Short-Term Effect of Acute Aerobic Exercise On Arterial Stiffness in People with Different Smoking Statuses

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Original Research Article

Keywords: aerobic exercise, arterial stiffness, cigarette smoking

Posted Date: September 17th, 2021

DOI: https://doi.org/10.21203/rs.3.rs-798856/v1

Abstract

Background

Smoking is strongly associated with arterial stiffness. Long-term regular aerobic exercise is an effective lifestyle intervention that improve arterial stiffness in healthy young people, however, the results of research on the immediate effect of short-term aerobic exercise on arterial stiffness in individuals with different smoking statuses have been inconsistent. The purpose of this study was to investigate the immediate effects of acute aerobic exercise on arterial stiffness in people with different smoking statuses.

Method:

People who participated in the sixth follow-up visit of the Kailuan Study (trial registration number: ChiCTR-TNRC-11001489) and participated in the fifth National Physical Fitness Monitoring were selected as subjects. All participants completed measurements of brachial–ankle pulse wave velocity, blood pressure, and heart rate before and after a two-stage load test on a power bicycle. The generalized linear model was established to analyze between-group differences in the change in brachial–ankle pulse wave velocity before and after aerobic exercise in people with different smoking statuses.

Results

There was a total of 940 male participants (36.82 ± 7.76 years old). On the basis of the smoking status, the subjects were divided into the following four groups: never smokers (n = 231), former smokers (n = 165), low-intensity smokers (n = 254), and high-intensity smokers (n = 290). After the two-stage load test, brachial–ankle pulse wave velocity was immediately decreased overall (1375.08 ± 209.09 vs. 1341.53 ± 208.04 cm/s, $P < 0.05$). The generalized linear model showed that after adjusting for confounding factors, the β-values and 95% confidence intervals of former smokers, low-intensity smokers, and high-intensity smokers were − 12.17 (− 30.08, 5.75), − 18.43 (− 34.69, − 2.16), and − 22.46 (− 38.39, − 6.54) cm/s compared with never smokers, respectively.

Conclusion

Our results suggest that a single short-term aerobic exercise can immediately improve arterial stiffness in people with different smoking statuses. and clinicians must prescribe individualized exercises for different groups of people to improve arterial stiffness, and reduce the damage to blood vessels caused by smoking.

Key Points:

- Short-term aerobic exercise can immediately improve arterial stiffness in people with different smoking statuses.
- Smoking appears to influence the vascular response to physical stress, and current smokers show a significant improvement in arterial stiffness after aerobic exercise compared with never smokers.
- Clinicians have the unique opportunity and professional responsibility to provide a visible presence of support and suggestions in order to improve the overall wellness of smokers through exercise.

Background

Arterial stiffness is not only a sign of vascular aging, but is also an independent risk factor for cardiovascular diseases, renal failure, cognitive dysfunction, and all-cause death[1–4]. Observational and longitudinal cohort studies have shown that age and blood pressure (BP) are the main risk factors for arterial stiffness[5, 6]. However, traditional risk factors, such as diabetes, smoking, and chronic inflammation, are also risk factors for arterial stiffness[7–9]. Arterial stiffness is significantly increased after smoking compared with before smoking in healthy young people[10]. Additionally, Tomiyama et al. found that the progression of arterial stiffness was significantly faster in smokers than in non-smokers of the same age[11].

In 2010, the American Heart Association suggested that an ideal healthy lifestyle, such as non-smoking, moderate exercise, and a reasonable diet, can reduce the risk of cardiovascular disease and all-cause death[12]. In particular, long-term regular aerobic exercise is an effective lifestyle intervention that reduces the damage to blood vessels caused by risk factors, such as smoking, hypertension, and diabetes[13–15]. However, the results of research on the immediate effect of aerobic exercise on arterial stiffness in individuals with different smoking statuses are inconsistent. Doonan et al. studied 24 smokers and found that arterial stiffness increased immediately after aerobic exercise[16]. A study of 12 healthy non-smokers showed that arterial stiffness decreased immediately after aerobic exercise[17]. These studies were small-sample studies on a Caucasian population.

To the best of our knowledge, there have been no large-sample studies on the immediate effect of aerobic exercise on arterial stiffness in people with different smoking statuses. Therefore, we used data from the Kailuan Study to investigate the immediate effects of aerobic exercise on arterial stiffness in people with different smoking statuses.

