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Original Article

Regular exercise ball training reduces arterial stiffness in sedentary middle-aged males

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Abstract. [Purpose] Reports suggest that static stretching, which improves body flexibility, could reduce arterial stiffness. Regular training using an exercise ball would increase flexibility in a different manner, compared to that from static stretching; however, it remains unclear whether such exercise can reduce arterial stiffness. This study aimed to clarify the effect of exercise ball training on arterial stiffness in sedentary middle-aged participants. [Participants and Methods] Fifteen healthy middle-aged males (age, 52 ± 12 years) were divided into a control group (n=7, CON) and an intervention group (n=8, INT). The CON group did not alter physical activity levels throughout the study period, while the INT group participated in supervised training sessions using an exercise ball for 20–30 min, 5 days/week, for a duration of 4 weeks. [Results] Exercise ball training significantly increased the sit-and-reach test score (CON, −3.8 ± 11.1% vs. INT, 33.8 ± 47.5%) and reduced cardio-ankle vascular index (CON, −0.8 ± 4.1% vs. INT, −5.7 ± 4.1%) and heart-ankle pulse wave velocity (CON, 1.6 ± 4.5% vs. INT, −4.2 ± 4.6%), as an index of arterial stiffness. [Conclusion] Four weeks of supervised training using an exercise ball as well as regular static stretching would increase body flexibility and reduce systemic arterial stiffness among sedentary middle-aged males.

Key words: Arteriosclerosis, Stability ball, Swiss ball

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INTRODUCTION

Arterial stiffness is widely assessed by pulse wave velocity (PWV) or cardio-ankle vascular index (CAVI), and gradually increases with age even in healthy individuals[1–3]. Increased arterial stiffness has been identified as an independent risk factor for future cardiovascular disease or mortality[4–6]. The prevention and treatment of arterial stiffening are thus important.

Body flexibility can physiologically relate to arterial stiffness, and some mechanisms such as structural and/or functional factors may contribute to the relationship between parameters of both. Indeed, cross-sectional studies have reported that poor trunk flexibility is associated with higher arterial stiffness[7, 8]. This relationship is independent of blood pressure (BP), which is a major confounding factor for arterial stiffness, and the relationship is observed in males, but not young and middle-aged females; revealing gender differences[7]. Moreover, human interventional studies have demonstrated that regular static stretching increases sit-and-reach score, as an index of trunk flexibility, and reduces arterial stiffness[9, 10]. Recent systematic

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reviews and meta-analyses of both single session and longitudinal intervention stretches identified significant effects in reducing arterial stiffness[11, 12]. However, the physiological relationship between regular stretching or flexibility intervention and arterial stiffness is not fully understood, and further investigations are required.

In the fields of physical therapy, athletic training, and exercise, exercise balls or Swiss balls are often utilized to stretch the trunk, lower back, lateral abdominal muscles, and other areas of the body[13–15]. Training using an exercise ball can stimulate core muscle tissues to balance and stabilize the body[13, 16, 17], and is generally expected to increase body flexibility with exercising through controlling the ball and increasing joint mobility[15]. Thus, in a manner slightly different from static stretching, regular exercise ball training may help verify reductions in arterial stiffness with increased flexibility. This information could also offer important new insights into the development of effective programs to prevent arterial stiffness and may contribute to a better understanding of the physiological relationship between flexibility training and arterial stiffness. To the best of our knowledge, however, no data are available regarding regular exercise using an exercise ball and arterial stiffness.

With this information as background, the primary aim of the present study was to investigate the effects of regular exercise intervention using an exercise ball on body flexibility and arterial stiffness in sedentary middle-aged males. On the basis of previous studies[9, 10, 15], we hypothesized that, as with regular static stretching, regular training using an exercise ball would increase body flexibility and then reduce arterial stiffness in sedentary middle-aged males.

