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The effects of stair climbing on arterial stiffness, blood pressure, and leg strength in postmenopausal women with stage 2 hypertension

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Abstract

Objective: Menopause is accompanied by a progressive arterial stiffening associated with increases in blood pressure (BP) and decline in muscular function. It is crucial to prevent or reduce the negative effects of menopause on vascular and muscular function by implementing appropriate lifestyle interventions, such as exercise training. We examined the effects of a stair climbing (SC) regimen on arterial stiffness (pulse wave velocity [PWV]), BP, and leg strength in postmenopausal women with stage 2 hypertension.

Methods: Using a parallel experimental design, participants were randomly assigned to either SC ($n = 21$) or nonexercising control group ($n = 20$) for 12 weeks. Participants in the SC group trained 4 d/wk, climbing 192 steps 2 to 5 times/d. Participants' brachial-to-ankle PWV (baPWV), BP, and leg strength were measured at baseline and after 12 weeks of their assigned intervention.

Results: There was a significant group by time interaction ($P < 0.05$) for baPWV, and systolic BP (SBP) and diastolic BP (DBP) which significantly decreased ($P < 0.05$), and leg strength which significantly increased ($P < 0.05$) after SC compared with no changes in the control. The changes in baPWV were correlated with changes in SBP ($r = 0.66$, $P < 0.05$) and leg strength ($r = -0.47$, $P < 0.05$).

Conclusions: SC led to reductions in arterial stiffness, BP, and increases in leg strength in stage 2 hypertensive postmenopausal women. The decrease in arterial stiffness partially explained the improvements in SBP and leg strength. SC may be an effective intervention in the prevention and treatment of menopause/aging-related vascular complications and muscle weakness.

Key Words: Arterial stiffness – Blood pressure – Stair exercise.

Menopause is accompanied by a progressive increase in arterial stiffness (pulse wave velocity [PWV]) that is mediated, at least in part, by decreases in estrogen levels and activity.[1] In postmenopausal women, increased brachial-to-ankle PWV (baPWV), an index of systemic arterial stiffness, has been associated with high systolic blood pressure (SBP)[1] leading to longitudinal increases in cardiovascular (CV) complications and mortality.[2,3] A high baPWV may also be involved in the age-related loss of muscle strength and mass known as sarcopenia, which preferentially affects the legs in women.[4,5] Indeed, several studies have shown that sarcopenia is inversely associated with baPWV,[4-6] and this relationship appears to be more important for women than men.[6] Moreover, the increased mortality risk in postmenopausal women with sarcopenia[7] may be related to the increase in baPWV.[3] Since increased muscle strength may have a protective effect against arterial stiffness[8] and hypertension,[9] interventions that could potentially improve PWV and muscle strength may result in CV benefits in postmenopausal women.

Although high-intensity resistance training is an effective intervention for improving muscle strength in postmenopausal women,[10] this exercise modality may increase PWV in middle-aged adults with prehypertension or hypertension.[11] Alternatively, combining aerobic and resistance training has been previously shown to decrease baPWV and BP in postmenopausal women; effectively counteracting the negative effects of resistance training on arterial stiffness, while still achieving strength improvements in this population.[12] However, due to perceived or actual barriers associated with traditional aerobic and resistance training (eg, lack of time, money, fitness facilities nearby; poor weather, and a sense of embarrassment), many postmenopausal women have difficulty adhering to traditional exercise programs and/or may stop exercising altogether.[13] It is crucial to address these barriers by implementing easy-accessible, low-cost, and inconspicuous modalities such as stair climbing (SC).

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Stair climbing is a feasible form of exercise that has no monetary cost, and is associated with a reduced mortality in different populations.[14] SC has both aerobic and resistance exercise components through the elevation of heart rate (HR) and one's own body weight during more than 5 minutes, resulting in improvement in both cardiorespiratory fitness and leg muscle strength in postmenopausal women.[15] Additionally, previous studies using SC have documented additional health benefits including increased fat loss, improved lipid profiles, and reduced risk of osteoporosis.[16,17] Yet, the effects of SC training on arterial stiffness and BP remains largely unexplored. The purpose of this investigation was to use a SC training program to test the hypothesis that this exercise modality would improve arterial stiffness and BP in postmenopausal women with stage 2 hypertension.

