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Effects of a 24-Week Combined Exercise and Dietary Intervention on Metabolic, Hormonal, and Reproductive Outcomes in Women with Insulin Resistance and Polycystic Ovary Syndrome

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ABSTRACT

Background: Polycystic ovary syndrome (PCOS) is frequently accompanied by insulin resistance, which plays a central role in the development of metabolic disturbances, hormonal imbalance, and impaired reproductive function. Lifestyle modification is widely recommended; however, the effectiveness of combining structured exercise with individualized dietary intervention remains inadequately documented.

Objective: This study examined the impact of a 24-week supervised lifestyle intervention incorporating exercise training and dietary guidance on metabolic, hormonal, physical, and reproductive outcomes in women with PCOS and insulin resistance

Methods: In this randomized controlled trial, 66 women were assigned to an intervention group (exercise plus dietary counseling, n = 33) or a control group (exercise only, n = 33). Outcomes assessed at baseline, 12 weeks, and 24 weeks included HOMA-IR, androgen profile, body composition, lipid profile, physical fitness, menstrual regularity, and ovulation status. Data were analyzed using mixed-model repeated-measures ANOVA.

Results: Compared with the control group, the participants in the intervention group showed significantly higher changes in insulin resistance, with HOMA-IR reduced from 4.82 ± 1.25 to 2.45 ± 0.87 at 24 weeks ($p < 0.001$, η^2 .= 0.26).A rise in ovulation from 24.2% to 78.8% was observed in the intervention cohort when compared with 39.4 % in the control cohort ($p < 0.01$). Furthermore, significant reduction of serum total testosterone and FAI were observed with elevated SHBG concentrations.

Conclusions: A 24-week supervised program combining structured exercise and individualized dietary counseling effectively improves metabolic, hormonal, fitness, and reproductive outcomes in women with PCOS and insulin resistance.

Keywords: Polycystic Ovary Syndrome, Insulin resistance, Lifestyle intervention, Exercise and diet

Reproductive function.

Introduction

The most prevalent endocrine and metabolic condition in reproductive-aged women is polycystic ovary syndrome (PCOS), which impacts millions of women around the world and is presented by a heterogeneous set of various reproductive, metabolic, and psychological symptoms (1). It is diagnosed using the Rotterdam criteria, which must include at least two of the following: oligo- or anovulation, clinical or biochemical hyperandrogenism, and polycystic ovarian morphology on ultrasound, all with other related disorders excluded (2). Such clinical heterogeneity makes PCOS a highly complex and multifactorial condition, which calls for individualized management approaches. There are also long-term metabolic and psychologic implications of PCOS that are not necessarily linked to its reproductive manifestation. Women with this cause of disability have a greater prevalence of insulin resistance (IR), impaired glucose tolerance, type 2 diabetes mellitus (T2DM), dyslipidemia, and cardiovascular disease (CVD) (3). PCOS, also, has been associated with increased levels of anxiety, depression, and poor health-related quality of life, in many cases associated with unpleasant clinical manifestations including hirsutism, acne, and weight gain.

These varied manifestations highlight the systemic effects and health impact of PCOS on the general population. The insulin resistance is a core yet modifiable pathogenic process in PCOS. Compensatory hyperinsulinemia amplifies the stimulatory action of luteinizing hormone (LH) on ovarian theca cells in insulin-resistant

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phenotypes, stimulating excessive androgen production and an abnormal, disrupted follicular maturation (4). This creates a positive feedback process of dysfunction of endocrine and metabolic processes. Nevertheless, the extent and clinical significance of IR vary among phenotypes, meaning that the aetiology of IR is complex and polygenic, based on environmental and lifestyle determinants.

Globally, PCOS affects approximately 6–20% of women of reproductive age, depending on diagnostic criteria and study population (5). Regional data from the Middle East and North Africa (MENA) suggest prevalence rates at the higher end of global estimates (6). Middle East and North African regional statistics indicate prevalence rates at the higher end of these global estimates (6).

