Journal of Exercise Science & Fitness 16 (2018) 73–77

Contents lists available at ScienceDirect

Journal of Exercise Science & Fitness

journal homepage: www.elsevier.com/locate/jesf

The relationship between arterial stiffness and maximal oxygen consumption in healthy young adults

Hyun Namgoong [a, 1], Dongmin Lee [a, 1], Moon-Hyon Hwang [c, d], Sewon Lee [b, d, *]

[a] Department of Human Movement Science, Graduate School, Incheon National University, Incheon, South Korea
[b] Division of Sport Science, Incheon National University, Incheon, South Korea
[c] Division of Health and Exercise Science, Incheon National University, Incheon, South Korea
[d] Sport Science Institute, Incheon National University, Incheon, South Korea

A R T I C L E I N F O

Article history:
Received 6 March 2018
Received in revised form
19 July 2018
Accepted 30 July 2018
Available online 17 August 2018

Keywords:
Arterial stiffness
Aerobic capacity
baPWV
VO_{2max}

A B S T R A C T

Objective: Arterial stiffness is associated with an increased risk of cardiovascular diseases in various populations. There was little research on the relationship between arterial stiffness and maximal aerobic capacity (VO_{2max}) in healthy young adults. The aim of this study was to investigate the relationship between VO_{2max} and arterial stiffness in young adults.
Methods: The subjects were 13 men and 10 women with mean age of 22.9 ± 0.7, 23.6 ± 0.4 years, respectively. Height, weight, body mass index, body fat (%), waist to hip ratio, total/high density lipoprotein (HDL)/low density lipoprotein (LDL) cholesterol, triglycerides, fasting glucose, blood pressure, heart rate, glycated hemoglobin and blood lactate were measured. In addition, peripheral arterial stiffness was assessed by measuring brachial-ankle pulse wave velocity (baPWV) and VO_{2max} was determined using graded exercise test.
Results: VO_{2max} had no significant correlation with baPWV ($r = 0.2$, $p = 0.2$). Total cholesterol correlated significantly to variables such as HDL ($r = 0.6$, $p = 0.0015$) and LDL cholesterol ($r = -0.6$, $p = 0.0018$). VO_{2max} had a significant association with triglyceride ($r = -0.5$, $p = 0.0033$).
Conclusions: This study suggests that there is no relationship between arterial stiffness and aerobic capacity in healthy young adults.

Introduction

Most cardiovascular risk factors such as hypertension, diabetes and endothelial dysfunction may contribute to alteration in the structure and function of arterial blood vessels.[1] Arterial stiffness represents deleterious vascular phenotypes in some pathophysiological condition such as diabetes, atherosclerosis and kidney disease, in this reason it is considered as an important surrogate marker to predict future cardiovascular outcomes.[2,3] Previous evidence has shown that arterial walls stiffen with age because aging process induced alterations in arterial wall tissue.[4,5] It has also been established that arterial stiffness increases with age in healthy individuals without overt cardiovascular disease (CVD), suggesting increasing age may be an independent risk factor for arterial stiffening.[5] To measure arterial stiffness, brachial-ankle pulse wave velocity (baPWV) has become a popular method because of an advantage of convenience to use.[6] Previous studies have shown that baPWV is highly related to risk factors for CVD and aerobic capacity.[7,8]

Both acute and chronic aerobic exercise has been suggested to reduce arterial stiffness by enhancing vascular endothelial function as well as by effectively acting on structural and functional changes in blood vessels.[5,9–11] Of these studies, Vaitkevicius et al. showed that a progressive increase in arterial stiffness with advancing age (96 men 21–91 years old and 50 women 26–96 years old) and the age-associated arterial stiffness is inversely related to exercise capacity measured by maximal aerobic capacity (VO_{2max}), suggesting arterial stiffness may be delayed by regular aerobic exercise.[5] The maximum oxygen uptake indicates the oxygen transport capacity of cardiovascular system and the ability of the tissue to utilize