METHODS

Participants

Forty-one (age 49-67 years) postmenopausal women with stage 2 hypertension (140-179 mm Hg SBP or 90-119 mm Hg DBP) from the Busan metropolitan area, Korea, participated in the present study. Menopause was defined as the absence of menstruation for at least 1 year. Hypertension was diagnosed by a physician before participation in the study. Participants were excluded if they had pulmonary, renal, adrenal, pituitary, severe psychiatric, thyroid, or CV diseases other than stage 2 hypertension, diabetes, and the use of hormone therapy (HT) during the 6 months before the study. Participants were also excluded if they were smokers or had any medication changes in the previous year. In addition, those who attended psychological or physical therapy, had a history of regular exercise, or received exercise training or weight loss program in the past year, were excluded to avoid potential confounders with the present trial. All participants received complete information about the study design and provided written informed consent. All protocols were approved by the Institutional Review Board of the Public Institutional Review Board designated by Ministry of Health and Welfare (SH-IRB 2017-13), registered in Clinicaltrials.gov (NCT03254251), and carried out in accordance with the Declaration of Helsinki.

Study design

We used a parallel experimental design. After an initial screening and familiarization session of study tests and procedures, eligible postmenopausal women were randomly assigned to a SC group or nonexercising control group for 12 weeks (Fig. 1). Allocation was stratified for SBP (>140 and <150 mm Hg [n = 15 in SC and n = 16 in control group] or ≥150 and <160 mm Hg [n = 5 in SC and n = 5 in control group]), and the sequence was generated by a computer-based number. Measurements were collected at baseline and after 12 weeks during the same time of the day (±1 hour) in the morning and after an overnight fast, and abstinence from caffeinated drinks, alcohol, and between 48 and 72 hours after the last exercise session. Participants on medication (Table 1) were asked to discontinue their medication the night and the morning before testing. Cardiovascular measurements were collected in a quiet temperature-controlled room (22-24°C) after at least 10 minutes of rest in the supine position. After the resting vascular measurements, body composition and leg muscle strength were assessed. Participants were instructed not to alter their regular lifestyle habits during the study period (verified through food/physical activity logs).

Stair climbing training program

Participants allocated to the SC group embarked on a 12-week progressive SC program. Each training session consisted of a general warm-up (5 minutes: slow and fast skipping, stretching) followed by the SC exercise, which was supervised by experienced personnel. The program began with two bouts of SC 4 days a week in weeks 1 and 2, increasing by one climb a day every 3 weeks. By the last 3 weeks (10-12) of the study, all participants were completing five climbs 4 days a week. During each climb, participants ascended 12 flights (192 steps with a total vertical displacement of 34.14 m) divided into three sets of four flights each, with a 2-minute rest period between each set. There was a 5-minute rest period between climbs that allowed the participants to reach the ground floor using an elevator, to avoid the negative effects of eccentric loads associated with descending stairs.[18] As a safety precaution, handrails were available. Participants were instructed to avoid any arm-pulling at the handrail. Some of our participants were taking medications that may affect HR during exercise; therefore, we prescribed the exercise pace/intensity at a 11 to 13 rating of perceived exertion (RPE) on the 6 to 20 Borg scale, according to the established guidelines for exercise in hypertensive individuals by the American College of Sports Medicine and other experts in the field.[19] The training protocol was adapted from prior literature on postmenopausal women and older individuals.[15,20] Participants in the nonexercising control group did not participate in a supervised exercise program and were encouraged to maintain their regular level of physical activity for the duration of the study.

