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The Effects of Mat Pilates Training on Vascular Function and Body Fatness in Obese Young Women With Elevated Blood Pressure

Alexei Wong,¹ Arturo Figueroa,² Stephen M. Fischer,² Reza Bagheri,³ and Song-Young Park⁴

¹Department of Health and Human Performance, Marymount University, Arlington, VA, USA;

²Department of Kinesiology and Sport Management, Texas Tech University, Lubbock, TX, USA;

³Department of Exercise Physiology, University of Isfahan, Isfahan, Iran;

⁴Department of Health and Kinesiology, University of Nebraska-Omaha, Omaha, NE, USA.

Abstract

BACKGROUND

Effective nonpharmacological interventions targeting the enhancement of vascular function and decline of body fatness (BF) in obese individuals are indispensable for the prevention of hypertension and cardiovascular events in young adults. Mat Pilates training (MPT) has gained significant popularity worldwide, yet its effects on vascular function and body composition are understudied. We examined the effects of MPT on vascular function and BF in young obese women with elevated blood pressure (BP).

METHODS

Twenty-eight young obese women with elevated BP were randomized to an MPT ($n = 14$) or a nonexercising control (CON, $n = 14$) group for 12 weeks. Systemic arterial stiffness (brachial-ankle pulse wave velocity (baPWV)), brachial and aortic BP, wave reflection (augmentation index (AIx)), plasma nitric oxide (NO) levels, and BF percentage (BF%) were assessed before and after 12 weeks.

RESULTS

MPT significantly reduced ($P < 0.05$) baPWV (-0.7 ± 0.2 m/s), AIx ($-4 \pm 1\%$), brachial systolic BP (-5 ± 1 mm Hg), aortic systolic BP (-6 ± 1 mm Hg), and BF% ($-2 \pm 1\%$), while significantly increasing plasma NO (6 ± 2 μ M) ($P < 0.05$) compared with

CON. MPT improved systemic arterial stiffness, aortic BP, wave reflection, circulating plasma NO, and BF% in young obese women with elevated BP.

CONCLUSIONS

MPT may be an effective intervention for the improvement of vascular function and BF in young obese women with elevated BP, a population at risk for hypertension and early vascular complications.

CLINICAL TRIALS REGISTRATION

Trial Number NCT03907384.

Keywords:

Adiposity, aortic blood pressure, arterial health, arterial stiffness, blood pressure, hypertension, Pilates exercise, wave reflection

Issue Section: Exercise

The prevalence of obesity among young adults has become a major public health concern. In fact, obesity is associated with a variety of vascular disorders, including hypertension and early development of arteriosclerosis and atherosclerosis, which are major cardiovascular (CV) risk factors. In young adults, arterial stiffness (pulse wave velocity (PWV)) is higher in the obese when compared with their lean and overweight counterparts.¹ While elevation in PWV is a characteristic of the aging process, obesity more negatively affects PWV in middle-aged and older women than men.² Moreover, obese individuals also present a raised pressure wave reflection (augmentation index (AIx))³ and aortic blood pressure (BP)⁴ that more precisely reflect left ventricular load and, thus, are better indexes of CV risk than brachial BP.⁵ Consequently, effective strategies aiming at improving aortic hemodynamics and arterial function in obese women are crucial for the prevention of hypertension and CV events at an early age.

It is well-documented that exercise is a vital factor in the prevention and management of vascular dysfunction.^{4,6} Although in obese populations aerobic (AT) and resistance training (RT) have been shown to effectively improve arterial function,^{4,7} obese women show a drop in adherence to traditional exercise and continue to experience considerable increases in weight and declines in vascular health.^{6,8} Hence, new exercise modalities are needed to improve

vascular function in obese females, which will ultimately decrease CV risk factors and improve CV health in this population.

Pilates is an exercise modality which has gained significant popularity worldwide, especially among women.^{9,10} Within Pilates there are many disciplines, with Mat Pilates (MP) being the most widely used today,¹¹ since its practice requires only economical materials and a limited space. This type of exercise includes a series of low intensity exercises using mainly body weight as external resistance, strengthening the trunk through isometric contraction of the core musculature while focusing on controlled breathing, flexibility, and posture.⁹ Despite the several press reports on its vascular benefits and its use as a strategy to ameliorate CV diseases, existing scientific literature is scarce.¹⁰ Hence, the aim of this study was to investigate the effects of MP training on vascular function (PWV, Alx, and BP) in young obese women with elevated BP, hypothesizing that MP would improve aortic hemodynamics and PWV in this population. We also evaluated levels of the key endothelial health marker and vasodilator nitric oxide (NO), as a mechanism that might help explain some potential favorable changes in vascular function.