* Corresponding author. Division of Sport Science and Sport Science Institute, Incheon National University, Bldg# 16, Room# 423, (Songdo-dong) 119 Academy-ro, Yeonsu-gu, Incheon, South Korea.
E-mail address: leesew@inu.ac.kr (S. Lee).
[1] Contributed equally to conduct of the studies.

https://doi.org/10.1016/j.jesf.2018.07.003

oxygen. The parameter is highly correlated with the cardiopulmonary endurance and is generally improved by endurance training and decreased with advancing age.[12] Previous evidence has shown an inverse relationship between cardiorespiratory fitness and CVD mortality, suggesting improving aerobic fitness is a key factor in cardiovascular health.[13,14] Graded Exercise Test (GXT) is a typical method to measure maximal oxygen uptake and is often used to examine the subject's risk of heart disease and cardiopulmonary endurance.[15,16] Augustine et al. have suggested that aortic stiffness is inversely associated with maximal oxygen consumption in the middle aged women with central obesity.[17] In this study, the authors suggested CVD risk factors such as insulin resistance, systemic inflammation and hemodynamic mechanical stress may be associated with aortic stiffness.[17] In addition, Tomoto et al. indicated that both baPWV and heart-ankle PWV are inversely correlated to aerobic capacity in wide range of age in the healthy men (18–64 years) and Arena et al. showed a relationship between VO_{2max} and aortic wave velocity in healthy middle aged subjects.[6,18] Taken together, aerobic capacity and arterial stiffness may be negatively correlated in disease condition such as obesity and advancing age. However, there is very limited research on the relationship between arterial stiffness and aerobic capacity in healthy young adults. Specifically, since Tomoto group showed various aerobic capacity levels and wide range of arterial stiffness in their various range of age group in 82 healthy men (18–64 years),[6] it is needed to investigate the relationship between arterial stiffness and aerobic capacity in healthy young men. In this regard, we investigated whether arterial stiffness is correlated with maximal oxygen consumption in young adults. Further, we also investigated the relationship between arterial stiffness and CVD risk factors (blood biomarkers including glycated hemoglobin (HbA1c), glucose and lipid profiles).

Methods

Participants

We calculated the sample size of this pilot study using G power program based on the results of a previously published study.[6] The total sample size was calculated to be at least 14 subjects. A healthy, young group comprising 23 subjects: 13 men (22.9 ± 0.7 years) and 10 women (23.6 ± 0.4 years) were participated in this study. We excluded subjects with a previous history of diagnosis or medication for hypertension and clinical CVD including ischemic heart disease. All subjects underwent both GXT by treadmill and evaluation of arterial stiffness by baPWV. All subjects were informed about the benefits and possible risks of the study and were participated in the study after signing a written consent form. This experimental protocol was reviewed and approved by the Institutional Review Board of Incheon National University.

Anthropometric and blood pressure measurement

All participants were arrived at the laboratory at the same time (around 10:00 a.m.) in the morning after at least 10 h overnight fasting. Body weight (kg), body mass index (BMI, kg/m^2), and body fat (%) were measured using a bioelectrical impedance method analyzer (Inbody 720, Biomedical, South Korea). The resting systolic blood pressure (SBP), diastolic blood pressure (DBP) from both arms and heart rate were measured in the seated position using an automated oscillometric blood pressure cuff (Ex-Plus 1300, Jawon Medical, South Korea).