PARTICIPANTS AND METHODS

Fifteen middle-aged Japanese male participants without chronic diseases that could affect cardiovascular, metabolism, or daily physical activity were recruited in our university. Mean age, height, body weight, body mass index (BMI), and body fat were 52 ± 12 years, 170.7 ± 8.9 cm, 68.0 ± 9.7 kg, 23.4 ± 2.9 kg/m^2, and 19.1 ± 5.5%, respectively. All participants were regularly engaged in desk work inside an office (>8 h/day), and none had participated in regular exercise programs for at least 2 years. No participants were taking any medications. Participants were matched for physical characteristics, particularly arterial stiffness, as nearly equal as possible and assigned to either a control group (CON group; n=7) or an intervention group (INT group; n=8). Participants were not provided with the option to self-select group allocations. The purpose, procedures, and risks of the study were explained to all participants and written informed consent was obtained before participating in the study, which was reviewed and approved by both the Human Ethics Committee at the Prefectural University of Kumamoto (approval no. 26-005) and the Osaka Institute of Technology (approval no. 2012-22). The study proceeded in accordance with the guidelines of the Declaration of Helsinki.

We firstly determined the appropriate and minimum sample sizes before the study using power calculations in G*Power 3.1 (Dusseldorf, Germany). A total sample size of at least 14–16 (7–8 per group) was determined as necessary to detect an effect size (ES) (f) of 0.25 (medium) at 80% power with an α of 5% using a within-between interaction of two-way repeated-measures analysis of variance (ANOVA). We further assumed that an alteration in arterial stiffness would be shown by a difference of >5–7% (ES (dz) of 1.3–1.5) in a pretest-posttest design according to previous findings[9, 10]. At least 6–7 participants were needed to detect this difference at 80% power with a two-tailed α of 5%. We therefore planned to recruit 7 participants to the CON group and 8 participants to the INT group (total sample size, n=15).

The experiment for each participant was conducted in a quiet, air-conditioned room at 22–24 °C at the same time of day and at the same number of hours after the last meal to avoid potential diurnal variations. Start times for each measurement were all within 07:00–09:00. Participants were required to abstain from alcohol and caffeine-containing beverages, to fast for >10 h before each test, and to avoid strenuous physical activity. We performed assessments at least 24 h after the most recent training session, to avoid any acute effects. In addition, participants were advised to eat the same habitual breakfast, lunch, and dinner the day before each measurement, and similar standard contents and mealtimes without irregularity between and within participants were confirmed by checklist questionnaire and face-to-face interviews. After these checks, measurements were conducted and recorded. Measurements of both groups were taken before and after the experimental period. In both groups, participants arrived at the laboratory and rested for at least 30 min, then completed the questionnaire and face-to-face interview, and underwent measurements of body composition, arterial stiffness, hemodynamic parameters, and physical fitness tests.

Body composition was determined by bioelectrical impedance using a TBF-410 body composition analyzer (Tanita Co., Tokyo, Japan), as described in our previous study[7, 9]. We measured the height, weight, and body fat of each participant without footwear in light clothing, then calculated the BMI, as weight in kilograms divided by height in meters squared. Day-to-day coefficients of variations (CVs) for body weight, body fat, and BMI were all <10% under our experimental conditions[7, 9].

After resting for >15 min, we measured PWV, BP, and heart rate (HR) with the participant supine using a semi-automated device (VS-1500AE/AN; Fukuda Denshi, Tokyo, Japan), as previously described[18, 19]. According to previous studies[20–22], CAVI, heart-ankle PWV (haPWV), heart-brachial PWV (hbPWV), and brachial-ankle PWV (baPWV) were calculated as indicators of arterial stiffness. Intraobserver CVs for CAVI, haPWV, hbPWV, and baPWV determined in the laboratory on two separate days were 3.6 ± 1.9%, 2.6 ± 2.6%, 4.2 ± 3.4%, and 2.7 ± 1.5%, respectively[18, 19, 23].

