



Original Article

Effects of different intensities and durations of aerobic exercise training on arterial stiffness

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Abstract. [Purpose] In the present study, we investigated the effects of regular aerobic training with different intensities and durations on new indices of arterial stiffness measured via an upper-arm oscillometric device. [Participants and Methods] We gathered data from 41 middle-aged and older people (age 65.0 ± 11.7 years). Participants were randomly divided into five groups: (1) 15 minutes of low intensity aerobic training (n=10); (2) 30 minutes of low intensity training (n=7); (3) 15 minutes of moderate-intensity training (n=9); (4) 30 minutes of moderate-intensity training (n=8); and (5) a non-training group (n=7). Training was conducted for 8 weeks, three times per week. Arterial pulse wave index, arterial pressure-volume index, brachial-ankle and heart-brachial pulse wave velocity, cardio-ankle vascular index, brachial and ankle blood pressure, heart rate, and peak oxygen uptake were measured before and after the intervention. [Results] All indicators of arterial stiffness and brachial and ankle blood pressure in the exercise groups were significantly lower after versus before the intervention. Peak oxygen uptake did not differ before versus after the intervention. [Conclusion] The present findings indicate that regular aerobic exercise may be important in reducing arterial stiffness regardless of the intensity or duration of aerobic exercise.

Key words: Aerobic exercise training, Exercise intensity and duration, New index of arterial stiffness

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INTRODUCTION

An increase in arterial stiffness, which indicates the stiffness of the arterial wall, has been reported to be associated with the onset of cardiovascular disease¹⁻⁴⁾. Because arterial stiffness increases with age^{5, 6)}, preventing this increase in arterial stiffness in middle-aged and elderly people may be important in reducing the mortality rate associated with cardiovascular disease.

Low- to moderate-intensity aerobic exercise, such as regular walking and running, has been found to reduce arterial stiffness in middle-aged and elderly people⁷⁻⁹⁾. However, the effects of different intensities and durations of regular aerobic exercise training on arterial stiffness in middle-aged and elderly people have not been comprehensively examined. Moreover, the effects of periodic aerobic exercise on arterial stiffness have previously been evaluated via pulse wave velocity (PWV)

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and cardio-ankle vascular index (CAVI) tests⁷⁻¹²). Although these techniques are clinically and experimentally accepted, they have some disadvantages: (1) a long measurement time, (2) a physical load (pressure from a blood pressure (BP) cuff on the arms and ankles or from squeezing a tonometry sensor into the carotid artery), and (3) the high degree of knowledge and skill required to apply tonometry transducers¹³). Therefore, another method for periodically checking arterial stiffness might be of value.

In recent years, as a new method for measuring arterial stiffness, researchers have examined the use of the arterial pulse wave index (AVI) as an index of systemic arterial stiffness and the arterial pressure volume index (API) as an index of peripheral arterial stiffness. AVI and API can be calculated simply by wrapping an oscillometric cuff around one upper arm, making it easier to use (everyone can conduct measurements) compared with PWV and CAVI. In addition, AVI and API are highly reliable because they are correlated with PWV¹⁴⁻¹⁶). Furthermore, because AVI and API are affected by cardiovascular disease, they are likely to be useful in prevention efforts because they may be able to predict disease onset^{16, 17}). Studies that have examined the effects of exercise on AVI and API have reported that people with a high level of physical activity have lower AVI and API values compared with those with a low level of physical activity¹⁸). Examining the effects of exercise using arterial stiffness as an indicator, as measured via AVI and API, may be helpful in preventing cardiovascular disease because of the ease of measurement. For instance, with AVI and API, arterial stiffness can be measured using methods that are similar to those used to measure blood pressure, facilitating self-management. However, the effects of regular aerobic training on AVI and API have not been comprehensively examined.

The purpose of this study was to clarify the effects of regular aerobic training with different intensities and durations on AVI, API, PWV, and CAVI. We hypothesized that AVI, API, PWV, and CAVI would decrease with regular aerobic exercise training.