Graded exercise test (GXT)

Maximum exercise testing was performed according to a Bruce protocol on a motor driven treadmill and maximal oxygen consumption was assessed in a controlled environment. Open circuit spirometry was used to assess cardiorespiratory fitness. The Bruce protocol is designed for healthy adults and this is a standard procedure of increasing speed and inclination on the treadmill. The initial load started at the speed of 1.7 miles per hour (mph) and an inclination of 10°. The speed was increased by approximately 0.8–0.9 mph and the slope was increased by 2° every 3 min whenever each step was done. Before each exercise session was initiated, we calibrated pneumotachometer and gas analysis according to manufacturer's instruction. A tightly sealed breathing mask connected to the airflow sensor was used. During the GXT, the oxygen uptake (VO_2), carbon dioxide production (VCO_2), pulmonary ventilation (VE) and respiratory exchange ratio (RER) were measured breath-to-breath through a stationary gas analyzer (Quark b2, COSMED, Germany). The maximal exercise test was continued until the subject voluntarily stopped. Blood lactate concentration was measured for VO_{2max} determination using an Accutrend Plus (Mannheim, Germany) before and after the GXT.

Blood analysis

Whole blood (35 μl) were collected from the fingertips after lancing the palm-side surface of a finger with lancet. Fasting blood glucose, triglycerides, high density lipoprotein (HDL), low density lipoprotein (LDL) and total cholesterol were immediately measured using a Cholestech LDX (Alere, Norway) according to manufacturer's protocol. In addition, 1.5 μl of whole blood was obtained from the fingertip and HbA1c was measured using an Afinion AS100 (Ballybrit Galway, Ireland).

Measurement of arterial stiffness

Pulse wave velocity (PWV) is a clinical method to measure arterial stiffness. PWV is usually assessed by measuring the time taken for a pulse wave to move a specified distance and is increased as arterial stiffness augments. baPWV, a validated arterial stiffness measurement, was assessed the supine position using a non-invasive device after 10 min of quiet rest according to manufacturer's protocol using a VP-1000 plus (Omron, Japan) by bilaterally collecting the brachial and the posterior tibialis (ankle) artery blood pressure.[19] Occlusion and cuffs were wrapped around both sides of the brachia and ankles and volume waveforms for the extremity were stored and analyzed automatically.

Statistical analyses

All data were presented as mean ± SD. Pearson's correlations were used to determine the relationships between measurement variables. We used paired *t*-test to determine the differences in circulating lactate concentration before and after the GXT. In addition, we used independent *t*-test to determine the differences in parameters between men and women. Statistical analyses were conducted using the GraphPad Prism version 6.05 (La Jolla, CA, USA). Statistical difference was considered significant at the $P < 0.05$ level.

Results

Basic clinical characteristics

Table 1 illustrates the basic characteristics of the study

Table 1
Basic characteristics of male and female subjects.

Variable	Male (n-13)	Female (n-10)	P value
Age (year)	22.9 ± 0.7	23.6 ± 0.4	0.4489
Height (cm)	176.5 ± 1.1	162.3 ± 2.0	<0.0001
Weight (kg)	72.1 ± 2.3	56.3 ± 3.8	0.0012
BMI(%)	23.1 ± 0.6	21.2 ± 1.0	0.0985
Body fat (%)	12.8 ± 0.9	25.0 ± 0.9	<0.0001
Total cholesterol (mg/dL)	148.4 ± 6.2	152.6 ± 8.7	0.6901
HDL (mg/dL)	59.3 ± 2.4	71.2 ± 7.1	0.0946
LDL (mg/dL)	71.8 ± 5.1	63.7 ± 6.6	0.3529
Triglycerides (mg/dL)	69.2 ± 6.5	94.0 ± 13.4	0.0883
Fasting glucose (mg/dL)	84.8 ± 2.9	92.7 ± 5.7	0.1975
HbA1c (%)	5.4 ± 0.1	5.2 ± 0.1	0.1729
SBP(L)/mmHg	123.0 ± 3.3	108.3 ± 3.0	0.004
DBP(L)/mmHg	71.8 ± 3.0	62.1 ± 1.9	0.02
SBP(R)/mmHg	122.3 ± 4.5	113.9 ± 3.3	0.1663
DBP(R)/mmHg	67.7 ± 2.4	64.4 ± 2.3	0.3378
Pulse rate (bpm)	75.2 ± 2.5	76.9 ± 4.0	0.7046
R-PWV(m/s)	1123.2 ± 47.8	958.3 ± 38.1	0.0177
L-PWV(m/s)	1119.2 ± 36.8	988.0 ± 43.6	0.031
VO2max (ml/kg/min)	55.2 ± 2.6	40.4 ± 2.6	0.0008
Lactate (before, mmol/L)	2.6 ± 0.3	2.5 ± 0.3	–
Lactate (after, mmol/L)	11.0 ± 1.1	13.0 ± 1.3	–

