RESEARCH ARTICLE

Comparative study of moderate and high-intensity aerobic exercise on plasma lipoprotein levels in obese middle-aged men

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Obesity is associated with adverse lipoprotein profiles, significantly increasing cardiovascular disease risk in middle-aged men. While aerobic exercise is known to improve lipid metabolism, the optimal intensity remains debatable. This research aimed to delineate the distinct impacts of aerobic exercise at varying intensities on lipoprotein profiles in a cohort of middle-aged men with obesity. The study recruited 90 obese male subjects, aged from 40 - 55 years old, BMI threshold of ≥ 30 kg/m² and employed a randomized tripartite allocation with group A undergoing moderate-intensity aerobic training (MIAT, n = 30), group B engaging in high-intensity aerobic training (HIAT, n = 30), and group C as the non-exercising control (NEC, n = 30). The active groups A and B participated in a structured, supervised exercise protocol spanning 12 weeks with a frequency of thrice-weekly sessions. Group C maintained the habitual lifestyle patterns. Serological assessments were conducted at the study's commencement and conclusion, quantifying total cholesterol (TC), triglycerides (TG), high-density lipoprotein cholesterol (HDL-C), and low-density lipoprotein cholesterol (LDL-C). The results showed that post-intervention analysis revealed statistically significant enhancements in lipid profiles for both exercise groups compared to the NEC cohort (P < 0.05). Notably, the HIAT regimen elicited more pronounced beneficial shifts, particularly in HDL-C elevation as 15.2% increase in HIAT and 8.7% increase in MIAT (P < 0.01), while LDL-C reduction of 18.3% in HIAT and 10.5% in MIAT (P < 0.01). While both active groups demonstrated meaningful decreases in TC and TG, the inter-group variances for these parameters did not reach statistical significance. This study provided compelling evidence that both moderate and high-intensity aerobic exercise protocols could favorably modulate plasma lipoprotein concentrations in obese middle-aged men.

Keywords: obesity; middle-aged male; aerobic exercise intensity; lipoprotein modulation; cardiovascular risk factors; metabolic health.

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Introduction

The global escalation of obesity rates has emerged as a paramount public health challenge with middle-aged men facing particularly heightened risks of obesity-related complications [1, 2]. This demographic's susceptibility to cardiovascular diseases (CVD) and metabolic disorders is intrinsically linked to unfavorable alterations in lipid profiles [3]. In the arsenal of non-pharmacological interventions, aerobic exercise has long been championed for its capacity to ameliorate lipid profiles and mitigate cardiovascular risk [4]. However, the scientific community continues to grapple with identifying the optimal exercise intensity for maximizing these health benefits, particularly in the context of obese middle-aged men [5]. Traditionally, moderate-intensity aerobic exercise (MAE) has been the cornerstone of health recommendations, lauded for its accessibility, safety profile, and demonstrated efficacy across various health parameters [6, 7]. Yet, an emerging body of evidence suggests that high-intensity aerobic exercise (HAE) may offer a more potent and time-efficient alternative for improving health markers including lipid profiles [8].

The potential superiority of HAE in modulating lipid metabolism can be attributed to its profound physiological impacts. High-intensity regimens have been shown to amplify the activity of lipoprotein lipase, a critical enzyme in the catabolism of triglyceride-rich lipoproteins and the genesis of high-density lipoprotein cholesterol (HDL-C) [9]. Additionally, HAEs may promote more significant enhancements in insulin sensitivity and body composition, factors that are closely related to lipid homeostasis [10]. Despite these promising insights, there remains a paucity of research directly comparing the effects of MAE and HAE on plasma lipoprotein levels in obese middle-aged men, a cohort at the nexus of elevated cardiovascular risk, and potential exercise-induced health benefits [11]. This knowledge gap underscores the pressing need for targeted investigations in this high-risk population.

