Effects of High-Intensity Interval Training on Improving Arterial Stiffness in Chinese Normal Weight Obese Female University Students: A Pilot Randomized Controlled Trial

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Abstract

Background: High intensity interval training (HIIT) has been reported to exert better effects on cardiovascular fitness in obesity, but little known about the arterial stiffness (AS) in normal weight obesity (NWO) females. Thus, this study investigated the changes of body composition, heart rate (HR), blood pressure (BP), blood lipids as well as the parameters of propensity for AS (arterial velocity pulse index (AVI) and arterial pressure volume index (API)).

Methods: Forty NWO female university students were randomly assigned to the control group ($n=20$) or the HIIT group (30 minutes at 90% HR_{max} , $n=20$). The participants in HIIT group accepted a four-week HIIT intervention for five days a week. The above parameters of body composition, cardiometabolic biomarkers, lipid profile, and AS were assessed before and after the HIIT intervention.

Results: HIIT significantly improved the body composition in decreasing the BMI ($p=0.001$), BF% ($p<0.001$), BFM ($p<0.001$), LBFM ($p<0.001$), LMC ($p=0.016$), and Obesity degree ($p=0.001$), and increased the SMM ($p=0.020$), Protein content ($p=0.035$), TBW ($p=0.017$), FFM ($p=0.019$), BCM ($p=0.020$), and Inbody score ($p<0.001$). HIIT also affected the cardiometabolic biomarkers by decreasing the HR ($p=0.001$), SBP ($p<0.001$), and DBP ($p<0.001$). As for the lipid profile, HIIT obviously ameliorated the blood lipids metabolism by decreasing the levels of TC ($p=0.001$), TG ($p<0.001$), LDL ($p<0.001$), and TC/HDL ($p<0.001$), and increasing the levels of HDL ($p<0.001$). In addition, the AS was improved by HIIT intervention through decreasing the AVI ($p<0.001$) and API ($p<0.001$).

Conclusions: Our results provided herein demonstrate that this pattern of a 4-week HIIT had a positive impact on physical fitness in the aspect of body composition, lipid profile, and cardiovascular function in NWO female university students.

Trial registration: ChiCTR2100050711. Registered 3 September 2021. Retrospectively registered.

Background

Obesity, as a disease and the independent risk factor of cardiovascular disease (CVD), has an annually increased global incidence. Traditionally, body mass index (BMI) is the most popular indicator used in obesity classification, but it fails to consider and distinguish body composition variables such as body fat percentage (BF%), lean mass, and body fat distribution. Therefore, BMI is prone to cause false-negatives and underestimate obesity prevalence, especially to those individuals with normal body weight and BMI ($< 25 \text{ kg/m}^2$) but with excessive BF % ($> 30\%$), which is called “normal weight obesity (NWO)” [1]. It has previously been shown that the incidence of Chinese NWO was high among university students, especially in females, which might be related to unhealthy lifestyles[2]. The main barriers for university students to obtain a healthy lifestyle were the busy schedule, academic stress, lack of time to exercise resulting in reduced physical activity/hypokinesia/sedentary behavior, overeating/hypercaloric diet/irregular diet patterns, and lack of sleep/irregular sleeping patterns[3–5]. Additional studies have reported that Chinese NWO university students have lower skeletal muscle mass and levels of physical

fitness, higher cardiometabolic risk, especially in females[6, 7]. Thus, NWO female university students should be paid enough attention to enhance their physical and mental health.

NWO is mainly defined using BF%, which means an increased amount of fat in the abdominal region, known as visceral adipose tissue (VAT). VAT is a major determinant of the occurrence of metabolic disorders and is associated with greater risk for CVD and developing obesity-related complications than general obesity[8, 9]. Hence, identification of NWO individuals as early as possible is an effective component for obesity prevention and treatment, and also will dramatically lower the occurrence of atherosclerosis and CVD in the future. Recent studies have suggested that NWO individuals often show cardiovascular metabolic disorders and dysfunction, and have higher rates of atherosclerosis compared to subjects with normal BMI and normal amounts of body fat. The above evidence implies that NWO individuals are more likely to develop significant future cardiovascular events[10, 11]. Arterial stiffness (AS) is one of the first indicators detected in both functional and structural changes of the arterial wall and plays an important role in CVD, also is considered to be an independent risk predictor of atherosclerosis and CVD[12]. Unfortunately, AS has a very close association with NWO, it has a strongly positive correlation with numerous NWO-induced anomalous parameters such as higher levels of systolic blood pressure, VAT, triglyceride (TG), and low-density lipoprotein-cholesterol (LDL) in contrast to the negative correlation with a lower level of high-density lipoprotein-cholesterol (HDL)[13].

Previously, noninvasive devices and methods such as the cardio ankle vascular index (CAVI), brachialankle pulse wave velocity (baPWV), and carotid artery intima-media thickness (IMT) have been used to evaluate AS and atherosclerosis in hypertensive patients. However, these approaches require a relatively long time to complete measurements and problems can be encountered in the skill and experience levels of persons conducting the measurements. Moreover, these instruments are uncomfortable for patients, because occlusion/sensing cuffs adapted to both arms and ankles must be used in the supine position[14]. Simpler and easier methods that can be used in daily clinical settings are required. In recent years, arterial pressure volume index (API) and the arterial velocity pulse index (AVI), which can be determined in a simple and non-invasive manner, have been used as new novel indices for AS. AVI is an index based on the ratio between velocity changes during brachial artery dilatation (systolic phase) and relaxation (diastolic phase), which reflects aortic elasticity and peripheral vascular resistance. The principle of API is that soft arteries with greater elasticity change volume more rapidly when the cuff pressure is reduced, which reflects the elasticity of the brachial artery and is considered to indicate the stage of atherosclerosis of peripheral arteries[15, 16]. In a healthy adult population, AVI and API values were significantly elevated in individuals with classical cardiometabolic and atherosclerotic risk factors (e.g., obesity, hypertension, diabetes, and dyslipidemia) and showed a positive correlation with IMT or CAVI, and they also have positive correlations with baPWV and preclinical carotid atherosclerosis regardless of the presence or absence of coronary artery disease, drawing attention to the usefulness of AVI and API[16–18]. Compared with conventional indices, they require shorter measurement times, have more comfortable postural requirements (in a sitting position), and involve the easier operation of the measurement devices. These merits make the use of AVI and API fit for use in screening preclinical atherosclerosis in broad clinical and public health settings. However, so far, studies on AVI and API have

been performed mainly in Japan, there have been no reports about using them to evaluate the AS of NWO female university students in China.

Although increasing evidence suggests that exercise is the most predominant non-pharmacological strategy for attenuating excessive VAT deposition and fight obesity and related complications[19], NWO female university students prefer diet to exercise. Among the main barriers for inactive individuals to physical activity and maintain a physically active lifestyle are the reported lack of time, access to sporting facilities, the financial costs of exercising, and the inability to adhere to lengthy exercise programs. Recently, as an emerging and promising, highly efficient, multi-stimulated, cost-saving means, and time-effective pattern of exercise intervention, high-intensity interval training (HIIT) is born at the right moment. HIIT involves several short sets of high-intensity bursts ($\geq 80\%$ of HRmax or $\geq 90\%$ of maximal oxygen uptake, often reaching anaerobic threshold) interspersed with low-intensity recovery or rest (65–80% of HRmax) [20, 21]. A growing body of evidence demonstrated that HIIT can be an effective alternative to traditional moderate-intensity continuous training (MICT). Compared with MICT, HIIT has unique advantages in treating overweight/obesity people, because it not only could lead to greater adipose tissue loss, more effectively reduce abdominal and visceral fat mass, and improve the body composition and dyslipidemia[22–24], but also could mediate larger decreases in systolic blood pressure[25], improve cardiorespiratory and vascular function, and reduce risk factors of CVD[22, 26]. Moreover, it's convenient and enjoyable for the public since the sport events and modes of HIIT are various and not limited to the specific stadium[27, 28]. As a result, HIIT has high unsupervised adherence rates in overweight and obese adults. However, despite clear evidence for the positive vascular function and cardiovascular adaptations following HIIT, it's still unclear whether HIIT could yield a beneficial effect on AVI/API and AS by improving the body composition and lipids metabolism of NWO female university students.