Values are means ± SD.
BMI, body mass index; DBP, diastolic blood pressure; HbA1c, hemoglobin A1c; HDL, high density lipoprotein; L, left; LDL, low density lipoprotein; PWV, pulse wave velocity; R, right; SBP, systolic blood pressure; VO_{2max}, maximal oxygen consumption.

population. The study included 13 men aged 22.9 ± 0.7 years and 10 women aged 23.6 ± 0.4 years. Most of variables including age, BMI, total/HDL/LDL cholesterol, triglycerides, fasting glucose, HbA1c, right SBP and DBP, heart rate were comparable between male and female subjects. We confirmed that all subjects did not have overt cardiometabolic disease. As we anticipated, the male participants were taller and had greater weight and VO_{2max} than female participants, whereas female had higher body fat than male subjects. Further, male had higher left SBP ($p = 0.004$) and DBP ($p = 0.02$) than female, whereas right SBP and DBP were comparable. Consistent with a previous study,[20] both right ($p = 0.0177$) and left ($p = 0.031$) baPWV were significantly lower in female compared to male subjects.

Blood lactate

The blood lactate concentration was significantly elevated after GXT exercise in both men and women (Table 1).

Correlation between left and right baPWV

We assessed the relationship between left and right baPWV in male ($r = 0.9739$) and female ($r = 0.9642$) subjects, respectively (Fig. 1). Because there was no significant difference between right and left baPWV ($p = 0.8$), we used a mean right/left baPWV value for further analysis.

Correlation analysis between all measurements

The correlation analysis between all measurements are shown in Table 2 and Fig. 2. Specifically, total cholesterol correlated significantly to variables such as LDL (Fig. 2A, $r = -0.63$, $p = 0.0018$) and HDL cholesterol (Fig. 2B, $r = 0.59$, $p = 0.001$). Interestingly, VO_{2max} had an inverse association with triglyceride (Fig. 2C, $r = -0.55$, $p = 0.0033$), whereas VO_{2max} had no significant correlation with baPWV (Fig. 2D, $r = 0.17$, $p = 0.2168$).

Discussion

Previous studies have indicated there was an inverse relationship between cardiorespiratory fitness and arterial stiffness in the middle aged obese women and endurance athletes, suggesting individuals with higher cardiorespiratory fitness may have less possibility to develop arterial stiffness subsequently a reduction to cardiovascular mortality risk.[17,21] In this regard, we hypothesized that our study would show similar findings in healthy young adults. However, in this study there was no relationship between arterial stiffness and aerobic capacity in healthy young adults (Fig. 2D).

Augustine et al. showed that VO_{2max} was negatively associated with cf-PWV in middle aged obese women.[17] In addition, Vaitkevicius et al. indicated that arterial stiffness increased with aging, suggesting arterial compliance may be affected by some pathological conditions such as obesity, hypertension and advancing age.[5]

In a recent study, an inverse correlation between arterial stiffness (baPWV) and aerobic capacity was statistically significant in various range of age group (18–64 years) in 82 healthy men.[6] However, the results of our study were different from the previous study because our study was conducted with only healthy young men (22.9 ± 0.7 years) and women (23.6 ± 0.4 years). Generally, VO_{2max} decreases gradually with advancing age, and the rate of decline is approximately 10% per decade after the age of 25 years.[22,23] Both the arterial stiffening and VO_{2max} decline occur as a consequence of aging. In this reason, we may not find significant association in this study because most of our young participants

