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Weighted vest intervention during whole-body circuit training improves serum resistin, insulin resistance, and cardiometabolic risk factors in normal-weight obese women

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ABSTRACT

Background and objectives: Obesity is a well-known cause of cardiovascular disease and metabolic disorders. Normal-weight obesity, where the body mass index(BMI) is within the normal range but the body fat percentage is high, also adversely impacts cardiovascular and metabolic health. This study explored the effects of whole-body circuit training using a weighted vest on serum resistin, insulin resistance, and cardiovascular disease risk factors in normal-weight obese women.

Methods: Thirty-six normal-weight obese women were divided into three groups: Weighted Vest Circuit Training (WVCT)(n = 12), Body Weight Circuit Training(BWCT)(n = 12), and a Control group(CON)(n = 12). Participants in the WVCT and BWCT groups engaged in whole-body circuit training three times per week for eight weeks. Serum resistin, cardiovascular disease risk factors, and insulin resistance were measured before and after the intervention.

Results: The study revealed significant and impactful findings. There were substantial improvements in body composition(Skeletal Muscle Mass: +7.5 %, $p = 0.042$, $d = 0.80$), Serum Resistin(-38.2 %, $p = 0.001$, $d = 0.85$), insulin resistance(HOMA-IR: 27.1 %, $p < 0.001$, $d = 0.88$), and a reduction in IL-6 levels(-25.4 %, $p = 0.082$, $d = 0.60$) in the WVCT group compared to the BWCT and CON groups. The WVCT group outperformed the other groups, demonstrating greater effectiveness in reducing cardiovascular risk factors.

Conclusion: These findings have significant implications for healthcare. Whole-body circuit training with weighted vests has effectively improved body composition, reduced serum resistin, and lowered insulin resistance, reducing cardiovascular disease risk factors in normal-weight obese women. These results could inform and enhance the treatment and management of obesity-related cardiovascular and metabolic disorders.

1. Introduction

Obesity is the storage of excess fat in the body, and the obese population is increasing exponentially worldwide.[1] Obesity increases the size and number of adipocytes, causing metabolic disorders.[2–4] A previous study has reported that approximately 29 % of normal-weight women were normal-weight obese.[5,6] Normal-weight obese individuals have a standard Body Mass Index(BMI) yet a body fat percentage of more than 30 % and a low skeletal muscle mass.[7,8] Normal-weight obesity has been reported to occur more frequently in women, and it damages their bodies due to the high percentage of body fat.[9–11] In addition, a study on the prevalence of cardiovascular disease of normal weight obesity through medical big data on Koreans found that normal-weight obesity had a stronger correlation with cardiovascular disease than general obesity,[12] and another study found that normal-weight women had a higher mortality rate from cardiovascular disease.[13]

It has been reported that normal-weight obesity is associated with a high risk of developing type 2 diabetes due to high body fat and low skeletal muscle mass.[5] It has also been reported that normal-weight obesity is associated with a 2.2-fold higher incidence of cardiovascular disease than in the general population.[2,13] High body fat increases resistin, one of the adipocytokines secreted by adipocytes. In turn, this increased resistin increases the cardiovascular disease risk factors IL-6

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(Interleukin-6) and hs-CRP(high-sensitivity C-reactive protein), causing inflammation in the body.[14] Therefore, normal-weight obese individuals should reduce cardiovascular disease factors and insulin resistance through improving body composition.

Serum resistin and cardiovascular disease risk factors can be reduced by exercise. Based on previous studies, Serum resistin decreased due to aerobic exercise with HR_{max} 60–80 % intensity four times a week for eight weeks.[15] In addition, aerobic exercise with an intensity of HR_{max} 55–65 % three times a week for eight weeks in middle-aged women who live a sedentary lifestyle significantly reduced the concentration of resistin in the blood.[16] However, aerobic exercise effectively reduces body fat and resistin, but there is a limit to increasing the amount of lean fat. Aerobic exercise is insufficient to improve dry obesity with high body fat and low skeletal muscle mass, and training is needed to see the effects of aerobic exercise and strength exercise to compensate for this. Circuit training can simultaneously reduce body fat and increase skeletal muscle by stimulating the whole body through a sequence of regularly circulating exercise forms(stations).[17,18] Whole-body circuit training using body weight can achieve aerobic and anaerobic training in a short time,[19] so the effects of training can be obtained more efficiently and in a shorter time than for complex training.[20] However, in some studies, circuit training using body weight alone did not increase skeletal muscle mass. A previous study related to the above reported that, for obese older women, while weight and body fat mass decreased, skeletal muscle mass did not increase with 50-min whole-body circuit training at 70 % HR_{max} three times a week for 12 weeks.[21] In the case of women with normal weight obesity, it is essential to reduce body fat. However, improving the low resting metabolic rate is crucial, so a training method to solve this problem is needed.

Recently, training has been conducted by wearing a weighted vest to increase skeletal muscle mass and improve exercise performance. Training using a weighted vest develops nerve roots through an increase in motor units compared to conventional training due to an increase in load. Moreover, the increased mechanical stress activates mTOR (mammalian Target of Rapamycin), a muscle protein synthesis factor, and promotes muscle protein synthesis. The result is a significant increase in muscle strength and skeletal muscle mass.[22,23] In addition, in postmenopausal women with osteoporosis, after treadmill aerobic training for 20 min at 50–60 % HRR(Heart Rate Reserve) intensity three times a week for six weeks, the group wearing a weighted vest(8 % of body weight) while training had lower body fat mass than the group not wearing a weighted vest.[24] Furthermore, wearing a weighted vest was also more effective at increasing skeletal muscle mass. In addition, a recent graded-exercise study with adults undertaking recreation training wearing 0 %, 5 %, and 10 % body-weight vests found that calorie consumption increased significantly only for the 10 % body-weight group.[25] Given these results, for normal-weight obese women, whole-body circuit training wearing the Weighted Vest is expected to reduce body fat and increase skeletal muscle mass.

The research findings above allow predictions about the positive results of whole-body circuit training using a Weighted Vest. Circuit training using a weighted vest is expected to be more effective for increasing skeletal muscle mass. The approach is also likely to reduce serum resistin concentration and cardiovascular risk factors as the percent body fat decreases and increases skeletal muscle mass. In addition, the resulting changes in body composition are expected to positively affect cardiovascular disease risk factors.

Therefore, this study hypothesizes that circuit training using a weighted vest will positively impact body composition, serum resistin, insulin resistance, and cardiovascular disease risk factors more than using only weight.

2. Materials and methods

2.1. Subjects

This study recruited subjects, normal-weight obese women in their 20s and 30s living in Seoul, Korea. Through a pre-survey, normal-weight obese women who had no particular medical disease and had not participated in a regular exercise program for the past six months were selected. In addition, only normal-weight obese women who had not taken oral contraceptives within the last six months and had regular menstrual cycles were recruited. This study was conducted with the approval of the Korea University Bioethics Committee(KUIRB-2020-0279-01). Following the Declaration of Helsinki, the purpose and procedures of this study were fully explained to the participants, and for participation in the study, the consent form and questionnaire were voluntarily filled out before proceeding. The number of study participants was set to achieve an effect size $\eta^2 = 0.095$, significance level 0.05, statistical power 0.85 in Repeated measures ANOVA within-between interaction using G * Power(gpower.software.informer.com/3.1). As a result of G * power calculation, the number of participants was calculated as 30 people. Therefore, 36 participants were recruited, considering dropouts due to injury or illness. Moreover, the participants were randomly placed into the Weighted Vest Circuit Training(WVCT) group, the Body Weighted Circuit Training group(BWCT), and the Control group(CON). The body composition of the study participants is shown in <Table 1>, and the criteria for determining normal-weight obesity were the body mass index in the normal range(18–25 kg/m^2), and factors with a body fat percentage of 30 % or more were recruited and established based on the criteria applied in previous studies.[9]

BMI: 18–25 kg / m^2

Percent Body Fat: 30 %

2.2. Experimental design

This experiment was a randomized control experiment. A paper indicating the three groups was placed in the box. The participants were blindfolded, and the paper was pulled out to allocate the group randomly. Moreover, participants were tested before(PRE) and after (POST) an eight-week treatment. Pre- and post-tests measured body composition, graded exercise tests, anaerobic power tests, maximum muscle strength(Squat 1RM), and blood pressure. The measurement procedure is shown in <Fig. 1>.