1. Material And Methods

1.1 Study population

The Kailuan Study is a study of cardiovascular, cerebrovascular, and related disease risk factors and interventions based on functional community populations in the Kailuan community in Tangshan, China. This study began in 2006 and participants were followed up every 2 years thereafter. National Physical Fitness Monitoring is a project in China that began in 2000 and is conducted every 5 years to systematically assess the nationwide physical fitness of individuals with sample surveys. The fifth iteration of National Physical Fitness Monitoring included four coal mining companies of the Kailuan community for sampling in 2020. Using the information database of employees that was established by these four companies, 1200 men aged 20–49 years were selected by random methods for physical testing. These tests included those for body morphology, physical function, and physical fitness. We also measured brachial–ankle pulse wave velocity (baPWV) before and after a two-stage load test. This study was performed in accordance with the Declaration of Helsinki and was approved by the Ethics Committee of the Kailuan General Hospital. All participants provided written informed consent.

1.2 Inclusion and exclusion criteria

In this study, individuals who participated in the sixth follow-up visit of the Kailuan Study and were selected to participate in the fifth National Physical Fitness Monitoring were included in our study. We excluded participants who did not have the two-stage load test performed or did not complete baPWV measurements (Figure 1).

1.3 Data collection

1.3.1 General information

The components of the investigation, anthropometric measurements, and biochemical testing have been previously described in detail[18]. Anthropometric indicators, including height, weight, body mass index (BMI), and other indicators, were derived from National Physical Fitness Monitoring data.

1.3.2 Experimental procedures

All subjects wore light clothes and conducted a two-stage load test on a power bicycle (GMCS-GLC3). All inspections were carried out in a quiet room with a comfortable temperature. Smoking and drinking were prohibited within 12 hours before exercise. The whole process was maintained for 7 minutes. The first 30 seconds was the zero-load warm-up stage. A load level (25 w) was then increased every 3 minutes for two times. The end of 30 seconds was the zero-load recovery stage. The pedaling speed was maintained at approximately 60 r/min during the whole process. The heart rate (HR) of the subjects was monitored in real time by an HR monitor worn on the inner side of the midpoint of the upper right arm. The maximum oxygen uptake was calculated by the power bicycle's system.

1.3.3 Measurement of baPWV, BP, and HR

Specially trained nurses used the BP-203 RPE III networked arterial stiffness detection device (Omron Health Medical [China] Co., Ltd.), as previously described[19, 20], and measurement of baPWV, BP, and HR was performed before and after the two-stage load test in all subjects. For the first measurement, participants in light clothes had not been smoking and were seated for at least 15 minutes in a room with the temperature controlled between 22°C and 25°C. The participants were then asked to lie down on an examination couch in the supine position and remain quiet during the measurement. Cuffs were wrapped on both arms and ankles. The lower edges of the arm cuffs were positioned 2–3 cm above the transverse striation of the cubital fossa, while the lower edges of the ankle cuffs were positioned 1–2 cm above the superior aspect of the medial malleolus. One heart sound detector was placed at the left and right edges of the sternum. Measurements were repeated twice for each subject, and the result of the second time was used as the final result.

All subjects repeated the measurements of baPWV, HR, BP, and mean arterial pressure (MAP) immediately after completing the exercise. Systolic blood pressure (SBP) and MAP measurements were taken from the right branchial artery, and the maximum of the left and right sides of baPWV was used for analysis.

1.4 Smoking status

The smoking status of the subjects (i.e., never smokers, former smokers, and current smokers) was assessed with a questionnaire. We ensured the accuracy of smoking information through a telephone follow-up survey. Never smokers were defined as having no history of smoking, former smokers[21] as not smoking for at least 6 months, and current smokers [22]as any who had smoked at least one cigarette per day for 1 year. Additionally, to calculate pack-years in current smokers, data on the average number of cigarettes smoked per day and the years of cigarette smoking were collected. Pack-years of smoking were defined as the average number of packs of cigarettes smoked per day multiplied by the duration of smoking in years[23]. On the basis of the number of cigarettes smoked per day, current smokers were classified into the two following groups: light-intensity (1–10 cigarettes/day) and heavy- intensity (>10 cigarettes/day) [24]. To further confirm our findings, we divided the smokers into low-intensity (≤4 pack-years) and high-intensity groups (>4 pack-years) in accordance with the pack-years as described in Celermajer et al.'s [25]study as well.