NWO female university students are a special population. In this study, we selected them as the research object, mainly aimed to evaluate the possible changes of their body composition and cardiovascular function, and then investigate and analyze the potential clinical effectiveness of short time HIIT in the treatment of the above changes.

Materials And Methods

Study participants

We enrolled one hundred and thirty-seven female college students with normal BMI (18.5-24.9 kg/m²) at the Shanghai University of Medicine and Health Sciences (Shanghai, China) from November to December 2020 after the exercise risk assessment. The experiment protocol was submitted to and approved by the institutional review board of the Shanghai University of Medicine and Health Sciences (2020-20YJCZH001-03), and all participants gave written informed consent before the study after procedures, associated risks, and potential benefits of participation had been explained, then the study was performed in accordance with the principles outlined in the Declaration of Helsinki.

Exclusion criteria were as follows: (1) physical limitations (e.g., musculoskeletal system injuries or/and osteoarticular diseases); (2) known cardiovascular and cerebrovascular diseases; (3) exercise-related dyspnea or respiratory alterations; (4) other contraindications to exercise.

After the exercise risk assessment, forty NWO subjects were screened using body composition measurement apparatus (InBody-770, Biospace Co., Seoul, Korea) according to the criteria of female NWO (BF%>30%, which is the NWO obesity cut-off for Asian adults)[10]. Participants were randomly divided into Control group (n=20) and HIIT group (n=20). Subjects in the control group did not take regular exercise and only participated in physical education once a week, while subjects in the HIIT group performed duration of 4-week HIIT. Both two groups were not interfered with the daily diet and other daily living behaviors. Outside implemented program, all participants were instructed to maintain their normal levels of physical activity and normal dietary patterns (and not to use any dietary supplements). 10 of the 40 participants (7 in the control group and 3 in the HIIT group) resigned from the study during the intervention due to personal reasons. Flow-chart diagram is detailed in Figure 1.

HIIT Intervention protocol

Participants in the HIIT group were familiarized with a week acclimatization training to acquaint the training session, learn the motor movement, and gradually adapt and increase the training intensity. After familiarization, the participants completed 4-week. The frequency of HIIT was five times a week. The HIIT intervention began with 10 min of warm-up (including the stretch of self-propelled lower extremity muscles, the world greatest stretch, and the rotator cuff muscle training) to prevent the sports injury. Then the training was performed with 9 min of high-intensity exercise combined motion (jumping jacks, run-ups, squat jump, burpee, high elbow plank, step jump, double knee lifts, mountain climbers, lunges in place; 40 s for each movement interspersed with 20 s for interval rest) followed by 1 min of recovery rest and this was repeated 3 bouts and ended with 10 min static stretching of upper and lower limb muscles. The intensity of training corresponded to 90% of the maximum heart rate (HR_{max}) which was monitored by Prince-100H (Heal Force, Shanghai, China) during the entire training session. The entire HIIT process is guided by professional coaches and supervised by athletic instructor in case of sports injury or exercise fatigue. HIIT intervention protocol is detailed in Figure 2.

Measurements

Body composition

Subjects were given complete instructions on the body composition analysis procedure and were instructed not to make any intense physical effort in the 8 h prior to body composition measurement. Body composition (Body weight; BMI; BF%, body fat percent; BFM, total body fat mass; LBFM, BFM of left arm; SMM, total body skeletal muscle mass; Protein; BMC, bone mineral content; FFM, fat free mass; LFFM, FFM of left arm; TBW, total body water; LTBW, TBW of left arm; LMC, Measured circumference of left arm; BCM, body cell mas; Inbody score, and Obesity Degree) was detected by InBody-770 (Cerritos, CA, USA) multi-frequency bioelectrical impedance (BIA) device before and after the 4-week HIIT

intervention. The subjects held the handle with both hands and abducted the upper limb 30° during the measurement. They were asked to take off their shoes, socks, hats, and heavy coats. Electronic products (e.g., mobile phones, earphones) and finger ring were also not permitted to carry. Handles and metal pedals were wiped with an alcohol cotton ball before each subject was tested.

Blood lipids

Fingertip blood samples (35 µL for each subject) were collected by capillary tube. Then they were added to a blood lipid test card quickly and examined by Cholesterol Monitoring system CCM-111 (Acon Biotech, Hangzhou, China) to detect the concentration of lipid profiles (TC, total cholesterol; TG, triglyceride; HDL; LDL; and TC/HDL).

Resting heart rate, blood pressure, and arterial stiffness

The left arm of resting heart rate (HR), systolic blood pressure (SBP), diastolic blood pressure (DBP), AVI, and API were all simultaneously measured using the PASESA AVE-2000 PLUS (Shisei Datum, Tokyo, Japan) with the subject in the sitting position. Measurements were taken in a quiet room with the temperature maintained at 20-26 °C. The above parameters were calculated before the intervention and the 7:00 am the day after HIIT completion. The subjects were forbidden drinking coffee and kept calm and stable during the measurement for avoiding the fluctuation of blood pressure.

Statistical analysis

All data are expressed as mean ± standard error (SE). The repeated measures ANOVA (group main effect and time by group interaction) within-between interaction design was used to evaluate indexes changes pre to post intervention through SPSS 26.0 software. If the interaction between time and group is significant, simple effect test analysis is needed. An alpha value of $p < 0.05$ was accepted as the minimal level of significance.

Results

Effects of HIIT on body composition of NWO females

As shown in Table 1, we found a significant time×group interaction in the aspects of Body weight ($F_{(1,28)}=21.348$, $p<0.001$, $\eta^2=0.433$), BMI ($F_{(1,28)}=11.249$, $p=0.002$, $\eta^2=0.287$), BF% ($F_{(1,28)}=46.558$, $p<0.001$, $\eta^2=0.624$), BFM ($F_{(1,28)}=68.409$, $p<0.001$, $\eta^2=0.710$), LBFM ($F_{(1,28)}=94.801$, $p<0.001$, $\eta^2=0.772$), SMM ($F_{(1,28)}=9.599$, $p=0.004$, $\eta^2=0.255$), protein content ($F_{(1,28)}=6.298$, $p=0.018$, $\eta^2=0.184$), BMC ($F_{(1,28)}=4.928$, $P=0.035$, $\eta^2=0.150$), LMC ($F_{(1,28)}=5.199$, $p=0.030$, $\eta^2=0.157$), TBW ($F_{(1,28)}=9.230$, $p=0.005$, $\eta^2=0.248$), FFM ($F_{(1,28)}=8.984$, $p=0.006$, $\eta^2=0.243$), BCM ($F_{(1,28)}=9.453$, $p=0.005$, $\eta^2=0.252$), Obesity degree ($F_{(1,28)}=10.698$, $p=0.003$, $\eta^2=0.276$), and Inbody score ($F_{(1,28)}=26.614$, $p<0.001$, $\eta^2=0.487$). However, there was no significant interaction effect in the LTBW ($F_{(1,28)}=2.822$, $p=0.104$,

$\eta^2=0.092$) and LFFM ($F_{(1,28)}=3.283$, $p=0.081$, $\eta^2=0.105$). No significant difference was seen in the above indexes between the two groups before the HIIT intervention. But compared with the subjects in the control group after the HIIT intervention, the BMI ($p=0.001$), BF% ($p<0.001$), BFM ($p<0.001$), LBFM ($p<0.001$), LMC ($p=0.016$), and Obesity degree ($p=0.001$) were markedly decreased, and the SMM ($p=0.020$), Protein content ($p=0.035$), TBW ($p=0.017$), FFM ($p=0.019$), BCM ($p=0.020$), and Inbody score ($p<0.001$) were significantly increased in the HIIT group. There were no differences in Body weight, BMC, LTBW, and LFFM between the two groups.

Before and after the intervention, the within-group comparisons showed that the HIIT group had significantly decreased Body weight ($p=0.007$), BMI ($p<0.001$), BF% ($p<0.001$), BFM ($p<0.001$), LBFM ($p<0.001$), and Obesity degree ($p=0.030$), but had significantly increased SMM ($p<0.001$), protein content ($p<0.001$), BMC ($p=0.008$), TBW ($p<0.001$), LTBW ($p=0.002$), FFM ($p<0.001$), FFM of left arm ($p=0.002$), BCM ($p<0.001$), and Inbody score ($p<0.001$), no significant difference in LMC. Meanwhile, the Control group had markedly increased Body weight ($p=0.001$), BMI ($p=0.040$), BF% ($p=0.040$), BFM ($p=0.002$), LBFM ($p<0.001$), and Obesity degree ($p=0.030$), no significant difference in SMM, protein content, BMC, TBW, LTBW, FFM, FFM of left arm, LMC, BCM, and Inbody score.