METHODS

Study design

A parallel experimental design was used in the current study. Following an initial screening and familiarization meeting, eligible participants were randomized into one of the following groups: MP or CON for 12 weeks. Randomization was stratified by body mass index (BMI) (>30 and <35 ($n = 9$ in the MP and $n = 8$ in the CON group) or ≥ 35 and <40 kg/m² ($n = 5$ in the MP and $n = 6$ in the CON group)) and the sequence was generated by a computer-based number. Investigators were blinded to group assignment. Vascular measurements were performed at baseline and after 12 weeks in a noiseless temperature-controlled room (22–24 °C), following at least 10 minutes of rest in the supine position. Body composition was assessed immediately after. Measurement requirements were as follows: (i) conducted in a fasted state in the morning hours and at the same time of the day (± 1 hour to avoid potential diurnal variations); (ii) between 48 and 72 hours after the last training session (to avoid any potential acute effects of exercise); (iii) conducted during the late-luteal phase (\geq day 19) of the menstrual

cycle to avoid possible effects of endogenous estrogens on vascular and autonomic function¹²; (iv) abstention from caffeine, alcohol, or unusual physical activity in the previous 24 hours. Participants were asked not to modify their regular lifestyles through the duration of the investigation. In addition, to minimize dietary variability the participants were required to submit 3-day food records at baseline and at 8 weeks of the assigned intervention.

Subjects

Twenty-eight young obese women (age 19–27 years) and BMI (30–40 kg/m²) were enrolled in this investigation. Based on the latest American College of Cardiology/American Heart Association guidelines, women had elevated BP (120–129 mm Hg systolic BP (SBP) and <80 mm Hg for diastolic BP (DBP)); but were free of chronic diseases (verified through medical history questionnaires). The participants were also nonsmokers and sedentary (defined as <90 minutes per week of regular exercise for the past 6 months). Women were excluded if they had BMI <30 and ≥40 kg/m², chronic diseases, gallstones, kidney stones, arthritis, recent operative wounds, metal implants or were taking oral contraceptives. Additional exclusion criteria were pregnancy, irregular/un- stable menstrual cycle, and/or taking any medications that affected the outcome variables. None of the participants had previous experience with MP. Women were recruited from around the community through announcements and direct communication. All participants provided written informed consent to participate in the study. The study protocol was approved by the Institutional Human Subject Committee and registered in Clinicaltrials.gov (NCT03907384).

Procedures

Anthropometry and body composition Body weight and height were measured to the nearest 0.1 kg and 1 cm, respectively, using a weighing scale (Life Measurement Inc, Concord, CA) and a stadiometer. BMI was calculated as weight/height (in kilograms per meter square). Fat mass (FM), body fat (BF%), and lean body mass were determined using a bioelectrical impedance meter (InBody 230; Biospace, Seoul, Korea) as previously described.¹³

Vascular function BP and brachial to ankle PWV (baPWV, a measure of systemic arterial stiffness) were assessed by a volume plethysmographer (VP-1000; Colin Co., Komaki, Aichi, Japan) as previously described.^{14,15} A commercially available applanation tonometer

(SphygmoCor; AtCor Medical Ltd, Sydney, Australia) was used with analysis software (version 8.0, SphygmoCor Cardiovascular Management Suite; AtCor Medical Ltd) for measurement of pulse wave analysis components. Aortic pulse waveforms were reconstructed by a validated generalized transfer function. Aortic SBP and DBP were obtained from the aortic wave, which is composed of a forward wave determined by the stroke volume, and a reflected wave that returns to the aorta from peripheral arterial sites.¹⁶ Augmented pressure (AP) is the difference between the second and first systolic peaks. The AIx is AP as a percentage of the aortic pulse pressure (PP). AIx was normalized to a heart rate (HR) of 75 beats/min (AIx@75), because it is negatively influenced by HR.¹⁶ Tr (time of reflection) is the travel time of the incident wave to reflecting peripheral sites and back to the aorta, it has been proposed as a marker of aortic stiffness.¹⁷ PP amplification was calculated as the brachial-to-aortic PP ratio.¹⁸ Two measurements were collected at each time point and averaged as previously described.¹⁴ The validity and reproducibility of noninvasive applanation tonometry measures have been previously shown.¹⁵ The intraclass correlation coefficient for all measurements derived from tonometry, calculated on 2 separate days in a subsample, was >0.90.