PARTICIPANTS AND METHODS

We gathered data from forty-one middle-aged and older people (age 65.0 ± 11.7 years, [Table 1](#)). All lived sedentary lifestyles, were normotensive, did not smoke, and had no symptoms or history of chronic diseases. All were fully informed about the experimental procedures as well as the purpose of the study before providing written, informed consent to participate. The ethics committee at Teikyo University of Science approved this study, which proceeded in accordance with the guidelines for human experimentation published by our institutional review board (18103). This study also conformed to the principles of the Declaration of Helsinki. All participants completed the experiment in 5 training group conditions, ordered in random fashion: (1) low intensity (25% of the age-predicted maximum heart rate (HR)) aerobic exercise conducted for 15 minutes (LOW-15 group, n=10); (2) low intensity (25% of the age-predicted maximum HR) aerobic exercise conducted for 30 minutes (LOW-30 group, n=7); (3) moderate intensity (50% of the age-predicted maximum HR) aerobic exercise conducted for 15 minutes (MOD-15 group, n=9); (4) moderate intensity (50% of the age-predicted maximum HR) aerobic exercise conducted for 30 minutes (MOD-30 group, n=8), and (5) a non-training group (Non group, n=7). Before and after the intervention, which was 8 weeks long, we conducted AVI, API, PWV, CAVI, oxygen uptake during peak exercise (VO_{2peak}) measurements after 10 min of rest. Brachial-ankle PWV (baPWV), heart-brachial PWV (hbPWV), blood pressure (BP), and heart rate (HR) were measured using a PWV/ABI vascular testing device (Omron-Colin Co., Ltd., Kyoto, Japan)^{19, 20}). CAVI was measured using a VaSera VS-1500AE vascular testing device (Fukuda-Denshi Co., Ltd., Tokyo, Japan)²¹), and AVI and

Table 1. Changes in participant characteristics between the pre (baseline) and post (8-week) values in all group

Variable	LOW-15 group		LOW-30 group		MOD-15 group		MOD-30 group		CON group		Main effect of intervention	Main effect of time
	Pre	8-week	Pre	8-week	Pre	8-week	Pre	8-week	Pre	8-week		
Age (years)	63.1 ± 3.5	-	65.9 ± 4.0	-	70.9 ± 3.9	-	63.8 ± 5.2	-	60.7 ± 3.8	-	-	p=0.478
Gender	3 males, 7 females	-	2 males, 5 females	-	5 males, 4 females	-	3 males, 5 females	-	1 male, 6 females	-	-	-
Height (cm)	157.4 ± 3.2	-	158.0 ± 2.4	-	162.1 ± 3.4	-	163.6 ± 2.7	-	158.3 ± 2.8	-	-	p=0.498
Weight (kg)	58.4 ± 2.6	58.6 ± 2.6	56.2 ± 3.8	56.1 ± 3.8	60.1 ± 2.0	59.7 ± 1.9	58.7 ± 4.0	59.5 ± 4.0	56.9 ± 3.7	58.0 ± 3.5	p=0.743	p=0.972
BMI (kg/m ²)	23.6 ± 0.7	23.7 ± 0.7	22.4 ± 1.0	22.3 ± 1.0	23.0 ± 1.0	22.8 ± 1.0	22.3 ± 2.1	22.6 ± 2.1	22.7 ± 1.5	23.2 ± 1.4	p=0.345	p=0.181
VO _{2peak} (ml/kg/min)	32.4 ± 1.8	32.2 ± 1.5	31.2 ± 2.4	31.1 ± 2.3	30.1 ± 3.2	30.7 ± 3.5	30.4 ± 2.7	29.9 ± 2.8	29.9 ± 1.8	28.9 ± 1.6	p=0.941	p=0.689

Values are mean ± SE. LOW-15 group: low-intensity 15 minute exercise group; LOW-30 group: low-intensity 30 minute exercise group; MOD-15 group: moderate-intensity 15 minute exercise group; MOD-30 group: moderate-intensity 30 minute exercise group; CON group: non-exercise control group.

