

Immediate Effects of Aerobic Exercise on Arterial Stiffness in Men with Different Blood Glucose Levels: Postprint

Authors: He Rong, Zhang Li, Li Peng, Zhang Xiaoling, Zhang Guo, Zang Yiran, Wu Shouling, Sun Lixia, Sun Lixia

Date: 2023-04-10T00:00:00+00:00

Abstract

Background Previous research on the benefits of aerobic exercise has primarily focused on its effects on long-term cardiovascular health and outcomes, with regular aerobic exercise shown to improve arterial stiffness. Studies have identified hyperglycemia as a factor that increases arterial stiffness, suggesting that hyperglycemia may attenuate the beneficial effects of aerobic exercise on arterial stiffness. To test this hypothesis, the present study measured arterial stiffness immediately after aerobic exercise to assess its acute effects, using data from the Kailuan Study to analyze the immediate impact of aerobic exercise on arterial stiffness across populations with different blood glucose levels.

Objective To investigate the immediate effects of aerobic exercise on arterial stiffness in populations with different blood glucose levels.

Methods This study enrolled participants who attended the 6th follow-up physical examination of the Kailuan Study (2018–2020) and completed brachial-ankle pulse wave velocity (baPWV) measurements before and after a two-stage bicycle ergometer load test at four enterprises affiliated with the Kailuan Group. Epidemiological surveys were conducted to collect general information (age, hypertension, hyperlipidemia, antihypertensive medication history, etc.), anthropometric indices [systolic blood pressure (SBP), diastolic blood pressure (DBP), etc.], and biochemical indicators (fasting blood glucose, etc.). Participants were stratified into quartile groups based on fasting blood glucose levels: Group Q1 (n=220): <5.00 mmol/L, Group Q2 (n=240): 5.00–<5.40 mmol/L, Group Q3 (n=230): 5.40–<5.81 mmol/L, and Group Q4 (n=234): ≥5.81 mmol/L. The two-stage bicycle ergometer load test served as the aerobic exercise intervention, with baPWV level used as the indicator of extremity arterial stiffness. Data related to baPWV before and after the test were collected [including SBP, DBP, mean arterial pressure (MAP), heart rate (HR), baPWV level, metabolic

equivalent (MET), maximal oxygen uptake (VO_{2max}), etc.], with pre-test and post-test measurements denoted as 1 and 2, respectively; differences between measurements were calculated (denoted as Δ baPWV, etc.). Inter-group differences in epidemiological survey data and baPWV-related parameters among Groups Q1, Q2, Q3, and Q4 were compared. Generalized linear regression models were employed to evaluate the influence of different blood glucose levels on baPWV before and after the two-stage bicycle ergometer load test.

Results A total of 924 participants met the inclusion criteria, with a mean age of (36.93 ± 7.72) years. Comparisons of epidemiological survey data revealed statistically significant differences among the four groups in age, hyperlipidemia, hypertension, antihypertensive medication history, systolic blood pressure, diastolic blood pressure, fasting blood glucose, high-sensitivity C-reactive protein, triglycerides, total cholesterol, high-density lipoprotein cholesterol, and low-density lipoprotein cholesterol ($P < 0.01$). Comparisons of baPWV-related parameters before and after the two-stage bicycle ergometer load test showed that HR2 was significantly higher than HR1 in Groups Q1, Q2, and Q3 ($P < 0.01$); baPWV2 was significantly higher than baPWV1 in Groups Q1, Q2, Q3, and Q4 ($P < 0.01$); and significant differences were observed among the four groups in SBP1, SBP2, DBP1, DBP2, MAP1, MAP2, baPWV1, and baPWV2 ($P < 0.01$). Compared with baPWV1, baPWV2 decreased by an average of 36.0 cm/s across populations with different blood glucose levels. Generalized linear regression analysis demonstrated that after adjusting for confounding factors, Δ baPWV level was significantly lower in Group Q1 compared with Group Q4 [b (95%CI) = -18.96 (-36.96, -0.96), $P = 0.04$].

Conclusion Aerobic exercise can acutely improve arterial stiffness; however, hyperglycemia attenuates this beneficial effect. Clinicians should design personalized aerobic exercise protocols for different populations to improve arteriosclerosis and delay vascular aging.

Full Text

Abstract

Background

Previous studies on the benefits of aerobic exercise have primarily focused on its long-term impact on cardiovascular health and outcomes, demonstrating that regular aerobic exercise can improve arterial stiffness. However, research also indicates that hyperglycemia is a factor that increases arterial stiffness, suggesting that elevated blood glucose may weaken the beneficial effects of aerobic exercise on arterial hardening. To test this hypothesis, this study utilized data from the Kailuan Study to analyze the immediate effects of aerobic exercise on arterial stiffness in populations with different blood glucose levels by measuring arterial stiffness immediately after aerobic exercise.

