, aortic systolic blood pressure; baPWV, brachial-ankle pulse wave velocity; bDBP, brachial diastolic blood pressure; bSBP, brachial systolic blood pressure; cfPWV, carotid-femoral PWV; CON, overweight/obese control; faPWV, femoral-ankle pulse wave velocity; HR, heart rate; Tr, reflection time; WBVT, whole-body vibration training. Data are mean ± s.e.m.
*P < 0.05, [†]P < 0.01, [‡]P < 0.001 different than baseline.
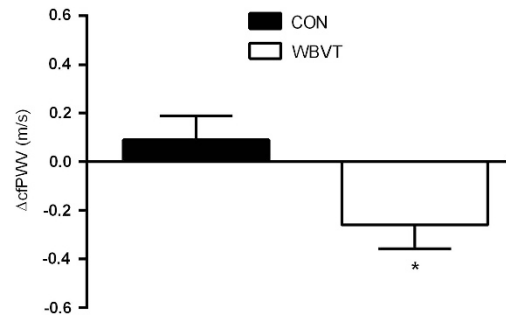[a]P < 0.05, [b]P < 0.01 different than CON.

Figure 2 Changes in aortic stiffness after 6 weeks of whole-body vibration training (WBVT, n = 25) and control (CON, n = 13). cfPWV, carotid-femoral pulse wave velocity. *P < 0.05 different than CON.

dynamic leg exercises in young[11] and postmenopausal women with obesity[12,26] and older adults.[31] Consistent with previous work,[11] our present findings demonstrate that dynamic WBVT reduced baPWV and faPWV in young overweight/obese women, suggesting that isometric exercises in WBVT are not required to promote arterial unstiffening. Therefore, the beneficial effects of WBVT are primarily revealed on the leg arteries in young and older women with obesity.[12,26] Yet, significant reductions in cfPWV differed from the CON group. Similar decreases in cfPWV, but not in faPWV, have been reported after intense aerobic training with longer duration in young and middle-aged lean women.[32] A recent meta-analysis concluded that aerobic training has a greater effect on baPWV than cfPWV, but this benefit is enhanced with higher intensity in participants with increased PWV.[33] In contrast, previous reports have indicated that short-term moderate- to high-intensity RT is ineffective to reduce cfPWV in young normotensive adults,[15,34] young men with

obesity[7] and middle-aged women.[32] Nonetheless, the only study that has observed decreases in faPWV, but not in cfPWV, following high-intensity RT was conducted for 8 weeks in young overweight prehypertensive adults,[34] a population with high cardiovascular risk and are, consequently, more prone for improvements in vascular parameters. In general, RT has shown neither negative nor positive influence on PWV.[33] Therefore, our findings are important because WBVT is an effective low-intensity strength exercise modality with positive effects on central and peripheral arterial stiffness in young women with obesity, a population at risk for early arterial aging.[35]

Higher aortic AIx and BP have been reported in women than in men as well as in obese than in lean individuals.[36,37] However, it is important to note that a current controversy exists on the impact of obesity on AIx.[6,7] Although obesity may increase AIx@75 in adolescents and young adults, it does not coexist with hypertension.[37] Women in this study were normotensive and exhibited an elevated AIx@75 (~13%) at baseline. These findings confirm previous reports from our group indicating that WBVT is effective in decreasing AIx@75 following 6 weeks of WBVT in young and older women with obesity.[11,38] This hemodynamic effect of WBVT has not been observed in most of the studies following high-intensity RT in young men[7,15] and older adults.[39] Only high-intensity aerobic training, but not high-intensity RT, has shown effectiveness in reducing AIx.[33] The exception was a study by Beck et al.[34] who reported that high-intensity RT reduced AIx@75 by 5.7% in young overweight prehypertensive adults. Interestingly, men in the previously addressed studies had negative AIx,[7,15] whereas Beck et al.[34] and the current study exhibited baseline values of 4% and 15%, respectively. Consistent with the previous study in young adults (26.7% women),[34] short-term strength training decreases AIx@75 mainly through reductions in leg arterial stiffness.