1.5 Related definitions

Hypertension was defined as (i) systolic blood pressure (SBP) ≥140 mmHg or diastolic blood pressure (DBP) ≥90 mmHg, or (ii) formerly diagnosed hypertension or using antihypertensive drugs[26]. Diabetes was defined as either a fasting blood glucose (FBG) level ≥7.0 mmol/L, self-reporting of a physician's diagnosis, or self-reported use of antidiabetic medication[27]. Changes in baPWV, HR, SBP, DBP, and MAP were calculated as follows: measurement value after exercise – measurement value before exercise.

1.6. Statistical analysis

SAS 9.4 (Version 9.4; SAS Institute, Cary, NC) was used for data analysis. Continuous variables that conformed to a normal distribution are presented as the mean ± standard deviation (±s). Data with a non-normal distribution are expressed as the median (interquartile range). Categorical variables are expressed as the number of samples (percentage). Demographic factors and hemodynamic parameters were compared between the groups using the Student's t test or the Wilcoxon rank sum test, as appropriate. Categorical variables were assessed using the χ^2 test for independence. The paired-sample t test was used to compare baPWV, HR, and BP values in each group before and after exercise.

A generalized linear model was established to evaluate between-group differences in hemodynamic parameters postexercise. When we evaluated the response to exercise, the model was adjusted for baseline HR, baseline MAP, baseline baPWV and age, BMI (continuous variables), triglyceride (TG) levels, education level (less than senior college or senior college or above), alcohol consumption (current drinker, yes or no), the time interval of baPWV measurement after exercise (time interval).

Generalized linear models were used to analyze differences in the change in baPWV (dependent variable) between the groups (i.e., different smoking statuses as independent variables). All analyses were adjusted for age and baseline baPWV (Model 1), and were further adjusted for BMI, TG levels, time interval, education level, alcohol consumption, baseline HR, and baseline MAP (Model 2). Analyses were also further adjusted for the change in MAP and the change in HR (Model 3). Between-group differences are described by the β-value and 95% confidence interval (CI).

We performed a sensitivity analysis as follows. 1) We repeated the above-mentioned generalized linear model for sensitivity analysis of smokers classified by pack-years. 2) To exclude the effect of inconsistencies in the time interval, hypertension, diabetes, taking antihypertensive drugs, stenosis, or blockage of the lower limbs, we excluded the variables of a time interval exceeding 26.3 minutes (95th quartile), hypertension, diabetes, taking antihypertensive drugs, and an ankle–brachial index ≤0.9 in the generalized linear model.

A *P* value <0.05 was considered statistically significant with a two-sided test.

2. Results

A total of 1200 employees of the Kailuan community participated in the fifth National Physical Fitness Monitoring, of whom 1138 participated in the sixth follow-up physical examination of the Kailuan Study. Those who did not have baPWV measured twice before and after exercise (n=185) and those without a two-stage load test (n=13) were excluded. Finally, 940 individuals were included for analysis (Figure 1).

2.1 Baseline characteristics of the study population

The study population had a mean age of 36.82±7.76 years (Table 1). On the basis of smoking status, the study population was divided into never smokers (n=231), former smokers (n=165), low-intensity smokers (n=254), and high-intensity smokers (n=290). There were significant differences in baseline SBP, baseline DBP, baseline MAP, baseline baPWV, age, TG levels, drinking habits, and education level among the four groups. Baseline SBP, baseline DBP, baseline MAP, baseline baPWV, TG levels, and rate of alcohol consumption in the high-intensity smoker group were significantly higher than those in the other three groups, and education level was lower than that in the other three groups (all $P<0.05$). After exercise, baPWV in all individuals was lower and HR was higher than those in all individuals before exercise (both $P<0.05$). There were no significant changes in SBP, DBP, or MAP before and after exercise.

2.2 Comparison of changes in BP, HR, and baPWV between the groups

After the two-stage load test on power bicycle, change in baPWV was negative, and change in SBP, change in DBP, and change in HR were positive (Table 2). After adjusting for confounding factors, the differences between the groups were significant (all $P<0.05$).

2.3 Generalized linear model estimation of between-group differences in the change in baPWV

In Model 3, with the never smokers as the control, the β-values and 95% CIs of former smokers, low-intensity smokers, and high-intensity smokers were −12.17(−30.08, 5.75), −18.43 (−34.69, −2.16), and −22.46 (−38.39, −6.54) cm/s, respectively (Table 3). For every increase in one standard deviation (6.76) in the number of cigarettes smoked, the β-value and 95% CI were −18.11 (−114.16, 77.95) cm/s.