Objective

To investigate the immediate effects of aerobic exercise on arterial stiffness in male populations with different blood glucose levels.

Methods

This study selected participants who attended the 6th follow-up physical examination of the Kailuan Study between 2018–2020 and completed brachial-ankle pulse wave velocity (baPWV) measurements before and after the secondary load test on a power bicycle at four enterprises affiliated with the Kailuan Group. Epidemiological surveys were conducted, including general information (age, hypertension, hyperlipidemia, antihypertensive medication history, etc.), anthropometric indicators [systolic blood pressure (SBP), diastolic blood pressure (DBP), etc.], and biochemical indicators (fasting blood glucose, etc.). Participants were divided into quartile groups based on fasting blood glucose levels: Q1 group (n=220): <5.00 mmol/L, Q2 group (n=240): 5.00–<5.40 mmol/L, Q3 group (n=230): 5.40–<5.81 mmol/L, and Q4 group (n=234): ≥ 5.81 mmol/L. These secondary load test on the power bicycle served as the form of aerobic exercise, with baPWV use etc.] were collected before (denoted as 1) and after (denoted as 2) the test, and the differences between the two measurements were calculated (denoted as Δ baPWV, etc.). Differences in epidemiological survey data and baPWV-related indicators were compared among the Q1, Q2, Q3, and Q4 groups. Generalized linear regression models were used to evaluate the impact of different blood glucose levels on baPWV before and after the secondary load test.

Results

A total of 924 eligible participants were enrolled with a mean age of (36.93 ± 7.72) years. Comparison of epidemiological survey data among the groups revealed statistically significant differences in reactive protein, triglycerides, total cholesterol, high-density lipoprotein cholesterol, and low-density lipoprotein cholesterol ($P < 0.01$). Comparison of baPWV-related data before and after the secondary load test showed that HR_{2} was higher than HR_{1} in the Q1, Q2, and Q3 groups ($P < 0.01$), while $baPWV_{2}$ was higher than $baPWV_{1}$ in all four groups ($P < 0.01$). Statistically significant differences were observed among the four groups in SBP_{1} , SBP_{2} , DBP_{1} , DBP_{2} , MAP_{1} , MAP_{2} , $baPWV_{1}$, and $baPWV_{2}$ ($P < 0.01$). Compared with $baPWV_{1}$, $baPWV_{2}$ decreased by an average of 36.0 cm/s across different blood glucose levels. Generalized linear regression analysis showed that after adjusting for confounding factors, the Δ baPWV level in the Q1 group was lower than that in the Q4 group [b (95%CI) = -18.96 (-36.96, -0.96), $P=0.04$].

Conclusion

Aerobic exercise can immediately improve arterial stiffness, but hyperglycemia attenuates this beneficial effect. Clinicians should design different aerobic exercise protocols for different populations to improve arteriosclerosis and delay vascular aging.

Keywords

Exercise; Diabetes mellitus; Vascular stiffness; Aerobic exercise; Fasting blood glucose; Pulse wave velocity; Arterial stiffness; Cardiovascular disease

Introduction

Aerobic exercise is a cornerstone for the prevention and treatment of chronic non-communicable diseases [1-4]. Long-term regular aerobic exercise not only reduces body weight [5], lowers blood glucose [6], and improves lipid metabolism [7], but also prevents arteriosclerosis and thereby reduces the incidence of cardiovascular and cerebrovascular diseases [8]. Even in secondary prevention of cardiovascular diseases, aerobic exercise plays a pivotal role [9]. Consequently, various guidelines recommend aerobic exercise as a primary healthy lifestyle intervention [1-4].

Arterial stiffness is an important indicator of arterial elasticity and function. Brachial-ankle pulse wave velocity (baPWV) is commonly used to evaluate arterial stiffness due to its non-invasive nature, ease of operation, and high reliability [10]. Previous research on the benefits of aerobic exercise has primarily focused on its long-term impact on cardiovascular health and outcomes [11-15]. Even studies examining short-term or immediate effects have mainly concentrated on blood pressure responses, with only a few small-sample studies investigating the effects of aerobic exercise on arterial stiffness, yielding inconsistent conclusions. For instance, Kobayashi et al. [16] found that arterial stiffness improved significantly immediately after aerobic exercise in 11 healthy young men, while another study of 24 young adults with diabetes found no significant improvement in arterial stiffness immediately after aerobic exercise [17]. Research has identified hyperglycemia as a factor that increases arterial stiffness [18-21], leading to the hypothesis that elevated blood glucose may weaken the beneficial effects of aerobic exercise on arterial hardening. To test this hypothesis, this study utilized data from the Kailuan Study combined with the 2020 5th National Physical Fitness Monitoring data to analyze the immediate effects of aerobic exercise on arterial stiffness in populations with different blood glucose levels, aiming to provide new clinical strategies for improving arteriosclerosis and delaying vascular aging, and to offer scientific guidance for designing aerobic exercise protocols for different populations.