In this study, the WBVT protocol reduced aSBP that more accurately reflect the loading conditions of the left ventricle than brachial SBP.[8] The decline in aSBP in this study is consistent with findings observed following high-intensity RT in young men with overweight and obesity.[7,15] Interestingly, these studies demonstrated no decreases in AIx or cfPWV, suggesting that reduction in central BP may precede changes in cfPWV in young adults.[5] We found that decreases in aSBP, augmented pressure and AIx@75 (measures of wave reflection) were related to the decrease in baPWV, a more peripheral measure of PWV. The constant mechanical stimulus to the leg arteries during the vibration exposure could explain the improvements in faPWV and AIx@75 via greater shear stress-mediated increases in circulating nitric oxide, as observed in young active women[40] and postmenopausal women with obesity.[13] It is pivotal to note that the
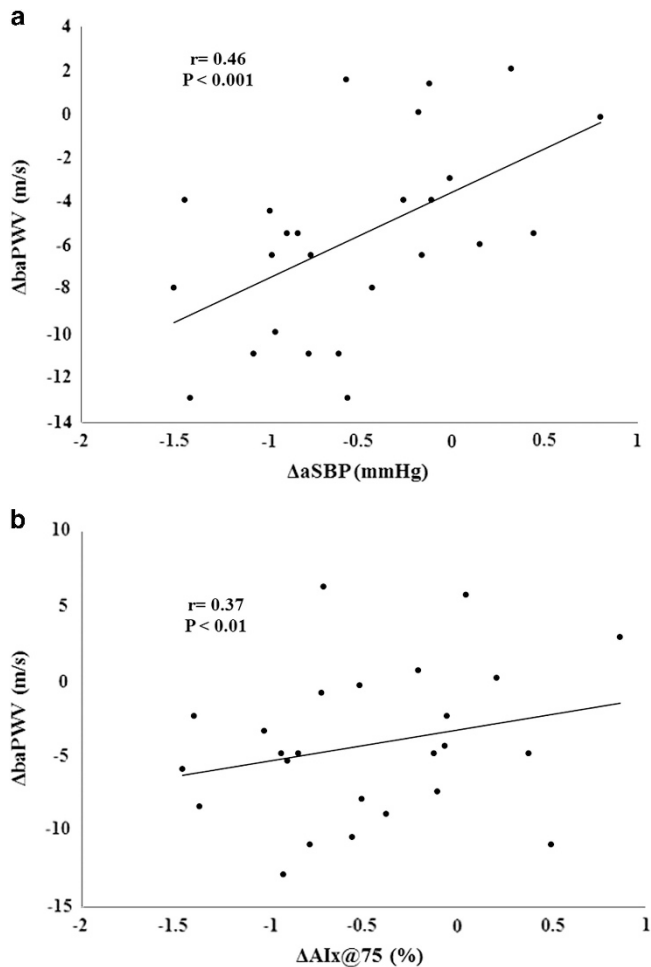
Figure 3 Relationships between changes in brachial-ankle pulse wave velocity (ΔbaPWV) with (a) aortic systolic blood pressure (ΔaSBP) and with (b) augmentation index adjusted to 75 beats per min (b.p.m.; ΔAIx@75).

clinical usefulness of wave reflection is more prominent in younger adults, especially in women because of higher AIx than men.[25]

Our finding of leg muscle strength increases following WBVT is in accordance with previous studies in untrained pre- and post-menopausal women with obesity following 6 to 12 weeks of WBVT.[11,18,38] Muscle strength is essential in the successful performance of daily-living tasks. Because various daily (for example, walking) and recreational (for example, running) activities involve repetitive contractions of the thigh muscles and individuals with obesity fatigue at a greater rate,[41] overall motor performance may be hindered. In addition, the increases in muscle strength seen in this study may have important clinical implications as muscle strength tends to decline at a faster rate than muscle mass with aging.[42] Therefore, incorporating a safe, time-efficient and low-intensity exercise modality to previously sedentary young women could not only serve as an alternative in the prevention and treatment of obesity-related vascular complications but also early muscle dysfunction. In this study, we noted that increases in leg muscle strength (~17.7%) were related to decreases in cfPWV. In contrast, Croymans *et al.*[7] did not observe decreases in cfPWV following a 12-week high-intensity RT in young obese men despite increases in leg muscle strength (~31.3%). Our findings suggest that WBVT leads to concurrent improvements in muscle strength and aortic stiffness in young obese women.

