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Original Article

Impact of regional and general aerobic exercise on molecular regulators of lipolysis and adipose tissue composition in obese women

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Abstract

This randomized controlled trial compared the effects of regional, general, and combined aerobic training on plasma lipolytic markers and subcutaneous fat reduction in obese women with abdominal or gluteofemoral fat accumulation. Sixty women (age 25–50 years; BMI ≥30 kg/m²) were assigned to general aerobic training (GATG; treadmill/cycling), regional aerobic training (RTG; targeted abdominal or lower-body rhythmic exercises), or combined training (CTG; 15 min general + 15 min regional), performed three times per week for 12 weeks at 55–75% heart rate reserve. Dietary intake was monitored to ensure no major changes. Anthropometric indices (weight, BMI, waist-to-hip ratio [WHR]) and plasma free fatty acids (FFAs), glycerol, and insulin were measured pre- and post-intervention. All groups demonstrated significant reductions in weight, BMI, WHR, and biochemical markers ($p<0.05$). The CTG achieved the greatest improvements: weight −6.38%, BMI −6.30%, WHR −13.13%, accompanied by the largest declines in FFAs, glycerol, and insulin. GATG showed superior systemic fat loss compared to RTG, but RTG still produced notable WHR and insulin reductions, suggesting a complementary role for localized exercise. The superior outcomes in CTG may reflect synergistic effects of global cardiovascular activation and targeted regional muscle engagement, potentially enhancing both systemic lipolysis and local adipose tissue responsiveness. Biochemical improvements, particularly reductions in fasting FFAs and glycerol, indicate enhanced adipocyte insulin sensitivity and lipid utilization. The pronounced insulin decline in CTG is clinically relevant for metabolic risk reduction. While "spot reduction" remains controversial, these findings support integrating regional movements within broader aerobic programs to address resistant fat depots. This study suggests that combining general and regional aerobic training offers a practical, scalable approach for improving metabolic health and body composition in obese women. Future research should employ imaging-based fat quantification, hormonal profiling, and long-term follow-up to clarify underlying mechanisms and optimize depot-specific exercise prescriptions.

Keywords: Regional aerobic training; General aerobic training; Combined exercise; Lipolytic markers; Free fatty acids; Glycerol; Insulin; Subcutaneous fat; Obese women; Waist-to-hip ratio.

1. Introduction

Obesity is a complex metabolic condition characterized not only by excess adiposity but also by the differential distribution and functional properties of adipose tissue depots [1-3]. It continues to pose a significant threat to global health, disproportionately affecting women due to sex-specific patterns of fat distribution [4]. Central (abdominal) and gluteofemoral fat deposits not only differ anatomically but also have distinct metabolic implications [4, 5]. While abdominal adiposity is strongly linked to cardio metabolic risk factors such as insulin resistance and dyslipidemia, gluteofemoral fat may offer protective effects yet is often resistant to conventional fat reduction strategies [6-9]. While general aerobic exercise (e.g., treadmill or cycling) is effective in reducing total and visceral adipose tissue, the efficacy of regional or localized aerobic training in selectively mobilizing subcutaneous fat remains controversial. Some studies report no significant site-specific fat loss, attributing this to systemic hormonal control of lipolysis [10, 11], while others have observed modest depot-specific effects potentially driven by increased local blood flow and muscle-adipose crosstalk [12, 13]. A recent meta-analysis concluded that localized exercise alone is insufficient to induce regional fat reduction [14], although combining aerobic exercise with adjunct therapies such as radiofrequency may enhance subcutaneous fat loss [15]. While both general aerobic and localized muscle activity increase lipolysis as evidenced by elevated plasma FFA and glycerol during and after exercise, systemic hormonal control predominates over any depot-specific effect.