According to previous studies[7, 9], trunk flexibility was assessed at least twice by the sit-and-reach test using a T-283 device (Toei Light, Tokyo, Japan), then the highest value was taken as the definitive value (CV, 6.4 ± 5.0%). Thereafter, handgrip strength was measured using a T.K.K. 5101 Grip-D dynamometer (Takei, Tokyo, Japan) with a precision of 0.1 kg (CV, 4.1 ± 2.6%). Measurements were made in duplicate, taking the highest value from the stronger hand for analysis[7, 9].

Habitual physical activity levels during the experimental period were assessed using the International Physical Activity Questionnaire -Short Form (IPAQ) translated into Japanese, as previously described[7, 9]. The INT group answered questions about regular physical activity other than the intervention training using the exercise ball. We also interviewed participants to determine whether levels of physical activity had changed during the study period compared with before.

Supervised exercise training was performed using an exercise ball (65 cm diameter; HATAS, Osaka, Japan) for approximately 20–30 min per training session, 5 days/week, for 4 weeks in a room with the temperature controlled to 22–24°C. The exercise ball was utilized as the tool for training to achieve an increase in body flexibility in a slight different manner from static stretching[15]. Training sessions started at 08:00, 12:00, 16:00, or 17:00, and each participant was instructed to exercise at the same start time and participate in only one training session per day. Expert instructors demonstrated exercises for participants in the INT group throughout the experimental period, such as moving the pelvis, bouncing and balancing on the ball, stretching, and maintaining poses (Fig. 1). Each exercise was conducted twice during one training session. To avoid participants becoming bored with the training program, training content was modified and rearranged between the first 2 weeks (Program I) and the last 2 weeks (Program II). All participants in the INT group completed 100% of all scheduled exercise sessions (20 sessions over a 4-week period). Participants in both groups were instructed to maintain their normal diet and to refrain from any other specific exercise training throughout the study period.

Results are presented as mean ± standard deviation (SD). Changes in parameters were analyzed by two-way (group ×period) repeated-measures ANOVA. When the F value was significant, the Bonferroni method was applied for post hoc multiple comparisons. Changes between pre- and post-training period tests were also analyzed by unpaired t-test. All data were analyzed using Excel Statistics version 3.21 (Bell Curve, Tokyo, Japan) and IBM SPSS Statistics version 25.0 J (IBM Japan, Tokyo, Japan). To quantify the magnitude of the experimental effect between pre- and post-training period tests, ES (dz) was calculated using G*Power 3.1. All significance levels were set at 5%.

RESULTS

No parameters differed significantly between CON and INT groups before the study. After the study period, body composition (body weight, BMI, and body fat) was not altered significantly in either group. Although handgrip strength tended to increase in the INT group after training (Pre, 40.4 ± 5.5 kg; Post, 43.1 ± 6.8 kg), no significant changes in handgrip strength were found in either group. However, two-way repeated-measures ANOVA indicated a significant interaction of sit-and-reach (p=0.020), and scores for the sit-and-reach test were significantly increased after training in the INT group (Pre, 29.7 ± 11.1 cm; Post, 36.2 ± 8.0 cm; ES (dz)=0.97, p=0.031), but not in the CON group (Pre, 30.4 ± 6.1 cm; Post, 29.2 ± 6.9 cm).