Effects of HIIT on heart rate and blood pressure of NWO females

As shown in Table 2, we found a significant time $\times$ group interaction in the aspects of resting HR ($F_{(1,28)}=37.780$, $p<0.001$, $\eta^2=0.574$), SBP ($F_{(1,28)}=23.125$, $p<0.001$, $\eta^2=0.452$), and DBP ($F_{(1,28)}=41.165$, $p<0.001$, $\eta^2=0.595$). There was no significant difference in HR, SBP, and DBP between the two groups before the HIIT intervention. However, compared with the control subjects after the HIIT intervention, the HR ($p=0.001$), SBP ($p<0.001$), and DBP ($p<0.001$) were obviously decreased in the HIIT group. Before and after the intervention, the within-group comparisons showed that the HIIT group had significantly decreased HR ($p<0.001$), SBP ($p=0.029$), and DBP ($p=0.006$), while the Control group had exactly opposite significant changes.

Effects of HIIT on blood lipids of NWO females

As shown in Table 3, we found a significant time $\times$ group interaction in the aspects of TC ($F_{(1,28)}=28.282$, $p<0.001$, $\eta^2=0.503$), TG ($F_{(1,28)}=59.777$, $p<0.001$, $\eta^2=0.681$), HDL ($F_{(1,28)}=103.813$, $p<0.001$, $\eta^2=0.788$), LDL ($F_{(1,28)}=96.371$, $p<0.001$, $\eta^2=0.775$), and TC/HDL ($F_{(1,28)}=81.708$, $p<0.001$, $\eta^2=0.745$). There was no significant difference in HR, SBP, and DBP between the two groups before the HIIT intervention. However, compared with the control subjects after the HIIT intervention, the levels of TC ($p=0.001$), TG ($p<0.001$), LDL ($p<0.001$), and TC/HDL ($p<0.001$) were lower while the level of HDL ($p<0.001$) was higher in the HIIT group. Before and after the intervention, the within-group comparisons showed that the HIIT group had markedly decreased TC ($p<0.001$), TG ($p<0.001$), LDL ($p<0.001$), and TC/HDL ($p<0.001$), but had markedly increased HDL ($p<0.001$). However, the Control group had obviously increased TG ($p=0.012$) and LDL ($p=0.032$), no significant difference in TC, HDL, and TC/HDL.

Effects of HIIT on AVI and API of NWO females

As shown in Table 4, we found a significant time $\times$ group interaction in the aspects of AVI ($F_{(1,28)}=98.496$, $p<0.001$, $\eta^2=0.779$) and API ($F_{(1,28)}=66.458$, $p<0.001$, $\eta^2=0.704$). There was no significant difference in HR, SBP, and DBP between the two groups before the HIIT intervention. However, compared with the control subjects after the HIIT intervention, both of the AVI ($p<0.001$) and API ($p<0.001$) are obviously decreased in the HIIT group. Before and after the intervention, the within-group comparisons showed that the HIIT group had obviously decreased AVI ($p<0.001$) and API ($p<0.001$), while the Control group only had significantly increased API ($p=0.015$) but no difference in AVI.

Discussion

There is strong evidence linking NWO and increased CVD and all-cause mortality, and women with NWO were 2.2 times more likely to die from CVD compared with those with low BF[10]. Female university students are the high incidence but underdiagnosed and understudied group of NWO. In this study, we used the bioelectrical impedance analyzer InBody-770 to measure and estimate the body composition and found, if left untreated, some significantly progressive adverse changes in NWO female university students, such as increased Body weight, BMI, BF%, BFM, BFM of left arm, and obesity degree, which will may aggravate the potential cardiovascular health hazard. Early numerous studies have validated that elevated BF% and BFM are associated with disturbances in lipids metabolism and cardiometabolic[29], which could impair cardiovascular function. Herein, if left untreated, we also found NWO females had obviously lifted resting HR, SBP, DBP, TG, and LDL over time. The normal range of SBP and DBP is respectively less than 120 and 80, however, both SBP and DBP were excessive in NWO females, implying the risk of hypertension. There was a study pointed out that the NWO subjects demonstrated left ventricle systolic and diastolic dysfunction, increased fibrosis intensity[30], so we recommend both systolic and diastolic BP should be evaluated to better define the metabolic and vascular profile of NWO females.

Previous evidence has shown that higher BMI, BP, TG, and LDL may cause persistent endothelial damage, which will lead to endothelial dysfunction and AS increase, and this is considered the first step in the progression of atherosclerosis[31]. Elevated HR is an important determinant of the mechanical properties of the vascular atherosclerotic lesions, which is related to the development and progression of vasculopathy[32, 33]. Two key points of HR elevation contribute to atherosclerosis: firstly, the elevated HR increases the oscillatory shear stress to lower the arterial distensibility. Secondly, it intensifies the pulsatile motion of the heart to hinder the local hemodynamics[34]. BP has been reported to be mediated by AS[35]. For example, elevated SBP is significantly associated with higher central arterial stiffness in healthy, normotensive men and women[36].

Blood-based biomarkers such as TC, TG, LDL, and HDL are well-established indicators of cardiovascular function risk. In this study, before the intervention, we found that the values of TC (suitable range < 5.20 mmol/L, edge elevated 5.20–6.20 mmol/L), TG (suitable range < 1.70 mmol/L, edge elevated 1.70–2.30 mmol/L), and LDL (suitable range 2.60–3.40 mmol/L, edge elevated 3.40–4.10 mmol/L) were within the

edge elevated range, and HDL (suitable range ≥ 1.00 mmol/L, abnormal range < 1.00 mmol/L) were within the abnormal range in NWO females. Similarly, if left untreated, these indicators were further elevated or were abnormal. The characteristic of atherosclerosis is visible atherosclerotic lesions in the artery walls, especially in the coronary artery and aorta. These lesions primarily occur due to excessive lipid deposition[37]. Therefore, atherosclerosis originates from the passive diffusion of circulating LDL through endothelial junctions into the vessel intima[38]. One of the most representative is the elevated levels of TC and LDL[37]. The reduction of LDL can further lower cardiovascular mortality. TG is the major component of triglyceride-rich lipoproteins (TRLs), which needs to combine with associated proteins into lipoprotein particles[39]. Recently, some studies report that TG and TC content within TRLs may contribute to the development of atherosclerotic cardiovascular disease[40, 41]. In addition, HDL enhancing foam cell cholesterol efflux is considered as the first step of reversing TC transport, which is a promising antiatherogenic strategy[42]. The sensitivity of TC/HDL value is higher than the pure TC or HDL, which is used to independently predict the severity of fatty liver caused by obesity, atherosclerotic, and coronary heart disease[43].

AS is considered one of the earliest detectable measures of vascular damage. However, it's very difficult to directly measure AS. In the last decade, a variety of non-invasive methods and devices such as CAVI, baPWV, cfPWV, IMT, and aortic augmentation index (aAI) has been used to evaluate atherosclerosis by assessing AS or impaired endothelial function. But currently available devices and methods are unsuitable for the patient screening or risk stratification in routine clinical practice owing to factors such as the postural requirements, variability among investigators, and time-consuming manual procedures. Recently, AVI and API, two novel non-invasive vascular indexes for evaluating systemic and peripheral AS, respectively, have been gaining attention. They are convenient, quick (about 1 min), and comfortable for systemic endothelial function and AS assessment using cuff oscillometry technologies and suprasystolic cuff oscillometric wave measurement (PASESA AVE-2000 PLUS, Japan) in the clinical setting. The AVI mainly reflects the AS from the aorta to the muscular artery and peripheral resistance, which is significantly associated with BMI, abdominal circumference, and TG[44]. While API mainly reflects the stiffness of the brachial artery, which is affected by coronary stenosis, arterial compliance and more sensitive to arterial SBP[45]. Meanwhile, they are both not only associated with baPWV, preclinical carotid arterial compliance, as well as AS in general populations[16, 44], but also with the number of cardiovascular risk factors, the Framingham risk score[46], and CAD[47]. These two new indexes are therefore expected to be useful clinically for predicting and evaluating the future risk of atherosclerotic diseases and cardiovascular events. However, data on subjects with NWO females remain scant, not even available in China.