Methods

Study Participants

This study selected participants who had previously attended the 6th follow-up physical examination of the Kailuan Study between 2018–2020, were selected for the 2020 5th National Physical Fitness Monitoring, and completed baPWV measurements before and after the secondary load test at four enterprises affiliated with the Kailuan Group. The Kailuan Study (ChiCTR-TNC-11001489) is a community-based survey and intervention study on cardiovascular disease risk

factors among functional community populations, initiated in July 2006. The Kailuan General Hospital and 10 affiliated hospitals are responsible for conducting health examinations for Kailuan Group employees (both active and retired), with follow-ups every two years. To systematically understand national physical fitness status and provide evidence for policies to enhance national fitness, the State General Administration of Sport conducted the 5th National Physical Fitness Monitoring in 2020 [22]. The survey used industries as sampling units, and based on the distribution characteristics of typical occupations in the coal industry, randomly selected 1,200 male employees aged 20–49 from four Kailuan Group enterprises as the sample population for physical fitness level testing at four Kailuan Group enterprises. The testing included the secondary load test on a power bicycle, sit-and-reach test, cardiopulmonary endurance test, body fat percentage, etc. Building upon the original measurements, this study added baPWV measurements before and after the secondary load test on the power bicycle.

Inclusion and Exclusion Criteria

Inclusion criteria: (1) Participants who attended the 6th follow-up physical examination of the Kailuan Study between 2018–2020 and were selected for the 2020 5th National Physical Fitness Monitoring; (2) Those who completed baPWV measurements before and after the secondary load test on the power bicycle; (3) Those who agreed to participate and signed informed consent.

Exclusion criteria: (1) Participants with missing fasting blood glucose data; (2) Those with incomplete secondary load test data. This study followed the Declaration of Helsinki and was approved by the Ethics Committee of Kailuan General Hospital ([2006] Ethics No. 5).

Data Collection

Epidemiological Survey Content The epidemiological survey included general information, anthropometric indicators, and biochemical test indicators. General information comprised age, gender, hypertension, hyperlipidemia, antihypertensive medication history, alcohol consumption, and physical exercise status. Anthropometric indicators included body weight, BMI, waist circumference, SBP, and DBP. Biochemical test indicators included fasting blood glucose, high-sensitivity C-reactive protein (hs-CRP), triglycerides, total cholesterol, high-density lipoprotein cholesterol (HDL-C), and low-density lipoprotein cholesterol (LDL-C). Detailed collection methods have been published in our previous studies [23–25].

Definitions and Diagnostic Criteria Hypertension was defined according to the *Chinese Guidelines for the Prevention and Treatment of Hypertension (2018 Revision)* [25] as SBP \geq 140 mmHg and/or DBP \geq 90 mmHg (1 mmHg = 0.133 kPa) without antihypertensive medication, or having a history of hypertension or taking antihypertensive medication. Hyperlipidemia was defined

according to the *Chinese Guidelines for the Prevention and Treatment of Dyslipidemia in Adults* [26] as meeting any of the following criteria: (1) total cholesterol > 5.72 mmol/L; (2) triglycerides > 1.70 mmol/L; (3) HDL-C < 0.91 mmol/L; (4) LDL-C > 3.64 mmol/L. BMI was calculated as weight (kg)/height² (m²). Smoking was defined as consuming at least one cigarette per day on average in the past year. Alcohol consumption was defined as drinking an average of 100 ml of liquor (alcohol content ≥ 50%) per day for ≥ 1 year. Physical exercise was defined as exercising ≥ 3 times per week for ≥ 30 minutes per session.

Fasting Blood Glucose Detection Participants underwent fasting blood glucose testing at the Health Examination Center of Kailuan General Hospital before December 31, 2020. After fasting for at least 8 hours, 5 ml of fasting elbow venous blood was drawn between 7:00–9:00 AM on the examination day. The blood was centrifuged at 3,000 r/min for 10 minutes at room temperature (24°C) with a centrifuge radius of 13 cm. The supernatant serum was collected and tested within 4 hours. Fasting blood glucose was measured using the hexokinase method with a coefficient of variation not exceeding 2% at 5.6 mmol/L and an upper linear limit of 33.3 mmol/L, using a Hitachi 7600 automatic biochemical analyzer with reagent kits provided by Zhongsheng Beikong Biotechnology Co., Ltd. Professional laboratory technicians strictly followed the operating manual, with batch quality control.