2.4 Sensitivity analysis

The results of the sensitivity analysis (Table 4) were consistent with those of the main analysis, which indicated that the main results were robust.

3. Discussion

Using a functional community population, this study showed that aerobic exercise immediately improved arterial stiffness in people with different smoking statuses. Additionally, arterial stiffness was significantly improved more after aerobic exercise in smokers compared with never smokers.

We found that immediately after aerobic exercise, baPWV was decreased by 33.55 cm/s compared with the resting level in participants with different smoking statuses. baPWV was significantly decreased after aerobic exercise, regardless of whether the participants were never smokers, former smokers, low-intensity smokers, or high-intensity smokers. This finding is similar to that by Yamato et al[28]. They found that baPWV in non-smoking healthy men (n = 26, age: 21.0 ± 1.0 years) was decreased by 33.5 cm/s after 15 minutes of aerobic exercise for 40 minutes. However, Doonan et al.'s[16] study of 24 healthy young smoking men and 53 non-smokers showed that carotid–femoral pulse wave velocity in smokers and non-smokers increased by 80 cm/s and 60 cm/s, respectively, after 5 minutes of exhausting exercise.

The possible reasons for this discrepancy between our study and Doonan et al.'s[16] study are as follows. The sample size of Doonan et al.'s study was small, the population was relatively young (26.06 ± 6.70 years), and the exercise style was more intense compared with our study. Additionally, the difference in the type of pulse wave velocity could be the reason for the inconsistent conclusion between the studies. A meta-analysis suggested that aerobic exercise had different effects on arterial stiffness of different segments. In this meta-analysis, after aerobic exercise, arterial stiffness in the peripheral segments was significantly improved, but it did not significantly improve arterial stiffness in the central segment[29].

Our study showed that there was a difference in the decrease in baPWV after aerobic exercise in people with different smoking statuses. After adjusting for related confounding factors, baPWV was more significantly immediately decreased in low-intensity smokers and high-intensity smokers than in non-smokers (by 18.43 and 22.46 cm/s, respectively). Arterial stiffness is mainly determined by two factors. One factor is that the structure of arteries affects arterial stiffness. A decrease in elastin in the middle layer of the arterial wall and an increase in fibrin cause changes in vascular structure, which increases arterial stiffness[30–33]. The other factor is that the functional status of arteries also affects arterial stiffness. Vascular endothelial cell dysfunction and nervous system activity disorders can affect vascular function, resulting in increased arterial stiffness[34, 35]. Long-term regular aerobic exercise improves vascular structure and function[36, 37], while short-term acute exercise rarely affects vascular structure[38]. Vascular endothelial cells of smokers are in a state of continuous contraction compared with non-smokers [33]. Therefore, endothelial function in smokers is more significantly improved after aerobic exercise than that in non-smokers under the action of various substances that are beneficial to the relaxation of vascular endothelial cells. We speculate that this difference in endothelial function is the reason why baPWV is more significantly improved in current smokers than in non-smokers after exercise.

Although we found that there was a difference in the decrease in baPWV after aerobic exercise in subjects with different smoking statuses, and this decrease in high-intensity smokers was more obvious, we did not examine the specific mechanism(s). Previous studies have shown that short-term aerobic exercise improves blood flow velocity, increases the shear stress between endothelial cells and blood, increases the levels of nitric oxide, prostaglandin, and other vasodilator factors, and decreases vasoconstrictors (e.g., endothelin)[39–42]. These processes cause the relaxation of vascular peripheral blood vessels and improve arterial stiffness. Additionally, an improvement in arterial stiffness after aerobic exercise may also be related to changes in the levels of circulatory metabolites. The Framingham study showed a significant reduction in circulating blood metabolites after aerobic exercise, which resulted in insulin resistance, body inflammation, and oxidative stress. Metabolites related to cardio-cerebral vascular protection were significantly increased[43]. The improvement of baPWV immediately after aerobic exercise in smokers may be related to smokers' sensitivity to the beneficial substances produced after aerobic exercise.