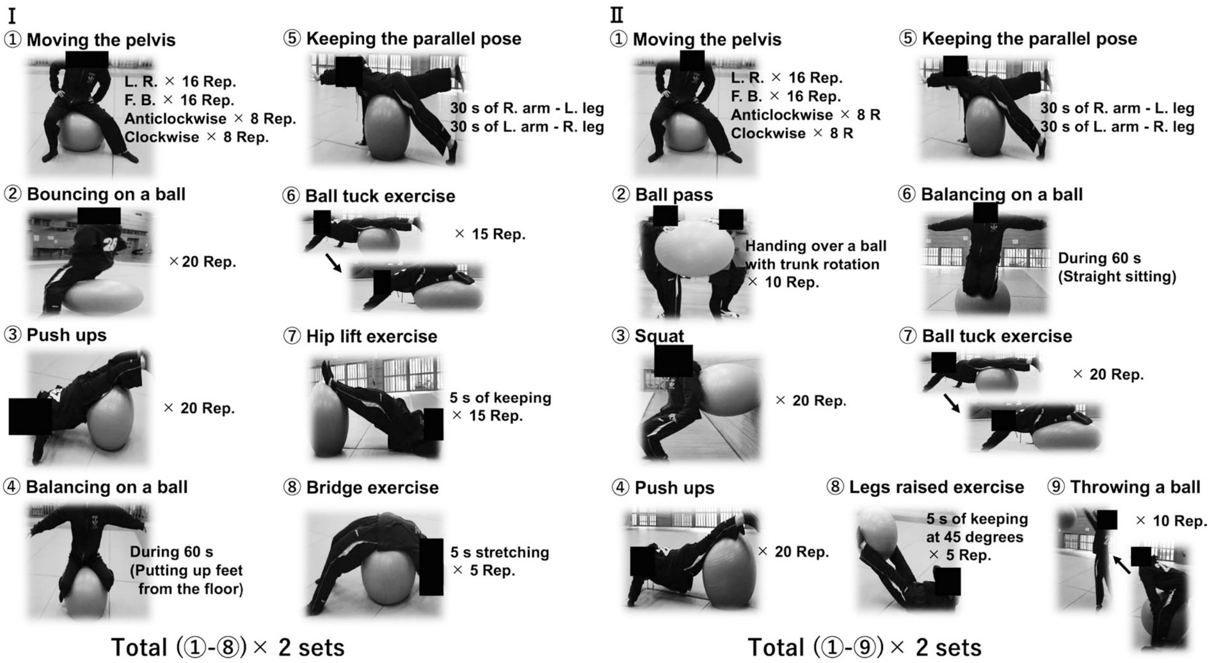

Fig. 1. Contents of exercise intervention programs using an exercise ball.
I: Program I; II: Program II; L: left; R: right; F: front; B: back; Rep: repetition. Programs I and II were conducted in the first 2 weeks and last 2 weeks, respectively.

Next, this study examined whether the increase in body flexibility associated with regular exercise ball training could affect the reduction in arterial stiffness. Two-way repeated-measures ANOVA indicated significant interactions of CAVI ($p=0.037$) and haPWV ($p=0.034$) (Table 1). Mean CAVI and haPWV significantly reduced only in the INT group after training (CAVI: ES (dz)=1.18, $p<0.001$; haPWV: ES (dz)=0.84, $p=0.048$). The results of baPWV in the INT group tended to reduce (baPWV reduced in 6 of 8 participants), but the difference did not reach a significant level. However, before and after the intervention, no significant changes in hbPWV were observed in either group. Neither HR nor BP at rest differed significantly after training in either group (Table 2). In addition, IPAQ score did not differ significantly between groups during the experimental period (CON, 25.8 ± 13.0 METs h/week vs. INT, 16.8 ± 16.1 METs h/week, ES (d)=0.62, $p=0.260$). All participants in both groups answered that physical activity levels had not changed between before and during the intervention period.

DISCUSSION

This is the first study to investigate the effects of regular training using an exercise ball on arterial stiffness in sedentary middle-aged male participants. The main new findings of this study were that 4 weeks of supervised exercise ball training induced an increase in sit-and-reach test scores and reductions in both CAVI and haPWV.