PWV and hemodynamics

Brachial-to-ankle PWV and BP were measured using a volume plethysmographic device (VP-1000; Colin Co., Komaki, Aichi, Japan). Electrocardiogram (ECG) electrodes were placed on the forearms, whereas a heart sound microphone was placed on the left parasternal border of the fourth intercostal space. HR was determined from the ECG. BP cuffs with pulse wave sensors were wrapped around both arms (brachial artery) and ankles (posterior tibial artery). BP, ECG, and pulse waveforms were simultaneously recorded for 10 seconds. The feet of the pulse waveforms were related to the R wave of the ECG to calculate transit time between the brachium and ankle (ΔTba). The path distances from the suprasternal notch to the brachial (Db) and to the ankle (Da) sensor were calculated using the following equations: $Db = 0.220 \times \text{height (cm)} - 2.07$ and $Da = 0.813 \times \text{height (cm)} + 2.33$. baPWV was calculated as $Da - Db/\Delta Tba$. The average of two measurements for the mean of the left and right

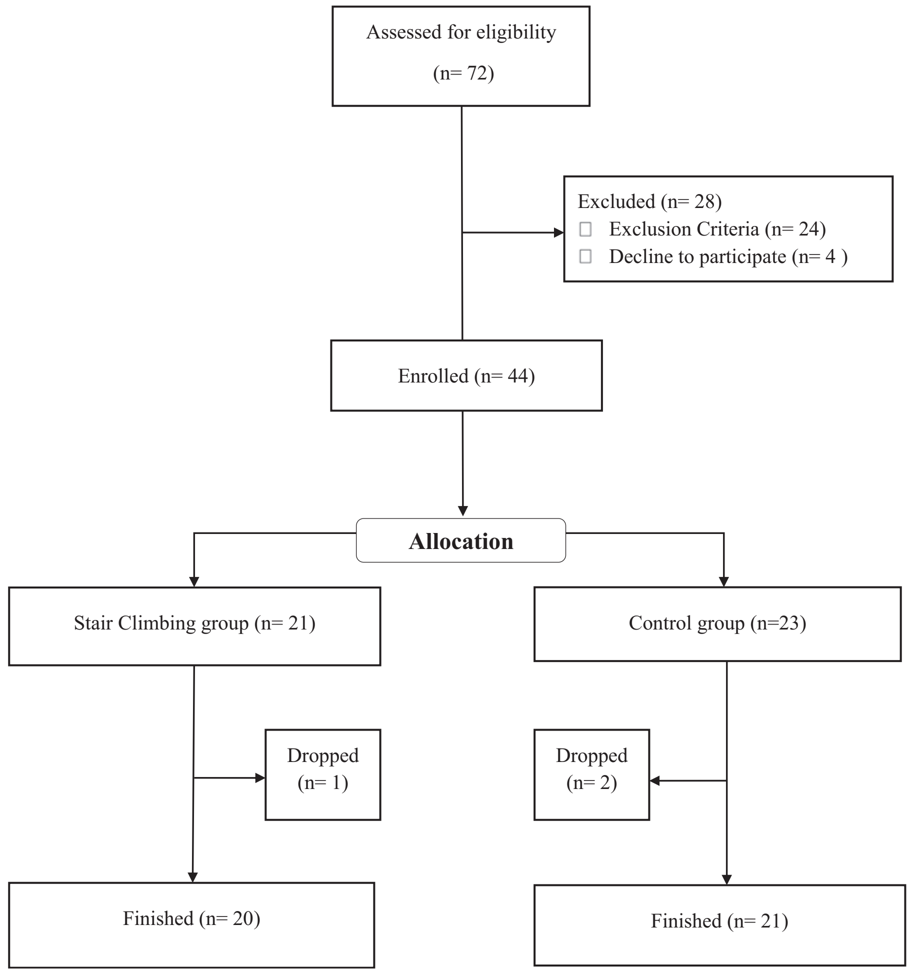

FIG. 1. Diagram for the experimental study.

baPWV was used in the analysis. The validity and reproducibility of noninvasive baPWV have been previously shown.[21] The interclass correlation coefficient for baPWV calculated on two separate days was 0.95.