Improving lifestyles and preventing and controlling multiple risk factors are still primary prevention measures for cardiovascular disease, which can effectively reduce the probability of adverse cardiovascular events[44]. Hamdy et al. found that long-term regular aerobic exercise delayed and reversed the process of vascular aging[45]. Our study showed that arterial stiffness in subjects with different smoking statuses was significantly immediately decreased after exercise compared with before exercise. However, this might not be a continuous change. If the exercise time is prolonged and the exercise frequency is increased, arterial stiffness may be maintained. Therefore, clinicians must prescribe individualized exercises for different groups of people to improve arterial stiffness, delay vascular aging, and reduce the damage to blood vessels caused by smoking.

This study has some limitations. (1) This was a cross-sectional study that was performed to examine the causal relationships between various factors and the difference in baPWV before and after exercise. (2) We did not find a dose–response relationship of the change in baPWV after aerobic exercise, possibly because we had difficulty in determining the specific number of cigarettes smoked per day. The number of cigarettes smoked was treated as a classification variable (1–10, 11–20, 21–30, 31–40, and > 40/day). Therefore, observing a dose–response relationship was difficult. (3) We used baPWV as a measurement of arterial stiffness instead of carotid–femoral pulse wave velocity, which is the gold standard. The validity and accuracy of baPWV against carotid–femoral pulse wave velocity have been demonstrated in previous studies [46], and the American Heart Association has also recommended baPWV as a common indicator for arterial stiffness [47]. (4) Women were not included in our study. Therefore, our results are not representative of all populations and need to be verified in other populations.

In summary, this study shows that a single aerobic exercise can immediately improve arterial stiffness in individuals with different smoking statuses. Additionally, immediate improvement of arterial stiffness in smokers is more obvious after aerobic exercise. Our findings may provide guidance for the customization of exercise prescription.

List Of Abbreviations

BP: blood pressure, SBP: systolic blood pressure, DBP: diastolic blood pressure, baPWV: brachial–ankle pulse wave velocity, HR: heart rate, MAP: mean arterial pressure, CI confidence interval, HDL-C: high-density lipoprotein, LDL-C: low-density lipoprotein, TC: total cholesterol, TG: Triglyceride, FBG: fasting blood glucose, Hs-CRP: high-sensitivity C-reactive protein.

Declarations

Ethics approval and consent to participate:

The research ethics were not required anymore, which had been authorized in the former study according to public policy statements of the dataset.

Consent for publication:

Not applicable.

Funding:

This work has been supported by the National Natural Science Foundation of China (No. 81870312).

Competing interest:

Xianxuan Wang, Guanzhi Chen, Zegui Huang, Yiran Zang, Zefeng Cai, Xiong Ding, Zekai Chen, Yulong Lan, Weijian Li, Wei Fang, Weiqiang Wu, Zhichao Chen, Shouling Wu, Youren Chen declare that they have no conflict of interest.

Availability of data and materials:

The datasets analyzed during the current study are available from the corresponding author on reasonable request.

Authors' contributions:

The study was designed by XW, SW, YC; XW, GC, ZH, YZ, ZC, XD analyzed and interpreted the data; YL, WL, WF, WW, ZC were responsible for drafting the manuscript. The manuscript was reviewed by YC and SW. All authors have read and approved the final manuscript.

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Trial registration:

Risk factors and intervention for cardiology, cerebrovascular and related disease (Kailuan Study), ChiCTR-TNRC-11001489. Registered 24 August 2011 - Observational study , https://www.chictr.org.cn/com/25/showproj.aspx?proj=8050