Because regular training using an exercise ball is known to increase body flexibility[15)], we focused on whether arterial stiffness would be reduced in association with body flexibility increases using the exercise ball as well as regular static

Table 1. Effects of intervention using an exercise ball on arterial stiffness

Variables		Pre	Post
CAVI, unit	CON	8.1 ± 0.9	8.0 ± 1.0
	INT	7.8 ± 1.2	7.4 ± 1.1**
haPWV, cm/s	CON	779 ± 83	789 ± 74
	INT	770 ± 115	734 ± 82*
hbPWV, cm/s	CON	677 ± 124	695 ± 98
	INT	627 ± 93	617 ± 85
baPWV, cm/s	CON	1,249 ± 95	1,248 ± 102
	INT	1,321 ± 262	1,236 ± 145

CAVI: cardio-ankle vascular index of arterial stiffness (adjusted for blood pressure); haPWV: heart-ankle pulse wave velocity, which reflects systemic arterial stiffness; hbPWV: heart-brachial pulse wave velocity, which reflects arterial stiffness of the upper limbs from the aorta to the brachium; baPWV: brachial-ankle pulse wave velocity, which reflects arterial stiffness of central (large arteries in the cardiothoracic region) and leg from the femoral to the ankle; CON: control group; INT: intervention group with regular supervised training using an exercise ball; Pre: before intervention; Pos: after intervention. *$p<0.05$ vs. each Pre; **$p<0.01$ vs. each Pre. Data are given as mean ± standard deviation (SD). Note that regular exercise ball training reduces systemic arterial stiffness indices in sedentary middle-aged males.

Table 2. Hemodynamic parameters before and after the study period

Variables		Pre	Post
Heart rate, beats/min	CON	59 ± 6	60 ± 7
	INT	64 ± 7	61 ± 12
Systolic BP, mmHg	CON	130 ± 9	134 ± 10
	INT	135 ± 22	134 ± 21
Diastolic BP, mmHg	CON	87 ± 12	89 ± 10
	INT	85 ± 16	83 ± 10
Mean BP, mmHg	CON	101 ± 11	104 ± 10
	INT	105 ± 21	101 ± 13
Pulse pressure, mmHg	CON	43 ± 5	45 ± 6
	INT	50 ± 9	51 ± 12

CON: Control group; INT: Intervention using an exercise ball group; BP: Blood pressure. Data are given as mean ± SD. Not statistically significant.

stretching in sedentary middle-aged male participants. Although our intervention using an exercise ball did not consist of only static stretching, significant increase in results from the sit-and-reach, as an index of body flexibility, were observed after our training intervention, supporting previous results[15]. Furthermore, after training, our results showed significant reductions in CAVI and haPWV as well as the results of static stretching[9, 10]. HR and BP *per se* can affect PWV values[24, 25], but these parameters were not significantly altered at the time of measuring arterial stiffness. The reduction in CAVI and haPWV thus strongly suggests a reduction in systemic arterial wall stiffness associated with increased flexibility after training. In general, the CAVI is an indicator of systemic PWV (*i.e*., haPWV) after adjusting for BP, and haPWV comprises hbPWV and baPWV elements[21, 22]. No significant change in hbPWV was observed, reflecting the arterial stiffness of the upper limbs from the aorta to the brachium[20]. Conversely, although the statistical level was not significant, baPWV in the INT group tended to reduce after training, which is explained by PWV elements of central (large arteries in the cardiothoracic region) and leg from the femoral to the ankle[26]. These data thus indicate that reductions in CAVI and haPWV might result from alternations in PWV elements from the thoracoabdominal level (brachium) to the ankle followed by increased flexibility associated with regular physical movements using the exercise ball. Our findings therefore suggest that 4 weeks of supervised training using an exercise ball as well as regular static stretching may well increase body flexibility and reduce systemic arterial stiffness in sedentary middle-aged male participants.

We can only speculate regarding the physiological mechanisms by which training using an exercise ball improves arterial stiffness. Acute, passive, one-legged stretching reduced peripheral arterial stiffness only in the stretched leg, and mechanical stress on the artery increased the shear rate and consequently may cause activation of endothelial functions that contribute to reduced arterial stiffness in humans[27–29]. In animal studies, passive stretching increased blood flow to skeletal muscle in the relaxation period, then enhanced endothelium-dependent vasodilatation only in the stretched limb[30]. Thus, direct activities using exercise ball-induced mechanical stimulation of the lower limbs, trunk, or cardiothoracic region may produce mechanical stretching of arteries or activation of endothelial functions, and may affect arterial stiffness. Alternatively, arterial stiffness is functionally determined by the vascular tone of the artery, which is partially regulated by the activity of the sympathetic nervous system[31]. A previous study reported that stretching can reduce aortic wave reflection magnitude, BP, and autonomic activity in obese postmenopausal women[32]. Thus, some neural factors can contribute to the regulation of body flexibility as well as arterial stiffness. However, direct in vivo evidence remains lacking regarding how physiological stimulation *per se* affects systemic arterial stiffness, and further studies are needed.