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For example, endurance exercise at moderate intensities significantly increases the rate of appearance of FFA and glycerol, enhancing whole-body fat oxidation [13]. In clinical trials of structured aerobic training, reductions in fasting FFA, glycerol Ra, and improved insulin sensitivity were observed, but these changes did not vary between exercised and non-exercised regions, indicating no site-specific lipolysis [16]. Thus, although localized muscle contractions may transiently elevate local adipose blood flow, regional subcutaneous fat reduction appears to be governed primarily by systemic regulatory mechanisms rather than mechanical activation [17]. De Souza Teixeira et al. (2016) reviewed evidence showing that aerobic exercise modulates free fatty acid metabolism and reduces chronic inflammation in both obesity and cancer cachexia, suggesting that exercise may improve metabolic and immune dysfunction by regulating lipolysis and pro-inflammatory pathways in these conditions [18]. Lipolytic markers such as plasma free fatty acids (FFAs), glycerol, and insulin serve as sensitive indicators of exercise-induced fat mobilization and metabolic adaptation. Although previous studies have demonstrated that combined aerobic and resistance training enhances body composition and lipolytic responses in overweight individuals[19], few investigations have directly compared the metabolic effects of regional versus general aerobic training modalities, particularly in women characterized by distinct fat distribution phenotypes. Despite these insights, limited research has explored the comparative molecular effects of general versus regional aerobic exercise on systemic lipolytic markers and depot-specific fat mobilization in individuals with distinct fat accumulation patterns. We hypothesize that combined training will yield superior improvements in lipolytic markers and fat reduction compared to either modality alone. The results aim to contribute to the development of sex-sensitive, depot-specific exercise prescriptions in clinical obesity care. Therefore, this study investigates the differential effects of regional (abdominal or gluteofemoral-focused) versus general aerobic training on plasma lipolytic markers and subcutaneous fat reduction in obese women. By evaluating both biochemical markers (FFA, glycerol) and anthropometric changes, this study aims to provide mechanistic insights into adipose tissue adaptability under region-specific aerobic stimuli**.**

2. Materials and Methods

2.1. Study design and participants

This 12-week randomized controlled trial aimed to assess and compare the effects of different aerobic training modalities regional, general, and combined on plasma lipolytic markers and subcutaneous fat in obese women. 60 women aged between 25 and 50 years (BMI ≥30 kg/m²), with visible fat accumulation predominantly in either the abdominal or gluteofemoral region, were recruited through public advertisements, community outreach programs, and referrals from the Weight and Health Control Clinic of Dr. Irandoust.

Before enrollment, all participants underwent a medical screening to ensure they met the inclusion criteria. Women were considered eligible if they had not participated in any structured exercise program or weight-reduction diet during the past three months and were not taking any medications or supplements that could influence hormonal status, metabolism, or lipid levels. Individuals with diagnosed cardiovascular, metabolic, or endocrine disorders, as well as those with musculoskeletal limitations that could affect physical activity, were excluded. All participants signed an informed consent form, and the institutional review board in accordance with the Declaration of Helsinki approved the study.

2.2. Intervention protocol

Participants were randomly assigned into three equal groups (n = 20 per group):

2.2.1. General Aerobic Training Group (GATG)

Participants engaged in traditional aerobic workouts, including cycling on a stationary bike and treadmill walking or running, with exercise intensity maintained at 55–75% of their heart rate reserve (HRR). Target heart rate was calculated using the Karvonen formula: Target HR = [(HRmax – HRrest) × intensity] + HRrest, where HRmax was estimated as 220 minus age, and HRrest was determined from the participant's measured resting heart rate. Each session lasted approximately 30 minutes and was conducted three times per week.

Regional Training Group (RTG): Participants in the localized aerobic training group engaged in a structured routine targeting the abdominal and lower-body regions. Each 30-minute session emphasized ground-based, rhythmic exercises aimed at activating regional muscle groups and enhancing local circulation. The protocol included movements such as supine leg raises, glute bridges, flutter kicks, mountain climbers, side-lying leg lifts, reverse crunches, modified bicycle crunches, seated knee tucks, low-platform step-ups, and standing side leg raises. Exercises were performed in 2 to 3 sets of 15 to 20 repetitions (or 30-second bouts for dynamic movements), with short recovery periods—approximately 20 to 30 seconds between exercises and 30 to 45 seconds between sets—to maintain aerobic engagement while allowing adequate muscular recovery. The selection of exercises was based on their relevance to the target regions, suitability for overweight individuals, and practicality in unsupervised or minimally equipped settings. Previous studies have suggested that region-specific aerobic movements may improve blood flow and enhance lipolytic responses in targeted subcutaneous fat depots, supporting the rationale for incorporating such localized routines [20].

2.2.2. Combined Training Group (CTG)

This group received a blended intervention consisting of 15 minutes of general aerobic exercise (cycling/treadmill) followed by 15 minutes of regional training in each session. Like the other groups, training occurred three times weekly for 12 weeks at the same target heart rate range (55–75% HRmax). All sessions were supervised by certified exercise physiologists to ensure safety and compliance.