Muscle strength

Muscle strength was assessed by the eight repetition maximum (8RM) test using a leg extension machine (Cybex 6000; Lumex, Albertson, NY). Women were familiarized with the exercise and lifting technique before 8RM measurement, which was achieved within five attempts. The 1RM was considered the highest weight that can be moved in good form eight times through a full range of motion. After a minimum of 72 hours, the 8RM was verified in all participants. The highest measurement from the 2 days of testing was considered the 8RM. After 12 weeks, the 8RM was performed 48 to 72 hours after the last exercise session following the same procedures. All 8RM tests were conducted by the same researcher who was unaware of group assignment. The 8RM has been shown to be safe and reliable in postmenopausal women with prehypertension and hypertension.[22]

Anthropometry and body composition

Body composition was assessed using an eight-polar tactile-electrode impedance meter (InBody 720; Biospace, Seoul, Korea), which simultaneously recorded bodyweight, fat mass, and fat-free mass. Height was measured with a stadiometer to the nearest 1 cm. Body mass index (BMI) was calculated as weight/height^2.

Statistical analysis

All parameters were normally distributed as shown by the Shapiro-Wilk test. Student's *t* test was used for group

TABLE 1. *Medication used by participants in the two study groups*

Medication	SC	Control
Angiotensin-converting enzyme inhibitors	5	3
Calcium channel blockers	2	4
Angiotensin II receptor blockers	5	6
Diuretics	3	4
Beta blockers	2	3
Gastric antacid	3	2
Antidepressants	1	0

Values for medication use are number of participants.
SC, stair climbing.

TABLE 2. *Participants' characteristics, blood pressure, arterial stiffness, and leg strength before and after 12 weeks of SC or control*

	SC (n = 20)		Control (n = 21)	
Variable	Before	After	Before	After
Age, y	59 ± 1	—	59 ± 1	—
Height, m	1.53 ± 0.01	—	1.55 ± 0.01	—
Body weight, kg	57.1 ± 2.0	56.2 ± 1.8[a]	56.7 ± 1.9	56.4 ± 1.8
BMI, kg/m^2	24.2 ± 0.8	23.9 ± 0.7[a]	23.8 ± 0.8	23.7 ± 0.8
Fat-free mass, kg	39.3 ± 1.6	39.1 ± 1.5	39.4 ± 1.6	39.0 ± 1.4
Fat mass, kg	17.8 ± 0.7	17.1 ± 0.7	17.3 ± 0.6	17.4 ± 0.7
Systolic BP, mm Hg	146 ± 1	139 ± 1[b,c]	147 ± 1	146 ± 1
Diastolic BP, mm Hg	89 ± 1	86 ± 1[b,c]	89 ± 1	89 ± 1
baPWV, m/s	14.3 ± 0.1	13.4 ± 0.2[b,c]	14.4 ± 0.1	14.3 ± 0.1
Heart rate, beats/min	68 ± 1	66 ± 1[b,c]	69 ± 1	69 ± 1
Leg strength, kg	30.2 ± 0.7	32.5 ± 0.6[a,c]	30.4 ± 0.6	30.2 ± 0.7

Data are mean ± standard error of the mean.
baPWV, brachial-to-ankle pulse wave velocity; BMI, body mass index; BP, blood pressure; SC, stair climbing.
[a] $P < 0.05$ different than before.
[b] $P < 0.01$ different than before.
[c] $P < 0.01$ different than control.