PCOS is a multifactorial disorder, with contributing factors including genetic predisposition, rapid lifestyle transitions, physical inactivity, and high consumption of refined carbohydrates and saturated fats. In Jordan, a cross-sectional study conducted among university-aged women using the Rotterdam criteria reported a prevalence of 16.8% (7). In contrast, national estimates indicate that 4.1% of women aged 15–49 years have been formally diagnosed with PCOS, representing a 31% increase since 1990 (8).

The level of public awareness has also been found to be low, with less than half of women showing sufficient awareness of the symptoms and risk factors associated with PCOS (9). The results highlight the necessity of preventive and therapeutic intervention measures in the community (10). Treatment of PCOS has been largely symptomatic, with a focus on menstrual, infertility, hirsutism, or metabolic abnormalities depending on personal priorities. Pharmacological interventions comprise combined oral contraceptives to control cycles, anti-androgens to treat hyperandrogenism, and insulin-sensitising agents, e.g., metformin, to treat metabolic dysfunction (1). Pharmacological treatments, however, are not always consistent and limited by the presence of side effects and compliance issues. On this basis, the international clinical guidelines suggest lifestyle modification as the initial, base intervention among women with PCOS who are overweight or obese (11).

This approach has a direct impact on the underlying metabolic pathologies of the syndrome, especially insulin resistance and its cardiometabolic consequences. Behavioral change, exercise, and dietary lifestyle modification are the main pillars of managing PCOS. It has been shown that even a small amount of weight loss of 5-10% of total body weight is a valuable step to insulin sensitivity, androgen reduction, restoration of ovulatory cycles, and fertility (12). Meta-analyses also provide support that dietary and exercise interventions are more effective than control conditions in enhancing insulin resistance, cardiometabolic and ovulation rates (13). Recent updates to international evidence-based PCOS guidelines and systematic reviews continue to support these findings, emphasising the effectiveness of structured lifestyle interventions in improving insulin sensitivity and reproductive outcomes (14).

PCOS is prevalent among women aged 20 to 44 years, indicating a global frequency of 6-20% contingent upon diagnostic criteria and sample size (5). Regional statistics indicate that prevalence rates in the Middle East and North Africa (MENA) are higher than those in the rest of the world (6). The factors may be a genetic predisposition, a fast change of lifestyle, the lack of physical activity, and the consumption of high-refined-carbohydrate and saturated-fat diets. Reports have indicated a prevalence of 16.8 percent among women of university-going age in a cross-sectional study on Jordan using the Rotterdam criteria (7), and nationally, 4.1 percent of women aged 15-49 years are diagnosed with PCOS, a 31 percent rise since 1990 (8). It has also been found that there is poor public awareness, as less than half of women showed sufficient knowledge of the symptoms and risk factors of PCOS (9). These results indicate that there is an urgent necessity to develop preventive and therapeutic community-based interventions.

The treatment of PCOS is mostly symptom-oriented, whereby it focuses on menstrual abnormalities, infertility, hirsutism, or metabolic disturbances depending on the priorities. Pharmacological therapies may be combined oral contraceptives to control the cycles, anti-androgens to treat hyperandrogenism, and insulin-sensitizing medications like metformin to treat metabolic dysfunction (1). Nevertheless, pharmacological interventions are known to be inconsistent in their results, and also they are constrained by side effects and compliance factors. In this regard, international clinical recommendations suggest lifestyle change as the primary, background treatment for women with PCOS with overweight or obesity (11). Such a treatment targets the underlying metabolic imbalances of the syndrome, specifically, the insulin resistance and associated cardiometabolic risk factors. Lifestyle changes that involve dietary and physical activities and behavior modification will continue to be the foundation of PCOS management. It has been proved that a small weight loss of 5-10 percent of the total body weight is greatly beneficial in increasing insulin sensitivity, lowering androgen levels, restoring ovulatory cycles, and improving fertility (12). Meta-analyses also affirm that dietary and exercise interventions are better in enhancing insulin resistance, cardiometabolic parameters, and ovulation rates than the control conditions (13).

Exercise also has well-reported positive effects on mental health in a healthy and a clinical population (15, 16). Recent meta-analytical evidence further indicates that structured aerobic and resistance exercise programmes significantly improve metabolic and hormonal profiles in women with PCO (17). The evidence is emerging that women with PCOS who engage in exercise have less depressive mood and better health-related quality life than their non-exercise counterparts (18, 19).