Blood sampling and analysis Venous blood samples were obtained from an antecubital vein around 8 AM \pm 1 hour, following an overnight fast. Blood was centrifuged and stored at -80°C for future analysis. To assess NO production, total nitrite/nitrate concentration was assayed using a commercially available Griess assay kit from Cayman Chemical (Ann Arbor, MI). The amount of nitrite/nitrate produced in the reaction mixture was determined spectrophotometrically at 540 nm (OD540) using a microplate reader.

Mat Pilates training The MP group participated in 3-one hour supervised training sessions per week for 12 weeks. All MP Sessions were performed in nonconsecutive days. The MP sessions were divided into the following stages: initial warm up and stretching (10 minutes), general conditioning consisting of MP exercises (40 minutes), and stretching and cooling down (10 minutes). The participants performed 12 basic MP exercises according to the 7 MP principles detailed in the books of Joseph Pilates¹⁹ and Siler.²⁰ One set of 6–10 repetitions was performed per exercise. Breathing, a core principle of MP, was performed by forced but controlled inspirations and exhalations, while relaxing and contracting the abdomen, respectively. Training intensity progressed by increasing the degrees of difficulty and

complexity of the exercise. Volume of training progressed over 12 weeks by increasing the number of repetitions per exercise: 6 repetitions in weeks 1–4, 8 repetitions in weeks 5–8, and 10 repetitions in weeks 9–12. All sessions were supervised by a certified MP instructor. The MP training protocol was adapted from prior studies that found improvements in BP, Alx, and body composition in different populations.^{21–23}

Statistical analysis

The Kolmogorov–Smirnov test was performed to check for normal distribution in all parameters. Group comparisons at baseline were carried out via Student's *t*-test. A 2 × 2 Analysis of variance with repeated measures [group (control × MP) × time (before × after 12 weeks)] was done to establish the effect of MP and time on dependent variables. A paired *t*-test was carried out for within-group post hoc analysis, if a significant interaction was detected. Pearson's correlation coefficients were used to examine associations between changes in significant variables. Because Mean Arterial Pressure is an important determinant of PWV,²⁴ we performed an additional 2 × 2 Analysis of variance with repeated measures with MAP as a covariate to determine if the changes in baPWV were influenced by BP. Analyses were carried out utilizing SPSS 25.0 for Windows (IBM SPSS Analytics, Armonk, NY). Data are expressed as mean ± SEM. Statistical significance was set at $P < 0.05$. To achieve a difference of 3–5% between the groups (control vs. MP) in SBP and Alx with a power of 80%, we needed a total sample size of at least 20 (10 subjects per group). This was determined by performing a power analysis calculation.^{22,23}

RESULTS

Anthropometry, body composition, and dietary characteristics before and after 12 weeks for the control and MP groups are presented in Table 1. Data are shown as means (SEM). Baseline parameters between the 2 groups were not significantly different ($P > 0.05$). There were significant group × time interactions for FM and BF% ($P < 0.05$) which significantly declined following MP compared with no changes after control. There were no significant changes in weight, BMI, lean body mass, and energy intake after MP or control. Parameters of vascular function at baseline and after 12 weeks for the control and MP groups are presented in Table 2. There was a significant group × time interaction ($P < 0.05$) for baPWV (Figure 1a), brachial SBP, DBP, and MAP, and aortic SBP, DBP, MAP, Alx, Alx@75 (Figure 1b), PP, and AP such that all

significantly decreased ($P < 0.05$) while plasma NO levels (Figure 1c) significantly increased ($P < 0.05$) after MP compared with no changes after control. Results did not differ when baPWV was adjusted to brachial MAP. The changes in Aix were correlated with changes in AP ($r = 0.70$, $P < 0.05$) and baPWV ($r = 0.59$, $P < 0.05$) in the MP group. No other correlations between changes were found. Additionally, there were no significant changes in Tr and HR after MP or control.