Table 1
Research participant characteristics and Pre-homogeneous verification.

Group	CON (n = 12)	BWCT (n = 12)	WVCT (n = 12)	p-value
Age (yrs)	27.00 ± 5.38	23.00 ± 2.26	24.25 ± 4.27	0.070
Height (cm)	161.10 ± 3.56	162.3 ± 6.19	162.50 ± 5.85	0.786
Body Weight (kg)	55.18 ± 5.93	57.56 ± 6.94	57.54 ± 8.41	0.650
BMI (kg/m^2)	21.20 ± 1.64	21.81 ± 1.76	21.73 ± 2.10	0.685
Skeletal Muscle Mass (kg)	20.58 ± 2.07	21.15 ± 3.04	20.99 ± 2.98	0.869
Percent Body Fat (%)	32.19 ± 1.93	32.82 ± 2.25	32.53 ± 2.40	0.816

Values are shown as Mean ± SEM; $p < 0.05$; BMI: Body Mass Index; CON: Control; BWCT: Body Weighted Circuit Training; WVCT: Weighted Vest Circuit Training.

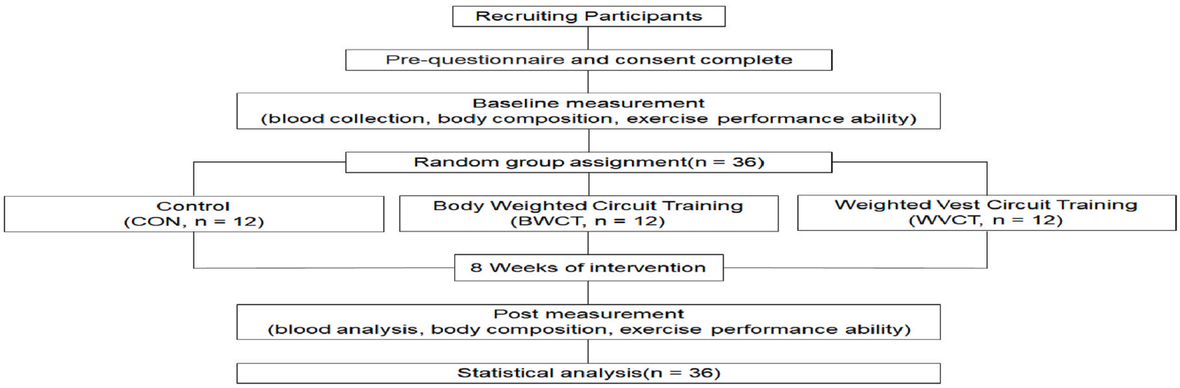


Fig. 1. Research procedure.

2.3. Measurement

(1) Body Composition

The body composition of the study subjects was measured twice, before(0 weeks) and after(8 weeks). After fasting for 12 h, the percent body fat, skeletal muscle mass, height, weight, and body mass index of all participants were measured using a bioelectrical resistance meter (Inbody 570, Biospace, Korea) and an automatic height weight meter (BSM 330, Biospace, Korea).[26] The participants were measured while wearing simple clothes(Pants, Short sleeves, Shorts). In addition, the improvement rate of normal-weight obesity was analyzed by comparing the percent body fat among body compositions pre- and post.

(2) Graded Exercise Test

Excessive physical activity was prohibited 24 h before the test, and the participants arrived in the laboratory 1 h before the graded exercise test measurement and were stabilized. The test began after the participants had lightly stretched as a warm-up, rested until reaching a stable heart rate, and wore a gas mask. Following the Modified Bruce Protocol, a treadmill was used for the graded exercise test. During the test, VO_{2max} was measured using a respiratory gas analyzer(Quark b2, Cosmed, Italy), and the internal temperature and humidity of the laboratory were maintained at 22 °C and 50 %, respectively. Heart rate was monitored throughout the exercise using a wireless heart rate monitor(RS400, Polar, Finland). Following the Modified Bruce Protocol, the load started at 1.7 mph, and the speed and gradient were increased every 3 min until the participants were exhausted. The test's discontinuation criteria were the respiratory exchange rate being 1.15 or higher, the oxygen intake remaining at a plateau despite increased exercise intensity, or the participant voluntarily expressing her intention to give up.[27]

(3) Maximum Anaerobic Power Test(Wingate Test)

After the study participants had arrived at the test location and rested sufficiently, they put on the wireless heart rate monitor. Once on the anaerobic power measuring equipment(Powermax II, Combi, Japan), the position of the saddle and handle was adjusted to match the participant's height and body shape. Afterward, a load of 1.6 kp was set for 5 min to warm up at an intensity of 70 % HR_{max}. For the anaerobic power(Wingate Test) measurement, maximum pedaling was performed for 30 s by setting the load to be participant weight(kg) x 0.075(kp). The maximum power was recorded as the maximum power generated every 5 s, and the participant was verbally encouraged to reach maximum power as their heart rate was checked.

(4) Maximum Muscle Strength(1RM: One-Repetition Maximum)

For participant safety, the barbell back squat 1RM was measured indirectly using a squat space(EcoHalfRackV2, Frogfitness, Korea).[28] If eight repetitions were exceeded, the measurement was repeated after 5 min.

1RM indirect measurement formula:

2-8 Reps expected weight / [1.0278 - (Reps x 0.0278)]

(5) Blood Sampling and Blood Pressure Measurement

The participants' menstrual cycles were noted, and blood was collected in the follicular phase when the hormone cycle was most stable for the blood. Participants visited the laboratory after 12 h of fasting to reduce interference of biochemical parameters due to food intake. The brachial artery blood pressure measurement was conducted after the subject arrived at the lab, sat on a chair with a backrest, and rested for 30 min. The blood pressure was then measured using a state-of-the-art automatic monitor(HEM-7121-E, Omron, Japan), ensuring the reliability and accuracy of the results. Afterward, blood samples were collected from the central forearm vein once before and after the intervention. All blood samples were immediately separated into plasma and serum by centrifugation at 3000 rpm for 15 min after collection and stored at −80 °C. All blood samples were immediately separated into plasma and serum by centrifugation at 3000 rpm for 15 min after collection and stored at −80 °C. According to the hormone analysis method, samples are divided into serum and plasma based on the presence or absence of anticoagulants in the blood collection tube. Each variable was measured twice using the Enzyme-Linked Immunosorbent Assay (ELISA), Immunoturbidimetry, Immunoassay, Enzymatic Method, and Enzymatic Colorimetric Method, utilizing the following instruments: Cobas C702 (Roche, Germany), ELx800 (BioTek, USA), Hitachi 7600 (Hitachi, Japan), Immulite 2000 (Siemens, USA), and Multiskan FC (Thermo Fisher, USA). The results were analyzed using the optimally fitted standard curve. Blood assays, analysis equipment, and the HOMA-IR formula are presented in <Table 2>.