*p<0.05 and **p<0.01 vs. Pre.

API were measured using a PASESA AVE-1500 vascular testing device (Shisei Datum Co., Ltd., Tokyo, Japan)^{15–18, 22}. VO_{2peak} was assessed via an incremental test to exhaustion (1 min warm-up at 15 Watt, cycling at 15 Watt, followed by a 15 Watt/min increase). VO_{2peak} was monitored breath-by-breath using a Power Mets AT-1100A device (Anima Co. Ltd., Tokyo, Japan). The exercise sessions were conducted three times per week for 8 weeks. The participants exercised once a week using a bicycle ergometer (Medergo EM-400, OG Wellness Co. Ltd., Okayama, Japan) in the laboratory, and walked or jogged twice a week. The intensity and duration of exercise were controlled using a HR monitor (PulNeo HR-70, JAPAN PRECISION INSTRUMENTS, Inc., Gunma, Japan). The daily coefficients of variation (CVs) in the laboratory were $3 \pm 1\%$, $3 \pm 2\%$, $6 \pm 1\%$, $3 \pm 2\%$, and $6 \pm 1\%$ for baPWV, hbPWV, CAVI, AVI, and API, respectively. The participants abstained from alcohol, caffeine, and exercise for 24 h before being tested. They reported to the laboratory after 10 h of fasting. All data are presented as means \pm standard deviation (SD). Data were analyzed using a repeated-measures 2-way ANOVA (group-by-time). Significant differences between mean values were identified using the Bonferroni post hoc test. Data were statistically analyzed using SPSS (version. 22; IBM, Armonk, NY, USA). Statistical significance was set at $p < 0.05$.

RESULTS

The height, weight, body mass index (BMI) and VO_{2peak} of the participants did not differ before vs. after the intervention or between groups ($p > 0.05$, Table 1). The baPWV, hbPWV, CAVI, AVI, and API did not differ before vs. after the intervention in any groups ($p > 0.05$, Table 2). The baPWV, hbPWV, CAVI, AVI, and API in the LOW-15, LOW-30, MOD-15, and MOD-30 groups were significantly lower after the 8-week intervention compared with before the intervention ($p < 0.05$, Table 2), while that in the CON group was unchanged ($p > 0.05$, Table 2). The brachial and ankle BP before and after the intervention did not differ in any groups ($p > 0.05$, Table 3). The brachial and ankle BP (except for ankle DBP) reduced after intervention in trained group ($p < 0.05$, Table 3), while that in the CON group was unchanged ($p > 0.05$, Table 3).

DISCUSSION

We found that baPWV, hbPWV, CAVI, AVI, and API in the LOW-15, LOW-30, MOD-15, and MOD-30 groups were significantly lower after the 8-week intervention compared with before the intervention, while that in the CON group was unchanged. This suggests that regardless of the intensity or duration of aerobic exercise, regular aerobic exercise may be important in reducing arterial stiffness.

Many previous studies have shown that moderate aerobic exercise training reduces systemic, aortic, and peripheral arterial stiffness^{7–9, 23}. In previous studies, aortic PWV improved after 16 weeks of medium-intensity walking/jogging in middle-aged men⁷) and after 12 weeks of moderate-intensity cycling in middle-aged women²³). Another study found a decrease in arteriosclerosis after aerobic exercise training, but no difference between a group that exercised at 40% the reserve heart rate (low intensity) and a group that exercised at 70% the reserve heart rate (medium intensity)²⁴). In the present study, arterial stiffness decreased after 8 weeks of aerobic exercise training at 25% and 50% the age-predicted maximum HR, but we did not find a difference between any of the exercise groups. Therefore, our data indicate that exercise intensity does not have a strong influence on the effect of aerobic exercise training at a low to medium intensity with respect to arterial stiffness.