Even when there is overwhelming evidence, the methodological constraints continue to exist in current trials. Most of them have been temporary, non-supervised, and general advice-based with no structured follow-up, resulting in intermittent adherence and lack of consistent results (20). Moreover, there exists a wide range of studies that vary in composition and advancement of dietary and exercise ingredients, which restrain comparability and setting out the best procedures. These loopholes provide the necessity of the well-designed, structured, and personalized lifestyle programmes since they must be based on the metabolic peculiarities and cultural background of the target groups.

The present study aimed to address these gaps by evaluating a structured, supervised lifestyle programme that integrates two evidence-based components: Exercise training is a progressive combination of aerobic and resistance exercise designed to enhance

cardiovascular fitness, increase skeletal muscle mass, and improve insulin sensitivity (21). Dietary modification; a personalized low-glycemic-index (GI) dietary plan with moderate protein intake to reduce postprandial insulin spikes, enhance satiety, and preserve lean mass (22).

This synergistic design was hypothesized to produce greater improvements in metabolic, reproductive, and psychological outcomes than general lifestyle advice alone. This prospective, randomized, double-blinded, controlled clinical trial examined the effects of a six-month supervised exercise and dietary intervention in women with PCOS. The main aim of this study was to assess the effectiveness of the intervention on insulin resistance as measured by the Homeostatic Model Assessment of Insulin Resistance (HOMA-IR). Secondary outcomes included the evaluation of menstrual regularity, ovulatory activity, hyperandrogenism, anthropometric measurements, lipid profile, and quality of life. The hypothesis was that the participants in the tailored intervention group would show much better improvements in all primary and secondary outcomes than the participants in the active control group of general health education.

The results of this study could be used to design reproducible, evidence-based lifestyle guidelines in the management of PCOS among the Middle Eastern groups. This study will improve metabolic and reproductive health outcomes in women with PCOS by developing a structured and culturally modified lifestyle intervention. The results of the study can enhance non-pharmacological management systems and guide local clinical practices that will eventually enhance the quality of life and the health of the affected women in the long term.

Materials and Methods

Study Design

This study was designed as a 6-month prospective, randomized, double-blind, and controlled clinical trial. Its main purpose was to determine the effectiveness of an extensive, monitored lifestyle change intervention of simultaneous aerobic and resistance exercise, combined with an individualised low-glycemic-index dietary programme, on insulin resistance and related metabolic, reproductive, and psychological outcomes in women with polycystic ovary syndrome (PCOS).

The sampling was done in the outpatient units of the Gynecology, Endocrinology, and Physical Therapy departments at the Flora Medical Center, Irbid, Jordan, between May 2024 and March 2025. The Institutional Review Board of Jerash University gave an ethical clearance (Approval No. 3\1\2025\2026). The protocol was in line with the 2013 amendment of the Declaration of Helsinki, and informed consent was provided by all participants before enrolment in writing.

Study Population

Participants

Participants were recruited from outpatient clinics and through local advertisements and social media platforms. All potential participants underwent clinical evaluation, laboratory investigations, and transvaginal or pelvic ultrasound to confirm the diagnosis of PCOS according to the Rotterdam 2003 criteria, which requires at least two of the following three features after exclusion of other aetiologias: oligo- or anovulation, clinical and/or biochemical hyperandrogenism, and polycystic ovarian morphology (≥12 follicles measuring 2–9 mm in diameter or ovarian volume >10 mL). Additional inclusion criteria were a BMI between 25 and 35 kg/m² (classified as overweight or class I obesity), a sedentary lifestyle (<150 minutes of structured physical activity per week during the past three months), and Willingness to comply with dietary and exercise protocols and attend regular follow-up visits.

Participants were excluded if they were pregnant or lactating. Diabetes mellitus, thyroid dysfunction, hyperprolactinemia, or Cushing's syndrome. Use of hormonal contraceptives, antiandrogens, or insulin-sensitizing agents within the preceding three months. Cardiovascular, hepatic, or renal disease. Orthopedic or neuromuscular conditions limiting exercise participation. Psychiatric disorders or substance abuse.