Our study has certain limitations. The effects of longer duration WBVT in young women remain to be elucidated. Because participants of this study were young women, measurements were scheduled based on their self-reported first day of the menstrual cycle. We minimized the confounding effects of menstrual cycle by only including women with regular menstrual cycle duration over at least the past 2 months.[21] Moreover, a clear mechanism to explain the results cannot be proposed because of lack of measurements of endothelial function that are valuable in the interpretation of vascular adaptations following exercise interventions. In addition, the protocol utilized in this study had unique characteristics and, therefore, limits its comparability to other studies utilizing conventional exercise modalities.

CONCLUSIONS

In conclusion, our findings demonstrate that dynamic WBVT is effective in improving arterial stiffness, wave reflection, aortic BP and muscle strength. Dynamic WBVT may be considered an efficient strength exercise modality at a young age for the prevention of future cardiovascular events. In addition, dynamic WBVT seems to be a safe and time-efficient exercise modality for young sedentary women with obesity.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

1 Nagai M, Ohkubo T, Murakami Y, Takashima N, Kadota A, Miyagawa N, Saito Y, Nishi N, Okuda N, Kiyohara Y, Nakagawa H, Nakamura Y, Fujiyoshi A, Abbott RD, Okamura T, Okayama A, Ueshima H, Miura KNIPPON DATA80/90/2010 Research Group. Secular trends of the impact of overweight and obesity on hypertension in Japan, 1980-2010. *Hypertens Res* 2015; **38**: 790–795.
2 Zebekakis PE, Nawrot T, Thijs L, Balkestein EJ, van der Heijden-Spek J, Van Bortel LM, Struijker-Boudier HA, Safar ME, Staessen JA. Obesity is associated with increased arterial stiffness from adolescence until old age. *J Hypertens* 2005; **23**: 1839–1846.
3 Wildman RP, Mackey RH, Bostom A, Thompson T, Sutton-Tyrrell K. Measures of obesity are associated with vascular stiffness in young and older adults. *Hypertension* 2003; **42**: 468–473.
4 Choo J, Shin C, Barinas-Mitchell E, Masaki K, Willcox BJ, Seto TB, Ueshima H, Lee S, Miura K, Venkitachalam L, Mackey RH, Evans RW, Kuller LH, Sutton-Tyrrell K, Sekikawa A. Regional pulse wave velocities and their cardiovascular risk factors among healthy middle-aged men: a cross-sectional population-based study. *BMC Cardiovasc Disord* 2014; **14**: 5.
5 Chen W, Li S, Fernandez C, Sun D, Lai C-C, Zhang T, Bazzano L, Urbina EM, Deng H-W. Temporal relationship between elevated blood pressure and arterial stiffening among middle-aged black and white adults: the Bogalusa Heart Study. *Am J Epidemiol* 2016; **183**: 599–608.
6 Urbina EM, Gao Z, Khoury PR, Martin LJ, Dolan LM. Insulin resistance and arterial stiffness in healthy adolescents and young adults. *Diabetologia* 2012; **55**: 625–631.
7 Croymans DM, Krell SL, Oh CS, Katiraie M, Lam CY, Harris RA, Roberts CK. Effects of resistance training on central blood pressure in obese young men. *J Hum Hypertens* 2014; **28**: 157–164.
8 Roman MJ, Devereux RB, Kizer JR, Lee ET, Galloway JM, Ali T, Umans JG, Howard B V. Central pressure more strongly relates to vascular disease and outcome than does brachial pressure: the Strong Heart Study. *Hypertension* 2007; **50**: 197–203.
9 Maslow AL, Sui X, Colabianchi N, Hussey J, Blair SN. Muscular strength and incident hypertension in normotensive and prehypertensive men. *Med Sci Sports Exerc* 2010; **42**: 288–295.
10 Ochi M, Kohara K, Tabara Y, Kido T, Uetani E, Ochi N, Igase M, Miki T. Arterial stiffness is associated with low thigh muscle mass in middle-aged to elderly men. *Atherosclerosis* 2010; **212**: 327–332.
11 Figueroa A, Gil R, Wong A, Hooshmand S, Park SY, Vicil F, Sanchez-Gonzalez MA. Whole-body vibration training reduces arterial stiffness, blood pressure and sympatho-vagal balance in young overweight/obese women. *Hypertens Res* 2012; **35**: 667–672.
12 Figueroa A, Alvarez-Alvarado S, Ormsbee MJ, Madzima TA, Campbell JC, Wong A. Impact of L-citrulline supplementation and whole-body vibration training on arterial stiffness and leg muscle function in obese postmenopausal women with high blood pressure. *Exp Gerontol* 2015; **63**: 35–40.