Secondary Load Test on Power Bicycle This study used the secondary load test on a power bicycle as the form of aerobic exercise. All tests were conducted on-site at room temperature (22–25°C). The GMCS-GLC3 power bicycle (Tianjin Xinghe Zhongbang Engineering Consulting Co., Ltd.), uniformly equipped by the National Physical Fitness Monitoring Center, was used for the secondary load exercise test. Participants were prohibited from smoking, drinking alcohol, consuming caffeine, or engaging in vigorous activity within 12 hours before the test. The secondary load test lasted 7 minutes, during which participants maintained a pedaling speed of 60 rpm throughout. The initial 30 seconds served as a warm-up phase with zero load, followed by two load increments (25 W each) every 3 minutes, and the final 30 seconds as a recovery phase with zero load.

baPWV-related Measurements Measurements were conducted once before and once immediately after the secondary load test on the power bicycle to reflect the immediate impact of the exercise. The BP-203RPE III network-based arteriosclerosis detection device (Omron Healthcare Co., Ltd., China) was used to measure SBP, DBP, MAP, HR, baPWV levels, MET, VO₂max, peak heart rate, and the time difference between the end of the secondary load test and the post-exercise baPWV measurement (hereinafter referred to as Time). Peak heart rate was monitored in real-time by a heart rate monitor worn on the middle of the right upper arm, and VO₂max was calculated and uploaded by the power bicycle's built-in system. During measurement, participants wore

light clothing, lay flat on a measurement bed without a pillow, placed their hands palm-up beside their bodies, and remained quiet. Medical staff aligned the upper arm cuff bladder markers with the bilateral brachial arteries and the lower limb cuff bladder markers with the medial sides of the bilateral ankle joints, and attached ECG acquisition devices to both wrists. Each participant was measured twice, with the second measurement used as the final result. This study used the larger value of the left and right baPWV for analysis and the right upper limb values for SBP and DBP.

Before the secondary load test, participants' SBP, DBP, MAP, HR, and baPWV levels were measured at rest (rest time ≥ 15 minutes) and recorded as SBP₁, DBP₁, MAP₁, HR₁, and baPWV₁. After the test, SBP, DBP, MAP, HR, and baPWV levels were measured again and recorded as SBP₂, DBP₂, MAP₂, HR₂, and baPWV₂. The differences between the two measurements were calculated and recorded as Δ SBP, Δ DBP, Δ MAP, Δ HR, and Δ baPWV. Subsequently, participants' MET, VO₂max, peak heart rate, and Time were recorded.

Grouping Method

Participants were divided into quartile groups based on their fasting blood glucose levels: Q1 group: <5.00 mmol/L, Q2 group: 5.00 – <5.40 mmol/L, Q3 group: 5.40 – <5.81 mmol/L, and Q4 group: ≥ 5.81 mmol/L.

Statistical Methods

Data were entered by uniformly trained professionals from each hospital and summarized and uploaded to an Oracle database by Kailuan General Hospital. SAS 9.4 software was used for statistical analysis. Normally distributed continuous variables were expressed as $(\bar{x} \pm s)$, with paired sample t-tests used for pre- and post-exercise data and one-way ANOVA for multi-group comparisons, with Scheffe's method for pairwise comparisons. Non-normally distributed continuous variables were expressed as $M(P_{25}, P_{75})$, with Kruskal-Wallis H test for inter-group comparisons and paired rank-sum test for pre- and post-exercise comparisons. Categorical variables were expressed as percentages, with χ^2 test for inter-group comparisons. Generalized linear regression models were used to evaluate the impact of different blood glucose levels on baPWV before and after the secondary load test, with $P < 0.05$ considered statistically significant.

Results

A total of 1,200 Kailuan Group employees were sampled for the 5th National Physical Fitness Monitoring, of which 1,128 attended the 6th follow-up examination of the Kailuan Study between 2018–2020. After excluding 116 participants who did not complete baPWV measurements before and after the secondary load test, 86 with missing fasting blood glucose data, and 2 with incomplete sec-

secondary load test data, 924 participants were finally included in the statistical analysis, with a mean age of (36.93 ± 7.72) years.

Comparison of Epidemiological Survey Data

Comparisons of epidemiological survey data among the groups showed statistically significant differences in age, hyperlipidemia, hypertension, antihypertensive medication history, SBP, DBP, fasting blood glucose, hs-CRP, triglycerides, total cholesterol, HDL-C, and LDL-C ($P < 0.01$). No statistically significant differences were found in alcohol consumption history, smoking history, physical exercise, body weight, BMI, or waist circumference among the four groups ($P > 0.05$). Pairwise comparisons within groups revealed that the Q4 group had higher proportions of age, hypertension, hyperlipidemia, and antihypertensive medication history than the Q1, Q2, and Q3 groups, and the Q3 group had higher age than the Q1 group ($P < 0.01$). The Q4 group had higher SBP and DBP than the Q1 and Q2 groups ($P < 0.01$). The Q4 group had higher hs-CRP, total cholesterol, and LDL-C levels, and the Q3 group had higher total cholesterol levels than the Q1 and Q2 groups ($P < 0.01$). The Q2 and Q3 groups had higher hs-CRP, and the Q3 and Q4 groups had higher triglycerides than the Q1 group. The Q2 group had lower total cholesterol than the Q3 group.