2.3. Dietary monitoring

Participants were instructed to maintain their habitual dietary patterns throughout the intervention period. A baseline energy requirement was calculated based on individual basal metabolic rate (BMR), adjusted for moderate physical activity. Dietary intake was monitored weekly using three-day food diaries, which were reviewed by a registered dietitian to ensure no major dietary changes occurred during the study[21].

2.4. Anthropometric and body composition measurements

Height and weight were measured using calibrated SECA stadiometers and digital scales (SECA GmbH, Germany). Body mass index (BMI) was calculated as weight (kg) divided by height squared (m^2). Subcutaneous fat was estimated using skinfold thickness measurements taken at the triceps, suprailiac, and thigh sites using a Lafayette skinfold caliper (Lafayette Instrument Company, Lafayette, IN, USA). All measurements were performed by the same trained technician to minimize inter-observer variability [22].

2.5. Biochemical assessments

Venous blood samples were collected from participants in the morning after a 10–12-hour overnight fast, both at baseline and at the end of the 12-week intervention. Plasma and serum were separated by centrifugation at 3000 rpm for 10 minutes and stored at −80°C until analysis.

Plasma glycerol and free fatty acids (FFAs) were quantified using commercially available enzymatic colorimetric kits (e.g., ZellBio GmbH, Germany). Serum insulin levels were measured using a high-sensitivity ELISA kit (e.g., Monobind Inc., USA), with assays performed in duplicate according to the manufacturer's protocols. All samples were processed in an ISO-certified laboratory, with intra-assay and inter-assay coefficients of variation maintained below 5% and 8%, respectively.

2.6. Statistical analysis

All data were analyzed using SPSS version 26.0 (IBM Corp., Armonk, NY, USA). Descriptive statistics were computed for all variables. One-way analysis of variance was used to evaluate between-group differences. When significant interactions were found, post hoc pairwise comparisons with Tukey correction were conducted. The level of statistical significance was set at $p < 0.05$.

3. Results

All three interventions, regional aerobic training (RTG), general aerobic training (GATG), and combined training (CTG), led to statistically significant improvements in anthropometric and biochemical parameters after the 12-week intervention ($p < 0.05$). However, the magnitude of change varied significantly between groups, with the CTG demonstrating the most substantial benefits across all outcomes.

As detailed in Table 1, the CTG achieved the greatest reductions in body weight, BMI, and waist-to-hip ratio (WHR), with mean decreases of 6.38%, 6.30%, and 13.13%, respectively. The GATG also showed considerable improvements: body weight decreased by 4.91%, BMI by 4.99%, and WHR by 9.18%. The RTG exhibited the smallest yet still significant changes, with reductions of 3.59% in weight, 3.53% in BMI, and 7.07% in WHR. Between-group analyses confirmed that all anthropometric improvements were significantly greater in the CTG compared to both the GATG and RTG ($p < 0.05$), highlighting the additive effect of combining general and regional aerobic stimuli.

With regard to plasma lipolytic and metabolic markers, significant differences were observed post-intervention, as illustrated in Figures 1–3.

Post-intervention insulin levels showed significant reductions across all groups, with the Combined Training Group (CTG) demonstrating the most substantial decline. As shown in Figure 1, the mean post-intervention insulin level in the CTG was significantly lower than in both the Regional Training Group (RTG) ($p=0.028$) and the General Aerobic Training Group (GATG) ($p=0.021$). There was

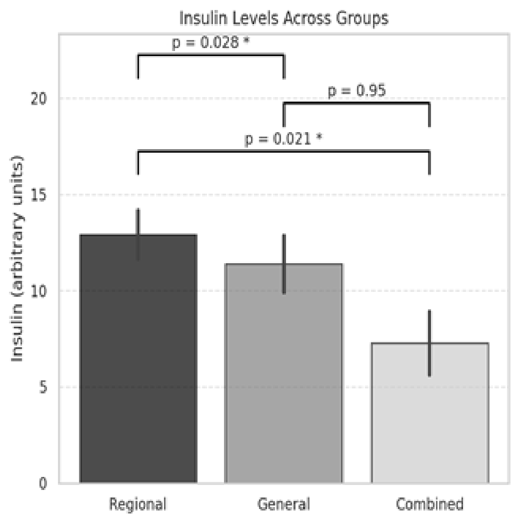

Fig. 1. Post-intervention insulin levels in the Regional, General, and Combined training groups. Significant between-group differences are indicated with corresponding p-values.