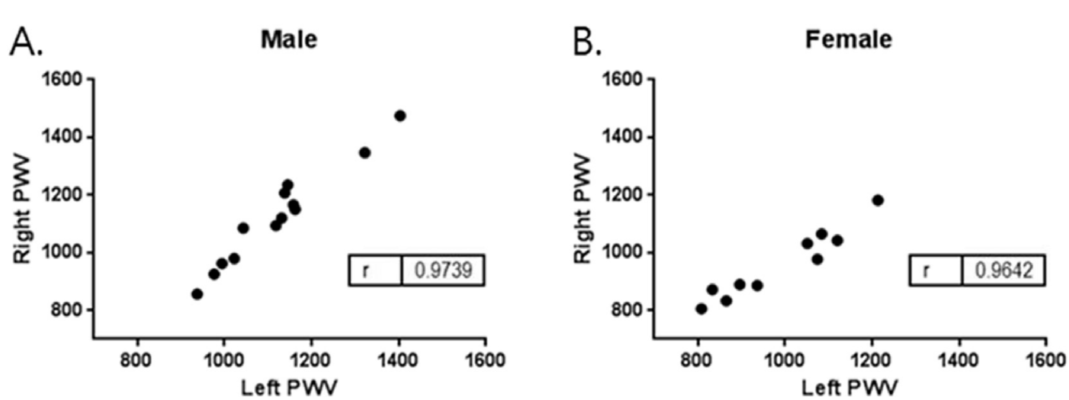

Fig. 1. Correlation between left and right baPWV in male(A) and female(B) subjects. There were the positive relationships between left and right PWV in both Male ($n = 13$) and female ($n = 10$).
PWV, pulse wave velocity.

Table 2
Results of Pearson's correlation analysis.

Variables	r-Values							
	Total-C	HDL	LDL	TG	Fasting glucose	HbA1c	VO2max	RL-PWV
Total-C		0.59**	−0.63**	0.05	−0.04	−0.08	−0.09	0.3
HDL			−0.32	−0.02	−0.09	−0.13	−0.25	−0.07
LDL				0.37	0.19	0.3	−0.18	−0.26
TG					0.16	0.13	−0.24	−0.22
Fasting glucose						0.19	−0.24	−0.22
HbA1c							0.1	−0.6
VO2max								0.17
RL-PWV								

The correlation analysis between all measurements. HbA1c, hemoglobin A1c; HDL, high density lipoprotein; LDL, low density lipoprotein; TG, triglycerides; Total-C, total cholesterol; RL-PWV, mean of right and left pulse wave velocity; VO_{2max}, maximal oxygen consumption. *p < 0.05 **p < 0.01.