Comparison of baPWV-related Data Before and After the Secondary Load Test

Comparisons of baPWV-related data before and after the secondary load test showed that HR_2 was higher than HR_1 in the total population ($P < 0.01$) and in the Q1, Q2, and Q3 groups ($P < 0.01$). $baPWV_2$ was higher than $baPWV_1$ in all four groups ($P < 0.01$). Statistically significant differences were observed among the four groups in SBP_1 , SBP_2 , DBP_1 , DBP_2 , MAP_1 , MAP_2 , $baPWV_1$, and $baPWV_2$ ($P < 0.01$). Pairwise comparisons showed that the Q4 group had higher DBP_2 , $baPWV_1$, and $baPWV_2$ than the Q1, Q2, and Q3 groups, and higher SBP_2 , DBP_1 , MAP_1 , and MAP_2 than the Q1 and Q2 groups ($P < 0.01$). Compared with $baPWV_1$, $baPWV_2$ decreased by an average of 36.0 cm/s in the total population. No statistically significant differences were found among the four groups in ΔSBP , ΔDBP , ΔMAP , HR_1 , HR_2 , ΔHR , $\Delta baPWV$, MET, VO_{2max} , peak heart rate, or Time ($P > 0.05$).

Using $\Delta baPWV$ as the dependent variable (assigned as actual values) and the Q4 group as the reference, generalized linear model analysis was performed with $baPWV_1$, age, BMI, waist circumference, hs-CRP, smoking history, alcohol consumption history, physical exercise, hypertension without medication, hypertension with medication, hyperlipidemia history, peak heart rate, ΔHR , ΔMAP , and Time as control variables. After adjusting for confounding factors, the results showed that compared with the Q4 group, the $\Delta baPWV$ level in the Q1 group was lower [b (95%CI) = -18.96 (-36.96, -0.96), $P = 0.04$].

Discussion

The key finding of this study is that aerobic exercise can indeed improve arterial stiffness, but hyperglycemia attenuates this beneficial effect, and this adverse effect is independent of traditional cardiovascular risk factors such as BMI and hypertension. Previous studies on the effects of aerobic exercise on arterial stiffness have shown that in healthy populations, aerobic exercise can significantly improve peripheral arterial stiffness [27]. Magalhães et al. [28] found that aerobic exercise reduced peripheral arterial stiffness (carotid distal pulse wave velocity, cdPWV) in diabetic populations. Another study of 11 healthy young men with a mean age of 21 years showed that peripheral arterial stiffness (Leg pulse wave velocity, LPWV) decreased after 30 minutes of aerobic exercise [16]. This study found that in young men with different blood glucose levels (mean age 36.93 ± 7.72 years), baPWV measured immediately after the secondary load test decreased compared with resting levels, with an average reduction of 36 cm/s. However, Kingwell et al. [29] reported that immediate arterial stiffness decreased by 80 cm/s after 30 minutes of power bicycle exercise in healthy men with a mean age of 24 years, which differs from our results. The authors speculate that this discrepancy may be due to the smaller sample size ($n=12$) in that study, resulting in a larger magnitude of change in arterial stiffness after aerobic exercise compared with our study.

This study observed differences in the magnitude of baPWV reduction after the secondary load test among different blood glucose level groups. After adjusting for multiple confounding factors, we found that compared with the highest fasting blood glucose group (Q4 group), the lowest fasting blood glucose group (Q1 group) had an additional 18.96 cm/s decrease in baPWV. This differs from some previous studies. A randomized crossover trial found that aerobic exercise had no significant effect on arterial stiffness in hyperglycemic populations ($n=24$) [17]. Additionally, Cooke et al. [30] used carotid-femoral pulse wave velocity (cfPWV) to observe the immediate effects of aerobic exercise on arterial stiffness in patients with type 2 diabetes ($n=66$) and non-diabetic patients ($n=61$), finding that compared with non-diabetic patients, patients with type 2 diabetes exhibited a 1.6 m/s increase in immediate arterial stiffness after 15 minutes of vigorous exercise. cfPWV is primarily used to evaluate central arterial stiffness, and research indicates that aerobic exercise has inconsistent effects on different arterial segments, with immediate post-exercise central arterial stiffness increasing relative to resting levels while peripheral arterial stiffness decreases [31]. The more intense exercise protocol, relatively small sample size, and use of cfPWV as the measurement index in the aforementioned studies may explain the differences from our results.