Table 1. Subjects characteristics and dietary composition before and after 12 weeks of MPT or Control

Variable	Cont rol ($n = 14$)		MPT ($n = 14$)	
	Before	After	Before	After
Age (y)	23 ± 1	—	22 ± 1	—
Height (m)	1.56 ± 0.02	—	1.55 ± 0.02	—
Body weight (kg)	83.6 ± 2.8	83.8 ± 2.6	82.4 ± 2.3	81.9 ± 2.6
BMI (kg/m ²)	34.4 ± 1.0	34.4 ± 0.9	34.3 ± 0.8	34.1 ± 0.8
LBM (kg)	46.4 ± 1.4	46.4 ± 1.2	45.6 ± 1.2	46.9 ± 1.3
FM (kg)	37.1 ± 1.2	37.4 ± 1.2	36.8 ± 1.0	34.9 ± 1.1*,†
BF (%)	44.4 ± 1.4	44.6 ± 1.3	44.7 ± 1.3	42.6 ± 1.4*,†
Energy intake (kcal/day)	2,522 ± 64	2,529 ± 68	2,545 ± 73	2,588 ± 80

Abbreviations: BF, body fat; BMI, body mass index; FM, fat mass; LBM, lean body mass; MPT, Mat Pilates training. Data are mean ± SEM.

* $P < 0.05$ different than before.

† $P < 0.05$ different than control.

DISCUSSION

MP has been proposed as a nonpharmacological intervention to ameliorate CV diseases through improvements in vascular benefits by several press reports in the last 2 decades.¹⁰ Yet, reliable literature on the measurable effects of MP on vascular function markers have only been reported within the last 6 years.^{22,23,25} Novel findings of the present study include improvements in systemic arterial stiffness and plasma NO levels after MP training, as all previous studies measured hemodynamic parameters. We found that 12 weeks of MP training resulted in

beneficial improvements in aortic hemodynamics, arterial stiffness, and plasma NO levels in young obese females with elevated BP, which indicate that MP training improves vascular function in this cohort. To our knowledge, this is the first study to evaluate the effects of MP training on resting vascular function (PWV, Alx, and BP) and plasma NO levels.

Table 2. Vascular function parameters and heart rate before and after 12 weeks of MPT or Control

Variable	Cont rol (<i>n</i> = 14)		MPT (<i>n</i> = 14)	
	Before	After	Before	After
Brachial SBP (mm Hg)	127 ± 2	128 ± 3	126 ± 2	121 ± 2 ^{*,†}
Brachial DBP (mm Hg)	75 ± 2	76 ± 2	76 ± 2	72 ± 2 ^{*,†}
Brachial PP (mm Hg)	52 ± 2	52 ± 2	50 ± 2	49 ± 2
Brachial MAP (mm Hg)	92 ± 2	93 ± 2	93 ± 2	88 ± 2 ^{*,†}
Aortic SBP (mm Hg)	119 ± 2	120 ± 3	118 ± 2	112 ± 2 ^{*,†}
Aortic DBP (mm Hg)	77 ± 2	77 ± 1	78 ± 2	74 ± 2 ^{*,†}
Aortic PP (mm Hg)	42 ± 2	43 ± 2	40 ± 2	38 ± 2 [*]
Aortic MAP (mm Hg)	91 ± 2	91 ± 2	91 ± 2	87 ± 2 ^{*,†}
PP amplification	1.24 ± 0.06	1.21 ± 0.07	1.25 ± 0.06	1.28 ± 0.06
Alx (%)	15 ± 2	15 ± 2	16 ± 2	12 ± 2 ^{*,†}
AP (mm Hg)	6 ± 2	6 ± 2	7 ± 2	4 ± 2 ^{*,†}
Time of reflection (ms)	146 ± 3	145 ± 4	143 ± 3	145 ± 4
Heart rate (beats/min)	64 ± 2	63 ± 2	65 ± 2	64 ± 2

Abbreviations: Alx, augmentation index; AP, augmented pressure; DBP, diastolic blood pressure; MPT, Mat Pilates training; PP, pulse pressure; SBP, systolic blood pressure. Data are mean ± SEM.

**P* < 0.05 different than before.

†*P* < 0.05 different than control.