AVI and API have emerged as surrogate markers of cardiovascular disease in obesity and a predictor for CVD events in adulthood. According to the manufacturer's instructions, the normal range of AVI is 11 to 15 (age 18–23), and the API is 15 to 22 (age 15–22). In the current study, we found both AVI and API exceeded the normal range in NWO female university students. Even worse, the API further increased in the Control group due to they did not get effective intervention. Combined with the abnormal body composition, BP, and lipids metabolism, these results strongly suggested that the NWO females have an

increased risk of arteriosclerosis and CVD. Early detection of the degree of arteriosclerosis in the NWO population and timely intervention are of great significance for preventing and treating cardiovascular and cerebrovascular diseases. The previous study has revealed that the enhanced AVI represents increased workload on the heart with elevated central BP and is highly correlated with the augmentation index. API is a useful predictor of future cardiovascular disease, which is independently associated with both the Framingham Cardiovascular Risk Score and the Suita Score[46]. Fujiwara et al. found that AVI and API were higher in patients with coronary artery disease and positively correlated with the severity of coronary artery stenosis[14]. Therefore, the higher values of AVI and API represent the higher propensity for AS and assess the potential risk of CVD in the NWO population. The mechanisms of NOW increasing AS and impairing the vascular function ascribe to chronic high fat accumulation, which stimulates multiple pro-inflammatory cytokines and elevates NOX-mediated ROS production, induces oxidative stress, provokes vascular endothelial cells functional disorder, and disturbs the secretion of vascularizing factors (nitric oxide synthase and nitric oxide) and vasoconstrictor factor (Ang-II and endothelin, vasoconstrictor)[48, 49]. Moreover, perivascular adipose tissue also seems to promote local inflammation and reduce capillary density and microvascular nitric oxide (NO, vasodilator) bioavailability to resulting in impaired endothelial function and vasodilatation, which will eventually accelerate the atherosclerotic process at an early stage[50].

Prescribing physical activity to people with obesity is no longer a rarity and in fact has become recognized as a necessity. In recent years, HIIT is among the most highly recommended measures for obesity because it is well tolerated and favorably affects cardiometabolic risk factors. Our study showed that 4-week HIIT effectively reduced the Body weight, BMI, BF%, BFM, LBFM, and obesity degree while increased SMM, protein content, BMC, FFM, LFFM, TBW, LTBW, BCM, and Inbody score in the HIIT group, only LMC had no difference. Interestingly, after HIIT intervention, most of the results of the between-group comparisons were in line with the within-group of the HIIT group except for no difference of body weight, BMC, LFFM, and LTBW. The main reason may be possibly due to the difference in sample size between the two groups (HIIT $n = 17$ vs. Control $n = 13$), it's also possible that the statistic method of repeated measures ANOVA may be overly strict. Nevertheless, based on these results, we were still able to demonstrate that short-term HIIT could be a potent stimulus for effectively improving the body composition in NWO females. Previous evidence allows us to speculate that these positive improvements in body composition after HIIT training were likely the result of an upregulation of bioenergetic oxidation (especially fat oxidation) and energy expenditure due to excess postexercise oxygen consumption (EPOC) [51, 52]. HIIT consumes large amounts of glycogen during exercise, so more fat will be oxidized during the recovery period to resynthesize glycogen. And, HIIT training may mobilize quite a bit of skeletal muscles, which also may activate the skeletal muscles' catabolism signaling mechanisms (especially lipodieresis) and increase muscle protein synthesis[53, 54]. Besides these, HIIT could promote the secretion of catecholamines, epinephrine, norepinephrine, and growth hormone, which will accelerate fat decomposition to achieve effective fat and body weight loss[26].

Previous studies elucidated that HIIT could decrease BMI, BF, and BFM in overweight and obesity[22, 55], and HIIT elicited superior benefits than MICT in weight control, fat loss (especially abdominal and visceral

fat), FFM, and SMM in both healthy and chronic illness populations [56–58]. Excessive amounts of cardiac adipose tissue are reported to be associated with CVD. HIIT has been shown to even reduce epicardial adipose tissue mass and cardiovascular risk in physically inactive participants with abdominal obesity[59]. The results imply that HIIT is a sustainable and training strategy for improving weight management. Furthermore, although generating a similar magnitude of improving BFM and waist circumference modest as the MICT does in overweight and obese individuals, HIIT can save nearly 40% time commitment each week[60]. Therefore, HIIT is considered as a time-efficient and effective exercise strategy for managing overweight and obesity.

However, to the best of our knowledge, little is known regarding the effects of HIIT on CVD factors, namely BP, lipids metabolism, and AVI/API, in NWO female university students. Firstly, BP is closely correlated with cardiovascular health, and hypertension has led to high cardiovascular morbidity and mortality worldwide[61]. Some studies have shown that HIIT had a superior function of decreasing resting HR, SBP, and DBP[62–64], and was associated with greater improvements in dealing with hypertension when compared to MICT among the hypertensive patients and the overweight/obesity adolescent girls[65–67]. These results are concordant with our findings. Secondly, HIIT has been reported to have the function of redressing lipid metabolism disorders in obesity[68, 69] and may be a preferable therapy for atherosclerosis. Our results demonstrated that 4-week HIIT could significantly reduce TC, TG, LDL, and TC/HDL, and raise HDL in the HIIT group, and the changes of these indexes were consistent with that of when compared with the controls. More importantly, HIIT could adjust these indexes to the normal ranges, and our finding was consistent with Fisher et al in overweight and obese young men[70]. Gripp et al. reported that most of the positive effects of the HIIT were also found to be longer-lasting and maintained after the suspension for 4 weeks[71]. Accumulation of LDL inside the blood vessels serves as a major cause of arteriosclerosis, while HIIT can prevent LDL accumulation[26]. Moreover, HIIT also can affect HDL function, including the promotion of reverse cholesterol transport and lipid peroxide transport clearing[72]. Therefore, this pattern of short-term HIIT will benefit the NWO females from ameliorating lipid metabolism.

Thirdly, although the effects of aerobic exercise on reducing AS and CVD risk have been investigated before, the relationship between AVI/API and HIIT improved NOW females AS has not been studied fully. Here, we examined for the first time the effect of HIIT on the two new arterial indices on AS in Chinese NWO female university students. We verified that HIIT could significantly lower the values of AVI and API to the normal ranges, and the fully automatic and rapid measurement of AVI/API may enhance the practical value in a large population to identify subjects at high risk of atherosclerosis. AS is mainly influenced by vascular endothelial function, HIIT has well-established beneficial effects on endothelial function in overweight men/adolescents and obese young women[73, 74]. Adaptive changes in endothelial function have been shown to depending (to a large extent) on the activity of eNOS, which induces NO production to relax smooth muscle cells, capillaries, and small arterioles, subsequently dilates blood vessels and increases arterial compliance in the muscular arteries[75, 76]. HIIT has been reported to increase endothelial eNOS protein content and NO availability, and caused significant improvements in brachial artery endothelial-dependent dilatation and aortic stiffness in obese individuals

with elevated CVD risk[77]. Additionally, a meta-analysis showed that HIIT was associated with up to a twofold increase in endothelial dilator function at the macrocirculatory level when compared with MICT in adults with metabolic and cardiovascular disease[78].

However, the mechanism of reducing the propensity for AS is still unclear in our study. There are many gaps in the literature on NWO unlike for overt obesity and further study should disclose the underlying relationship between the HIIT and the vascular adaptation in improving the AS in NWO female university students and explore the molecular mechanisms. It should be noted that the exercise risk assessment needs to be carried out before the formulation of HIIT prescription, and the adaptive training along with the increasing intensity and sufficient warm-up, relaxation, and cooling-down are essential for avoiding sports fatigue and sports injuries even the concurrently health risk. In this study, we did not observe any adverse exercise events (e.g., muscle injury, overfatigue, syncope, palpitation, angina, abnormal fluctuation of blood pressure, nausea, vomiting, dyspnea) during the HIIT intervention. Hence, HIIT utilization is safe for NWO females. Last but not least, large, multicenter, and prospective studies are required to establish the optimal HIIT protocols for NWO female university students.