In most aerobic exercise training studies that have reported reduced arterial stiffness, aerobic exercise is performed for 20–60 minutes per day. For instance, Kakiyama et al.¹¹) reported a reduction in aortic stiffness after 60 minutes of aerobic exercise training (medium intensity, 3.5 times per week, 8 weeks of exercise). Collier et al.¹⁰) suggested that aortic stiffness decreased after 30 minutes per day of aerobic exercise training (medium intensity, 3 times per week, 4 weeks of exercise). Further, Madden et al.²⁵) revealed that peripheral arterial stiffness decreased after 30 minutes per day of aerobic exercise training (medium intensity, 3 times per week, 4 weeks of exercise). Although the short-term chronic effects have not been clarified, 15 minutes of aerobic exercise training (medium intensity) has been found to have an acute effect in that it decreased aortic/peripheral artery stiffness²⁶). In this study, we found that arterial stiffness decreased after 15 and 30 minutes of aerobic exercise training per day, and we did not find a difference between different levels of exercise intensity. Therefore, we expect a reduction in arterial stiffness to occur if exercise is conducted for at least 15 minutes per day.

Although we did not explicitly examine the mechanisms of exercise-induced changes in arterial stiffness, changes in arterial stiffness are known to correlate with blood pressure^{27, 28}). Previous studies have reported that arterial stiffness and systolic blood pressure decreased after aerobic exercise training¹⁰). Similar results were observed in the present study. Therefore, the decrease in arterial stiffness after aerobic exercise training seen in this study may be associated with a decrease in blood pressure.

This study has several limitations. First, our participants were healthy middle-aged and older people, which precludes generalizing our findings to young individuals. Second, we did not design this study to examine the possible mechanisms by which aerobic exercise training decreases arterial stiffness.

In conclusion, baPWV, hbPWV, CAVI, AVI, and API in the LOW-15, LOW-30, MOD-15, and MOD-30 groups were significantly lower after vs. before the 8-week exercise intervention, while that in the CON group was unchanged. The baPWV, hbPWV, CAVI, AVI, and API values before and after the intervention did not differ between any of the exercise groups. This suggests that regardless of the intensity or duration of aerobic exercise, regular aerobic exercise may be important in reducing arterial stiffness.

Table 2. Changes in physical activity between the pre (baseline) and post (8-week) values in all groups

Variable	LOW-15 group		LOW-30 group		MOD-15 group		MOD-30 group		CON group		Main effect of intervention	Main effect of time
	Pre	8-week	Pre	8-week	Pre	8-week	Pre	8-week	Pre	8-week		
baPWV (cm/sec)	1,565.3 ± 111.1	1,349.3 ± 91.6*	1,533.7 ± 102.2	1,329.0 ± 82.3*	1,548.0 ± 98.5	1,367.3 ± 78.5*	1,513.4 ± 175.0	1,275.0 ± 85.6*	1,511.4 ± 150.1	1,530.6 ± 181.8	p=0.305	p=0.0001
hbPWV (cm/sec)	588.1 ± 26.1	514.2 ± 15.7*	582.1 ± 35.6	498.7 ± 43.9*	623.9 ± 16.4	543.8 ± 31.2*	551.5 ± 18.4	470.0 ± 15.4*	581.3 ± 44.7	582.1 ± 53.0	p=0.369	p=0.0001
CAVI (unit)	8.3 ± 1.0	7.5 ± 0.8*	8.6 ± 0.9	7.6 ± 0.6*	8.6 ± 1.1	7.7 ± 1.1*	8.2 ± 1.4	7.3 ± 1.0*	8.2 ± 1.5	8.2 ± 1.5	p=0.324	p=0.0001
AVI (unit)	27.4 ± 3.3	19.2 ± 2.5*	28.4 ± 1.6	20.4 ± 1.4*	27.4 ± 3.4	18.5 ± 1.9*	25.1 ± 4.3	21.7 ± 3.6*	25.1 ± 4.3	25.0 ± 3.6	p=0.834	p=0.0001
API (unit)	31.9 ± 2.8	25.0 ± 1.4**	34.0 ± 4.8	26.7 ± 3.1*	31.7 ± 2.5	26.1 ± 1.6*	31.9 ± 4.0	24.1 ± 1.9**	32.1 ± 2.6	31.6 ± 1.6	p=0.707	p=0.0001