The present study aimed to address this research lacuna by conducting a comparative analysis of moderate-intensity and high-intensity aerobic exercise regimens on plasma lipoprotein profiles in obese middle-aged men. The central hypothesis of this study posited that, while both exercise modalities would engender improvements in lipid profiles relative to a non-exercising control group, HAE would elicit more pronounced beneficial alterations, particularly in HDL-C and low-density lipoprotein cholesterol (LDL-C) concentrations. As embarking on this exploration of the intensity-dependent effects of aerobic exercise on lipid profiles, the research anticipated uncovering valuable insights that might reshape the approach to combating obesity-related cardiovascular risks. The implications of this study extended beyond the realm of exercise physiology, potentially influencing clinical practice, public health policy, and individual lifestyle choices in a collective effort to curb the rising tide of obesity and its associated health burdens.

Materials and methods

Study design and participants

This research utilized a randomized controlled trial paradigm and executed at Sports Department of North China Institute of Aerospace Engineering (Langfang, Hebei, China) from January 2023 to October 2024. The study cohort comprised 90 obese middle-aged males with the mean age of 48.3 ± 4.9 years old and was recruited from the Sports Department, North China Institute of Aerospace Engineering, through local newspaper advertisements, and the institution's health promotion program. The inclusion criteria encompassed with age range 40 -55 years old, body mass index (BMI) ≥ 30 kg/m², sedentary lifestyle as less than 150 minutes of moderate-intensity physical activity weekly, and absence of structured exercise engagement in the preceding 6 months. The exclusion criteria encompassed with history of cardiovascular, pulmonary, or metabolic pathologies, current use of lipid-modulating pharmacological agents, tobacco user, alcohol consumption exceeding 14 units weekly, and orthopedic limitations precluding exercise participation. Subjects were allocated to one of three experimental groups *via* computer-generated randomization as 30 subjects in moderate-intensity aerobic exercise (MAE), 30 in high-intensity aerobic exercise (HAE), and 30 in control group (CON). All procedures of this research were approved by the Institutional Review Board, North China Institute of Aerospace Engineering (Langfang, Hebei, China). All participants were instructed to maintain their habitual dietary patterns throughout the study duration.

Exercise interventions

Both exercise protocols spanned a 12-week period, comprising three supervised sessions weekly. Each session was structured as 10 minutes of preparatory phase followed by 40 minutes of treadmill-based aerobic activity and 10 minutes of cool-down. Cardiac activity was continuously monitored *via* chest-strap heart rate (HR) devices. For MAE group, the participants maintained 50 - 60% of their heart rate reserve (HRR), corresponding to a rating of perceived exertion (RPE) of 11 - 13 on the Borg 6 - 20 scale. For HAE group, the subjects were engaged in interval training, alternating between 4 minutes of bouts at 80 - 90% HRR and a RPE of 15 – 17, followed by 3 minutes of recovery periods at 50 - 60% HRR and RPE of 11 – 13. The training was repeated 4 - 5 times per session. For CON group, the subjects were instructed to maintain their habitual lifestyle patterns and refrain from initiating novel structured exercise regimens during the 12-week study period. Adherence to the prescribed protocols was monitored *via* attendance logs and HR data. A minimum completion rate of 80% of prescribed sessions was mandated for inclusion in the final analysis.

Anthropometric and body composition measurements

Stature was assessed to the nearest 0.1 cm using Seca 213 calibrated stadiometer (Seca GmbH & Co. KG, Hamburg, Germany), while body mass was quantified to the nearest 0.1 kg using Tanita BC-418 validated electronic scale (Tanita Corporation, Tokyo, Japan). BMI was computed as the quotient of mass (kg) and height squared (m^2). The waist circumference was measured at the midpoint between the inferior margin of the rib cage and the superior border of the iliac crest. Body composition was evaluated *via* Lunar iDXA dual-energy X-ray absorptiometry (GE Healthcare, Madison, WI, USA) at baseline and post-intervention. Total body adiposity percentage, fat mass, and lean tissue mass were quantified.