Table 1. Baseline and post-intervention anthropometric data by group (Mean ± SD).

Variable/Groups	Regional Training (n = 20)	General Training (n = 20)	Combined Training (n = 20)
Age (years)	35.10 ± 7.19	36.80 ± 6.90	36.65 ± 7.36
Height (cm)	163.80 ± 3.52	160.62 ± 5.02	161.65 ± 4.85
Weight (pre, kg)	82.74 ± 3.51	82.55 ± 5.07	82.90 ± 7.62
Weight (post, kg)	79.77 ± 0.52	78.50 ± 0.52	77.61 ± 7.00
WHR (pre)	0.99 ± 0.04	0.98 ± 0.05	0.99 ± 0.04
WHR (post)	0.92 ± 0.29	0.89 ± 0.04	0.86 ± 0.03
BMI (pre, kg/m²)	30.87 ± 2.61	32.05 ± 2.57	31.74 ± 2.84
BMI (post, kg/m²)	29.78 ± 2.87	30.45 ± 2.35	29.74 ± 2.86
Weight Changes (%)	−3.59%	−4.91%	−6.38%
WHR **Changes (%)**	−7.07%	−9.18%	−13.13%
BMI Changes (%)	−3.53%	−4.99%	−6.30%

no significant difference in post-intervention insulin levels between the RTG and GATG (p=0.95).

The analysis of post-intervention glycerol levels revealed a significant increase in the General and Combined Training Groups compared to the Regional Group (Figure 2). The mean post-intervention glycerol level in the CTG was significantly higher than in the RTG (p=0.001). Similarly, the mean glycerol level in the GATG was significantly higher than in the RTG (p=0.016). The difference in post-intervention glycerol levels between the GATG and CTG was not statistically significant (p=0.06).

All three groups showed a decline in plasma FFAs post-intervention, with significant differences observed between groups. As detailed in Figure 3, the mean post-intervention FFAs in the CTG were significantly lower than in the RTG (p=0.008). The GATG also showed a significantly lower mean FFA level compared to the RTG (p=0.044). No statistically significant difference was found between the GATG and CTG in post-intervention FFA levels (p=0.44).

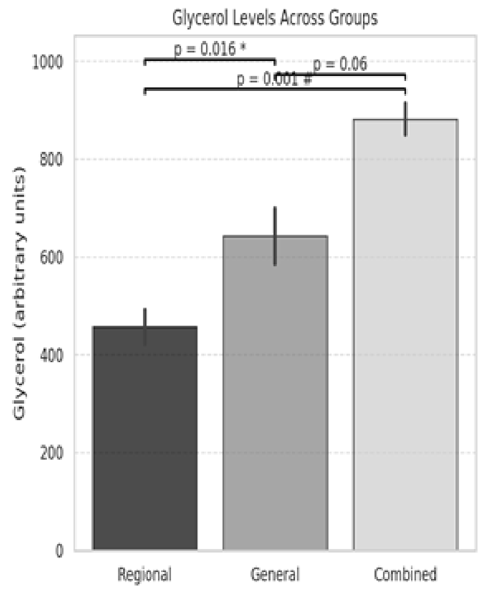

Fig. 2. Post-intervention glycerol levels in the Regional, General, and Combined training groups. Statistically significant differences between groups are annotated with exact p-values and corresponding symbols.

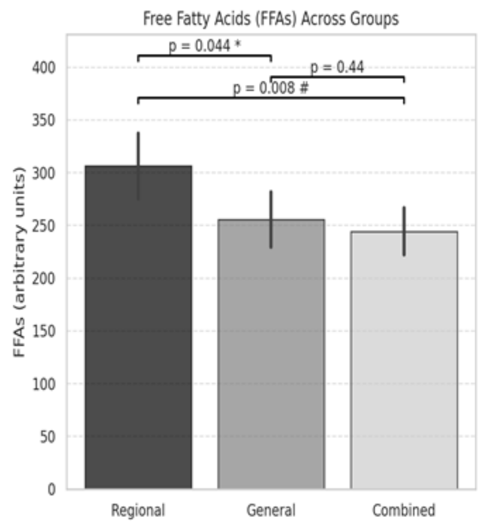

Fig. 3. Post-intervention free fatty acid (FFA) levels in the Regional, General, and Combined training groups. Statistically significant differences are indicated using exact p-values and appropriate symbols.