Our results point toward clinically and physiologically important implications. Regular aerobic exercise and stretching are known to induce an approximately 5–6% reduction in arterial stiffness[9, 33]. Conversely, the present data showed that 4 weeks of supervised training using an exercise ball produced a 5.7 ± 4.1% reduction in CAVI and a 4.2 ± 4.6% reduction in haPWV as indexes of arterial stiffness. Intervention using an exercise ball may thus induce similar or somewhat smaller changes in arterial stiffness compared with relatively low- to moderate-intensity aerobic exercise or stretching for middle-aged individuals[9, 33]. However, each 1-m/s increase in PWV corresponds to a >10% increase in the risk of cardiovascular events or mortality[5, 6], so reductions in arterial stiffness are considered of paramount importance. Moreover, although general stretch programs involve low-intensity exercises at approximately 2.5 metabolic equivalents[34, 35], training using an exercise ball is often used as a safer, easier type of exercise along with stretching, particularly for middle-aged and older individuals[14, 15]. Accordingly, these findings imply that training using an exercise ball might lead to the development of new strategies to prevent increases in arterial stiffness in group or personal interventions in the sports gym, office, or home. Further applications using an exercise ball are expected.

The present study has several limitations. First, we calculated the minimum sample size, but the number of participants was actually small. Further large-scale interventions are thus required. Second, this study could not assess cardiorespiratory fitness (*i.e.*, maximum oxygen uptake) or circulating lipid and glucose profiles in our participants. However, all participants were healthy adults with no apparent chronic diseases, and were thus considered unlikely to be at high risk of atherosclerosis.

In conclusion, this study examined the effects of regular training using an exercise ball on arterial stiffness. The findings suggest that 4 weeks of supervised training using an exercise ball as well as regular static stretching would increase body flexibility and reduce systemic arterial stiffness among sedentary middle-aged male participants. These findings therefore could have important implications for the development of new and effective exercise prescription programs to reduce arterial stiffness. The results may also contribute to a better understanding of the physiological relationship between flexibility training and arterial stiffness.

Author contributions

Conceived and designed the study: HI, NC, NM, and MN. Performed the study: HI, NC, NM, and MN. Analyzed the data: HI, NC, NM, and MN. Interpreted the data: HI, NC, NM, MI, TN, and MN. Wrote the first draft of article: HI, NC, NM, and MN. All authors read and approved the final version of the article.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation. Because the Ethics Committee of our institution restricted for participant privacy protection, our raw data cannot be shared publicly via on-line network.

Conflict of interest

The authors have no conflict of interest to declare.