Limitations

The study was designed as a prospective, randomized controlled trial (RCT) exercise intervention trial comparing the effects of a 4-week HIIT training program on NOW female university students. While, this study has some limitations that should be considered before interpreting the results. First, the sample size was relatively small and the control group had a higher attrition rate (35%), probably because they didn't see the weight loss or benefit. In contrast, the HIIT group had high adherence. Even so, it did not prevent us from seeing clear differences between the two groups, and the magnitude of the beneficial effects of HIIT on NWO females' AS was adequate. Second, although it has been reported that HIIT may result in suppressed appetite[79], participants were instructed to not alter their diet behaviors for the duration of the intervention, change in habitual energy intake was not monitored, which may affect the final results. Third, we did not examine the arterial compliance, reflected wave, vascular endothelial function, or female hormones, which could have important effects on AS.

Conclusion

All in all, our observations suggest that HIIT is an effective and acceptable activity for NWO female university students, and we provide up-to-date evidence on the impact of short-term HIIT in obviously improving body composition and abnormal lipid metabolism, reducing BP and AVI/API, as expected. These changes caused by HIIT will be hugely beneficial for reducing AS and CVD risk, and enhancing NWO female university students' physical fitness and well-being.

Abbreviations

HIIT: High Intensity Interval Training; NWO: Normal Weight Obesity; BMI: Body Mass Index; AS: Arterial Stiffness; HR: Heart Rate; BP: Blood Pressure; SBP: Systolic Blood Pressure; DBP: Diastolic Blood Pressure; AVI: Arterial Velocity Pulse Index; API: Arterial Pressure Volume Index; CVD: Cardiovascular Disease; BF%: Body Fat Percentage; VAT: Visceral Adipose Tissue; TC: Total Cholesterol; TG: Triglyceride; LDL: Low-Density Lipoprotein-Cholesterol; HDL: High-Density Lipoprotein-Cholesterol; CAVI: Cardio Ankle Vascular Index; baPWV: brachialankle Pulse Wave Velocity; IMT: Intima-Media Thickness; aAI: Aortic Augmentation Index; MICT: Moderate-Intensity Continuous Training; BFM: Body Fat Mass; LBFM: BFM of Left Arm; SMM: Skeletal Muscle Mass; BMC: Bone Mineral Content; FFM: Fat Free Mass; LFFM: FFM of Left Arm; TBW: Total Body Water; LTBW: Total Body Water of Left Arm; LMC: Measured Circumference of Left Arm; BCM: Body Cell Mas; TRLs: Triglyceride-Rich Lipoproteins; RCT: Randomized Controlled Trial.

Declarations

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Authors' contributions

JH, LZ, and RY contributed equally to this work. JH and MC co-conceptualised the idea and co-designed the study, MC and RY obtained funding, JH, LZ, and RY collected data, analysed and interpreted the data, LW and LL oversaw intervention implementation and data collection, YY, SJ, RC, QL, and YR performed the experiment. All authors have read and approved the final version for submission.

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Availability of data and materials

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

Ethics approval and consent to participate

The study protocol was approved by the institutional review board of the Shanghai University of Medicine and Health Sciences (2020-20YJCZH001-03) and Prevention Ethical Review Committee (ChiCTR2100050711) and all participants in the study provided written informed consent before taking part in the study.

Consent for publication

Not applicable.

Competing interests

The authors report no conflicts of interest in this work.

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References

1. Oliveros E, Somers VK, Sochor O, Goel K, Lopez-Jimenez F: **The concept of normal weight obesity.** *Prog Cardiovasc Dis* 2014, **56**:426-433.
2. Maitiniyazi G, Chen Y, Qiu YY, Xie ZX, He JY, Xia SF: **Characteristics of Body Composition and Lifestyle in Chinese University Students with Normal-Weight Obesity: A Cross-Sectional Study.** *Diabetes Metab Syndr Obes* 2021, **14**:3427-3436.
3. Radwan H, Hasan HA, Ismat H, Hakim H, Khalid H, Al-Fityani L, Mohammed R, Ayman A: **Body Mass Index Perception, Body Image Dissatisfaction and Their Relations with Weight-Related Behaviors among University Students.** *Int J Environ Res Public Health* 2019, **16**.
4. Pop LM, Iorga M, Sipos LR, Iurcov R: **Gender Differences in Healthy Lifestyle, Body Consciousness, and the Use of Social Networks among Medical Students.** *Medicina (Kaunas)* 2021, **57**.
5. Juarascio A, Forman E, Timko CA, Butryn M, Goodwin C: **The development and validation of the food craving acceptance and action questionnaire (FAAQ).** *Eat Behav* 2011, **12**:182-187.
6. Zhang M, Schumann M, Huang T, Tormakangas T, Cheng S: **Normal weight obesity and physical fitness in Chinese university students: an overlooked association.** *BMC Public Health* 2018, **18**:1334.
7. Tian Q, Wang H, Kaudimba KK, Guo S, Zhang H, Gao S, Wang R, Luan X, Lee JKW, Chen P, et al: **Characteristics of Physical Fitness and Cardiometabolic Risk in Chinese University Students with Normal-Weight Obesity: A Cross-Sectional Study.** *Diabetes Metab Syndr Obes* 2020, **13**:4157-4167.
8. Yusuf S, Hawken S, Ounpuu S, Bautista L, Franzosi MG, Commerford P, Lang CC, Rumboldt Z, Onen CL, Lisheng L, et al: **Obesity and the risk of myocardial infarction in 27,000 participants from 52 countries: a case-control study.** *Lancet* 2005, **366**:1640-1649.
9. Despres JP, Lemieux I: **Abdominal obesity and metabolic syndrome.** *Nature* 2006, **444**:881-887.
10. Oliveros E, Somers VK, Sochor O, Goel K, Lopez-Jimenez F: **The Concept of Normal Weight Obesity.** *progress in cardiovascular diseases* 2014, **56**:426-433.

11. De Lorenzo A, Martinoli R, Vaia F, Di Renzo L: **Normal weight obese (NWO) women: an evaluation of a candidate new syndrome.** *Nutr Metab Cardiovasc Dis* 2006, **16**:513-523.
12. Lee JG, Joo SJ: **Arterial stiffness and cardiovascular risk.** *Korean J Intern Med* 2019, **34**:504-506.
13. Kim S, Kyung C, Park JS, Lee SP, Kim HK, Ahn CW, Kim KR, Kang S: **Normal-weight obesity is associated with increased risk of subclinical atherosclerosis.** *Cardiovasc Diabetol* 2015, **14**:58.
14. Fujiwara K, Shimada K, Nishitani-Yokoyama M, Kunimoto M, Matsubara T, Matsumori R, Abulimiti A, Aikawa T, Ouchi S, Shimizu M, et al: **Arterial Stiffness Index and Exercise Tolerance in Patients Undergoing Cardiac Rehabilitation.** *Int Heart J* 2021, **62**:230-237.
15. Sueta D, Yamamoto E, Tanaka T, Hirata Y, Sakamoto K, Tsujita K, Kojima S, Nishiyama K, Kaikita K, Hokimoto S, et al: **The accuracy of central blood pressure waveform by novel mathematical transformation of non-invasive measurement.** *Int J Cardiol* 2015, **189**:244-246.
16. Komine H, Asai Y, Yokoi T, Yoshizawa M: **Non-invasive assessment of arterial stiffness using oscillometric blood pressure measurement.** *Biomed Eng Online* 2012, **11**:6.
17. Okamoto M, Nakamura F, Musha T, Kobayashi Y: **Association between novel arterial stiffness indices and risk factors of cardiovascular disease.** *BMC Cardiovasc Disord* 2016, **16**:211.
18. Zhang Y, Yin P, Xu Z, Xie Y, Wang C, Fan Y, Liang F, Yin Z: **Non-Invasive Assessment of Early Atherosclerosis Based on New Arterial Stiffness Indices Measured with an Upper-Arm Oscillometric Device.** *Tohoku J Exp Med* 2017, **241**:263-270.
19. Zhang H, Tong TK, Kong Z, Shi Q, Liu Y, Nie J: **Exercise training-induced visceral fat loss in obese women: The role of training intensity and modality.** *Scand J Med Sci Sports* 2021, **31**:30-43.
20. Robinson MM, Lowe VJ, Nair KS: **Increased Brain Glucose Uptake After 12 Weeks of Aerobic High-Intensity Interval Training in Young and Older Adults.** *J Clin Endocrinol Metab* 2018, **103**:221-227.
21. Nokia MS, Lensu S, Ahtiainen JP, Johansson PP, Koch LG, Britton SL, Kainulainen H: **Physical exercise increases adult hippocampal neurogenesis in male rats provided it is aerobic and sustained.** *J Physiol* 2016, **594**:1855-1873.
22. Campbell WW, Kraus WE, Powell KE, Haskell WL, Janz KF, Jakicic JM, Troiano RP, Sprow K, Torres A, Piercy KL, et al: **High-Intensity Interval Training for Cardiometabolic Disease Prevention.** *Med Sci Sports Exerc* 2019, **51**:1220-1226.
23. Keating SE, Johnson NA, Mielke GI, Coombes JS: **A systematic review and meta-analysis of interval training versus moderate-intensity continuous training on body adiposity.** *Obes Rev* 2017, **18**:943-964.
24. Miguet M, Fearnbach NS, Metz L, Khammassi M, Julian V, Cardenoux C, Pereira B, Boirie Y, Duclos M, Thivel D: **Effect of HIIT versus MICT on body composition and energy intake in dietary restrained and unrestrained adolescents with obesity.** *Appl Physiol Nutr Metab* 2020, **45**:437-445.
25. Garcia-Hermoso A, Cerrillo-Urbina AJ, Herrera-Valenzuela T, Cristi-Montero C, Saavedra JM, Martinez-Vizcaino V: **Is high-intensity interval training more effective on improving cardiometabolic risk and aerobic capacity than other forms of exercise in overweight and obese youth? A meta-analysis.** *Obes Rev* 2016, **17**:531-540.