comparisons at baseline. A 2 × 2 analysis of variance (ANOVA) with repeated measures (group [control and SC] × time [before and after 12 weeks]) with Bonferonni adjustments was used to determine the effects of SC and time on dependent variables. If a significant main effect or interaction was noted, paired *t* test was used for post hoc comparisons. Pearson's correlations were used to analyze the relationship between changes in leg strength, baPWV, and BP. Analyses were performed using SPSS 21.0 for Windows (IBM SPSS Analytics, Armonk, NY). Data are presented as mean ± SEM. Statistical significance was set at $P < 0.05$. A power analysis calculation determined a minimum sample size of 28 (14 each group) would allow the observation of a difference of 3% to 5% between the groups (SC vs control) on the primary study outcome variable of baPWV with a power of 80%.[23]

RESULTS

Forty-one participants were included in the statistical analysis as three participants decided to discontinue their participation in the study because of time commitment (Fig. 1). Compliance to the SC training was 97%. Importantly, none of the participants in the SC group reported any unfavorable symptoms/signs or adverse side effects resulting from SC.

Participant characteristics, BP, arterial stiffness, HR, and strength at baseline and after 12 weeks for the control and SC group are presented in Table 2 (data are shown as means ± SEM). Baseline parameters between the two groups were not significantly different ($P > 0.05$). There were significant group × time interactions ($P < 0.05$) for baPWV, SBP, DBP, and HR which significantly decreased ($P < 0.01$); and for leg strength which significantly increased ($P < 0.05$). There were significant ($P < 0.05$) decreases in weight and BMI in the SC group in comparison with baseline, but the changes were not different compared with the control. The changes in baPWV were correlated with changes in SBP ($r = 0.66$, $P < 0.05$; Fig. 2A) and leg strength ($r = -0.47$, $P < 0.05$; Fig. 2B). There were no significant changes in fat-free mass and fat mass after SC or control.

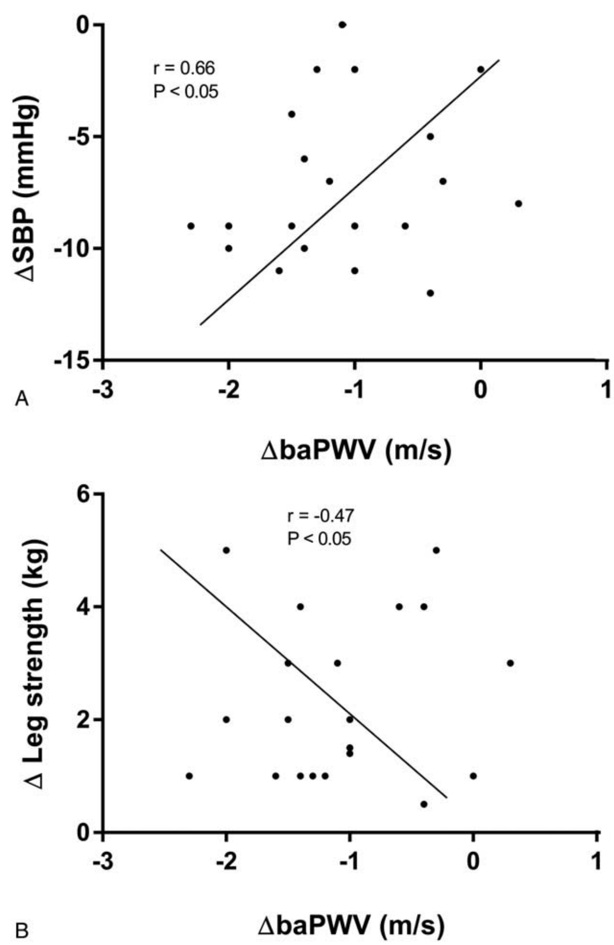

FIG. 2. Relationship between the changes in brachial-ankle pulse wave velocity (ΔbaPWV) with (**A**) systolic blood pressure (ΔSBP) and with (**B**) leg strength (Δleg strength). baPWV, brachial-to-ankle pulse wave velocity; SBP, systolic blood pressure.

DISCUSSION

We found that 12 weeks of SC training resulted in beneficial reductions of arterial stiffness and BP. The SC intervention also resulted in an increase in muscle strength, which correlated with changes in arterial stiffness (decreased baPWV). Our results indicate that SC improves resting CV profile and strength in stage 2 hypertensive postmenopausal women. To our knowledge, this is the first study to evaluate the effects of SC on arterial stiffness as was done in this study, and also in postmenopausal women with hypertension.