Sample Size Estimation

The determination of the sample size was done through G*Power (version 3.1.9.7) with the primary endpoint being the change in HOMA-IR between the groups with time. With 80 percent power, 0.05 0.25 (assuming a medium effect size), and a 0.05 (assuming 2-way repeated-measures ANOVA; group x time), one would need 60 participants (30 in each group). The number of participants recruited was 70 in order to take into consideration the expected non-compliance or attrition rate of 15.

Randomization and Blinding

After baseline tests, the participants were randomly assigned to either the Intervention Group (structured, supervised diet modification and exercise therapy) or the Control Group (exercise therapy alone) at a 1:1 ratio using a computer-generated randomization list. Concealment of allocation was done using sequentially numbered, opaque and sealed envelopes made by an independent researcher who was not part of data collection and analysis procedures. Blinding was maintained in two stages: (a) the participants were told that they will be given a lifestyle change and exercise programme but not which form of change in intensity and supervision; (b) the outcome evaluators were independent and not told which group to assess.

Interventions

Intervention Group

The participants of the intervention group were provided with a detailed, monitored lifestyle change programme that combined a systematic physical activity programme with personalised nutrition education. The programme was delivered under the supervision of the certified physiotherapists and dietitians in order to make sure that the programme would be safe, encourage compliance, and lead to gradual development. The exercise program was based on the recommendations of the American College of Sports Medicine (ACSM) on the exercise of overweight and insulin-resistant individuals and lasted six months (24weeks) during which participants exercised three times per week on non-consecutive days.

Every 60-minute session was made up of a 10-minute warm -up that included light aerobic exercise (e.g., treadmill walking or

stationary biking at 40-50% of maximum heart rate (HRmax)) and dynamic stretching of the major muscle groups. The aerobic training session was 25 minutes of moderate-intensity continuous exercise at 60-75% HRmax, which is measured by heart-rate monitors and the Borg Rating of Perceived Exertion (RPE 12-14). To maintain the exercise and prevent the overuse injury, aerobic modalities were alternated between treadmill walking, cycling, and elliptical training.

The resistance training segment, lasting 20 minutes, involved a circuit of six to eight exercises, which focused on large muscles (leg press, chest press, late pulldown, shoulder press, seated row, abdominal crunch, and leg curl). The starting intensity was established at 50% of one-repetition maximum (1RM) and increased by 5–10% every four weeks, depending on the participant tolerance and reassessment of the participants. The exercises were maintained between two and three sets of 10-12 repetitions separated by rest periods of 60-90 seconds. Sessions were completed by a 5 -minute cool-down, including soft stretching and breathing activities to aid in recovery and avoid post-exercise hypotension. Each session was done under professional supervision to check the vital signs and technique used and avoid injury. Each session was counted and those who attended at least 80 % of the sessions were considered to be adherent to the intervention protocol.

Dietary Intervention

All the participants were given individualized nutrition plans that were drawn up by a registered clinical dietitian, depending on the energy needs and metabolism. The amount of calories was prescribed to cause an energy deficit of between 500 and 750 kcal per day as compared to the estimated energy maintenance needs, which was calculated using the Mifflin-St Jeor equation and modified to the level of physical activity. The macronutrient content included 45-50% carbohydrates, preferably of low-glycemic-index (GI < 55) sources, 20-25% protein (approximately 1.0–1.2 g/kg body weight per day), and 25-30% fat, with saturated fat intake being less than 7% of total energy consumption. The meal patterns were organized according to three main meals and two snacks every day, separated by 3 - 4 hours to maintain stable energy levels and appetite management.

This diet focused on foods that are rich in nutrients, such as whole grains, legumes, fruits, vegetables, lean meat, and low-fat dairy, and limited refined sugars, sweetened beverages, and processed foods. Hydration was promoted, aiming at 1.5–2.0 liters of fluid consumption per day. Participants were educated and given feedback and encouraged to adhere to the therapy through a series of bi-weekly nutritional counseling sessions. Adherence to the dietary guidelines was checked monthly through the food diary (3 days), and the results were analyzed using the Nutri Survey software (EBIS pro, Germany) to assess the intake of nutrients and the quality of the diet.