2.4. Training protocol

This study was conducted from July 1, 2020, to November 30, 2020; whole-body circuit training was conducted three times a week for eight weeks in Korea University's athletic physiology laboratory. Before and after training, a 5-min stretching routine was performed as warm-up and cool-down. Modifying and supplementing the whole-body circuit training protocol of the previous study,[20] the training protocol included nine exercise stations that used the large muscle groups of the whole body(Fig. 2). The calorie consumption during training was adjusted to 200 kcal before the program was carried out. In addition, the weight of the weighted vest was 10 % of the body weight, and the load was set by rounding to one decimal place. During exercise, the training intensity

Table 2
Blood analysis methods, reagents, and HOMA-IR Formula.

Method	Analysis method	Target Hormone & Marker	Reagent	Analyzer (Country)
ELISA (Enzyme-Linked Immunosorbent Assay)	Serum	Human Resistin	Human Resistin ELISA kit (AssayPro, USA)	ELx800 (USA)
		Human Interleukin-6 (IL-6)	Human Interleukin-6 ELISA kit (AssayPro, USA)	Multiskan FC (USA)
Immunoturbidimetry	Serum	hs-CRP (High-sensitivity C-Reactive Protein)	CRPHS (Roche, Germany)	Cobas C702 (Germany)
IA (Immunoassay)	Plasma	Insulin	Immulite2000 (Dpc, USA)	Immulite2000 (Siemens, USA)
Enzymatic Method	Plasma	Glucose (Blood Sugar)	GLUC3 (Roche, Germany)	Cobas C702 (Roche, Germany)
		Free Fatty Acid (FFA)	SCIDIA NEFAZYME (Hitachi, Japan)	Hitachi 7600 (Hitachi, Japan)
Enzymatic Colorimetric Method	Serum	Total Cholesterol (TC)	CHOLHiCo Gen.2 (Roche, Germany)	Cobas C702 (Roche, Germany)
		HDL-Cholesterol (HDL-C)	HDL-C Gen.3 (Roche, Germany)	Cobas C702 (Roche, Germany)
		LDL-Cholesterol (LDL-C)	LDL-C Gen.2 (Roche, Germany)	Cobas C702 (Roche, Germany)
		Triglyceride (TG)	TRIGL (Roche, Germany)	Cobas C702 (Roche, Germany)

HOMA-IR(Homeostasis Model Assessment of Insulin Resistance) Formula = Fasting Insulin (uU/mL) × Fasting Glucose (mg/dL)/405.

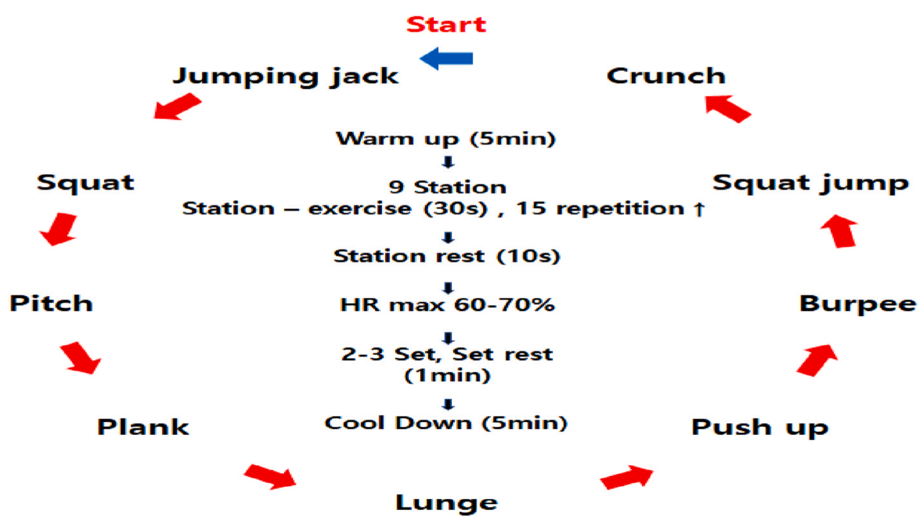


Fig. 2. Training protocol.

and amount of exercise were monitored using a wireless heart rate monitor and a momentum meter(A370, Polar, Finland). The target heart rate was set according to the Karvonen formula [(resting heart rate x 60–70 %) + resting heart rate], and 2–3 SETs were performed according to the amount of exercise required. One minute break time was given between sets. Before the experiment, to adapt to the equipment and injury prevention, all participants wore a weighted vest of 5 % of their body weight twice a week for two weeks. They then proceeded with just 1 SET of the Whole-body circuit training protocol.

2.5. Data analysis

All the data collected in this study was statistically processed using SPSS ver. 25.0(SPSS Inc, Chicago, USA). All parameters are presented as mean and standard deviations. Repeated measures ANOVA was conducted to determine the differences between the measured values of the three groups(WVCT, BWCT, CON) over time. For group comparisons at different time points(pre- and post-intervention) within each group, paired t-tests were used to assess the significance of changes. The Bonferroni method was used as a post hoc test to adjust for multiple comparisons following the ANOVA. If no interaction was apparent, the main effect of the independent variable was confirmed, and the statistical significance level was set at $p < .05$.

Cohen's d was calculated to measure the effect size for the paired t-tests, representing the magnitude of the difference between pre- and post-intervention within each group.

We used Pearson correlation coefficients to assess relationships between variables, a widely accepted method in statistical analysis. The significance of the correlation was evaluated at $p < .05$.

The rate of improvement in normal weight obesity was expressed as a percentage of changes according to the criteria for determining this study (Percent Body Fat, Body Mass Index).

3. Results

This study's results were derived by analyzing the differences in the data before and after eight weeks of training by normal-weight obese women.

3.1. Changes in body composition, Exercise Performance Ability, and blood pressure

<Table 3> shows the results of analyzing changes in body composition, Exercise Performance Ability, and Blood pressure.

After eight weeks of training, weight(kg) showed no interaction between time and group($df = 2$, $F = 0.892$, $p = 0.419$, 95 % CI [−0.5, 0.2], *effect size* $d = 0.10$). The WVCT group showed a reduction in weight by 4.4 %($p = 0.028$, 95 % CI [−1.2, −0.3], *effect size* $d = 0.30$), but no significant difference occurred when comparing the main effects($p = 0.080$; $p = 0.051$; $p = 0.609$).

BMI(kg/m^2) did not show any change. There was no interaction between the time point and group($df = 2$, $F = 0.238$, $p = 0.789$, 95 % CI [−0.2, 0.1], *effect size* $d = 0.05$). The WVCT group showed a slight reduction in BMI by 0.3 %($p = 0.283$, 95 % CI [−0.3, 0.2], *effect size* $d = 0.10$), but this was not statistically significant.

An interaction between the time point and group in Skeletal Muscle Mass(kg) was found($df = 2$, $F = 3.193$, $p = 0.042$, 95 % CI [0.2, 1.1], *effect size* $d = 0.55$). In the WVCT group, Skeletal Muscle Mass increased significantly by 5.5 % post-training compared to pre-training($p = 0.000$, 95 % CI [1.0, 2.0], *effect size* $d = 0.80$). There was no significant change between the BWCT group and the CON group post- and pre-training($p = 0.448$; $p = 0.477$, 95 % CI [−0.3, 0.2], *effect size* $d = 0.20$)(Fig. 3).