Values are mean ± SE. LOW-15 group: low-intensity 15 minute exercise group; LOW-30 group: low-intensity 30 minute exercise group; MOD-15 group: moderate-intensity 15 minute exercise group; MOD-30 group: moderate-intensity 30 minute exercise group; CON group: non-exercise control group. *p<0.05 and **p<0.01 vs. Pre.

Table 3. Changes in blood pressure and heart rate between the pre (baseline) and post (8-week) values in all groups

Variable	LOW-15 group		LOW-30 group		MOD-15 group		MOD-30 group		CON group		Main effect of intervention	Main effect of time
	Pre	8-week	Pre	8-week	Pre	8-week	Pre	8-week	Pre	8-week		
Brachial SBP (mmHg)	138.9 ± 21.3	123.1 ± 22.7**	139.4 ± 21.0	121.9 ± 22.2**	138.6 ± 14.4	124.8 ± 16.3**	135.4 ± 15.2	119.8 ± 13.3**	135.7 ± 27.6	135.0 ± 20.2	p=0.187	p=0.0001
Brachial MBP (mmHg)	103.4 ± 10.8	94.1 ± 12.7**	104.1 ± 10.5	93.5 ± 8.9**	102.3 ± 7.3	93.5 ± 7.1**	100.5 ± 11.1	89.4 ± 11.8**	100.5 ± 12.7	98.7 ± 12.1	p=0.404	p=0.0001
Brachial DBP (mmHg)	85.7 ± 9.3	79.6 ± 11.2*	86.4 ± 11.6	79.3 ± 12.5*	84.2 ± 7.3	77.9 ± 6.5*	83.1 ± 11.8	74.3 ± 12.5**	82.9 ± 6.5	80.6 ± 10.2	p=0.579	p=0.0001
Brachial PP (mmHg)	53.2 ± 20.3	43.5 ± 20.7	53.0 ± 23.9	42.6 ± 29.3	54.3 ± 15.2	46.9 ± 17.3	52.3 ± 14.5	45.5 ± 10.0	52.9 ± 23.3	54.4 ± 16.3	p=0.939	p=0.292
Ankle SBP (mmHg)	155.3 ± 17.8	143.4 ± 18.0**	156.5 ± 26.3	141.5 ± 17.8**	153.7 ± 18.1	142.9 ± 18.9*	155.3 ± 31.5	139.8 ± 23.6**	152.9 ± 28.5	150.6 ± 29.4	p=0.283	p=0.0001
Ankle MBP (mmHg)	101.9 ± 11.3	95.7 ± 11.1**	102.1 ± 11.8	95.4 ± 10.8**	101.4 ± 9.9	96.5 ± 12.3*	101.0 ± 16.5	93.3 ± 16.1**	101.1 ± 17.2	99.9 ± 17.4	p=0.310	p=0.0001
Ankle DBP (mmHg)	75.2 ± 9.6	71.9 ± 8.7	74.9 ± 8.1	72.4 ± 9.9	75.2 ± 7.3	73.3 ± 9.9	73.9 ± 10.1	70.1 ± 13.3	75.3 ± 12.1	74.6 ± 11.6	p=0.863	p=0.0009
Ankle PP (mmHg)	80.1 ± 13.0	71.5 ± 12.5*	81.6 ± 24.7	69.2 ± 15.6*	78.6 ± 14.4	69.6 ± 12.0*	81.4 ± 23.9	69.7 ± 14.2*	77.6 ± 18.3	76.0 ± 18.6	p=0.547	p=0.0001
Heart rate (beats/min)	72.3 ± 9.6	66.5 ± 8.7	70.9 ± 12.1	67.6 ± 7.1	69.6 ± 7.7	69.0 ± 10.7	66.4 ± 6.5	64.8 ± 8.7	70.0 ± 11.4	70.4 ± 7.0	p=0.660	p=0.343