Although this study found differences in the immediate post-exercise baPWV reduction among different blood glucose level groups, with more pronounced decreases in lower blood glucose groups, this was an observational study and could not explore specific mechanisms. Based on previous research, possible mechanisms include: (1) Chronic hyperglycemia leads to the formation of advanced

glycation end-products, with glucose cross-linking with collagen in arteries, altering the balance between elastin and collagen [32]. (2) Hyperglycemia activates protein kinase C, leading to reactive oxygen species production and inflammation that may alter the structural and functional integrity of the vascular wall [32-33]. (3) Due to changes in the intrinsic properties of arterial walls in hyperglycemic populations, the positive effects of aerobic exercise on arterial stiffness are weakened, resulting in inconsistent effects across different blood glucose levels. Additionally, considering that the short-duration power bicycle secondary load test only induced functional rather than structural changes in blood vessels, this may also contribute to the more pronounced baPWV reduction in lower blood glucose populations compared with hyperglycemic populations. Short-duration aerobic exercise increases blood flow velocity, generating shear stress that induces vascular endothelial cells to release prostaglandins, nitric oxide, and other vasodilatory factors, causing vascular smooth muscle relaxation and improving vascular function, thereby improving arterial stiffness [34-36]. However, hyperglycemic populations may exhibit impaired vascular endothelial cell function and dysregulated nervous system activity, leading to compromised arterial function [37] that may result in less significant baPWV improvement after aerobic exercise.

Improving lifestyle and controlling multiple risk factors remain primary preventive measures for cardiovascular disease, and various guidelines recommend aerobic exercise as the main healthy lifestyle approach. Systematic reviews and meta-analyses indicate that long-term aerobic exercise is needed to reduce arterial stiffness in adults [26]. However, our results show that a single session of aerobic exercise can also reduce peripheral arterial stiffness. Related studies suggest that the effect of short-duration aerobic exercise on baPWV represents a functional rather than structural change [26], meaning this change is not sustained and will return to baseline levels. Since short-duration aerobic exercise cannot provide sufficient stimulus to promote structural changes in arteries, increasing the frequency or total duration of aerobic exercise may help maintain the beneficial effects on arterial stiffness over time to achieve structural improvements. For hyperglycemic populations, more aggressive exercise prescriptions may be needed to provide sufficient stimulus to induce arterial structural changes to counteract the adverse effects of hyperglycemia. Therefore, clinicians should design different aerobic exercise protocols for different populations to improve arteriosclerosis and delay vascular aging.

In summary, a single session of aerobic exercise can improve arterial stiffness, with immediate post-exercise reductions in arterial stiffness, but hyperglycemia attenuates this beneficial effect. This study is a large-sample study based on a young population in northern China, and few previous studies have examined the immediate effects of aerobic exercise on arterial stiffness in different blood glucose level populations. However, several limitations exist. First, the study population is heterogeneous, consisting only of young men, which limits the generalizability of the findings to middle-aged, elderly, or female individuals. Second, blood glucose values were determined based on a single fasting glu-

cose measurement, which may introduce some misclassification bias regarding glycemic status. Finally, due to site constraints, this study could only obtain a single measurement at one time point after the secondary load test and did not precisely define “immediate,” which means the results have some limitations in generalizability. Future studies with repeated measurements of arterial stiffness after aerobic exercise are needed to further investigate whether and for how long the beneficial effects of aerobic exercise on arterial stiffness persist.

References

- [1] BULL F C, AL-ANSARI S S, BIDDLE S, et al. World Health Organization 2020 guidelines on physical activity and sedentary behaviour[J]. *Br J Sports Med*, 2020, 54(24):1451-1462. DOI:10.1136/bjsports-2020-102955.
- [2] ZHAO D, LIU J, WANG M, et al. Epidemiology of cardiovascular disease in China: current features and implications[J]. *Nat Rev Cardiol*, 2019, 16(4):203-212. DOI:10.1038/s41569-018-0119-4.
- [3] THOMPSON P D, ARENA R, RIEBE D, et al. ACSM’s new preparticipation health screening recommendations from ACSM’s guidelines for exercise testing and prescription, ninth edition[J]. *Curr Sports Med Rep*, 2013, 12(4):215-217. DOI:10.1249/JSR.0b013e31829a68cf.
- [4] SCHULZE M B, HU F B. Primary prevention of diabetes: what can be done and how much can be prevented?[J]. *Annu Rev Public Health*, 2005, 26:445-467. DOI:10.1146/annurev.publhealth.26.021304.144532.
- [5] PETERSEN K S, BLANCH N, KEOGH J B, et al. Effect of weight loss on pulse wave velocity: systematic review and meta-analysis[J]. *Arterioscler Thromb Vasc Biol*, 2015, 35(1):243-252. DOI:10.1161/ATVBAHA.114.304798.
- [6] BOULÉ N G, HADDAD E, KENNY G P, et al. Effects of exercise on glycemic control and body mass in type 2 diabetes mellitus: a meta-analysis of controlled clinical trials[J]. *JAMA*, 2001, 286(10):1218-1227. DOI:10.1001/jama.286.10.1218.
- [7] BALDUCCI S, LEONETTI F, DI MARIO U, et al. Is a long-term aerobic plus resistance training program feasible for and effective on metabolic profiles in type 2 diabetic patients?[J]. *Diabetes Care*, 2004, 27(3):841-842. DOI:10.2337/diacare.27.3.841.
- [8] ASHOR A W, LARA J, SIERVO M, et al. Effects of exercise modalities on arterial stiffness and wave reflection: a systematic review and meta-analysis of randomized controlled trials[J]. *PLoS One*, 2014, 9(10):e110034. DOI:10.1371/journal.pone.0110034.
- [9] SCHULER G, ADAMS V, GOTO Y. Role of exercise in the prevention of cardiovascular disease: results, mechanisms, and new perspectives[J]. *Eur Heart*