Interaction between the time point and group was apparent regarding Percent Body Fat(%)($df = 2$, $F = 10.721$, $p = 0.000$, 95 % CI [−3.0, −1.5], *effect size* $d = 1.10$). For the WVCT group and the BWCT group, Percent Body fat decreased significantly by 8.9 % and 7.9 %, respectively, between pre- and post-training($p = 0.002$; $p = 0.002$, 95 % CI [−2.5, −1.0], *effect size* $d = 0.75$), whereas for the CON group, it did not($p = 0.740$, 95 % CI [−0.4, 0.5], *effect size* $d = 0.05$). Furthermore, considering Percent Body Fat, post-training, the WVCT, and the BWCT groups showed significant differences from the CON group($p = 0.003$; $p = 0.019$, 95 % CI [−2.8, −0.9], *effect size* $d = 0.70$)(Fig. 3).

After eight weeks of training, there was an interaction between time and group in VO_{2max}(ml/kg/min)($df = 2$, $F = 4.899$, $p = 0.014$, 95 % CI [1.2, 3.5], *effect size* $d = 0.65$). In the WVCT and BWCT groups, VO_{2max} significantly increased by 12.7 % and 9.4 %, respectively, post-training compared to before($p = 0.000$; $p = 0.040$, 95 % CI [2.0, 4.0], *effect size* $d = 0.85$). In contrast, the CON group showed no significant change($p = 0.743$, 95 % CI [−0.5, 0.3], *effect size* $d = 0.10$). The WVCT group showed a significant increase in VO_{2max} compared to the BWCT and CON groups($p = 0.004$; $p = 0.001$, 95 % CI [1.5, 3.2], *effect size* $d = 0.75$) (Fig. 4).

Peak Power Output(W) showed an interaction between time and group($df = 2$, $F = 12.953$, $p = 0.000$, 95 % CI [5.0, 15.0], *effect size* $d = 0.90$). For the WVCT and BWCT groups, maximum anaerobic power increased significantly by 15.0 % and 10.5 % respectively, post-training compared to pre-post($p = 0.000$; $p = 0.001$, 95 % CI [8.0, 12.0], *effect size* $d = 1.00$), whereas the CON group showed no such significant change($p = 0.109$, 95 % CI [−1.0, 2.0], *effect size* $d = 0.15$). After training, the WVCT group Peak Power Output increased significantly compared to the CON group($p = 0.019$, 95 % CI [4.0, 9.0], *effect size* $d = 0.80$)(Fig. 4).

For Squat 1RM(kg), there was an interaction between time and group ($df = 2$, $F = 16.313$, $p = 0.000$, 95 % CI [5.0, 10.0], *effect size* $d = 1.20$). In the WVCT group and the BWCT group, Squat 1RM increased significantly by 30.7 % and 25.1 %, respectively, post-training compared to before($p = 0.000$; $p = 0.003$, 95 % CI [6.0, 12.0], *effect size* $d = 1.00$). In contrast, the CON group showed no significant change($p = 0.149$, 95 % CI [−2.0, 1.0], *effect size* $d = 0.25$). After training, the WVCT group increased significantly compared to the BWCT and CON groups($p = 0.013$; $p = 0.001$, 95 % CI [3.0, 7.0], *effect size* $d = 0.85$).

With SBP(mmHg), there was no interaction between the time point and group($df = 2$, $F = 0.187$, $p = 0.831$, 95 % CI [−2.0, 1.0], *effect size* $d = 0.10$). After training, the WVCT group exhibited an intergroup difference compared to the BWCT and CON groups, with SBP decreasing by 3.5 %($p = 0.039$; $p = 0.032$, 95 % CI [−4.0, −1.5], *effect size* $d = 0.70$).

DBP(mmHg) showed no significant change between time points or groups. There was no interaction between the time point and group($df = 2$, $F = 0.150$, $p = 0.861$, 95 % CI [−1.5, 1.0], *effect size* $d = 0.05$). The WVCT group showed a slight reduction in DBP by 1.0 %($p = 0.131$, 95 % CI [−2.0, 0.5], *effect size* $d = 0.10$), but this change was not statistically significant.

Pearson correlation coefficients were calculated to evaluate the relationships between key variables, such as changes in Skeletal Muscle Mass, Percent Body Fat, VO_{2max}, and Peak Power Output. Significant correlations were found between the increase in Skeletal Muscle Mass and the decrease in Percent Body Fat($r = -0.65$, $p < 0.01$), as well as between the improvement in VO_{2max} and the increase in Peak Power Output($r = 0.70$, $p < 0.01$).

3.2. Changes in biochemical parameters

<Table 4> shows the results of analyzing changes in Biochemical Parameters.

Resistin(ng/ml) showed an interaction between the time point and group($df = 2$, $F = 8.528$, $p = .001$, 95 % CI [−15.0, −5.2], *effect size* $d = 0.85$). There was a significant decrease post-training for the WVCT and BWCT groups compared to pre-training($p = .000$, $p = .006$), with a reduction rate of 38.2 % for the WVCT group and 29.8 % for the BWCT group. The CON group had no significant difference($p = .306$, 95 % CI [−3.0, 1.0], *effect size* $d = 0.15$). After training, the WVCT and BWCT groups showed significant differences from the CON group($p = .001$; $p = .007$)(Fig. 5).

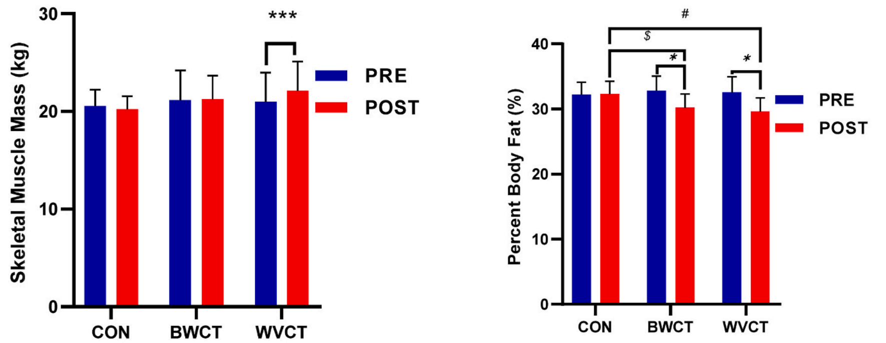
Glucose(mg/dL) showed no interaction between the time point and group($df = 2$, $F = 0.801$, $p = .457$, 95 % CI [−2.5, 1.5], *effect size* $d = 0.10$). After training, the WVCT group differed from the CON group with a decrease of 3.6 %($p = .048$, 95 % CI [−4.0, −0.1], *effect size* $d = 0.35$).

Insulin(uU/ml) showed an interaction between the time point and group($df = 2$, $F = 17.171$, $p = .000$, 95 % CI [−2.5, −0.8], *effect size* $d = 1.00$). For the WVCT group, the value decreased significantly by 27.9 % pre-to post-training($p = .002$, 95 % CI [−3.0, −1.0], *effect size* $d = 0.85$), while for the CON group, it significantly increased by 22.4 % post-training($p = .000$, 95 % CI [1.2, 2.5], *effect size* $d = 0.80$). There was no

Table 3
Descriptive statistics of Body Composition, Exercise Performance Ability, and Blood pressure.