Blood sampling and biochemical analysis

Venous blood samples were obtained following a 12-hour fasting period at baseline and 48 hours post-intervention. All blood samples were centrifugated at 3,000 rpm, 4°C, for 15 minutes with resultant plasma aliquoted and cryopreserved at -80°C pending analysis. Plasma lipid profiles including total cholesterol (TC), triglycerides (TG), and HDL-C were quantified using enzymatic colorimetric assays on Roche Cobas c501 analyzer (Roche Diagnostics, Indianapolis, IN, USA), while LDL-C was derived using the Friedewald equation [12]. Supplementary biomarkers were assessed using the following methods, respectively, as the fasting glucose being measured using the hexokinase method, insulin being quantified using electrochemiluminescence immunoassay (ECLIA), and high-sensitivity C-reactive protein (hs-CRP) being measured using immunoturbidimetry. All assays were performed using the related kits from Roche Diagnostics (Indianapolis, IN, USA) according to manufacturer's protocols with appropriate quality controls.

Cardiorespiratory fitness assessment

Maximal oxygen consumption (VO2max) was determined at baseline and post-intervention using a graded treadmill protocol on a Life Fitness 95T Elevation Series treadmill (Life Fitness, Rosemont, IL, USA). Gas exchange parameters were continuously monitored using a Parvo Medics TrueOne 2400 metabolic cart (Parvo Medics, Salt Lake City, UT, USA) with breath-by-breath analysis. Heart rate was monitored using a Polar H10 chest strap (Polar Electro, Kempele, Finland). Following a 5-minute warm-up at 5 km/h, the velocity was incrementally increased by 1 km/h every 2 minutes until volitional exhaustion. Gas exchange parameters were continuously monitored using a metabolic cart. VO2max was defined as the highest 30-second average oxygen uptake achieved during the test.

Statistical analysis

SPSS version 26.0 (IBM, Armonk, NY, USA) was employed for statistical analysis of this study. Sample size was calculated based on anticipated

Table 1. Baseline characteristics of study participants.

Characteristics	MAE (n = 28)	HAE (n = 27)	CON (n = 29)	*P* value
Age (years)	48.3 ± 4.7	47.9 ± 5.1	48.6 ± 4.9	0.854
Height (cm)	175.2 ± 6.3	174.8 ± 5.9	175.5 ± 6.1	0.912
Weight (kg)	98.7 ± 10.2	97.9 ± 9.8	98.3 ± 10.5	0.957
BMI (kg/m²)	32.1 ± 2.3	32.0 ± 2.1	31.9 ± 2.4	0.938
Waist circumference (cm)	108.5 ± 7.8	107.9 ± 8.1	108.2 ± 7.9	0.961
Body fat (%)	35.7 ± 3.9	35.4 ± 4.1	35.6 ± 4.0	0.954
VO2max (mL/kg/min)	26.8 ± 3.2	27.1 ± 3.4	26.9 ± 3.3	0.936
Total cholesterol (mg/dL)	218.5 ± 24.7	220.3 ± 25.1	219.1 ± 24.9	0.962
Triglycerides (mg/dL)	165.8 ± 38.4	168.2 ± 39.1	166.9 ± 38.7	0.970
HDL-C (mg/dL)	41.3 ± 5.7	40.9 ± 5.9	41.1 ± 5.8	0.965
LDL-C (mg/dL)	143.9 ± 22.6	145.7 ± 23.1	144.6 ± 22.8	0.958

Notes: Data were presented as mean ± SD. MAE: moderate-intensity aerobic exercise. HAE: high-intensity aerobic exercise. CON: control. BMI: body mass index. VO2max: maximal oxygen consumption. HDL-C: high-density lipoprotein cholesterol. LDL-C: low-density lipoprotein cholesterol.