13 Wong A, Alvarez-Alvarado S, Jaime SJ, Kinsey AW, Spicer MT, Madzima TA, Figueroa A. Combined whole-body vibration training and l-citrulline supplementation improves pressure wave reflection in obese postmenopausal women. *Appl Physiol Nutr Metab* 2016; **41**: 292–297.

14 Winett RA, Carpinelli RN. Potential health-related benefits of resistance training. *Prev Med (Baltim)* 2001; **33**: 503–513.

15 Heffernan KS, Fahs CA, Iwamoto GA, Jae SY, Wilund KR, Woods JA, Fernhall B. Resistance exercise training reduces central blood pressure and improves microvascular function in African American and white men. *Atherosclerosis* 2009; **207**: 220–226.

16 Cortez-Cooper MY, DeVan AE, Anton MM, Farrar RP, Beckwith KA, Todd JS, Tanaka H. Effects of high intensity resistance training on arterial stiffness and wave reflection in women. *Am J Hypertens* 2005; **18**: 930–934.

17 Verschueren SMP, Roelants M, Delecluse C, Swinnen S, Vanderschueren D, Boonen S. Effect of 6-month whole body vibration training on hip density, muscle strength, and postural control in postmenopausal women: a randomized controlled pilot study. *J Bone Miner Res* 2004; **19**: 352–359.

18 Machado A, García-López D, González-Gallego J, Garatachea N. Whole-body vibration training increases muscle strength and mass in older women: a randomized-controlled trial. *Scand J Med Sci Sports* 2010; **20**: 200–207.

19 Bush JA, Blog GL, Kang J, Faigenbaum AD, Ratamess NA. Effects of quadriceps strength after static and dynamic whole-body vibration exercise. *J Strength Cond Res* 2015; **29**: 1367–1377.

20 Dipla K, Kousoula D, Zafeiridis A, Karatrantou K, Nikolaidis MG, Kyparos A, Gerodimos V, Vrabas IS. Exaggerated haemodynamic and neural responses to involuntary contractions induced by whole-body vibration in normotensive obese versus lean women. *Exp Physiol* 2016; **101**: 717–730.

21 Adkisson EJ, Casey DP, Beck DT, Gurovich AN, Martin JS, Braith RW. Central, peripheral and resistance arterial reactivity: fluctuates during the phases of the menstrual cycle. *Exp Biol Med (Maywood)* 2010; **235**: 111–118.

22 Yamashina A, Tomiyama H, Takeda K, Tsuda H, Arai T, Hirose K, Koji Y, Hori S, Yamamoto Y. Validity, reproducibility, and clinical significance of noninvasive brachial-ankle pulse wave velocity measurement. *Hypertens Res* 2002; **25**: 359–364.

23 Munakata M, Ito N, Nunokawa T, Yoshinaga K. Utility of automated brachial ankle pulse wave velocity measurements in hypertensive patients. *Am J Hypertens* 2003; **16**: 653–657.

24 Murgo JP, Westerhof N, Giolma JP, Altobelli SA. Aortic input impedance in normal man: relationship to pressure wave forms. *Circulation* 1980; **62**: 105–116.

25 McEniery CM, Yasmin, Hall IR, Qasem A, Wilkinson IB, Cockcroft JR. Normal vascular aging: differential effects on wave reflection and aortic pulse wave velocity: the Anglo-Cardiff Collaborative Trial (ACCT). *J Am Coll Cardiol* 2005; **46**: 1753–1760.

26 Figueroa A, Kalfon R, Madzima TA, Wong A. Whole-body vibration exercise training reduces arterial stiffness in postmenopausal women with prehypertension and hypertension. *Menopause* 2014; **21**: 131–136.

27 Jang SY, Ju EY, Huh EH, Kim JH, Kim D-K. Determinants of brachial-ankle pulse wave velocity and carotid-femoral pulse wave velocity in healthy Koreans. *J Korean Med Sci* 2014; **29**: 798–804.