Variable	CON (n = 12)		BWCT (n = 12)		WVCT (n = 12)		p
	PRE	POST	PRE	POST	PRE	POST	
Body Weight (kg)	55.18 ± 5.93	54.55 ± 3.80	57.56 ± 6.94	56.50 ± 6.26	57.54 ± 8.41	55.00 ± 7.19	0.419
BMI (kg/m^2)	21.20 ± 1.64	21.02 ± 1.17	21.81 ± 1.76	21.42 ± 1.58	21.73 ± 2.10	21.66 ± 2.59	0.789
Squat 1RM (kg)	30.50 ± 9.68	32.08 ± 10.62	25.33 ± 5.97	36.33 ± 11.60	28.58 ± 5.38	46.58 ± 5.37	0.000***
SBP (mmHg)	112.17 ± 9.73	111.33 ± 10.82	113.42 ± 9.69	111 ± 8.28	104.92 ± 11.97	101.42 ± 7.42	0.831
DBP (mmHg)	72.58 ± 3.68	76.14 ± 6.63	71.75 ± 6.87	73.50 ± 5.84	70.75 ± 6.40	72.58 ± 5.98	0.861

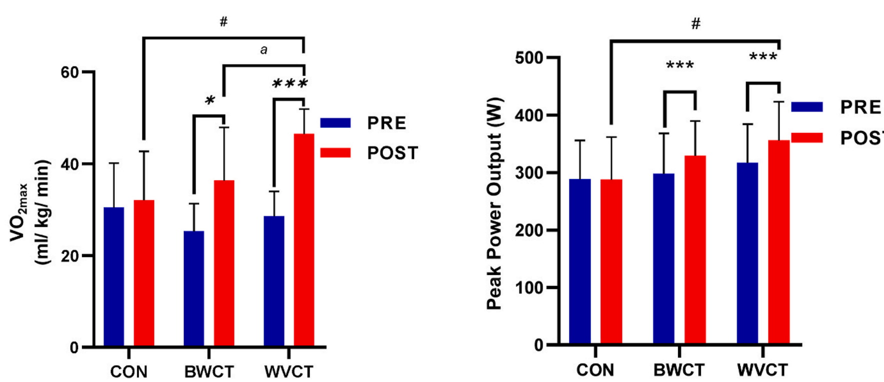
Values are shown as Mean ± SEM; ***$p < .001$; CON: Control; BWCT: Body Weight Circuit Training; WVCT: Weighted Vest Circuit Training; PRE: Pre-intervention; POST: Post-intervention; BMI: Body Mass Index; VO_{2max}: Maximal Oxygen Uptake; SBP: Systolic Blood Pressure; DBP: Diastolic Blood Pressure; Squat 1RM: Squat One-Repetition Maximum.



(A) Comparison of changes in Skeletal Muscle Mass.
*** : $p < .001$; CON : Control; BWCT : Body Weight Circuit Training; WVCT : Weighted Vest Circuit Training.

(B) Comparison of changes in Percent Body Fat.
*: $p < .05$; #: WVCT vs CON; $: BWCT vs CON; CON : Control; BWCT : Body Weight Circuit Training; WVCT : Weighted Vest Circuit Training.

Fig. 3. Changes in body composition. (A) Skeletal muscle mass; (B) percent body fat.
(A) Comparison of changes in Skeletal Muscle Mass.
***: $p < .001$; CON: Control; BWCT: Body Weight Circuit Training; WVCT: Weighted Vest Circuit Training.
(B) Comparison of changes in Percent Body Fat.
*: $p < .05$; #: WVCT vs CON; $: BWCT vs CON; CON: Control; BWCT: Body Weight Circuit Training; WVCT: Weighted Vest Circuit Training.



(A) Comparison of changes in $VO_{2max.}$
* : $p < .05$; $p < .001$; #: WVCT vs CON; a: WVCT vs BWCT ; CON : Control; BWCT : Body Weight Circuit Training; WVCT : Weighted Vest Circuit Training

(B) Comparison of changes in Peak Power Output.
*: $p < .001$; #: WVCT vs CON; CON : Control; BWCT : Body Weight Circuit Training; WVCT : Weighted Vest Circuit Training.

Fig. 4. Changes in exercise performance ability. (A) VO_{2max}; (B)Peak Power output.
(A) Comparison of changes in $VO_{2max.}$
*: $p < .05$; $p < .001$; #: WVCT vs CON; a: WVCT vs BWCT; CON: Control; BWCT: Body Weight Circuit Training; WVCT: Weighted Vest Circuit Training
(B) Comparison of changes in Peak Power Output.
*: $p < .001$; #: WVCT vs CON; CON: Control; BWCT: Body Weight Circuit Training; WVCT: Weighted Vest Circuit Training.

change for the BWCT group($p = .293$, 95 % *CI* [−1.0, 0.5], *effect size d* = 0.10). After training, the WVCT and the BWCT groups showed inter-group differences compared to the CON group($p = .000$; $p = .000$).

HOMA-IR showed an interaction between the time point and group ($df = 2$, $F = 16.938$, $p = .000$, 95 % *CI* [−1.0, −0.3], *effect size d* = 0.95). For the WVCT group, the value decreased significantly by 27.1 % post-training($p = .002$, 95 % *CI* [−1.2, −0.4], *effect size d* = 0.88). In contrast, the CON group significantly increased by 18.7 % post-training($p = .001$, 95 % *CI* [0.3, 0.9], *effect size d* = 0.75). For the BWCT group, no change was observed($p = .399$, 95 % *CI* [−0.5, 0.2], *effect size d* = 0.15). After training, the WVCT and BWCT groups showed inter-group differences compared to the CON group($p = .000$; $p = .000$) (Fig. 5).

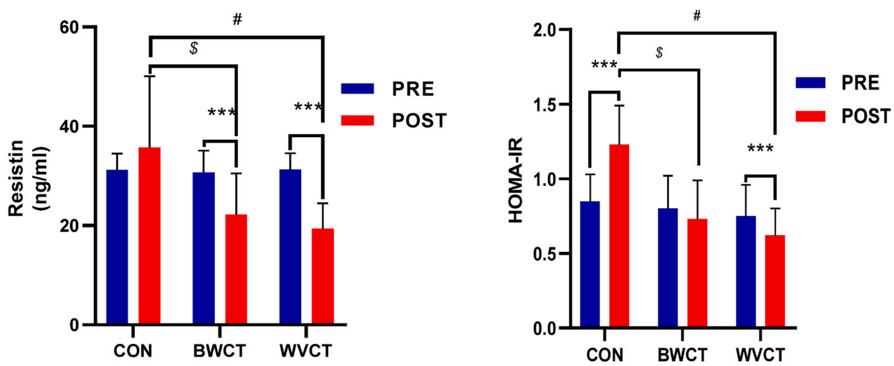
IL-6(pg/ml) showed no interaction between time and group($df = 2$, $F = 20.698$, $p = .082$, 95 % *CI* [−6.0, −1.2], *effect size d* = 0.70). With the WVCT and BWCT groups, there was a significant decrease of 25.4 % and 18.9 %, respectively, post-training compared to before($p = .000$, $p = .003$). There was no change for the control group($p = .557$, 95 % *CI* [−0.9, 0.5], *effect size d* = 0.05). After training, the WVCT and BWCT groups significantly decreased in IL-6 compared to the CON group($p = .022$; $p = .038$)(Fig. 6).