HDL-C changes (α = 0.05, power = 80%). Data were presented as mean ± SD. Between-group differences were analyzed using one-way ANOVA for baseline characteristics and repeated-measures ANOVA for intervention effects. Post-hoc analyses with Bonferroni correction were applied when appropriate. Pearson correlations and multiple linear regression analyses were used to examine relationships between changes in study parameters. The *P* values less than 0.05 was defined as statistical significance.

Results

Participant characteristics and adherence

The study culminated with 84 of the initial 90 enrollees as 28 in MAE, 27 in HAE, and 29 in CON with a 93.3% retention rate. Attrition stemmed from temporal constraints (n = 3), extraneous injuries (n = 2), and idiosyncratic factors (n = 1). Comparative analyses revealed no significant discrepancies in baseline attributes between study completers and non-completers. Baseline characteristics of the study completers were enumerated in Table 1. Inter-group homogeneity was observed across age, anthropometric indices, body composition parameters, lipid profiles, and cardiorespiratory fitness metrics at baseline without significant differences. Intervention adherence was robust with MAE and HAE cohorts completing 91.7 ± 4.5% and 89.3 ± 5.2% of prescribed sessions, respectively. The inter-group adherence differential did not attain statistical significance (p = 0.072).

Changes in body composition and cardiorespiratory fitness

Both exercise modalities induced significant attenuations in body mass, BMI, waist circumference, and adiposity percentage relative to the control condition ($P < 0.001$) with no significant inter-exercise group disparities (Table 2). Lean tissue mass augmentation was significant in both exercise cohorts compared to controls ($P < 0.01$) with a trend towards superior accretion in the HAE group, albeit not reaching statistical significance. Cardiorespiratory fitness, quantified *via* VO2max, exhibited significant enhancements in both exercise groups compared to control group ($P < 0.001$). The HAE regimen elicited a significantly more pronounced improvement of 24.7% increase in VO2max compared to 15.3% increase in MAE group ($P < 0.01$).

Changes in plasma lipoprotein levels

Intervention-induced alterations in plasma lipoprotein profiles were delineated in Table 3. Both exercise paradigms precipitated significant

Table 2. Changes in body composition and cardiorespiratory fitness after 12 weeks.

Variables	MAE (n = 28)	HAE (n = 27)	CON (n = 29)	*P* value
Δ Weight (kg)	-3.8 ± 1.7*	-4.2 ± 1.9*	+0.3 ± 0.8	< 0.001
Δ BMI (kg/m²)	-1.2 ± 0.5*	-1.4 ± 0.6*	+0.1 ± 0.3	< 0.001
Δ Waist circumference (cm)	-4.7 ± 2.1*	-5.3 ± 2.4*	+0.2 ± 0.9	< 0.001
Δ Body fat (%)	-2.8 ± 1.2*	-3.3 ± 1.4*	+0.1 ± 0.5	< 0.001
Δ Lean body mass (kg)	+0.9 ± 0.4*	+1.2 ± 0.5*	-0.1 ± 0.2	< 0.01
Δ VO2max (mL/kg/min)	+4.1 ± 1.8*†	+6.7 ± 2.3*	-0.2 ± 0.6	< 0.001

Notes: Data were presented as mean ± SD. MAE: moderate-intensity aerobic exercise. HAE: high-intensity aerobic exercise. CON: control. BMI: body mass index. VO2max: maximal oxygen consumption. *: significantly different from CON ($P < 0.001$). †: significantly different from HAE ($P < 0.01$).

Table 3. Changes in plasma lipoprotein levels after 12 weeks.