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Tables

Table 1
Baseline participant characteristics

	All n = 940	Never n = 231	Former n = 165	Light Smoking n = 254	Moderate Smoking n = 290	P
Demographic factors						
Age (year)	36.82 ± 7.76	37.18 ± 8.11	39.20 ± 6.97	34.36 ± 7.70	37.50 ± 7.64	< 0.01
BMI (kg/m2)	26.25 ± 3.89	26.45 ± 3.61	26.28 ± 3.50	25.82 ± 4.15	26.45 ± 4.05	0.14
Laboratory parameters						
HDL-C (mmol/L)	1.37 ± 0.36	1.34 ± 0.27	1.39 ± 0.34	1.34 ± 0.29	1.40 ± 0.48	0.17
LDL-C (mmol/L)	2.81 ± 0.82	2.82 ± 1.03	2.81 ± 0.80	2.78 ± 0.72	2.84 ± 0.71	0.89
TC (mmol/L)	4.78 ± 1.09	4.72 ± 0.90	4.76 ± 1.15	4.74 ± 1.32	4.88 ± 0.98	0.33
TG (mmol/L)	1.20(0.83,1.91)	1.15(0.77,1.88)	1.19(0.79,1.78)	1.09(0.84,1.72)	1.35(0.90,2.12)	< 0.01
FBG (mmol/L)	5.51 ± 0.94	5.54 ± 0.76	5.52 ± 0.81	5.47 ± 0.79	5.51 ± 1.22	0.89
Hs-CRP (mg/L)	0.28(0.00,1.50)	0.30(0.00,1.50)	0.25(0.00,1.50)	0.18(0.00,1.05)	0.40(0.00,1.70)	0.05
Drinker, n (%)	523(55.64)	108(46.75)	83(50.30)	144(56.69)	188(64.83)	< 0.01
Physical activity, n (%)	352(37.45)	79(34.20)	63(38.18)	96(37.80)	114(39.31)	0.64
Education ≥ senior college, n (%)	184(19.57)	62(26.84)	36(21.82)	51(20.08)	35(12.07)	< 0.01
Diabetes mellitus, n (%)	66(7.02)	20(8.66)	14(8.48)	15(5.91)	17(5.86)	0.46
Hypertension, n (%)	319(33.94)	80(34.63)	50(30.30)	86(33.86)	103(35.52)	0.22
Anti-hypertension agents, n (%)	94(10.00)	29(12.55)	19(11.52)	17(6.69)	29(10.00)	0.13
Arterial stiffness and hemodynamics (measured supine)						
Pre-exercise SBP (mmHg)	131.84 ± 15.97	132.38 ± 17.61	130.16 ± 15.46	129.99 ± 14.81	133.99 ± 15.66	0.01
Post-exercise SBP (mmHg)	132.34 ± 14.83	133.09 ± 14.45	131.20 ± 15.18	130.88 ± 14.57	133.67 ± 15.05	0.10
Pre-exercise DBP (mmHg)	78.99 ± 11.27	78.65 ± 12.04	78.87 ± 11.13	77.27 ± 11.51	80.84 ± 10.26	< 0.01
Post-exercise DBP (mmHg)	79.35 ± 10.92	79.79 ± 10.75*	79.34 ± 11.12	77.51 ± 11.43	80.63 ± 10.30	< 0.01
Pre-exercise MAP (mmHg)	99.09 ± 12.91	98.35 ± 13.88	98.28 ± 12.84	97.54 ± 12.32	101.50 ± 12.38	< 0.01
Post-exercise MAP (mmHg)	99.42 ± 11.95	99.74 ± 11.76*	99.24 ± 12.45	97.71 ± 11.67	100.77 ± 11.94	0.03
Pre-exercise HR (bpm)	80.24 ± 12.54	79.04 ± 13.97	77.85 ± 12.54	81.82 ± 12.51	81.18 ± 11.03	< 0.01
Post-exercise HR (bpm)	85.73 ± 13.56*	85.13 ± 14.46*	82.67 ± 13.59*	87.23 ± 13.71*	86.64 ± 12.40*	< 0.01

Note: BMI, body mass index; HDL-C, high-density lipoprotein; LDL-C, low-density lipoprotein; TC, total cholesterol; TG, Triglyceride; FBG, fasting blood glucose; Hs-CRP, high-sensitivity C-reactive protein; SBP, systolic blood pressure; DBP, diastolic blood pressure; MAP, mean arterial pressure; HR, heart rate; baPWV, brachial-ankle pulse wave velocity.

**P*< 0.05 against pre-exercise value.

	All n = 940	Never n = 231	Former n = 165	Light Smoking n = 254	Moderate Smoking n = 290	P
Pre-exercise baPWV (cm/s)	1375.08 ± 209.09	1384.32 + 220.35	1368.85 ± 218.41	1345.80 ± 194.43	1396.92 ± 204.75	0.03
Post-exercise baPWV (cm/s)	1341.53 ± 208.04*	1361.32 ± 216.35*	1341.83 ± 221.97*	1305.55 ± 195.90*	1357.10 ± 200.32*	< 0.01
Time interval (min)	7.13(4.93,11.16)	6.98(5.13,10.43)	7.57(4.95,12.60)	6.89(5.00,11.05)	7.02(4.73,11.15)	0.42

Note: BMI, body mass index; HDL-C, high-density lipoprotein; LDL-C, low-density lipoprotein; TC, total cholesterol; TG, Triglyceride; FBG, fasting blood glucose; Hs-CRP, high-sensitivity C-reactive protein; SBP, systolic blood pressure; DBP, diastolic blood pressure; MAP, mean arterial pressure; HR, heart rate; baPWV, brachial-ankle pulse wave velocity.