In the present study, the SC intervention significantly decreased baPWV which reveals an improved arterial stiffness. Decreases in aortic PWV have been previously reported after 4 weeks of aerobic training in prehypertensive and hypertensive patients.[11] Conversely, high-intensity resistance training increases aortic PWV and leg PWV, the main components of baPWV,[21] in middle-age adults with prehypertension and hypertension.[11] Furthermore, the combination of resistance training and aerobic training has reduced baPWV in normotensive (1.3 m/s)[12,24] and hypertensive (0.7 m/s) postmenopausal women.[24] Interestingly, the observed decrease in baPWV in the present study (0.9 m/s) is smaller than previously reported (2.1 m/s) in postmenopausal women after daily bench step exercise (which mimics SC activity to some degree) for a training period of 12 weeks.[23] A possible explanation for this marked difference in baPWV improvement between the current and previous study may be related to hypertensive status, as exercise training produces fewer improvements in baPWV in hypertensive postmenopausal women than in postmenopausal women without hypertension (improvements are cut by almost a half in those with hypertension).[24] This appears to result from poor vascular structure and function in hypertensives.[24] Nevertheless, we have shown that our SC program decreases baPWV by a substantial 0.9 m/s (7%) in hypertensive postmenopausal women, a population with high prevalence of CV events and mortality,[2,3] that also has a decreased potential for arterial unstiffening after exercise training.[24] A meta-analysis of 12 cohort studies found an increase of 1 m/s in baPWV to be associated with a 12% increase in the risk of CV events in adults with high CVD risk.[3] Additionally, recent evidence suggests that baPWV is an independent predictor of future development of CVD in adults with low and moderate CVD risk.[25] Therefore, the 0.9 m/s decrease in baPWV seen with SC training would be considered clinically meaningful.

In terms of the effects of SC on BP, the results of the present study showed reductions in SBP (~7 mm Hg) and DBP (~3 mm Hg) in the SC group, whereas there were no significant decreases in the control group. Based on the new American Heart Association guidelines, this decrease in SBP dropped the BP values of our participants from stage 2 to stage 1 hypertension. These findings are in agreement with that of Ohta et al[23] who noted similar decreases in SBP and DBP after 12 weeks of a bench step intervention in postmenopausal women. Moreover, both aerobic training alone and resistance exercise training alone have reduced SBP and DBP by 4 and 3 to 4 mm Hg, respectively, in middle-aged and older adults with prehypertension and hypertension.[11] Additionally, the combination of resistance training and aerobic training has been shown to reduce both resting SBP and DBP in normotensive[12,24] and hypertensive[24] postmenopausal women. Epidemiological data show that in hypertensives, a reduction in resting SBP of 2 mm Hg is likely to reduce the mortality from stroke by 6% and coronary heart disease by 4%.[26] Therefore, our findings of decreased 7 mm Hg in resting SBP in the current study may have potential clinical implications in older women.

Increased baPWV has been reported to be predictive of the progression of elevated BP to hypertension.[27] It has been recently recognized that arterial stiffening precedes the development of the age-related isolated systolic hypertension.[28] Our findings showing that SC decreased BP may be partially explained by the noted changes in baPWV. Hence, it can be suggested that SC may be effective in preventing the further progression of hypertension in postmenopausal women, which may, in part, be explained by improvements in systemic arterial stiffness as indicated by the positive correlation found between reductions in baPWV and SBP. One potential mechanism responsible for decreases in baPWV and subsequently BP reduction could be an increase in nitric oxide (NO) levels. Several lines of evidence point out that NO plays a role in arterial stiffness by improving endothelial vasodilatory function. Indeed, a 12-week bench step exercise (which somewhat simulates SC) intervention has been shown to increase circulating NO in postmenopausal women.[23] Hence, increases in NO via SC training may improve arterial stiffness, leading to reductions in BP. Another potential mechanism underlying the effects of SC on BP is the improvement of autonomic function. In the current study, SC decreased resting HR. This finding in hypertensive postmenopausal women is not surprising since it was expected that HR would decrease as a result of enhanced parasympathetic activity after exercise training.[29] This improved parasympathetic action (vagus nerve) decreases BP and myocardial workload through reductions in inotropy and afterload.[30]