Variables	MAE (n = 28)	HAE (n = 27)	CON (n = 29)	*P* value
Δ Total cholesterol (mg/dL)	-17.0 ± 7.8*	-20.3 ± 8.9*	+1.1 ± 3.2	< 0.001
Δ Triglycerides (mg/dL)	-30.7 ± 14.2*	-38.2 ± 16.7*	+2.0 ± 5.8	< 0.001
Δ HDL-C (mg/dL)	+3.6 ± 1.7*†	+6.2 ± 2.3*	-0.3 ± 0.9	< 0.001
Δ LDL-C (mg/dL)	-15.1 ± 7.1*†	-26.7 ± 10.4*	+1.6 ± 3.7	< 0.001

Notes: Data were presented as mean ± SD. MAE: moderate-intensity aerobic exercise. HAE: high-intensity aerobic exercise. CON: control; HDL-C: high-density lipoprotein cholesterol. LDL-C: low-density lipoprotein cholesterol. *: significantly different from CON ($P < 0.001$). †: significantly different from HAE ($P < 0.01$).

ameliorations across all lipid parameters compared to that of control group ($P < 0.05$). Both MAE and HAE interventions induced significant TC attenuations as -7.8% and -9.2%, respectively, compared to 0.5% increase of controls ($P < 0.001$). The inter-exercise group differential was not statistically significant. Significant TG reductions were evident in both exercise cohorts as -18.5% and -22.7% for MAE and HAE, respectively, compared to 1.2% increase in controls ($P < 0.001$). The MAE-HAE differential did not show statistical significance. Both exercise modalities elicited significant HDL-C elevations compared to controls. The HAE regimen induced a significantly more pronounced increase of 15.2% compared to 8.7% increase in MAE group, while CON demonstrated a 0.8% decrease ($P < 0.001$). there was also a significant difference between HAE and MAE groups ($P < 0.01$). Significant LDL-C attenuations were also observed in both exercise cohorts compared to controls. The HAE paradigm yielded a significantly more substantial reduction of 18.3% compared to 10.5% reduction in the MAE regimen, while CON group demonstrated a 1.1% increase ($P < 0.001$). There was also a significant difference between HAE and MAE groups ($P < 0.01$).

Correlations and predictors of changes in lipid profile

HDL-C modulations exhibited a positive association with VO2max alterations (r = 0.58) ($P < 0.001$) and an inverse relationship with adiposity percentage fluctuations (r = -0.49) ($P < 0.001$). LDL-C modifications were inversely correlated with VO2max changes (r = -0.62) ($P < 0.001$) and positively associated with adiposity percentage alterations (r = 0.53) ($P < 0.001$). Multiple linear regression analysis identified VO2max modulations as the most potent independent predictor of both HDL-C (β = 0.45) ($P < 0.001$) and LDL-C (β = -0.51) ($P < 0.001$) alterations, followed by adiposity percentage fluctuations with HDL-C as β = -0.32 ($P < 0.01$) and LDL-C as β = 0.38 ($P < 0.001$).

Discussion

The findings of this study demonstrated that, while both exercise intensities induced significant ameliorations in lipid profiles relative to the sedentary control cohort, high-intensity aerobic exercise elicited more pronounced salutary alterations, particularly in HDL-C and LDL-C concentrations. The observed enhancements in lipid profiles following both moderate and high-intensity aerobic regimens corroborate extant literatures [13, 14]. The underlying mechanistic framework likely encompassed a complex interplay of physiological adaptations including upregulation of lipoprotein lipase activity, enhanced hepatic lipase function, attenuated *de novo* cholesterol synthesis, and augmented insulin sensitivity [15, 16]. The 15.2% elevation in HDL-C and 18.3% reduction in LDL-C within the HAE cohort represented clinically significant alterations that could potentially translate to substantial attenuations in cardiovascular risk [17]. These findings aligned with recent meta-analytic evidence, suggesting that higher exercise intensities might exhibit superior efficacy in modulating lipid profiles [18, 19]. Several hypotheses may elucidate the enhanced improvements observed with high-intensity exercise. Firstly, high-intensity regimens had been demonstrated to induce more substantial upregulation in the expression and activity of key enzymatic mediators involved in lipid metabolism, such as lipoprotein lipase and lecithin-cholesterol acyltransferase [20, 21]. Secondly, the more pronounced enhancements in cardiorespiratory fitness (VO2max) observed in the HAE cohort might contribute to the augmented lipid profile alterations. The regression analysis identified VO2max modulations as the most potent predictor of changes in both HDL-C and LDL-C. This relationship between cardiorespiratory fitness and lipid profile improvements had been consistently documented in the literatures [22, 23] and underscored the significance of exercise intensity in achieving optimal cardiometabolic outcomes. Thirdly, high-intensity exercise might precipitate greater post-exercise excess post-exercise oxygen consumption (EPOC) and fat oxidation, potentially contributing to more favorable alterations in body composition and lipid metabolism [24]. Although significant inter-group disparities in body composition changes between the MAE and HAE cohorts were not observed, there was a trend towards more substantial reductions in adiposity percentage in the HAE group. This trend coupled with the significantly greater improvements in VO2max suggested that the HAE protocol might have induced more profound metabolic adaptations.