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REFERENCES

1) Avolio AP, Deng FQ, Li WQ, et al.: Effects of aging on arterial distensibility in populations with high and low prevalence of hypertension: comparison between urban and rural communities in China. Circulation, 1985, 71: 202–210. [Medline] [CrossRef]
2) Tomiyama H, Yamashina A, Arai T, et al.: Influences of age and gender on results of noninvasive brachial-ankle pulse wave velocity measurement—a survey of 12517 subjects. Atherosclerosis, 2003, 166: 303–309. [Medline] [CrossRef]
3) Shirai K, Hiruta N, Song M, et al.: Cardio-ankle vascular index (CAVI) as a novel indicator of arterial stiffness: theory, evidence and perspectives. J Atheroscler Thromb, 2011, 18: 924–938. [Medline] [CrossRef]
4) Kim ED, Ballew SH, Tanaka H, et al.: Short-term prognostic impact of arterial stiffness in older adults without prevalent cardiovascular disease. Hypertension, 2019, 74: 1373–1382. [Medline] [CrossRef]
5) Vlachopoulos C, Aznaouridis K, Stefanadis C: Prediction of cardiovascular events and all-cause mortality with arterial stiffness: a systematic review and meta-analysis. J Am Coll Cardiol, 2010, 55: 1318–1327. [Medline] [CrossRef]
6) Vlachopoulos C, Aznaouridis K, Terentes-Printzios D, et al.: Prediction of cardiovascular events and all-cause mortality with brachial-ankle elasticity index: a systematic review and meta-analysis. Hypertension, 2012, 60: 556–562. [Medline] [CrossRef]
7) Nishiwaki M, Kurobe K, Kiuchi A, et al.: Sex differences in flexibility-arterial stiffness relationship and its application for diagnosis of arterial stiffening: a cross-sectional observational study. PLoS One, 2014, 9: e113646. [Medline] [CrossRef]
8) Yamamoto K, Kawano H, Gando Y, et al.: Poor trunk flexibility is associated with arterial stiffening. Am J Physiol Heart Circ Physiol, 2009, 297: H1314–H1318. [Medline] [CrossRef]
9) Nishiwaki M, Yonemura H, Kurobe K, et al.: Four weeks of regular static stretching reduces arterial stiffness in middle-aged men. Springerplus, 2015, 4: 555. [Medline] [CrossRef]
10) Shinno H, Kurose S, Yamanaka Y, et al.: Evaluation of a static stretching intervention on vascular endothelial function and arterial stiffness. Eur J Sport Sci, 2017, 17: 586–592. [Medline] [CrossRef]
11) Kato M, Nihei Green F, Hotta K, et al.: The efficacy of stretching exercises on arterial stiffness in middle-aged and older adults: a meta-analysis of randomized and non-randomized controlled trials. Int J Environ Res Public Health, 2020, 17: 17. [Medline] [CrossRef]
12) Thomas E, Bellafiore M, Gentile A, et al.: Cardiovascular responses to muscle stretching: a systematic review and meta-analysis. Int J Sports Med, 2021, 42: 481–493. [Medline]
13) Escamilla RF, Lewis C, Pecson A, et al.: Muscle activation among supine, prone, and side position exercises with and without a Swiss ball. Sports Health, 2016, 8: 372–379. [Medline] [CrossRef]
14) Kim JJ, Song GB, Park EC: Effects of Swiss ball exercise and resistance exercise on respiratory function and trunk control ability in patients with scoliosis. J Phys Ther Sci, 2015, 27: 1775–1778. [Medline] [CrossRef]
15) Sekendiz B, Cuğ M, Korkusuz F: Effects of Swiss-ball core strength training on strength, endurance, flexibility, and balance in sedentary women. J Strength Cond Res, 2010, 24: 3032–3040. [Medline] [CrossRef]
16) Escamilla RF, Lewis C, Bell D, et al.: Core muscle activation during Swiss ball and traditional abdominal exercises. J Orthop Sports Phys Ther, 2010, 40: 265–276. [Medline] [CrossRef]
17) Marshall PW, Murphy BA: Core stability exercises on and off a Swiss ball. Arch Phys Med Rehabil, 2005, 86: 242–249. [Medline] [CrossRef]
18) Nishiwaki M, Takahara K, Matsumoto N: Arterial stiffness in young adult swimmers. Eur J Appl Physiol, 2017, 117: 131–138. [Medline] [CrossRef]
19) Nishiwaki M, Nakano Y, Matsumoto N: Effects of regular high-cocoa chocolate intake on arterial stiffness and metabolic characteristics during exercise. Nutrition, 2019, 60: 53–58. [Medline] [CrossRef]
20) Sugawara J, Tomoto T, Tanaka H: Heart-to-brachium pulse wave velocity as a measure of proximal aortic stiffness: MRI and longitudinal studies. Am J Hypertens, 2019, 32: 146–154. [Medline] [CrossRef]
21) Kume D, Nishiwaki M, Hotta N, et al.: Impact of acute mental stress on segmental arterial stiffness. Eur J Appl Physiol, 2020, 120: 2247–2257. [Medline] [CrossRef]
22) Ogawa N, Nanayama Tanaka C, Ishido M, et al.: Poor walking speed is associated with higher segment-specific arterial stiffness in older adult Japanese community dwellers: a cross-sectional study. Front Physiol, 2020, 11: 587215. [Medline] [CrossRef]
23) Nishiwaki M, Yamaguchi T, Nishida R, et al.: Dose of alcohol from beer required for acute reduction in arterial stiffness. Front Physiol, 2020, 11: 1033. [Medline] [CrossRef]
24) Benetos A, Laurent S, Hoeks AP, et al.: Arterial alterations with aging and high blood pressure. A noninvasive study of carotid and femoral arteries. Arterioscler Thromb, 1993, 13: 90–97. [Medline] [CrossRef]
25) Lantelme P, Mestre C, Lievre M, et al.: Heart rate: an important confounder of pulse wave velocity assessment. Hypertension, 2002, 39: 1083–1087. [Medline] [CrossRef]