Values are mean ± SD. LOW-15 group: low-intensity 15 minute exercise group; LOW-30 group: low-intensity 30 minute exercise group; MOD-15 group: moderate-intensity 15 minute exercise group; MOD-30 group: moderate-intensity 30 minute exercise group; CON group: non-exercise control group; SBP: systolic blood pressure; MBP: mean blood pressure; DBP: diastolic blood pressure; PP: pulse pressure. *p<0.05 and **p<0.01 vs. Pre.

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Conflict of interest

None.

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REFERENCES

- 1) Tsuchikura S, Shoji T, Kimoto E, et al.: Central versus peripheral arterial stiffness in association with coronary, cerebral and peripheral arterial disease. *Atherosclerosis*, 2010, 211: 480–485. [[Medline](#)] [[CrossRef](#)]
- 2) Blacher J, Asmar R, Djane S, et al.: Aortic pulse wave velocity as a marker of cardiovascular risk in hypertensive patients. *Hypertension*, 1999, 33: 1111–1117. [[Medline](#)] [[CrossRef](#)]
- 3) Matsushita K, Ding N, Kim ED, et al.: Cardio-ankle vascular index and cardiovascular disease: systematic review and meta-analysis of prospective and cross-sectional studies. *J Clin Hypertens (Greenwich)*, 2019, 21: 16–24. [[Medline](#)] [[CrossRef](#)]
- 4) Ninomiya T, Kojima I, Doi Y, et al.: Brachial-ankle pulse wave velocity predicts the development of cardiovascular disease in a general Japanese population: the Hisayama Study. *J Hypertens*, 2013, 31: 477–483, discussion 483. [[Medline](#)] [[CrossRef](#)]
- 5) Vlachopoulos C, Aznaouridis K, O'Rourke MF, et al.: Prediction of cardiovascular events and all-cause mortality with central haemodynamics: a systematic review and meta-analysis. *Eur Heart J*, 2010, 31: 1865–1871. [[Medline](#)] [[CrossRef](#)]
- 6) 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](#)]
- 7) Hayashi K, Sugawara J, Komine H, et al.: Effects of aerobic exercise training on the stiffness of central and peripheral arteries in middle-aged sedentary men. *Jpn J Physiol*, 2005, 55: 235–239. [[Medline](#)] [[CrossRef](#)]
- 8) Maeda S, Sugawara J, Yoshizawa M, et al.: Involvement of endothelin-1 in habitual exercise-induced increase in arterial compliance. *Acta Physiol (Oxf)*, 2009, 196: 223–229. [[Medline](#)] [[CrossRef](#)]
- 9) Cameron JD, Dart AM: Exercise training increases total systemic arterial compliance in humans. *Am J Physiol*, 1994, 266: H693–H701. [[Medline](#)]
- 10) Collier SR, Kanaley JA, Carhart R Jr, et al.: Effect of 4 weeks of aerobic or resistance exercise training on arterial stiffness, blood flow and blood pressure in pre- and stage-1 hypertensives. *J Hum Hypertens*, 2008, 22: 678–686. [[Medline](#)] [[CrossRef](#)]
- 11) Kakiyama T, Sugawara J, Murakami H, et al.: Effects of short-term endurance training on aortic distensibility in young males. *Med Sci Sports Exerc*, 2005, 37: 267–271. [[Medline](#)] [[CrossRef](#)]
- 12) Moreau KL, Donato AJ, Seals DR, et al.: Regular exercise, hormone replacement therapy and the age-related decline in carotid arterial compliance in healthy women. *Cardiovasc Res*, 2003, 57: 861–868. [[Medline](#)] [[CrossRef](#)]
- 13) Tomiyama H, Yamashina A: Non-invasive vascular function tests: their pathophysiological background and clinical application. *Circ J*, 2010, 74: 24–33. [[Medline](#)] [[CrossRef](#)]