Leg extension strength increased after 12 weeks of SC training in the present study, confirming previous findings by Loy et al[15] that SC effectively improves leg strength in postmenopausal women. In contrast, Donath et al[20] reported no changes in leg strength after 8 weeks of SC in healthy older individuals (mean age 71 years). Possible explanations for this discrepancy are that the lower volume of work and duration of the intervention, sex differences, and health status in the previous investigation may have contributed to the lack of improvement in leg strength. This notion is supported by the difference in training period and frequency in the previous study (8 weeks, three times a week) compared with the current study and the study by Loy et al.[15] (12 weeks, four times a week). Thus, a higher volume of SC, through a prolonged training period or frequency, elicits improvement in leg strength. Because the change fat-free mass after 12 weeks of SC training was no different than the control group in our study, muscle strength gains would be primarily attributed to neural adaptations rather than muscle hypertrophy. Indeed, increased muscle strength per se may be of clinical importance as decreased leg muscle strength outpaces the loss of lean mass in older women.[31] Since leg strength loss is 2.6% per year in older women,[31] the ~6% difference in strength gain after the SC intervention might correspond to the reversal of muscle strength loss that is experienced in 2 years. Therefore, incorporating an easy accessible, no-cost, and discrete exercise modality such as SC in hypertensive postmenopausal women could not only serve as an alternative in the prevention and treatment of menopause/aging-related vascular complications but also early muscle dysfunction. In this study, we noted an interesting correlation between the improvement in leg strength and the decrease in baPWV. These findings indicate that the participants who showed higher increase in strength were the ones who showed higher decrease in baPWV. Although it is not possible to infer causality from correlations, that is, whether the decrease in baPWV leads to the improvement of leg strength or vice versa, the present findings are consistent with the model proposed by Fahs et al[8] and Maslow et al[9] in which the positive alterations in muscle strength may explain a reduced arterial stiffness and a lower incidence of hypertension. These authors proposed that traditional and nontraditional risk factors such as low-density lipoprotein cholesterol, highhigh-density lipoprotein cholesterol, improved endothelial function and muscle blood flow, low inflammation, increased lean tissue, and insulin sensitivity may partly mediate the noted negative association between muscular strength and arterial stiffness.

Our study has certain limitations. First, the study duration was relatively short and it is unclear whether a longer intervention period would result in greater reductions in BP and arterial stiffness. Second, the sample was restricted to stage 2 hypertensive postmenopausal women and therefore, the reported results are not truly representative of all hypertensives and may not be generalized to other populations. Third, we did not measure other measures of fitness such as cardiorespiratory capacity. However, SC is well-known to improve this fitness component in different populations,[17,20] including postmenopausal women.[15] Fourth, although we collected food/physical activity logs and recommended not to change activities of daily living, any additional nonreported caloric intake or physical activity may have contributed to changes in body weight and BMI or lack of changes in body composition. Finally, the present study did not examine the effects of both stair ascending and descending, which might be a limitation in terms of transferability and external validity. However, stair descending was not used to minimize the risk of falls and avoid the negative effects of eccentric contractions associated with descending stairs[18]; and to determine whether benefits could be elicited using concentric stair ascent alone.

CONCLUSIONS

Our findings indicate that SC training is effective for improving systemic arterial stiffness, BP, and leg muscle strength in postmenopausal women with stage 2 hypertension. Our results support the use of SC for the improvement of hypertension and frailty in postmenopausal women.

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