J, 2013, 34(24):1790-1799. DOI:10.1093/eurheartj/eh111.

[10] OHKUMA T, NINOMIYA T, TOMIYAMA H, et al. Brachial-ankle pulse wave velocity and the risk prediction of cardiovascular disease: an individual participant data meta-analysis[J]. *Hypertension*, 2017, 69(6):1045-1052. DOI:10.1161/HYPERTENSIONAHA.117.09097.

[11] TANAKA H, DINENNO F A, MONAHAN K D, et al. Aging, habitual exercise, and dynamic arterial compliance[J]. *Circulation*, 2000, 102(11):1270-1275. DOI:10.1161/01.cir.102.11.1270.

[12] MIYACHI M. Effects of resistance training on arterial stiffness: a meta-analysis[J]. *Br J Sports Med*, 2013, 47(6):393-396. DOI:10.1136/bjsports-2012-090488.

[13] MONAHAN K D, TANAKA H, DINENNO F A, et al. Central arterial compliance is associated with age- and habitual exercise-related differences in cardiovascular baroreflex sensitivity[J]. *Circulation*, 2001, 104(14):1627-1632. DOI:10.1161/hc3901.096670.

[14] MONTERO D, ROCHE E, MARTINEZ-RODRIGUEZ A. The impact of aerobic exercise training on arterial stiffness in pre- and hypertensive subjects: a systematic review and meta-analysis[J]. *Int J Cardiol*, 2014, 173(3):361-368. DOI:10.1016/j.ijcard.2014.03.072.

[15] SHIBATA S, FUJIMOTO N, HASTINGS J L, et al. The effect of lifelong exercise frequency on arterial stiffness[J]. *J Physiol*, 2018, 596(14):2783-2795. DOI:10.1113/JP275301.

[16] KOBAYASHI R, YOSHIDA S, OKAMOTO T. Effects of acute aerobic exercise on arterial stiffness before and after glucose ingestion[J]. *Int J Sports Med*, 2017, 38(1):12-18. DOI:10.1055/s-0042-115019.

[17] WAY K L, LEE A S, TWIGG S M, et al. The effect of acute aerobic exercise on central arterial stiffness, wave reflections, and hemodynamics in adults with diabetes: a randomized cross-over design[J]. *J Sport Health Sci*, 2021, 10(4):499-506. DOI:10.1016/j.jshs.2020.02.009.

[18] 韩旭, 刘倩, 马一涵, 等. 非糖尿病人群空腹血糖水平对动脉僵硬度进展的影响 [J]. *中华高血压杂志*, 2021, 29(1):41-47. DOI:10.16439/j.issn.1673-7245.2021.01.010.

[19] FU S H, CHEN W J, LUO L M, et al. Roles of fasting and postprandial blood glucose in the effect of type 2 diabetes on central arterial stiffness: a 5-year prospective community-based analysis[J]. *Diabetol Metab Syndr*, 2017, 9:33. DOI:10.1186/s13098-017-0231-3.

[20] SHIN J Y, LEE H R, LEE D C. Increased arterial stiffness in healthy subjects with high-normal glucose levels and in subjects with pre-diabetes[J]. *Cardiovasc Diabetol*, 2011, 10:30. DOI:10.1186/1475-2840-10-30.

[21] LOEHR L R, MEYER M L, POON A K, et al. Prediabetes and diabetes are associated with arterial stiffness in older adults: the ARIC study[J]. *Am J*

Hypertens, 2016, 29(9):1038-1045. DOI:10.1093/ajh/hpw036.

[22] 体育总局关于开展第五次国民体质监测的通知 [EB/OL]. (2019-02-02)[2021-08-02]. http://www.gov.cn/xinwen/2019-02/02/content_{5363384}.htm.

[23] WANG J, LIU L P, ZHOU Y, et al. Increased fasting glucose and the prevalence of arterial stiffness: a cross-sectional study in Chinese adults[J]. *Neurol Res*, 2014, 36(5):427-433. DOI:10.1179/1743132814Y.0000000345.