**P* < 0.05 against pre-exercise value.

Table 2
Between – group differences in arterial stiffness and hemodynamics in initial response exercise each parameter

All n = 940	Never n = 231	Former n = 165	Light Smoking n = 254	Moderate Smoking n = 290	*P	**P	
MET	12.16 (12.02,12.31)	12.53 (12.246,12.82)	12.17 (11.82, 12.51)	12.02 (11.74, 12.29)	12.00 (11.74, 12.26)	0.11	< 0.01
VO2max(ml/kg/min)	3.19 (3.16,3.23)	3.27 (3.19,3.34)	3.20 (3.11,3.28)	3.15 (3.08,3.23)	3.17 (3.10,3.24)	0.03	< 0.01
Peak heat rate	139.40 (138.54,140.23)	138.73 (137.02,140.44)	138.95 (136.91,140.98)	130.26 (138.61,141.91)	139.40 (137.88,140.93)	< 0.01	< 0.01
△SBP(mmHg)	0.49 (− 0.17,1.16)	0.74 (− 0.59,2.08)	1.25 (− 0.34,2.84)	0.64 (− 0.65,1.94)	−0.26 (− 1.45,0.93)	< 0.01	< 0.01
△DBP(mmHg)	0.36 (− 0.07,0.79)	0.84 (0.02,1.67)	0.34 (− 0.62,1.31)	0.22 (− 0.56,1.01)	0.10 (− 0.63,0.84)	< 0.01	< 0.01
△MAP(mmHg)	0.33 (− 0.19, 0.85)	1.15 (0.28,2.01)	0.50 (− 0.54,1.53)	0.20 (− 0.64,1.04)	−0.20 (− 0.98,0.57)	< 0.01	< 0.01
△HR(bpm)	1.59 (0.94,2.24)	3.66 (2.36,4.96)	0.72 (− 0.83,2.28)	0.85 (− 0.41, 2.11)	1.08 (− 0.08,2.25)	< 0.01	< 0.01
△Bapwv (cm/s)	−33.55 (− 39.69, − 27.42)	−23.53 (− 35.89, − 11.16)	−29.46 (− 44.20, − 14.71)	−37.21 (− 49.18, − 25.24)	−40.67 (− 51.72, − 29.63)	< 0.01	< 0.01

Note: Adjusted means (95% CI) are presented.

*P:MET, VO2max, Peak heat rate, △SBP/△DBP/△MAP/△HR/△baPWV are adjusted for age, BMI;

**P: MET, VO2max, Peak heat rate, △SBP/△DBP/△MAP/△HR/△baPWV are adjusted for the baseline HR/MAP/baPWV and age, BMI, TG, education level, alcohol consumption, the time interval of baPWV measurement after exercise.

SBP, systolic blood pressure; DBP, diastolic blood pressure; MAP, mean arterial pressure; HR, heart rate; baPWV ,brachial-ankle pulse wave velocity, MET, Metabolic Equivalent; VO2max, maximal oxygen consumption; △SBP/△DBP/△MAP/△HR/△baPWV, post-exercise value minus pre-exercise value.

Table 3
Generalized linear model analysis results of the between-group difference of △baPWV with different smoking statuses

	Smoking status	**N**	**β**	**95% CI**
Model 1	Never	231	ref	
	Former	165	−11.32	−29.72,7.08
	Light Smoker, ≤ 10 cigarettes/day	254	−15.80	−32.27, − 0.68
	Moderate Smoker, 10 cigarettes/day	290	−15.77	−31.61,0.07
	P for trend	0.05		
	Daily Cigarette Consumption, per SD (6.26)		6.99	−91.61,105.94
Model 2	Never	231	ref	
	Former	165	−13.67	−30.73,4.40
	Light Smoker, ≤ 10 cigarettes/day	254	−20.76	−37.17, − 4.36
	Moderate Smoker, 10 cigarettes/day	290	−24.80	−40.86, − 8.73
	P for trend	< 0.01		
	Daily Cigarette Consumption, per SD (6.26)		−21.34	−118.27,75.59
Model 3	Never	231	ref	
	Former	165	−12.17	−30.08,5.75
	Light Smoker, ≤ 10 cigarettes/day	254	−18.43	−34.69, − 2.16
	Moderate Smoker, 10 cigarettes/day	290	−22.46	−38.39, − 6.54
	P for trend	< 0.01		
	Daily Cigarette Consumption, per SD (6.26)		−18.11	−114.16,77.95

R^2 = 0.10, Model 1: included age, the baseline values of baPWV;

R^2 = 0.14, Model 2: included Model 1 covariates plus BMI, the baseline values of HR/ MAP, TG, Time, drinker, education;

R^2 = 0.16, Model 3: included Model 2 covariates plus △HR, △MAP.