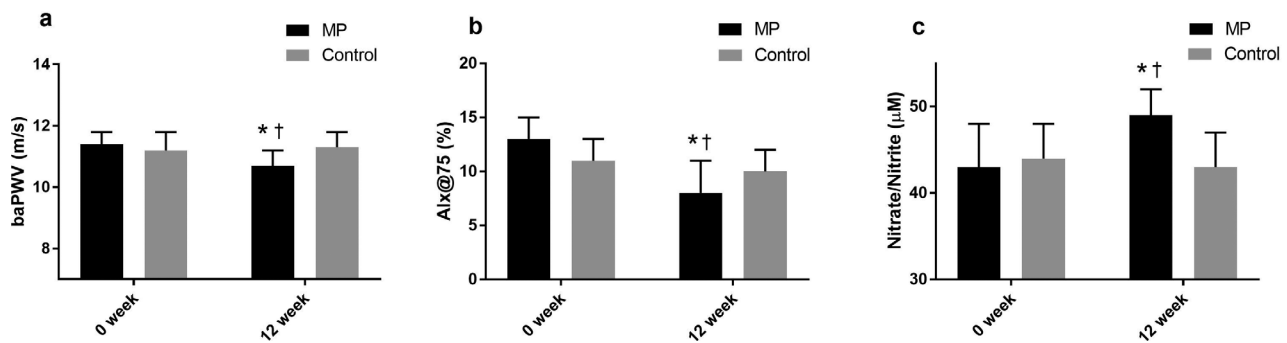


Figure 1. The changes observed in (a) brachial-ankle pulse wave velocity (baPWV); (b) augmentation index adjusted to a heart rate of 75 bpm (Alx@75); (c) nitrate/nitrite from 0 to 12 weeks using Mat Pilates (MP) or Control. * $P < 0.05$ from 0 to 12 weeks within-group; † $P < 0.05$ between MP and Control (group-by-time interaction).

Our MP intervention significantly decreased baPWV in young obese females with elevated BP, which reflects a decrease in systemic arterial stiffness. The main components of baPWV are carotid–femoral PWV and femoral–tibial PWV, which correspond to stiffness of the aorta and leg arteries, respectively.¹⁵ Current literature shows that obesity does not elevate aortic PWV²⁶; yet, there are increases in arm²⁷ and leg PWV.²⁸ Our data exhibited no change in Tr and PP amplification, suggesting that the decrease in baPWV was not influenced by aortic stiffness but by a reduction in peripheral arterial stiffness. In support to our findings, Beck and colleagues²⁹ observed decreases in leg PWV, but not in aortic PWV, following 2 months of high intensity RT in young overweight adults with elevated BP (a population with high CV risk similar to the one examined in the present study). However, a meta-analysis by Ashor *et al.*³⁰ concluded that RT has neither negative nor positive effects on PWV. Moreover, it was determined that AT decreases both aortic PWV and leg PWV, which consequently decreases baPWV, and this improvement is boosted with higher intensity in individuals with increased arterial stiffness.³⁰ Our findings are important because MP is effective lowering systemic arterial stiffness in young obese women, a population at risk for early arterial complications.

We found that MP training decreased brachial SBP (–4 mm Hg) and aortic SBP (–5 mm Hg). Similar to our findings, a 12-week investigation reported declines in brachial SBP (–3 mm Hg) and aortic SBP (–4 mm Hg) in both active individuals with prior Pilates experience and sedentary individuals after MP training.²² Additionally, results from a previous

randomized, controlled clinical trial show decreases in brachial SBP and DBP after 16 weeks of MP training in hypertensive women that were taking BP medication.²³ Marinda *et al.*²⁵ noted decreases in brachial SBP (-6 mm Hg) after 8 weeks of MP in elderly women. In a recent review, Gonzáles *et al.* propose MP as an effective BP lowering intervention and suggest that its hypotensive effect may be due in part to the isometric component of this type of exercise.³¹ On that note, various meta-analyses have suggested that isometric training produce similar hypotensive effects to those of AT in individuals with elevated BP.³² As adherence to aerobic exercise is low in obese populations,³³ MP might provide a BP lowering viable alternative to traditional AT. However, further studies in different populations are needed to validate our claim.

The Alx is the difference between the late and early systolic peak (AP) relative to aortic PP. Considering that Alx can be negatively influenced by HR, the Alx is frequently normalized to 75 beats/min.¹⁶ Our findings revealed that MP training significantly reduced Alx and Alx@75, which seems relevant as our participants exhibited an elevated Alx (~16%) and Alx@75 (~13%) at baseline for their age.¹⁶ Since Tr and HR were not affected by MP training, the decline in Alx can be accredited to a decrease in the magnitude of the reflected wave, which determines aortic SBP and PP.¹⁶ This notion is confirmed by a decrease in AP as well as the positive correlations between changes in Alx with changes in AP and baPWV (includes peripheral arterial stiffness, which affects wave reflection), in the current study. These findings agree with a previous report that found decreases in Alx in sedentary individuals after 12 weeks of MP training.²² Recent meta-analytic work showed that only traditional AT, but not RT, is effective at reducing Alx.³⁰ However, obese women have a reduced compliance to long sessions of AT, especially at high intensity.⁸ As women exhibit higher Alx than men and obese compared with lean individuals;^{34,35} our findings may be of utmost clinical importance for obese women with elevated BP, a cohort at high risk of developing CV complications related to an increase in AP and PP.³⁶ Aortic SBP, PP, and Alx are positively associated with left ventricle filling pressure in women with hypertension,³⁴ indicating the increased risk of ventricular diastolic dysfunction due to arterial pulsatile load in women. Our findings suggest, therefore, that the reductions in aortic SBP and PP evoked by MP training were largely driven by a decrease in wave