[24] ZHENG M Y, ZHANG X Y, CHEN S H, et al. Arterial stiffness preceding diabetes: a longitudinal study[J]. *Circ Res*, 2020, 127(12):1491-1498. DOI:10.1161/CIRCRESAHA.120.317950.

[25] 中国高血压防治指南修订委员会, 高血压联盟(中国), 中华医学会心血管病学分会, 等. 中国高血压防治指南(2018年修订版)[J]. *中国心血管杂志*, 2019, 24(1):24-56.

[26] 中国成人血脂异常防治指南制订联合委员会. 中国成人血脂异常防治指南 [J]. *中华心血管病杂志*, 2007, 35(5):390-419. DOI:10.3760/j.issn:0253-3758.2007.05.003.

[27] SAZ-LARA A, CAVERO-REDONDO I, ÁLVAREZ-BUENO C, et al. The acute effect of exercise on arterial stiffness in healthy subjects: a meta-analysis[J]. *J Clin Med*, 2021, 10(2):291. DOI:10.3390/jcm10020291.

[28] MAGALHÃES J P, MELO X, CORREIA I R, et al. Effects of combined training with different intensities on vascular health in patients with type 2 diabetes: a 1-year randomized controlled trial[J]. *Cardiovasc Diabetol*, 2019, 18(1):34. DOI:10.1186/s12933-019-0840-2.

[29] KINGWELL B A, BERRY K L, CAMERON J D, et al. Arterial compliance increases after moderate-intensity cycling[J]. *Am J Physiol*, 1997, 273(5):H2186-H2191. DOI:10.1152/ajpheart.1997.273.5.H2186.

[30] COOKE A B, DASGUPTA K, SPRONCK B, et al. Adults with type 2 diabetes mellitus exhibit a greater exercise-induced increase in arterial stiffness and vessel hemodynamics[J]. *Hypertension*, 2020, 75(6):1565-1573. DOI:10.1161/HYPERTENSIONAHA.120.14778.

[31] MUTTER A F, COOKE A B, SALEH O, et al. A systematic review on the effect of acute aerobic exercise on arterial stiffness reveals a differential response in the upper and lower arterial segments[J]. *Hypertens Res*, 2017, 40(2):146-172. DOI:10.1038/hr.2016.111.

[32] ARONSON D. Cross-linking of glycated collagen in the pathogenesis of arterial and myocardial stiffening of aging and diabetes[J]. *J Hypertens*, 2003, 21(1):3-12. DOI:10.1097/00004872-200301000-00002.

[33] MAZZONE T, CHAIT A, PLUTZKY J. Cardiovascular disease risk in type 2 diabetes mellitus: insights from mechanistic studies[J]. *Lancet*, 2008, 371(9626):1800-1809. DOI:10.1016/S0140-6736(08)60768-0.

[34] HIGASHI Y, YOSHIKUMI M. Exercise and endothelial function: role of endothelium-derived nitric oxide and oxidative stress in healthy sub-

jects and hypertensive patients[J]. *Pharmacol Ther*, 2004, 102(1):87-96. DOI:10.1016/j.pharmthera.2004.02.003.

[35] YANG Z, WANG J M, CHEN L, et al. Acute exercise-induced nitric oxide production contributes to upregulation of circulating endothelial progenitor cells in healthy subjects[J]. *J Hum Hypertens*, 2007, 21(6):452-460. DOI:10.1038/sj.jhh.1002171.

[36] KOZAKOVA M, PALOMBO C. Vascular ageing and aerobic exercise[J]. *Int J Environ Res Public Health*, 2021, 18(20):10666. DOI:10.3390/ijerph182010666.

[37] LACOLLEY P, REGNAULT V, SEGERS P, et al. Vascular smooth muscle cells and arterial stiffening: relevance in development, aging, and disease[J]. *Physiol Rev*, 2017, 97(4):1555-1617. DOI:10.1152/physrev.00003.2017.

Author Contributions: HE Rong was responsible for designing the research protocol, selecting participants, conducting surveys, data collection, cleaning, statistical analysis, chart preparation, manuscript writing, and final revision, and takes responsibility for the paper. ZHANG Li was responsible for research surveys and data cleaning. ZHANG Li, LI Peng, ZHANG Xiaoling, ZHANG Guo, and ZANG Yiran were responsible for data collection. WU Shouling was responsible for research ideas and proposing research propositions. SUN Lixia was responsible for quality control and review of the article, overall responsibility for the article, and supervision.

Conflict of Interest Statement: The authors declare no conflicts of interest.

Received Date: December 19, 2022; **Revised Date:** March 16, 2023

Editor: WANG Shiyue

Note: Figure translations are in progress. See original paper for figures.

Source: ChinaXiv — Machine translation. Verify with original.