For hs-CRP(mg/L), an interaction between the time point and group was found($df = 2$, $F = 13.206$, $p = .000$, 95 % *CI* [0.1, 0.7], *effect size d* = 0.90). There was a significant increase in the CON group post-training by 51.6 % compared to the pre-group($p = .003$), but no change was observed with the WVCT and BWCT groups($p = .075$; $p = .135$, 95 % *CI* [−0.1, 0.4], *effect size d* = 0.25). After training, the WVCT and BWCT

Table 4
Descriptive statistics of quantity of Biochemical Parameters.

Variable	CON (n = 12)		BWCT (n = 12)		WVCT (n = 12)		*p*
	PRE	POST	PRE	POST	PRE	POST	
Glucose (mg/dL)	82.08 ± 4.01	79.75 ± 4.33	79.75 ± 4.33	77.33 ± 4.54	80.58 ± 9.19	77.33 ± 4.54	0.457
Insulin (uU/ml)	6.64 ± 1.42	6.61 ± 1.72	6.61 ± 1.72	4.91 ± 1.42	5.93 ± 1.69	4.91 ± 1.42	0.000***
TC (mg/dL)	170.75 ± 31.10	172.08 ± 28.60	183.08 ± 28.05	179.42 ± 30.31	189.33 ± 32.96	169.75 ± 21.41	0.049*
LDL-C (mg/dL)	99.92 ± 28.15	101.92 ± 27.93	111.33 ± 17.41	109.33 ± 13.12	109.67 ± 30.69	87.75 ± 22.66	0.006*
HDL-C (mg/dL)	61.92 ± 5.92	57.33 ± 5.12	62.75 ± 16.81	59.50 ± 11.55	66.25 ± 10.23	68.25 ± 8.58	0.161
Free fatty acid (uEq/L)	854.17 ± 204.99	812.83 ± 244.95	832.75 ± 359.75	857.33 ± 326.62	960.00 ± 364.51	809.08 ± 227.42	0.245
Triglyceride (mg/dL)	60.08 ± 21.11	70.08 ± 16.33	68.08 ± 29.97	75.08 ± 26.20	51.17 ± 22.71	48.33 ± 21.86	0.390

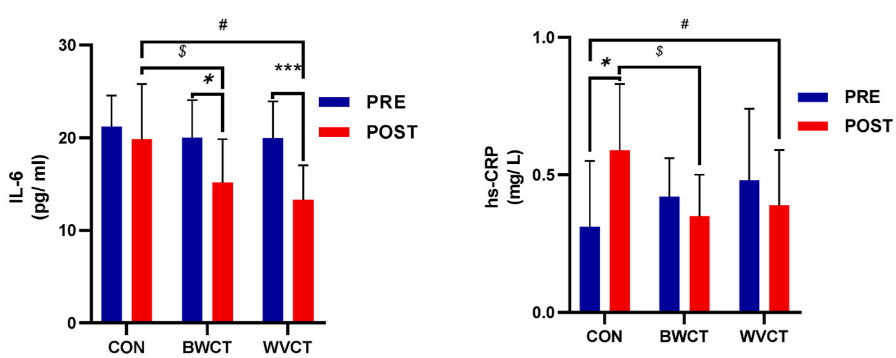
Values are shown as Mean ± SEM; *$p < .05$; ***$p < .001$; CON: Control; BWCT: Body Weight Circuit Training; WVCT: Weighted Vest Circuit Training; PRE: Pre-intervention; POST: Post-intervention; HOMA-IR: Homeostatic Model Assessment of Insulin Resistance; IL-6: Interleukin-6; hs-CRP: High-sensitivity C-Reactive Protein; TC: Total Cholesterol; HDL-C: High-Density Lipoprotein Cholesterol; LDL-C: Low-Density Lipoprotein Cholesterol.



(A) Comparison of changes in Serum Resistin.
*: $p < .001$; #: WVCT vs CON; $: BWCT vs CON; CON : Control; BWCT : Body Weight Circuit Training; WVCT : Weighted Vest Circuit Training.

(B) Comparison of changes in HOMA-IR.
*: $p < .05$; #: WVCT vs CON; $: BWCT vs CON; CON : Control; BWCT : Body Weight Circuit Training; WVCT : Weighted Vest Circuit Training.

Fig. 5. Changes in Serum Resistin and Insulin Resistance. (A) Serum Resistin; (B) HOMA-IR.
(A) Comparison of changes in Serum Resistin.
*: $p < .001$; #: WVCT vs CON; $: BWCT vs CON; CON: Control; BWCT: Body Weight Circuit Training; WVCT: Weighted Vest Circuit Training.
(B) Comparison of changes in HOMA-IR.
*: $p < .05$; #: WVCT vs CON; $: BWCT vs CON; CON: Control; BWCT: Body Weight Circuit Training; WVCT: Weighted Vest Circuit Training.



(A) Comparison of changes in Serum IL-6.
*: $p < .05$; $p < .001$; #: WVCT vs CON; $: BWCT vs CON; CON : Control; BWCT : Body Weight Circuit Training; WVCT : Weighted Vest Circuit Training.

(B) Comparison of changes in Serum hs-CRP.
*: $p< .05$; #: WVCT vs CON; $: BWCT vs CON; CON : Control; BWCT : Body Weight Circuit Training; WVCT : Weighted Vest Circuit Training.

Fig. 6. Changes in Cardiovascular Disease Risk Factors. (A) Serum IL-6; (B) Serum hs-CRP.
(A) Comparison of changes in Serum IL-6.
*: $p < .05$; $p < .001$; #: WVCT vs CON; $: BWCT vs CON; CON: Control; BWCT: Body Weight Circuit Training; WVCT: Weighted Vest Circuit Training.
(B) Comparison of changes in Serum hs-CRP.
*: $p < .05$; #: WVCT vs CON; $: BWCT vs CON; CON: Control; BWCT: Body Weight Circuit Training; WVCT: Weighted Vest Circuit Training.

groups showed intergroup differences compared to the CON group($p = .035$; $p = .013$) (Fig. 6).

For TC(mg/dL), an interaction between the time point and group was found($df = 2$, $F = 3.303$, $p = .049$, 95 % CI [−15.0, −1.5], *effect size* $d = 0.60$). The WVCT group showed a significant decrease of 10.4 % post-training compared to pre-training($p = .016$), but no change was observed with the BWCT and CON groups($p = .569$; $p = .784$, 95 % CI [−2.0, 2.5], *effect size* $d = 0.10$).

For LDL-C(mg/dL), an interaction between the time point and group was observed($df = 2$, $F = 6.292$, $p = .005$, 95 % CI [−20.0, −2.5], *effect size* $d = 0.75$). The WVCT group showed a significant decrease of 18.7 % post-training compared to the pre-training($p = .011$), but no change was found in the BWCT and CON groups($p = .562$; $p = .668$, 95 % CI [−3.0, 2.0], *effect size* $d = 0.15$).

With HDL-C(mg/dL), there was no interaction between the time point and group($df = 2$, $F = 1.930$, $p = .161$, 95 % CI [−4.5, 2.0], *effect size* $d = 0.20$). There was a significant decrease in the CON group post-training by 7.4 % compared to the pre-training($p = .000$, 95 % CI [−5.0, −1.5], *effect size* $d = 0.65$), whereas no change was observed in the WVCT and BWCT groups($p = .479$; $p = .342$, 95 % CI [−2.0, 1.0], *effect size* $d = 0.10$). After training, the WVCT group showed a group difference compared to the CON group($p = .014$).