26. Su L, Fu J, Sun S, Zhao G, Cheng W, Dou C, Quan M: **Effects of HIIT and MICT on cardiovascular risk factors in adults with overweight and/or obesity: A meta-analysis.** *PLoS One* 2019, **14**:e0210644.
27. Bartlett JD, Close GL, MacLaren DP, Gregson W, Drust B, Morton JP: **High-intensity interval running is perceived to be more enjoyable than moderate-intensity continuous exercise: implications for exercise adherence.** *J Sports Sci* 2011, **29**:547-553.
28. Reitlo LS, Sandbakk SB, Viken H, Aspvik NP, Ingebrigtsen JE, Tan X, Wisloff U, Stensvold D: **Exercise patterns in older adults instructed to follow moderate- or high-intensity exercise protocol - the generation 100 study.** *BMC Geriatr* 2018, **18**:208.
29. Anderson JW, Konz EC: **Obesity and disease management: effects of weight loss on comorbid conditions.** *Obes Res* 2001, **9 Suppl 4**:326S-334S.
30. Kosmala W, Jedrzejuk D, Derzhko R, Przewlocka-Kosmala M, Mysiak A, Bednarek-Tupikowska G: **Left ventricular function impairment in patients with normal-weight obesity: contribution of abdominal fat deposition, profibrotic state, reduced insulin sensitivity, and proinflammatory activation.** *Circ Cardiovasc Imaging* 2012, **5**:349-356.
31. Tanaka H, Dinunno FA, Monahan KD, Clevenger CM, DeSouza CA, Seals DR: **Aging, habitual exercise, and dynamic arterial compliance.** *Circulation* 2000, **102**:1270-1275.
32. Grassi G: **Impact of heart rate on arterial stiffness: virtual vs. real assessment.** *J Hypertens* 2020, **38**:2382-2383.
33. Liu JJ, Liu S, Gurung RL, Ang K, Ee Tang W, Sum CF, Tavintharan S, Hadjadj S, Lim SC: **Arterial Stiffness Modulates the Association of Resting Heart Rate With Rapid Renal Function Decline in Individuals With Type 2 Diabetes Mellitus.** *Arterioscler Thromb Vasc Biol* 2019, **39**:2437-2444.
34. Giannoglou GD, Chatzizisis YS, Zamboulis C, Parcharidis GE, Mikhailidis DP, Louridas GE: **Elevated heart rate and atherosclerosis: an overview of the pathogenetic mechanisms.** *Int J Cardiol* 2008, **126**:302-312.
35. Wu S, Jin C, Li S, Zheng X, Zhang X, Cui L, Gao X: **Aging, Arterial Stiffness, and Blood Pressure Association in Chinese Adults.** *Hypertension* 2019, **73**:893-899.
36. Mitchell GF, Parise H, Benjamin EJ, Larson MG, Keyes MJ, Vita JA, Vasan RS, Levy D: **Changes in arterial stiffness and wave reflection with advancing age in healthy men and women: the Framingham Heart Study.** *Hypertension* 2004, **43**:1239-1245.
37. Zhang Y, Gu Y, Chen Y, Huang Z, Li M, Jiang W, Chen J, Rao W, Luo S, Chen Y, et al: **Dingxin Recipe IV attenuates atherosclerosis by regulating lipid metabolism through LXR-alpha/SREBP1 pathway and modulating the gut microbiota in ApoE(-/-) mice fed with HFD.** *J Ethnopharmacol* 2021, **266**:113436.
38. Peters EB, Kibbe MR: **Nanomaterials to Resolve Atherosclerosis.** *ACS Biomater Sci Eng* 2020, **6**:3693-3712.
39. Peng J, Luo F, Ruan G, Peng R, Li X: **Hypertriglyceridemia and atherosclerosis.** *Lipids Health Dis* 2017, **16**:233.
40. Gupta M, Blumenthal C, Chatterjee S, Bandyopadhyay D, Jain V, Lavie CJ, Virani SS, Ray KK, Aronow WS, Ghosh RK: **Novel emerging therapies in atherosclerosis targeting lipid metabolism.** *Expert Opin*

41. Sandesara PB, Virani SS, Fazio S, Shapiro MD: **The Forgotten Lipids: Triglycerides, Remnant Cholesterol, and Atherosclerotic Cardiovascular Disease Risk.** *Endocr Rev* 2019, **40**:537-557.
42. Ouimet M, Barrett TJ, Fisher EA: **HDL and Reverse Cholesterol Transport.** *Circ Res* 2019, **124**:1505-1518.
43. Agirbasli M, Tanrikulu A, Acar Sevim B, Azizy M, Bekiroglu N: **Total cholesterol-to-high-density lipoprotein cholesterol ratio predicts high-sensitivity C-reactive protein levels in Turkish children.** *J Clin Lipidol* 2015, **9**:195-200.
44. Yamanashi H, Koyamatsu J, Nagayoshi M, Shimizu Y, Kawashiri SY, Kondo H, Fukui S, Tamai M, Maeda T: **Screening Validity of Arterial Pressure-Volume Index and Arterial Velocity-Pulse Index for Preclinical Atherosclerosis in Japanese Community-Dwelling Adults: the Nagasaki Islands Study.** *J Atheroscler Thromb* 2018, **25**:792-798.
45. Ueda T, Miura S, Suematsu Y, Shiga Y, Kuwano T, Sugihara M, Ike A, Iwata A, Nishikawa H, Fujimi K, Saku K: **Association of Arterial Pressure Volume Index With the Presence of Significantly Stenosed Coronary Vessels.** *J Clin Med Res* 2016, **8**:598-604.
46. Sasaki-Nakashima R, Kino T, Chen L, Doi H, Minegishi S, Abe K, Sugano T, Taguri M, Ishigami T: **Successful prediction of cardiovascular risk by new non-invasive vascular indexes using suprasystolic cuff oscillometric waveform analysis.** *J Cardiol* 2017, **69**:30-37.
47. Tazawa Y, Mori N, Ogawa Y, Ito O, Kohzuki M: **Arterial Stiffness Measured with the Cuff Oscillometric Method Is Predictive of Exercise Capacity in Patients with Cardiac Diseases.** *Tohoku J Exp Med* 2016, **239**:127-134.
48. Aroor AR, Jia G, Sowers JR: **Cellular mechanisms underlying obesity-induced arterial stiffness.** *Am J Physiol Regul Integr Comp Physiol* 2018, **314**:R387-R398.
49. Jean N, Somers VK, Sochor O, Medina-Inojosa J, Llano EM, Lopez-Jimenez F: **Normal-weight obesity: implications for cardiovascular health.** *Curr Atheroscler Rep* 2014, **16**:464.
50. Wagenmakers AJ, Strauss JA, Shepherd SO, Keske MA, Cocks M: **Increased muscle blood supply and transendothelial nutrient and insulin transport induced by food intake and exercise: effect of obesity and ageing.** *J Physiol* 2016, **594**:2207-2222.
51. Vaccari F, Passaro A, D'Amuri A, Sanz JM, Di Vece F, Capatti E, Magnesa B, Comelli M, Mavelli I, Grassi B, et al: **Effects of 3-month high-intensity interval training vs. moderate endurance training and 4-month follow-up on fat metabolism, cardiorespiratory function and mitochondrial respiration in obese adults.** *Eur J Appl Physiol* 2020, **120**:1787-1803.
52. Lazzer S, Tringali G, Caccavale M, De Micheli R, Abbruzzese L, Sartorio A: **Effects of high-intensity interval training on physical capacities and substrate oxidation rate in obese adolescents.** *J Endocrinol Invest* 2017, **40**:217-226.
53. MacInnis MJ, Gibala MJ: **Physiological adaptations to interval training and the role of exercise intensity.** *J Physiol* 2017, **595**:2915-2930.