26) Sugawara J, Hayashi K, Yokoi T, et al.: Brachial-ankle pulse wave velocity: an index of central arterial stiffness? J Hum Hypertens, 2005, 19: 401–406. [Medline] [CrossRef]
27) Yamato Y, Hasegawa N, Fujie S, et al.: Acute effect of stretching one leg on regional arterial stiffness in young men. Eur J Appl Physiol, 2017, 117: 1227–1232. [Medline] [CrossRef]
28) Yamato Y, Higaki Y, Fujie S, et al.: Acute effect of passive one-legged intermittent static stretching on regional blood flow in young men. Eur J Appl Physiol, 2021, 121: 331–337. [Medline] [CrossRef]
29) Hotta K, Batchelor WB, Graven J, et al.: Daily passive muscle stretching improves flow-mediated dilation of popliteal artery and 6-minute walk test in elderly patients with stable symptomatic peripheral artery disease. Cardiovasc Revasc Med, 2019, 20: 642–648. [Medline] [CrossRef]
30) Hotta K, Behnke BJ, Arjmandi B, et al.: Daily muscle stretching enhances blood flow, endothelial function, capillarity, vascular volume and connectivity in aged skeletal muscle. J Physiol, 2018, 596: 1903–1917. [Medline] [CrossRef]
31) Sugawara J, Komine H, Hayashi K, et al.: Reduction in alpha-adrenergic receptor-mediated vascular tone contributes to improved arterial compliance with endurance training. Int J Cardiol, 2009, 135: 346–352. [Medline] [CrossRef]
32) Wong A, Figueroa A: Eight weeks of stretching training reduces aortic wave reflection magnitude and blood pressure in obese postmenopausal women. J Hum Hypertens, 2014, 28: 246–250. [Medline] [CrossRef]
33) Guimarães GV, Ciolac EG, Carvalho VO, et al.: Effects of continuous vs. interval exercise training on blood pressure and arterial stiffness in treated hypertension. Hypertens Res, 2010, 33: 627–632. [Medline] [CrossRef]
34) Ainsworth BE, Haskell WL, Whitt MC, et al.: Compendium of physical activities: an update of activity codes and MET intensities. Med Sci Sports Exerc, 2000, 32: S498–S504. [Medline] [CrossRef]
35) Garber CE, Blissmer B, Deschenes MR, et al. American College of Sports Medicine: American College of Sports Medicine position stand. Quantity and quality of exercise for developing and maintaining cardiorespiratory, musculoskeletal, and neuromotor fitness in apparently healthy adults: guidance for prescribing exercise. Med Sci Sports Exerc, 2011, 43: 1334–1359. [Medline] [CrossRef]