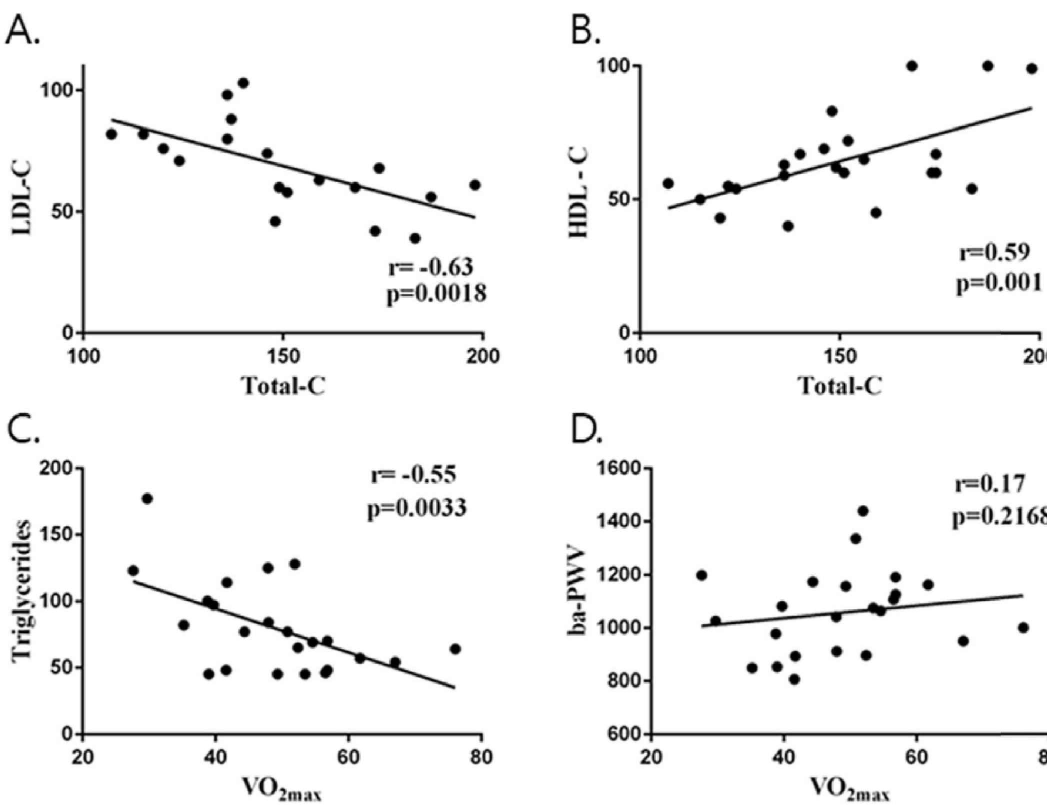

Fig. 2. Relation between Total-C and LDL-C (A) or HDL-C (B). Relation between VO_{2max} and triglycerides (C) or ba-PWV (D). There was a significant correlation between Total C and LDL-C and HDL-C. And there was a correlation between VO_{2max} and triglycerides, whereas baPWV had no significant correlation with VO_{2max} (n = 23).
HDL, high density lipoprotein; LDL, low density lipoprotein; Total-C, total cholesterol; ba-PWV, brachial-ankle pulse wave velocity.

had relatively good arterial compliance and VO_{2max}. Therefore, it may be necessary to investigate the correlation between arterial stiffness and VO_{2max} in older rather than young adults. In addition, Vaitkevicius et al. indicated that intervention such as regular endurance exercise may reduce arterial stiffness in aging population.[5] Taken together, this suggests increased obesity and hypertension may lead to arterial stiffness as maximal aerobic capacity declines with age. For this reason, this finding suggests that maintenance and enhancement of maximal oxygen uptake by exercise may be an important factor in vascular health. Therefore, it is plausible to conclude that regular exercise may ameliorate arterial stiffness induced by some pathophysiological conditions including metabolic dysfunction and aging.

Another issue to consider is that different methods to measure arterial stiffness were used in these studies. Generally, there are two ways to measure arterial stiffness. cf-PWV measured by Doppler flowmeter or applanation tonometry is considered as the gold standard method for evaluating aortic stiffness.[24,25] Alternatively, baPWV has received great attention because of convenience of use for large-scale population studies and high association with CVD risk factors.[20,26–29] Elevation of baPWV has an association with augmented cf-PWV and increased baPWV may be an independent predictor of all-cause mortality in the general population.[27,28,30] Thus, the baPWV may be considered as a reasonable and convenient method to replace cf-PWV.

In our study, we found that aerobic capacity had an only significant association with triglyceride level in healthy subjects. Overweight is associated with lower levels of physical activity and physical function in older population.[31] Also, oxygen consumption per kilogram of body weight declined as fatness increased in adolescent females.[32] Furthermore, Augustine et al. suggested that higher maximal oxygen consumption may indirectly reduce aortic stiffness through beneficial effects on CVD risk factors including insulin resistance.[17] In a previous animal study, the low aerobic capacity runners had more visceral adiposity, higher plasma triglycerides, and elevated plasma free fatty acids compared with the high aerobic capacity runners in rat.[33] Taken together, these studies support the notion that impaired lipid metabolism may link poor aerobic capacity to cardiometabolic risk factors. Additional studies are needed to investigate the relationship between dyslipidemia and arterial stiffness.