54. Blue MNM, Smith-Ryan AE, Trexler ET, Hirsch KR: **The effects of high intensity interval training on muscle size and quality in overweight and obese adults.** *J Sci Med Sport* 2018, **21**:207-212.
55. Plavsic L, Knezevic OM, Sovtic A, Minic P, Vukovic R, Mazibrada I, Stanojlovi O, Hrnacic D, Rasic-Markovic A, Macut D: **Effects of high-intensity interval training and nutrition advice on cardiometabolic__markers and aerobic fitness in adolescent girls with obesity.** *Randomized Controlled Trial Appl Physiol Nutr Metab* 2020, **45**:294-300.
56. Ramírez-Vélez R, Hernández-Quiñones PA, Tordecilla-Sanders A, Álvarez C, Ramírez-Campillo R, Izquierdo M, Correa-Bautista JE, Garcia-Hermoso A, Garcia RG: **Effectiveness of HIIT compared to moderate continuous training in improving vascular parameters in inactive adults.** *Lipids in Health and Disease* 2019, **8**:42.
57. Maillard F, Rousset S, Pereira B, Traore A, de Pradel Del Amaze P, Boirie Y, Duclos M, Boisseau N: **High-intensity interval training reduces abdominal fat mass in postmenopausal women with type 2 diabetes.** *Diabetes Metab* 2016, **42**:433-441.
58. Cvetkovic N, Stojanovic E, Stojiljkovic N, Nikolic D, Scanlan AT, Milanovic Z: **Exercise training in overweight and obese children: Recreational football and high-intensity interval training provide similar benefits to physical fitness.** *Scand J Med Sci Sports* 2018, **28** Suppl 1:18-32.
59. Christensen RH, Wedell-Neergaard AS, Lehrskov LL, Legaard GE, Dorph E, Larsen MK, Launbo N, Fagerlind SR, Seide SK, Nymand S, et al: **Effect of Aerobic and Resistance Exercise on Cardiac Adipose Tissues: Secondary Analyses From a Randomized Clinical Trial.** *JAMA Cardiol* 2019, **4**:778-787.
60. Wewege M, van den Berg R, Ward RE, Keech A: **The effects of high-intensity interval training vs. moderate-intensity continuous training on body composition in overweight and obese adults: a systematic review and meta-analysis.** *Obes Rev* 2017, **18**:635-646.
61. James PA, Oparil S, Carter BL, Cushman WC, Dennison-Himmelfarb C, Handler J, Lackland DT, LeFevre ML, MacKenzie TD, Ogedegbe O, et al: **2014 evidence-based guideline for the management of high blood pressure in adults: report from the panel members appointed to the Eighth Joint National Committee (JNC 8).** *JAMA* 2014, **311**:507-520.
62. Batacan RB, Jr., Duncan MJ, Dalbo VJ, Tucker PS, Fenning AS: **Effects of high-intensity interval training on cardiometabolic health: a systematic review and meta-analysis of intervention studies.** *Br J Sports Med* 2017, **51**:494-503.
63. Liu J, Zhu L, Su Y: **Comparative Effectiveness of High-Intensity Interval Training and Moderate-Intensity Continuous Training for Cardiometabolic Risk Factors and Cardiorespiratory Fitness in Childhood Obesity: A Meta-Analysis of Randomized Controlled Trials.** *Front Physiol* 2020, **11**:214.
64. Way KL, Sultana RN, Sabag A, Baker MK, Johnson NA: **The effect of high Intensity interval training versus moderate intensity continuous training on arterial stiffness and 24h blood pressure responses: A systematic review and meta-analysis.** *J Sci Med Sport* 2019, **22**:385-391.
65. Plavsic L, Knezevic OM, Sovtic A, Minic P, Vukovic R, Mazibrada I, Stanojlovic O, Hrnacic D, Rasic-Markovic A, Macut D: **Effects of high-intensity interval training and nutrition advice on**

- cardiometabolic markers and aerobic fitness in adolescent girls with obesity.** *Appl Physiol Nutr Metab* 2020, **45**:294-300.
66. Delgado-Floody P, Izquierdo M, Ramirez-Velez R, Caamano-Navarrete F, Moris R, Jerez-Mayorga D, Andrade DC, Alvarez C: **Effect of High-Intensity Interval Training on Body Composition, Cardiorespiratory Fitness, Blood Pressure, and Substrate Utilization During Exercise Among Prehypertensive and Hypertensive Patients With Excessive Adiposity.** *Front Physiol* 2020, **11**:558910.
 67. Costa EC, Hay JL, Kehler DS, Boreskie KF, Arora RC, Umpierre D, Sz wajcer A, Duhamel TA: **Effects of High-Intensity Interval Training Versus Moderate-Intensity Continuous Training On Blood Pressure in Adults with Pre- to Established Hypertension: A Systematic Review and Meta-Analysis of Randomized Trials.** *Sports Med* 2018, **48**:2127-2142.
 68. Davis RAH, Halbrooks JE, Watkins EE, Fisher G, Hunter GR, Nagy TR, Plaisance EP: **High-intensity interval training and calorie restriction promote remodeling of glucose and lipid metabolism in diet-induced obesity.** *Am J Physiol Endocrinol Metab* 2017, **313**:E243-E256.
 69. Ryan BJ, Schleh MW, Ahn C, Ludzki AC, Gillen JB, Varshney P, Van Pelt DW, Pitchford LM, Chenevert TL, Gioscia-Ryan RA, et al: **Moderate-Intensity Exercise and High-Intensity Interval Training Affect Insulin Sensitivity Similarly in Obese Adults.** *J Clin Endocrinol Metab* 2020, **105**.
 70. Fisher G, Brown AW, Bohan Brown MM, Alcorn A, Noles C, Winwood L, Resuehr H, George B, Jeansonne MM, Allison DB: **High Intensity Interval- vs Moderate Intensity- Training for Improving Cardiometabolic Health in Overweight or Obese Males: A Randomized Controlled Trial.** *PLoS One* 2015, **10**:e0138853.
 71. Gripp F, Nava RC, Cassilhas RC, Esteves EA, Magalhaes COD, Dias-Peixoto MF, de Castro Magalhaes F, Amorim FT: **HIIT is superior than MICT on cardiometabolic health during training and detraining.** *Eur J Appl Physiol* 2021, **121**:159-172.
 72. Matsuo T, So R, Shimojo N, Tanaka K: **Effect of aerobic exercise training followed by a low-calorie diet on metabolic syndrome risk factors in men.** *Nutr Metab Cardiovasc Dis* 2015, **25**:832-838.
 73. da Silva MR, Wacławovsky G, Perin L, Camboim I, Eibel B, Lehnen AM: **Effects of high-intensity interval training on endothelial function, lipid profile, body composition and physical fitness in normal-weight and overweight-obese adolescents: A clinical trial.** *Physiol Behav* 2020, **213**:112728.
 74. Kong Z, Sun S, Liu M, Shi Q: **Short-Term High-Intensity Interval Training on Body Composition and Blood Glucose in Overweight and Obese Young Women.** *J Diabetes Res* 2016, **2016**:4073618.
 75. Laughlin MH, Yang HT, Tharp DL, Rector RS, Padilla J, Bowles DK: **Vascular cell transcriptomic changes to exercise training differ directionally along and between skeletal muscle arteriolar trees.** *Microcirculation* 2017, **24**.
 76. Saz-Lara A, Cavero-Redondo I, Alvarez-Bueno C, Notario-Pacheco B, Ruiz-Grao MC, Martinez-Vizcaino V: **The Acute Effect of Exercise on Arterial Stiffness in Healthy Subjects: A Meta-Analysis.** *J Clin Med* 2021, **10**.
 77. Sawyer BJ, Tucker WJ, Bhammar DM, Ryder JR, Sweazea KL, Gaesser GA: **Effects of high-intensity interval training and moderate-intensity continuous training on endothelial function and**

cardiometabolic risk markers in obese adults. *J Appl Physiol* (1985) 2016, **121**:279-288.