4. Discussion

This study aimed to evaluate and compare the effects of regional, general, and combined aerobic training protocols on body composition and plasma lipolytic markers, including free fatty acids (FFAs), glycerol, and insulin in obese women with central or gluteofemoral fat accumulation. All three interventions led to statistically significant reductions in body weight, BMI, waist-to-hip ratio (WHR), and biochemical markers; however, the combined training group demonstrated the most pronounced improvements across all variables. These findings underscore the superiority of integrative exercise strategies that combine global cardiovascular activation with regional muscle engagement in achieving meaningful metabolic and anthropometric benefits.

In terms of anthropometric outcomes, the combined group exhibited a 6.38% reduction in body weight, a 6.30% decrease in BMI, and a 13.13% improvement in WHR. These changes were significantly greater than those observed in the general or regional training groups, suggesting that blending systemic aerobic load with localized muscular activation yields synergistic effects on fat mobilization and distribution. Previous studies have demonstrated that general aerobic exercise enhances whole-body lipid oxidation by increasing mitochondrial biogenesis and stimulating catecholamine-induced lipolysis[12, 23]. However, the addition of regional exercise may further augment this response through increased blood flow and thermal activity in specific adipose depots, potentially promoting enhanced local triglyceride breakdown [13, 14].

The most notable biochemical changes were observed in the combined group, where FFAs and glycerol showed substantial reductions. Elevated fasting FFAs are a hallmark of insulin resistance and impaired lipid metabolism in obese individuals. Their post-intervention decline in all groups, especially the combined group, may indicate improved adipocyte insulin sensitivity and a more efficient substrate utilization profile[15, 16]. Moreover, glycerol levels, which reflect intracellular lipolysis of stored triglycerides, also declined significantly. These patterns are consistent with previous reports indicating that repeated aerobic exercise promotes favorable alterations in lipolytic enzyme activity and hormonal balance, particularly when large muscle masses are recruited simultaneously [12, 24].

Importantly, serum insulin levels also decreased significantly in all three groups, with the most substantial decline again seen in the combined group. Given the close interplay between insulin and lipid metabolism, wherein hyperinsulinemia inhibits hormone-sensitive lipase and suppresses lipolysis, this result suggests improved insulin action following the interventions. These improvements in insulin sensitivity may be attributed to enhanced GLUT-4 translocation, improved mitochondrial oxidative capacity, and decreased adipose inflammation—all well-documented consequences of regular aerobic exercise [23]. In light of the higher baseline cardiometabolic risk associated with abdominal obesity, the marked insulin reduction in this cohort is clinically significant.

The findings on WHR deserve additional attention. The superior improvement in the combined group may be linked to the well-documented metabolic heterogeneity between abdominal and gluteofemoral fat depots. Abdominal fat, particularly visceral adipose tissue, is more metabolically active and responsive to catecholamine-induced lipolysis, whereas gluteofemoral fat is generally more resistant to mobilization due to higher alpha-2 adrenergic receptor density and lower perfusion rates[6, 7]. Therefore, integrating regional training targeting these resistant areas may help overcome local barriers to fat oxidation by enhancing capillarization and thermal effects in subcutaneous tissues, although the evidence for this mechanism remains mixed[13, 14, 19].

Concept of "spot reduction," the theory that localized fat is selectively lost by region-specific exercise, remains controversial, as systemic hormonal regulation is the dominant force in lipolysis during energy deficit [10, 11]. However, there is some evidence that even if systemic control is dominant, regional aerobic exercise might still assist in mobilization of localized fat through mechanical and hemodynamic action. For instance, rhythmic contraction of adjacent muscles augments perfusion of subcutaneous adipose tissue, enabling lipolytic hormone delivery and removal of free fatty acids and glycerol [12, 13]. Increased perfusion as such can transiently increase lipolytic activity in specific depots, particularly when exercised under fasting or during sustained energy expenditure [20]. In addition, local thermal responses generated during repeated muscle activity may, over time, produce augmented adipose tissue metabolism and capillary density capable of sensitizing otherwise refractory fat deposits such as gluteofemoral adipose tissue[13, 14, 19]. Although these local adaptations are likely to be modest compared with the total impact of overall aerobic exercise, they may contribute to the large WHR and insulin decreases observed in the regional training group. The achieved gains suggest that while spot reduction is not possible in isolation, local aerobic movements can complement whole-body fat loss by enhancing local adipose tissue function. This is particularly relevant in groups where some fat depots e.g., gluteofemoral fat in women are metabolically inert and less responsive to conventional exercise[6-9]. Thus, the addition of local exercises may offer an intense intervention to improve body composition outcomes in persons with refractory subcutaneous fat deposition.