There are a few considerations in this study. First, we did not control menstrual cycle in our female subjects because fluctuating female sex hormones do not appear to influence arterial stiffness based on previous studies.[34–36] However, some studies showed that arterial stiffness underwent major changes during the menstrual cycle.[36,37] In future study, it may be needed to control menstrual cycle for female participants. Second, as a pilot study, our study included only 23 young healthy adults (13 men and 10 women, respectively). For this reason, our findings could not be generalized to all healthy young adults.

Conclusion

The study results indicated that there was no relationship between arterial stiffness and maximal aerobic capacity in healthy young adults. Because young participants had relatively good maximal aerobic capacity and arterial compliance, it appeared to be difficult to find an inverse relationship between arterial stiffness and maximal aerobic capacity.

Conflicts of interest

The authors have no financial conflicts.

Acknowledgements

This study was supported by grant from Incheon National University Research Grant in 2015.

Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.jesf.2018.07.003.

References

1. Shirwany N, Zou M. Arterial stiffness: a brief review. *Acta Pharm Sin*. 2010;31:1267–1276.
2. Zieman S, Melenovsky V, Kass D. Mechanisms, pathophysiology, and therapy of arterial stiffness. *Arterioscler Thromb Vasc Biol*. 2005;25:932–943.
3. Della Corte V, Tuttolomondo A, Pecoraro R, et al. Inflammation, endothelial dysfunction and arterial stiffness as therapeutic targets in cardiovascular medicine. *Curr Pharm Des*. 2016;22:4658–4668.
4. Lee H, Oh B. Aging and arterial stiffness. *Circ J*. 2010;74:2257–2262.
5. Vaitkevicius P, Fleg J, Engel J, et al. Effects of age and aerobic capacity on arterial stiffness in healthy adults. *Circulation*. 1993;88:1456–1462.
6. Tomoto T, Maeda S, Sugawara J. Relation between arterial stiffness and aerobic capacity: importance of proximal aortic stiffness. *Eur J Sport Sci*. 2017;17:571–575.
7. Sung J, Choi S, Choi Y, et al. The relationship between arterial stiffness and increase in blood pressure during exercise in normotensive persons. *J Hypertens*. 2012;30:587–591.
8. 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.
9. Siasos G, Athanasiou D, Terzis G, et al. Acute effects of different types of aerobic exercise on endothelial function and arterial stiffness. *Eur J Prev Cardiol*. 2016;23:1565–1572.
10. Donley D, Fournier S, Reger B, et al. Aerobic exercise training reduces arterial stiffness in metabolic syndrome. *J Appl Physiol*. 2014;116:1396–1404.
11. Currie K, Thomas S, Goodman J. Effects of short-term endurance exercise training on vascular function in young males. *Eur J Appl Physiol*. 2009;107:211–218.
12. Betik A, Hepple R. Determinants of VO2 max decline with aging: an integrated perspective. *Appl Physiol Nutr Metab*. 2008;33:130–140.
13. Blair S, Kohl H, Barlow C. Physical activity, physical fitness, and all-cause mortality in women: do women need to be active? *J Am Coll Nutr*. 1993;12:368–371.
14. Nauman J, Nes B, Lavie C, et al. Prediction of cardiovascular mortality by estimated cardiorespiratory fitness independent of traditional risk factors: the HUNT study. *Mayo Clin Proc*. 2017;92:218–227.
15. Mier C, Alexander R, Mageean A. Achievement of VO2max criteria during a continuous graded exercise test and a verification stage performed by college athletes. *J Strength Cond Res*. 2012;26:2648–2654.