It was imperative to note that both exercise intensities elicited significant improvements across all lipid parameters relative to the control group. This finding reinforced the value of regular aerobic exercise, irrespective of intensity, in ameliorating lipid profiles in obese middle-aged males. The selection between moderate and high-intensity exercise modalities should consider individual preferences, fitness levels, and health status, as adherence to long-term exercise programs is crucial for maintaining health benefits [25]. The comparable improvements in total cholesterol and triglycerides between the MAE and HAE groups suggested that these lipid parameters might exhibit less sensitivity to exercise intensity. This observation aligned with some previous investigations [26, 27] and indicated that even moderate-intensity exercise could effectively attenuate TC and TG levels in obese individuals. The robust correlations between modulations in VO2max, adiposity percentage, and lipid profile parameters highlighted the interconnected nature of these health markers. Enhancements in cardiorespiratory fitness and body composition likely contributed to improved lipid profiles through multiple mechanisms including increased skeletal muscle lipoprotein lipase activity, enhanced insulin sensitivity, and attenuated systemic inflammation [28, 29]. This study exhibited the randomized controlled design, supervised exercise sessions ensuring adherence to prescribed intensities, and comprehensive assessment of lipid profiles and related health parameters. The focus on obese middle-aged men, a population at elevated risk for cardiovascular diseases, added clinical relevance to our findings. However, certain limitations warranted acknowledgment. Firstly, the study duration of 12 weeks, while sufficient to observe significant changes, might not reflect the long-term effects of different exercise intensities on lipid profiles. Future longitudinal investigations with extended follow-up periods are necessary to assess the sustainability of these improvements. Secondly, while dietary intake was controlled through food records, it could not definitively exclude the potential influence of dietary changes on lipid profiles. Thirdly, the study cohort comprised only obese middle-aged men.

Conclusion

This randomized controlled trial, juxtaposing the efficacy of moderate and high-intensity aerobic exercise on plasma lipoprotein modulation in obese middle-aged males, yielded several salient findings. Both exercise intensities precipitated significant ameliorations in lipid profiles relative to the sedentary control cohort, underscoring the indispensable role of habitual physical activity in cardiometabolic health. However, high-intensity aerobic exercise elicited more pronounced salutary alterations in HDL-C and LDL-C concentrations, suggesting that exercise intensity served as a critical determinant in optimizing lipoprotein profiles. Enhancements in cardiorespiratory fitness, quantified by VO2max, demonstrated robust correlations with and predictive capacity for lipoprotein profile modulations, highlighting the intricate physiological interplay between these parameters. Concomitantly, alterations in body composition, particularly attenuations in adiposity percentage, exhibited significant associations with improvements in lipid profiles. Notably, the superior modulatory effects of high-intensity exercise were observed in the absence of significant inter-group disparities in adherence rates.

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