Free fatty acid(uEq/L)($df = 2$, $F = 1.470$, $p = .245$, 95 % CI [−50.0, 20.0], *effect size* $d = 0.20$). The WVCT group decreased significantly by 15.7 % post-training compared to before($p = .042$, 95 % CI [−80.0, −10.0], *effect size* $d = 0.60$), while the BWCT group and the CON group remained the same($p = .612$; $p = .459$).

There was no interaction between time and group for Triglyceride (mg/dL) ($df = 2$, $F = 0.970$, $p = .390$, 95 % CI [−10.0, 5.0], *effect size* $d = 0.15$). After training, the WVCT group showed an intergroup difference compared to the BWCT and CON groups, with a reduction rate of 22.8 % ($p = .005$; $p = .020$).

The improvement rate(%) of normal-weight obesity was 58.33 % for the WVCT group and 25 % for the BWCT group. Improvement was observed only in the two groups; no change was observed in the CON group.

Pearson correlation analysis revealed significant relationships between several vital variables. A significant negative correlation was found between the decrease in Resistin and the reduction in HOMA-IR($r = −0.68$, $p < 0.01$), indicating that as Resistin levels decreased, insulin resistance improved. Additionally, there was a significant positive correlation between the increase in VO_{2max} and the decrease in Percent Body Fat($r = 0.72$, $p < 0.01$). Other notable correlations included the relationship between the decrease in IL-6 and the reduction in hs-CRP($r = 0.65$, $p < 0.01$), as well as the correlation between the reduction in LDL-C and the decrease in TC($r = 0.60$, $p < 0.01$).

4. Discussion

This study, which confirmed the significant effects of whole-body circuit training on normal obese women using a weighted vest for eight weeks, provides crucial insights into improving body composition, particularly regarding serum resistin, insulin resistance, and cardiovascular disease risk factors.

Regarding body composition, this study showed that skeletal muscle mass increased significantly in the WVCT group, and percent body fat decreased significantly in both the WVCT and BWCT groups. Circuit training is a method in which short breaks are set during resistance training, and these short breaks during exercise stimulate growth hormone secretion.[29] Additionally, circuit training using the whole body simultaneously reduces body fat through aerobic training and maintains Skeletal muscle mass through resistance training.[30] The increased mechanical load promotes the secretion of growth hormone, IGF-1 (Insulin-Like Growth Factor-1), and anabolic hormones and activates mTOR.[31–33] The current study concluded that using a weighted vest for whole-body circuit training rather than conventional whole-body circuit training improved body composition due to increased mechanical stress.

This study significantly increased VO_{2max} in the WVCT group with a weighted vest and the BWCT group without a weighted vest. The effect after training was significantly higher in the WVCT group. Systemic circuit training effectively improves cardiopulmonary function due to the nature of endurance training.[20] However, the VO_{2max} difference between the BWCT and WVCT groups is considered to be the effect of exercise intensity. Previous studies have shown that higher exercise intensity results in more activation of PGC-1α(Peroxisome proliferator-activated receptor gamma coactivator-1 alpha), increasing the density and size of mitochondria.[34,35] Both groups received the same exercise regimen, but the WVCT group had higher exercise intensity due to the weighted vest's effect. This result was thought to be a complex effect due to the activity of PGC-1a, improved mitochondria, vasodilation ability, and increased skeletal muscle mass.

The training regime used in this study improved maximum anaerobic power(Peak Power Output) in the WVCT and BWCT groups. Squat 1RM increased in both the WVCT and BWCT groups, but the increase was significantly higher for the WVCT group. A previous study conducted whole-body resistance training on postmenopausal women wearing a weighted vest weighing up to 40lb three times a week for nine months and reported a 16–33 % increase in lower extremity muscle strength and an average 13 % improvement in lower skeletal muscle.[36] When using a weighted vest, the load is higher than when exercising with only body weight, and this activates motor units and increases the FT fiber mobilization rate.[37,38] In this study, the anaerobic maximum power and squat 1RM were significantly higher in the WVCT group. These results are likely to result from an increase in skeletal muscle mass due to an increase in the mobilization rate of FT fibers in the WVCT group as an effect of a weighted vest. In addition, the increase in exercise performance is likely due to the participants' relatively low initial physical strength level and lack of previous exercise experience.

Blood pressure, a key indicator of cardiovascular and stroke diseases, is directly associated with cardiovascular disease and causes various complications.[39] Our study's results show a significant reduction in systolic blood pressure in the WVCT group compared to the BWCT group, with no significant change in diastolic blood pressure. This is a significant finding, suggesting that the training regime can potentially improve cardiovascular health. Previous studies have reported that people with normal blood pressure had difficulty changing their blood pressure at[40] and decreased further with higher than low exercise intensity.[41] High-intensity exercise has been shown to increase the activity of the sympathetic nervous system and promote the recovery of the parasympathetic nervous system at rest, thereby improving overall cardiovascular health.[42] These changes in the autonomic nervous system may be associated with a decrease in blood pressure, and the significant decrease in systolic blood pressure in the WVCT group with weighted vests, in particular, can be interpreted as a result of these autonomic nervous system regulations. The subjects in this study had blood pressure within the normal range before training, and the decrease in blood pressure in the WVCT group is thought to be due to the higher intensity of exercise.

Resistin is one of the adipocytokines secreted by adipocytes and promotes cardiovascular disease by increasing insulin resistance and inducing inflammation.[43] Serum resistin concentration has also been reported to positively correlate with body fat mass,[44,45] and insulin resistance.[46] In this study, the serum resistin concentration was significantly decreased in both the WVCT and BWCT groups. In previous studies, serum resistin concentration decreased mainly through aerobic and combined training.[47,48] Aerobic training by women in their 20s using a treadmill at 70–80 % HR_{max} for eight weeks, four times a week, was found to cause serum resistin concentration to decrease.[49] Similarly, serum resistin concentration was significantly reduced in a study of overweight adolescents undergoing aerobic training using a treadmill, rowing machine, and cycle ergometer at an intensity of 60–85 % VO_{2max} three times a week for eight weeks.[50] Previous studies have reported decreased serum resistin concentration due to reduced body fat.[47–50] In this study, the decrease in serum resistin concentration is likely due to the reduction in percent body fat and free fatty aid as an effect of aerobic training in circuit training.

As a result of this study, plasma insulin concentration and HOMA-IR decreased significantly post-training in the WVCT group. However, there was not a significant change in plasma glucose concentration. A previous study found that, for postmenopausal women, conducting whole-body circuit training three times a week for 12 weeks caused glucose, insulin, and HOMA-IR to decrease.[51] Increased skeletal muscle mass has been shown to improve insulin sensitivity, reduce plasma insulin, and improve glycogen storage and glucose uptake in muscle, resulting in improved HOMA-IR.[52,53] In addition, decreased serum resistin has been shown to improve IRS-1 and thus improve insulin resistance.[54–56] Accordingly, in this study, the increase in skeletal muscle mass and decreased serum resistin concentration in the WVCT group affected the insulin receptor(IRS-1), improving insulin resistance.