16. Shin S, Park J, Park S, et al. Utility of graded exercise tolerance tests for prediction of cardiovascular mortality in old age: the Rancho Bernardo Study. *Int J Cardiol*. 2015;181:323–327.
17. Augustine J, Yoon E, Choo J, et al. The relationship between cardiorespiratory fitness and aortic stiffness in women with central obesity. *J Womens Health*. 2016;25:680–686.
18. Arena R, Arrowood J, Fei D, et al. Maximal aerobic capacity and the oxygen uptake efficiency slope as predictors of large artery stiffness in apparently healthy subjects. *J Cardiopulm Rehabil Prev*. 2009;29:248–254.
19. Jung S, Park J, Lee S. Arterial stiffness is inversely associated with a better running record in a full course marathon race. *J Exerc Nutrition Biochem*. 2014;18:355–359.
20. 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.
21. Denham J, Brown N, Tomaszewski M, et al. Aortic augmentation index in endurance athletes: a role for cardiorespiratory fitness. *Eur J Appl Physiol*. 2016;116:1537–1544.
22. Astrand I. Aerobic work capacity in men and women with special reference to age. *Acta Physiol Scand Suppl*. 1960;49:1–92.
23. Hawkins S, Wiswell R. Rate and mechanism of maximal oxygen consumption decline with aging: implications for exercise training. *Sports Med*. 2003;33:877–888.
24. Doupis J, Papanas N, Cohen A, et al. Pulse wave analysis by applanation tonometry for the measurement of arterial stiffness. *Open Cardiovasc Med J*. 2016;10:188–195.
25. Stoner L, Young J, Fryer S. Assessments of arterial stiffness and endothelial function using pulse wave analysis. *Int J Vasc Med*. 2012;2012:903107.
26. Yamashina A, Tomiyama H, Takeda K, et al. Validity, reproducibility, and clinical significance of noninvasive brachial-ankle pulse wave velocity measurement. *Hypertens Res*. 2002;25:359–364.
27. Turin T, Kita Y, Rumana N, et al. Brachial-ankle pulse wave velocity predicts all-cause mortality in the general population: findings from the Takashima study, Japan. *Hypertens Res*. 2010;33:922–925.
28. Tanaka H, Munakata M, Kawano Y, et al. Comparison between carotid-femoral and brachial-ankle pulse wave velocity as measures of arterial stiffness. *J Hypertens*. 2009;27:2022–2027.
29. 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.
30. Willum-Hansen T, Staessen J, Torp-Pedersen C, et al. Prognostic value of aortic pulse wave velocity as index of arterial stiffness in the general population. *Circulation*. 2006;113:664–670.
31. Riebe D, Blissmer B, Greaney M, et al. The relationship between obesity, physical activity, and physical function in older adults. *J Aging Health*. 2009;21:1159–1178.
32. Rowland T. Effects of obesity on aerobic fitness in adolescent females. *Am J Dis Child*. 1991;145:764–768.
33. Wisloff U, Najjar S, Ellingsen O, et al. Cardiovascular risk factors emerge after artificial selection for low aerobic capacity. *Science*. 2005;307:418–420.
34. Priest S, Shenouda N, MacDonald M. The effect of sex, menstrual cycle phase, and monophasic oral contraceptive pill use on local and central arterial stiffness in young adults. *Am J Physiol Heart Circ Physiol*. 2018 Apr 20. https://doi.org/10.1152/ajpheart.00039.2018 [Epub ahead of print].
35. Ounis-Skali N, Mitchell G, Solomon C, et al. Changes in central arterial pressure waveforms during the normal menstrual cycle. *J Investig Med*. 2006;54:321–326.
36. Hayashi K, Miyachi M, Seno N, et al. Variations in carotid arterial compliance during the menstrual cycle in young women. *Exp Physiol*. 2006;91:465–472.
37. Robb A, Mills N, Din J, et al. Influence of the menstrual cycle, pregnancy, and preeclampsia on arterial stiffness. *Hypertension*. 2009;53:952–958.