28 Desamericq G, Tissot C-M, Akakpo S, Tropeano A-I, Millasseau S, Macquin-Mavier I. Carotid-femoral pulse wave velocity is not increased in obesity. *Am J Hypertens* 2015; **28**: 546–551.

29 Kappus RM, Fahs CA, Smith D, Horn GP, Agiovlasitis S, Rossow L, Jae SY, Heffernan KS, Fernhall B. Obesity and overweight associated with increased carotid diameter and decreased arterial function in young otherwise healthy men. *Am J Hypertens* 2014; **27**: 628–634.

30 Snijder MB, Henry RMA, Visser M, Dekker JM, Seidell JC, Ferreira I, Bouter LM, Yudkin JS, Westerhof N, Stehouwer CDA. Regional body composition as a determinant of arterial stiffness in the elderly: the Hoorn Study. *J Hypertens* 2004; **22**: 2339–2347.

31 Lai C-L, Chen H-Y, Tseng S-Y, Liao W-C, Liu B-T, Lee M-C, Chen H-S. Effect of whole-body vibration for 3 months on arterial stiffness in the middle-aged and elderly. *Clin Interv Aging* 2014; **9**: 821–828.

32 Yoshizawa M, Maeda S, Miyaki A, Misono M, Saito Y, Tanabe K, Kuno S, Ajisaka R. Effect of 12 weeks of moderate-intensity resistance training on arterial stiffness: a randomised controlled trial in women aged 32-59 years. *Br J Sports Med* 2009; **43**: 615–618.

33 Ashor AW, Lara J, Siervo M, Celis-Morales C, Mathers JC. Effects of exercise modalities on arterial stiffness and wave reflection: a systematic review and meta-analysis of randomized controlled trials. *PLoS ONE* 2014; **9**: e110034.

34 Beck DT, Martin JS, Casey DP, Braith RW. Exercise training reduces peripheral arterial stiffness and myocardial oxygen demand in young prehypertensive subjects. *Am J Hypertens* 2013; **26**: 1093–1102.

35 Jordan J, Nilsson PM, Kotsis V, Olsen MH, Grassi G, Yumuk V, Hauner H, Zahorska-Markiewicz B, Toplak H, Engeli S, Finer N. Joint scientific statement of the European Association for the Study of Obesity and the European Society of Hypertension: obesity and early vascular ageing. *J Hypertens* 2015; **33**: 425–434.

36 Krzesiński P, Stańczyk A, Gielerak G, Uziębło-Życzkowska B, Kurpaska M, Piotrowicz K, Skrobowski A. Sex determines cardiovascular hemodynamics in hypertension. *J Hum Hypertens* 2015; **29**: 610–617.

37 Urbina EM, Kimball TR, Khoury PR, Daniels SR, Dolan LM. Increased arterial stiffness is found in adolescents with obesity or obesity-related type 2 diabetes mellitus. *J Hypertens* 2010; **28**: 1692–1698.

38 Figueroa A, Kalfon R, Madzima TA, Wong A. Effects of whole-body vibration exercise training on aortic wave reflection and muscle strength in postmenopausal women with prehypertension and hypertension. *J Hum Hypertens* 2014; **28**: 118–122.

39 Casey DP, Beck DT, Braith RW. Progressive resistance training without volume increases does not alter arterial stiffness and aortic wave reflection. *Exp Biol Med (Maywood)* 2007; **232**: 1228–1235.

40 Humphries B, Fenning A, Dugan E, Guinane J, MacRae K. Whole-body vibration effects on bone mineral density in women with or without resistance training. *Aviat Space Environ Med* 2009; **80**: 1025–1031.

41 Maffiuletti NA, Jubeau M, Munzinger U, Bizzini M, Agosti F, De Col A, Lafortuna CL, Sartorio A. Differences in quadriceps muscle strength and fatigue between lean and obese subjects. *Eur J Appl Physiol* 2007; **101**: 51–59.

42 Goodpaster BH, Park SW, Harris TB, Kritchevsky SB, Nevitt M, Schwartz AV, Simonsick EM, Tylavsky FA, Visser M, Newman AB. The loss of skeletal muscle strength, mass, and quality in older adults: the health, aging and body composition study. *J Gerontol A Biol Sci Med Sci* 2006; **61**: 1059–1104.