78. Ramos JS, Dalleck LC, Tjonna AE, Beetham KS, Coombes JS: **The impact of high-intensity interval training versus moderate-intensity continuous training on vascular function: a systematic review and meta-analysis.** *Sports Med* 2015, **45**:679-692.

79. Boutcher SH: **High-intensity intermittent exercise and fat loss.** *J Obes* 2011, **2011**:868305.

Tables

Table 1 Effects of HIIT on body composition of NWO females

	Control (n=13)		HIIT (n=17)		df		p-value		η^2	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Body weight (kg)	58.34±1.18	59.85±1.24 [△]	58.61±1.03	57.56±1.08 ^{**}	0.031	1.939	0.862	0.175	0.001	0.065
BMI (kg/m ²)	22.15±0.31	23.21±0.46 [△]	21.93±0.28	21.03±0.41 ^{**}	0.270	12.560	0.607	0.001	0.010	0.310
BF (%)	33.93±0.72	35.55±0.56 [△]	33.52±0.63	28.34±0.40 ^{***}	0.184	92.648	0.671	0.000	0.007	0.768
BFM (kg)	19.79±0.58	21.34±0.58 [△]	19.67±0.51	16.32±0.51 ^{**}	0.027	42.303	0.870	0.000	0.001	0.602
LBFM (kg)	1.41±0.05	1.56±0.05 [△]	1.38±0.04	1.10±0.04 ^{**}	0.239	42.207	0.628	0.000	0.008	0.628
SMM (kg)	20.69±0.53	20.64±0.49	20.87±0.46	22.25±0.43 ^{**}	0.065	6.061	0.800	0.020	0.002	0.178
Protein (kg)	7.51±0.17	7.55±0.17	7.61±0.15	8.04±0.15 ^{**}	0.180	4.900	0.675	0.035	0.006	0.149
BMC (kg)	2.39±0.06	2.37±0.05	2.39±0.05	2.51±0.05 ^{**}	0.011	3.966	0.978	0.056	0.000	0.124
FFM (kg)	38.55±0.88	38.51±0.83	38.95±0.77	41.24±0.72 ^{**}	0.116	6.214	0.735	0.019	0.004	0.182
LFFM (kg)	1.71±0.05	1.73±0.06	1.69±0.04	1.80±0.05 ^{**}	0.106	0.809	0.747	0.376	0.004	0.028
TBW (kg)	28.18±0.65	28.18±0.60	28.51±0.57	30.21±0.53 ^{**}	0.147	6.438	0.704	0.017	0.005	0.187
LTBW (kg)	1.33±0.04	1.35±0.05	1.31±0.04	1.40±0.04 ^{**}	0.057	0.753	0.814	0.393	0.002	0.026
LMC (cm)	27.98±0.26	28.52±0.41	27.68±0.22	27.12±0.34 [*]	0.785	6.641	0.383	0.016	0.027	0.192
BCM (kg)	24.92±0.57	24.87±0.54	25.13±0.50	26.64±0.47 ^{**}	0.079	6.091	0.781	0.020	0.003	0.179
Inbody score	68.85±0.74	68.08±0.69	68.94±0.65	74.00±0.60 ^{***}	0.009	42.337	0.924	0.000	0.000	0.602
Obesity degree	105.62±1.53	110.46±2.21 [△]	104.47±1.34	100.12±1.93 ^{***}	0.318	12.476	0.578	0.001	0.011	0.308

Data are presented as mean±standard error (SE). ^{**} $p<0.05$, HIIT group (post) vs. Control group (post); [#] $p<0.05$, ^{##} $p<0.01$, pre vs. post in HIIT group; [△] $p<0.05$, ^{△△} $p<0.01$, pre vs. post in Control group. BMI, Body mass index; BF, Body fat; BFM, Body fat mass; LBFM, BFM of left arm; SMM, Skeletal muscle mass; BMC, Bone mineral content; FFM, Fat free mass; LFFM, FFM of left arm; TBW, Total body water; LTBW, Total body water of left arm; LMC, Measured circumference of left arm; BCM, Body cell mas.

Table 2 Effects of HIIT on heart rate and blood pressure of NWO females

	Control (n=13)		HIIT (n=17)		df		p-value		η^2	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
HR (bpm)	91.00±2.77	95.69±2.39 [△]	84.41±2.42	76.59±2.09 ^{***}	0.495	36.282	0.488	0.000	0.017	0.564
SBP (mmHg)	117.08±2.22	127.62±3.07 [△]	115.77±1.95	107.41±2.68 ^{**}	0.197	24.624	0.660	0.000	0.007	0.468
DBP (mmHg)	78.00±1.99	90.92±2.00 ^{△△}	75.82±1.74	70.24±1.75 ^{***}	0.678	60.632	0.417	0.000	0.024	0.684

Data are presented as mean±standard error (SE). ^{**} $p<0.05$, HIIT group (post) vs. Control group (post); [#] $p<0.05$, ^{##} $p<0.01$, pre vs. post in HIIT group; [△] $p<0.05$, ^{△△} $p<0.01$, pre vs. post in Control group. HR, Heart rate; SBP, Systolic blood pressure; DBP, Diastolic blood pressure

Table 3 Effects of HIIT on blood lipid of NWO females

	Control (n=13)		HIIT (n=17)		df		p - value		η^2	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
TC (mmol/L)	5.42±0.15	5.59±0.11	5.49±0.13	5.03±0.09 ^{**}	0.128	14.882	0.723	0.001	0.005	0.347
TG (mmol/L)	2.09±0.08	2.23±0.06 [△]	2.03±0.07	1.62±0.05 ^{**}	0.287	65.006	0.596	0.000	0.010	0.699
HDL (mmol/L)	0.88±0.05	0.84±0.06	0.90±0.05	1.53±0.05 ^{**}	0.121	87.585	0.730	0.000	0.004	0.758
LDL (mmol/L)	3.64±0.09	3.78±0.08 [△]	3.57±0.08	2.89±0.07 ^{**}	0.323	73.401	0.575	0.000	0.011	0.724
TC/HDL	6.52±0.42	6.89±0.28	6.29±0.37	3.36±0.25 ^{**}	5.824	16.505	0.023	0.000	0.172	0.371

Data are presented as mean±standard error (SE). ^{**} $p<0.05$, HIIT group (post) vs. Control group (post); ^{##} $p<0.01$, pre vs. post in HIIT group; [△] $p<0.05$, pre vs. post in Control group. TC, Total cholesterol; TG, Triglyceride; HDL, High-density lipoprotein; LDL, Low-density lipoprotein; TC/HDL, Total cholesterol/High-density lipoprotein

Table 4 Effects of HIIT on AVI and API of NWO females

	Control (n=13)		HIIT (n=17)		df		p - value		η^2	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
AVI	17.69±0.54	18.23±0.44	17.35±0.47	12.24±0.39 ^{**}	0.227	103.892	0.637	0.000	0.008	0.788
API	26.46±0.83	28.54±0.70 [△]	26.65±0.83	20.06±0.61 ^{**}	0.022	83.242	0.884	0.000	0.001	0.748

Data are presented as mean±standard error (SE). ^{**} $p<0.05$, HIIT group (post) vs. Control group (post); ^{##} $p<0.01$, pre vs. post in HIIT group; [△] $p<0.05$, pre vs. post in Control group. AVI, Arterial velocity pulse index; API, Arterial pressure volume index.

Figures

Figure 1

Flow chart diagram. The recruiting and screening process of normal weight obesity (NWO) female university students for study protocol. The assessment indicators include the body composition, lipid profile, and cardiovascular function.

Figure 2

HIIT intervention protocol. The HIIT combined motion is composed of jumping jacks, run-ups, squat jump, burpee, high elbow plank, step jump, double knee lifts, mountain climbers, lunges in place. After 4-week, the body composition, lipid profile, and cardiovascular function is detected to observe the effect of HIIT.