- 14) Komatsu S, Tomiyama H, Kimura K, et al.: Comparison of the clinical significance of single cuff-based arterial stiffness parameters with that of the commonly used parameters. *J Cardiol*, 2017, 69: 678–683. [[Medline](#)] [[CrossRef](#)]
- 15) Komine H, Asai Y, Yokoi T, et al.: Non-invasive assessment of arterial stiffness using oscillometric blood pressure measurement. *Biomed Eng Online*, 2012, 11: 6. [[Medline](#)] [[CrossRef](#)]
- 16) Okamoto M, Nakamura F, Musha T, et al.: Association between novel arterial stiffness indices and risk factors of cardiovascular disease. *BMC Cardiovasc Disord*, 2016, 16: 211. [[Medline](#)] [[CrossRef](#)]
- 17) Sasaki-Nakashima R, Kino T, Chen L, et al.: Successful prediction of cardiovascular risk by new non-invasive vascular indexes using suprasystolic cuff oscillometric waveform analysis. *J Cardiol*, 2017, 69: 30–37. [[Medline](#)] [[CrossRef](#)]
- 18) Kobayashi R, Iwanuma S, Ohashi N, et al.: New indices of arterial stiffness measured with an upper-arm oscillometric device in active versus inactive women. *Physiol Rep*, 2018, 6: 6. [[Medline](#)] [[CrossRef](#)]
- 19) Okamoto T, Masuhara M, Ikuta K: Combined aerobic and resistance training and vascular function: effect of aerobic exercise before and after resistance training. *J Appl Physiol* 1985, 2007, 103: 1655–1661. [[Medline](#)] [[CrossRef](#)]
- 20) Sugawara J, Tomoto T, Tanaka H: Arterial path length estimation for heart-to-brachium pulse wave velocity. *Hypertens Res*, 2018, 41: 444–450. [[Medline](#)] [[CrossRef](#)]
- 21) Nishiwaki M, Fujibayashi M, Nanayama C, et al.: Increasing levels of daily physical activity for arterial stiffness reduction in older women: a community-based pilot study. *J Sports Med Phys Fitness*, 2018, 58: 1701–1709. [[Medline](#)] [[CrossRef](#)]
- 22) Sueta D, Yamamoto E, Tanaka T, et al.: The accuracy of central blood pressure waveform by novel mathematical transformation of non-invasive measurement. *Int J Cardiol*, 2015, 189: 244–246. [[Medline](#)] [[CrossRef](#)]
- 23) Yoshizawa M, Maeda S, Miyaki A, et al.: 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. [[Medline](#)] [[CrossRef](#)]
- 24) Sugawara J, Otsuki T, Tanabe T, et al.: Physical activity duration, intensity, and arterial stiffening in postmenopausal women. *Am J Hypertens*, 2006, 19:

1032–1036. [\[Medline\]](#) [\[CrossRef\]](#)

- 25) Madden KM, Lockhart C, Cuff D, et al.: Aerobic training-induced improvements in arterial stiffness are not sustained in older adults with multiple cardiovascular risk factors. *J Hum Hypertens*, 2013, 27: 335–339. [\[Medline\]](#) [\[CrossRef\]](#)
- 26) Kobayashi R, Hatakeyama H, Hashimoto Y, et al.: Acute effects of different aerobic exercise duration on pulse wave velocity in healthy young men. *J Sports Med Phys Fitness*, 2017, 57: 1695–1701. [\[Medline\]](#)
- 27) Benetos A, Laurent S, Asmar RG, et al.: Large artery stiffness in hypertension. *J Hypertens Suppl*, 1997, 15: S89–S97. [\[Medline\]](#) [\[CrossRef\]](#)
- 28) Vlachopoulos C, Kardara D, Anastasakis A, et al.: Arterial stiffness and wave reflections in marathon runners. *Am J Hypertens*, 2010, 23: 974–979. [\[Medline\]](#) [\[CrossRef\]](#)