Normal-weight obese people have a body weight and BMI within the normal range, but their percentage of body fat is the same as that of obese people. A high percentage of body fat increases cytokine IL-6, an inflammatory substance, and promotes hs-CRP production in the liver.[57] The increase in IL-6 and hs-CRP deteriorates vascular function and promotes cardiovascular disease. The results of this study show that the concentration of serum IL-6 is significantly decreased in both the WVCT and BWCT groups. While there was no significant difference in hs-CRP, there was a decreasing trend in the WVCT and BWCT groups. In a previous study conducting combined training five times a week for eight weeks, serum IL-6 and CRP concentrations were significantly reduced.[58] In the current study, the concentration of serum IL-6 decreased, and the concentration of hs-CRP in blood tended to decline. The level of resistin in the blood affects the level of IL-6 because it activates NF-kβ(Nuclear Factor - Kappa β) and AP-1(Activator protein - 1).[59,60] Therefore, this study's decrease in serum IL-6 concentration results from reduced resistin concentration. It has also been reported that hs-CRP is a protein affected by diet, age, training intensity, and training duration.[61] The lack of change in serum hs-CRP concentration is thought to be due to the participants' lack of control over daily life and low initial fitness levels.

Total cholesterol and LDL-C cause hypercholesterolemia and increase the prevalence of cardiovascular disease. In addition, total cholesterol and LDL-C positively correlate with the percentage of body fat.[62,63] In the current study, serum total cholesterol and LDL-C levels significantly decreased only in the WVCT group. In a previous study, middle-aged women underwent circuit training for 30 min twice a week for 12 weeks, and serum total cholesterol and LDL-C levels decreased. LDL-C concentration in obese men decreased due to 60-min Whole-body circuit training at 60 % HR_{max} intensity three times a week for 12 weeks.[30] Previous studies have reported that this results from reduced body fat. In the current study, the reduction in LDL-C and total cholesterol in the WVCT group is thought to result from improved body composition.

HDL-C prevents cardiovascular disease and plays a role in protecting blood vessels. This study showed no significant change in serum HDL-C concentration after training. In another study, complex, aerobic, and resistance training conducted five times a week for 12 weeks with obese people led to no significant change in HDL-C concentration in all groups.[64] Another study, in which circuit training was conducted three times a week for 12 weeks with obese female college students, showed no change in serum HDL-C concentration.[65] Previous studies reported that serum HDL-C did not increase because it was affected by diet, training intensity, type, and time.[64,65] Therefore, the result of this study is considered to be the result of the same reason as the previous study, and it is considered that the HDL-C concentration in the blood of the research subjects did not increase further because it was within the normal range.

High body fat in normal-weight obesity increases blood lipid concentration, and high blood lipid concentration in the body increases the incidence of hypercholesterolemia and cardiovascular disease.[66] Therefore, blood lipid concentration should be reduced through exercise. In the current study, plasma free fatty acid levels were significantly decreased in the WVCT group. In a previous study in which type 2 diabetic patients were subjected to resistance training with 50–60 % of 1RM twice a week for eight weeks and 15 times 1–2 SET, no change in plasma free fatty acid concentration was observed.[67] In another study of obese adults, training three times a week for four weeks at 50–70 % $VO2_{peak}$ for 15 min showed decreased free fatty acid in the blood.[68] Additionally, adult males' plasma free fatty acid concentration was significantly reduced due to circuit training with 8 - 12RM three times a week for four weeks.[69] The increase in free fatty acid oxidation is affected by AMPK(AMP-activated protein kinase) activity,[70] and AMPK is affected by exercise intensity.[71] In this study, the Weighted Vest increased the contractile force of the skeletal muscle, and this is considered to have increased the amount of free fatty acid oxidation by further inducing the activation of AMPK.

In the current study, serum triglycerides did not show significant change. It has been reported that long-term training and endurance training, such as marathons, have reduced triglycerides.[72] Various factors, such as diet and lifestyle, also influence them. Therefore, the absence of change in triglycerides in this study is likely due to the participants' diets, their daily lives requiring perfect control, and the short duration of the training period.

In this study, we found that normal-weight obesity was improved only in the WVCT and BWCT groups, with the WVCT group showing a higher improvement rate of 58.33 % compared to the BWCT group's 25 %. This suggests that weighted vest training could be a valuable tool in clinical practice for improving skeletal muscle mass and lipids in normal-weight obese women, thereby enhancing their health and well-being.

The correlation analysis in this study has elucidated a significant association between body composition and exercise performance in normal-weight obese women. A negative correlation($r = -0.65$, $p < 0.01$) was found between an increase in skeletal muscle mass and a decrease in body fat percentage, suggesting that muscles may contribute to fat burning by increasing energy consumption in the body. This result is consistent with previous studies showing that the basal metabolic rate increases as muscle mass increases and fat is effectively burned, decreasing body fat.[73] These correlations support that circuit training using weighted vests is practical in promoting body fat loss while maintaining or increasing muscle mass.

Furthermore, the positive correlation between VO_{2max} and maximum power output($r = 0.70$, $p < 0.01$) highlights the positive effects of cardiopulmonary function enhancement on exercise performance. High VO_{2max} means the cardiovascular system can efficiently deliver oxygen and generate energy. Previous studies have reported that an increase in maximum oxygen intake leads to an increase in cardiac output, mitochondrial density, and size, which improves the ability to deliver oxygen to muscles and improves the ability to oxidize lactate, thereby improving the maximum power output.[74] Thus, circuit training using a weighted vest can be evaluated as an effective program to maximize further the ability to perform exercise.

In this study, the long-term effect of the study protocol could not be confirmed by proceeding for eight weeks, which was relatively short. In addition, it could have affected the research results because physical activity, diet, and daily life could not be controlled. Therefore, in future studies, more samples and the identification of detailed biochemical variables through a thorough diet and daily life control are necessary.

5. Limitation

Although heart rate was monitored using a wireless meter, it was not separately recorded. The study design stipulated that participants would be excluded from the final analysis if their participation rate was below 80 %. However, all study subjects had a participation rate exceeding 90

%, with no dropouts. Since the subjects' lifestyle, diet, and sleep patterns could not be controlled, they were advised to maintain their usual routines before participating in the experiment and to refrain from engaging in any physical activities other than the experimental exercise program. To prevent COVID-19 transmission, the same researcher individually trained the subjects. It is important to note that double-blinding was not achieved in this study. Therefore, future research should address these limitations to confirm the effects of whole-body circuit training with weighted vests on cardiovascular disease, insulin resistance, and body composition in normal-weight obese women.

6. Conclusions

In conclusion, eight weeks of whole-body circuit training with a weighted vest significantly improved body composition, serum resistin levels, and insulin resistance in normal-weight obese women. This intervention was more effective than body weight circuit training alone, indicating the potential of weighted vest training for reducing cardiometabolic risk factors in this population. Future studies should explore the long-term benefits and optimal training protocols for maximizing health outcomes in normal-weight obese individuals.

Informed consent statement

After explaining the purpose, method, and potential risks of the study to all participants, the consent form was signed, and participants who were willing to participate voluntarily were recruited. Moreover, written informed consent has been obtained from the patients to publish this paper.

Author contributions

Jiwoong Kim: Conceptualization, Methodology, Software, Writing - Original draft preparation, Writing - Review & Editing, Project administration. Eunsook Kim: Visualization, Investigation. Dohyun Kim: Software, Formal analysis. Sungjin Yoon: Supervision, Conceptualization, Project administration.

Institutional Review Board statement

The study was approved by the Institutional Review Board of Korea University(KUIRB-2020-0279-01) before the experiment. It was conducted according to their guidelines and the Declaration of Helsinki (1964).

Conflicts of interest

The authors declare no conflict of interest.

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