Interestingly, the regional training group, while less effective overall, still showed meaningful improvements in WHR and insulin, suggesting that localized aerobic activity is not entirely metabolically inert. While the idea of “spot reduction” remains controversial and generally unsupported by robust clinical trials, the modest improvements observed here support the possibility that regional training may serve a complementary role in broader exercise regimens[14]. A possible explanation is that increased blood flow in trained regions enhances lipolytic response during concurrent systemic energy deficits, although systemic endocrine factors ultimately dictate the extent of fat loss. Our results also indirectly support emerging evidence that the timing, intensity, and type of aerobic stimulus interact with depot-specific adipocyte responsiveness and circadian rhythms. While not directly measured in this study, these contextual factors may help explain variability in participant outcomes and should be considered in future research [25]. Furthermore, sex-specific differences in fat distribution and hormonal profiles likely played a role in the differential responses seen in this all-female cohort, as women tend to have higher gluteofemoral fat and different patterns of adrenergic receptor distribution[4, 5]. Overall, the results reinforce the notion that systemic metabolic regulation dominates over purely localized mechanical effects. However, combining regional and general aerobic training appears to enhance overall efficacy, possibly by improving both central and peripheral adipose tissue responsiveness to exercise. This aligns with previous studies that advocate for multimodal interventions in obesity management and underscores the potential of personalized exercise prescriptions that address both physiological and psychological goals, such as aesthetic concerns about fat distribution.

From a clinical and practical standpoint, the use of accessible, non-invasive anthropometric assessments and cost-effective aerobic training methods in this study offers a scalable model for obesity interventions in real-world settings. Structured programs that combine traditional cardiovascular training with rhythmic, regionally-targeted exercises may optimize outcomes in obese women, particularly those with resistant fat depots. Despite its strengths, this study has several limitations. The use of skinfold measurements and WHR as proxies for fat loss, while practical, lacks the precision of advanced imaging modalities such as DEXA or MRI, which could offer more granular insights into depot-specific fat changes. Moreover, hormonal mediators of lipolysis (e.g., catecholamines, cortisol) and inflammatory markers (e.g., adiponectin, TNF-α) were not assessed, limiting our understanding of the underlying molecular mechanisms. Additionally, the sample was restricted to middle-aged obese women, which may reduce generalizability to other populations, including men or younger individuals.

Future studies should incorporate imaging-based evaluations and comprehensive hormonal profiling to more precisely examine the mechanisms driving fat distribution changes. Investigating long-term maintenance of fat loss and insulin sensitivity post-intervention would also enhance understanding of program sustainability. Moreover, studies examining the role of exercise timing (e.g., morning vs. evening), menstrual cycle phase, and gene–environment interactions could provide further insight into individualized responses to different exercise modalities. Healthcare professionals designing obesity interventions should consider combining general aerobic exercise with region-specific movements to maximize metabolic and aesthetic outcomes. Programs tailored to individuals’ fat distribution profiles may improve both physiological health and patient motivation. Emphasizing adherence-friendly, home-based routines using bodyweight exercises or minimal equipment may further enhance program accessibility and effectiveness.

This study demonstrates that combining regional and general aerobic exercise yields superior benefits in reducing body fat and improving metabolic markers compared to either modality alone in obese women. The integrated approach not only enhances systemic lipolysis but also promotes regional adipose tissue responsiveness, leading to significant improvements in insulin sensitivity and body composition. While localized aerobic training contributes modestly when performed independently, its combination with whole-body aerobic exercise appears to create synergistic effects that overcome limitations of spot reduction.

These findings support the incorporation of tailored, multimodal aerobic programs in obesity management, particularly for targeting resistant fat depots and metabolic risk factors. Future investigations employing advanced imaging and molecular analyses are warranted to further elucidate the complex interplay between exercise modality, fat distribution, and metabolic health.

Authors' contributions

K.I. contributed to the conceptualization of the study, data collection, and manuscript writing. E.S. was involved in data analysis, manuscript drafting, and revision. M.T. contributed to the refinement of the research concept and the English editing of the manuscript. G.Z. participated in data section preparation and manuscript revision. All authors contributed to and approved the final version of the manuscript.

Transparency statement

Data are available for research purposes upon reasonable request to the corresponding author.

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Declaration of interest

The authors report no conflict of interest.

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