MAP, mean arterial pressure; HR, heart rate; baPWV ,brachial-ankle pulse wave velocity, BMI, body mass index; TG, Triglyceride; Time interval: the time of interval measurement duration;△(changes) from baseline comparisons;△HR/△MAP, Post-exercise minus baseline.

Figures

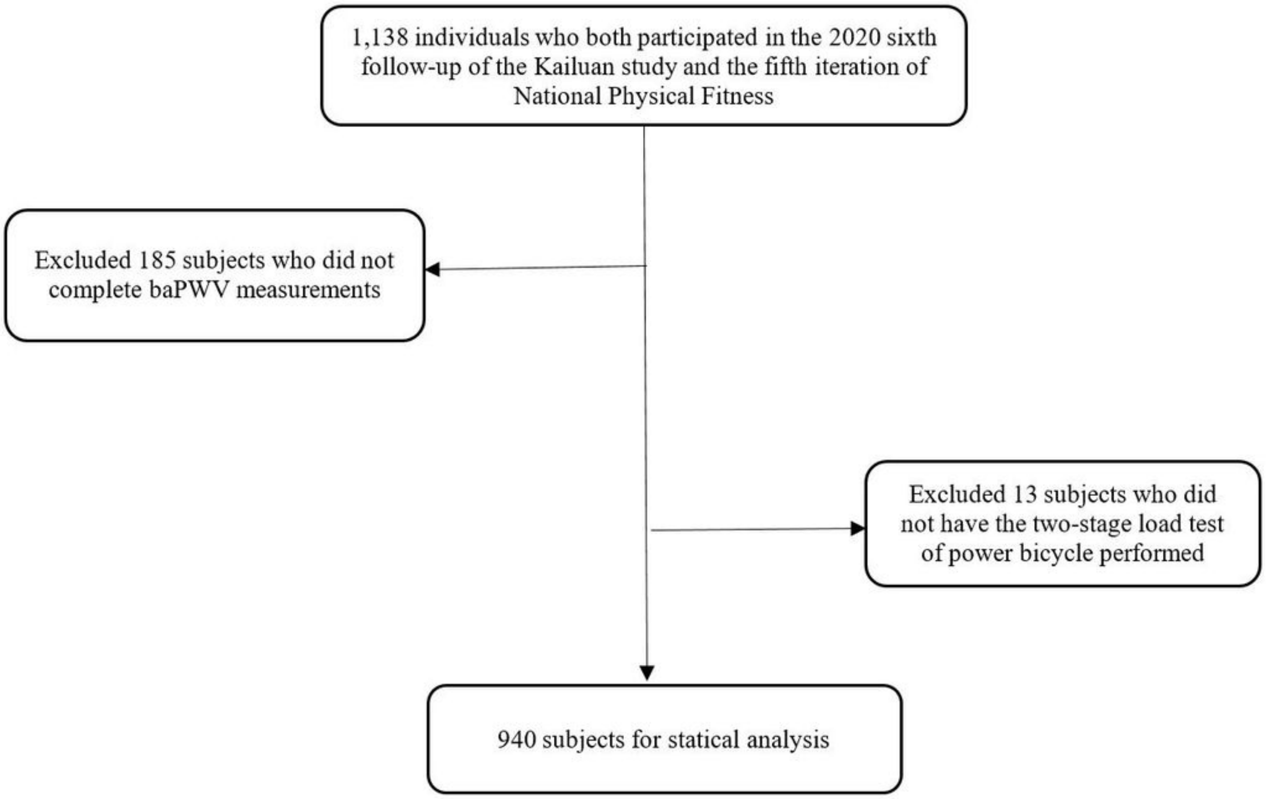

Figure 1

Inclusion/exclusion flowchart for study participant

Supplementary Files

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