reflection (Alx and AP) without involvement of the timing of the reflected wave, which is determined by aortic stiffness.

The MP program was also effective for increasing plasma NO levels, suggesting an improvement in endothelial function. It is suggested that regular bouts of exercise upregulate the L-arginine-NO pathway³⁷ as the endothelium is stimulated by muscle contraction-mediated mechanical stimulation secondary to increased blood flow and shear stress.³⁷ Similar to our results, NO levels were reported to rise following 1–3 months of AT or RT in several populations.^{38,39} Notably, while previous research examined NO levels after AT or RT, this investigation is the first to assess increases in plasma NO metabolites after MP training.

Early vascular dysfunction demonstrated as increased aortic PWV and Alx is determined by adiposity in young individuals with normal and elevated BP.³ The findings of the present study support MP training as a useful intervention for decreasing adiposity in young obese women with elevated BP. Reducing BF (especially abdominal fat) is imperative for reducing the risk of CV disease in obese adults, as there is a positive association between abdominal fat and CV disease as well as metabolic abnormalities.⁴⁰ Our results are in accordance with those of Fourie *et al.*⁴¹ and Rogers *et al.*⁴² who found decreases of 1–2% in BF in elderly women following an 8-week MP training. The reduction in BF% was attributed to FM loss, which did not affect body weight due to a concurrent nonsignificant increase in lean body mass. Weight loss with energy restricted diet reduces aortic and leg PWV in obese women; however, this dietary approach results in muscle mass loss. Obesity is associated with arterial stiffening as result of increased leptin and inflammatory molecules released from FM.⁴³ Therefore, FM loss is associated with reduction in arterial stiffness by reducing circulating leptin, which impairs endothelial vasodilation via reduced NO synthesis.⁴³ Arterial stiffness is increased in young obese without hypertension even after controlling for BP,³⁵ suggesting that vascular remodeling precedes hypertension in young obese adults. In the present study, reduction in baPWV persisted after controlling for the distending pressure (MAP), suggesting that improvement in vascular function may reduce the risk of hypertension.²⁴ The present study adds to the current knowledge that MP training improves adiposity and BP, the main risk factors of the metabolic syndrome.

The possible mechanisms for this favorable adaptation in BF are an amplified

metabolic demand, oxygen uptake, and postexercise energy expenditure, all of which result in a greater caloric expenditure and a reduction in BF%.⁴⁴ As for the mechanisms responsible for improvements in systemic arterial stiffness, aortic BP, and wave reflection after MP training, our current results show that increased NO production may be involved in these favorable changes in vascular function via a healthier endothelium.

Our study has certain limitations, such as the lack of measurement of cardiac and vascular autonomic function, which could have served a role in explaining the mechanisms behind some of our findings. We did not assess systemic vascular resistance or the magnitude of the forward and backward waves by separation analysis, which would have provided mechanistic evidence for the changes in hemodynamic variables. Because plasma NO is an indirect method to assess endothelial function, the finding has to be interpreted with caution since circulating NO can be influenced by diet and menstrual cycle, specifically at the time of ovulation.⁴⁵ We used bioelectrical impedance to extrapolate body composition, which may not be as precise as other established methods such as dual-energy x-ray absorptiometry and air displacement plethysmography. Furthermore, We assessed young obese women with elevated BP; therefore, the same positive responses cannot be guaranteed in other populations. An additional limitation is the duration of our MP intervention. It is possible longer interventions could produce more positive vascular adaptations. For this reason, future studies should implement longer periods and greater frequency of training. In conclusion, the present findings indicate that MP training is a valuable form of exercise training for improving systemic arterial stiffness, aortic BP and wave reflection in young obese women with elevated SBP. Additionally, MP seems to be an effective intervention to reduce BF% in obese women.

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DISCLOSURE

The authors declared no conflict of interest.

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