Control Group

The control group participants only participated in the structured exercise programme and received no dietary counseling or dietary changes. The exercise programme used by the control group was similar to that of the intervention group, and it was based on the American College of Sports Medicine (ACSM) guidelines for overweight and insulin-resistant persons. It included a six-month (24-week) supervised programme that was conducted 3 times per week on non-consecutive days, and each session was about sixty minutes. The sessions began with a ten-minute warm-up consisting of light aerobic activity and dynamic stretching, followed by twenty-five minutes of moderate-intensity aerobic exercise at 60-75% of the maximum heart rate (HRmax), and concluded with twenty minutes of resistance training that included six to eight exercises targeting the major muscle groups, starting at an initial intensity of 50% of one repetition maximum (1RM) with progressive loading. At the end of every session, there was a five-minute cool-down of light stretching and breathing exercises. Each session was conducted under the guidance of certified physiotherapists to ensure technique, safety, and compliance. Regular attendance was noted where participants were required to attend at least 80% of the sessions as being in compliance with the exercise programme.

Outcome Measures

All the measurements were taken at the baseline (week 0), mid-intervention (week 12), and post-intervention (week 24). The participants were asked to starve for at least 10 hours, avoid caffeine and intense exercise 24 hours before the test, and arrange the tests at the early follicular phase (days 2-5 of the menstrual cycle).

Primary Outcome

The measure of insulin resistance entailed the Homeostatic Model Assessment of Insulin Resistance (HOMA-IR). Venous blood samples were fasted between 8:00 and 9:00 a.m. after an overnight fast of at least 10 hours. A standardized enzyme-linked immunosorbent assay (ELISA) was used to measure the concentration of serum glucose, and an enzyme colorimetric assay was used to measure the level of fasting insulin. The HOMA-IR index was estimated based on the following formula: HOMA-IR = [Fasting insulin (μU/mL) × Fasting glucose (mg/dL)] / 405. The measurements were done at three time points, namely, baseline (pre-intervention), 12 weeks after the intervention (mid-intervention), and the end of the 24-week intervention to observe the temporal variation in insulin sensitivity (23).

Secondary Outcomes

Reproductive Function

Reproductive activity was measured as the menstrual regularity and ovulation status, which are the key indicators of endocrine and ovarian functions in insulin-resistant women and polycystic ovary syndrome. Menstrual regularity was measured as the number of menstrual cycles that took place in the 6-month intervention, which is a strong proxy of ovulatory cyclicity and hormonal balance. Biochemical confirmation of ovulation was done by measuring mid-luteal serum progesterone; a value above 3 ng/mL was considered successful ovulation. The methodological technique is the gold standard of ovulation verification due to its high specificity and sensitivity (>90%) (24). Measures of hormones were conducted at baseline and at 12 and 24 weeks of the intervention.

Hormonal Profile

Quantitative measurements of hormonal parameters, i.e., serum total testosterone, dehydroepiandrosterone sulphate (DHEAS), and sex hormone-binding globulin (SHBG) were per-

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Hormonal Profile

Quantitative measurements of hormonal parameters, i.e., serum total testosterone, dehydroepiandrosterone sulphate (DHEAS), and sex hormone-binding globulin (SHBG) were performed using standardized chemiluminescent immunoassays. Such assays show great sensitivity, accuracy, and reproducibility in the endocrine research setting. Then the Free Androgen Index (FAI) was determined (Total Testosterone / SHBG) x 100 and is a good surrogate measure of bioavailable androgens. This index correlates well with clinical manifestations of hyperandrogenism and it has good test-retest reliability and internal consistency in populations with hormonal dysregulation (25, 26). The baseline, 12-week, and 24-week intervention period assessments were conducted.

Body Composition Indices and Anthropometric.

Standardized protocols were used to take anthropometric measurements in order to make them accurate and reproducible. Measuring weight and height was done using calibrated scales up to the nearest 0.1 kg and 0.1 cm, respectively; body mass index (BMI) was calculated as weight (kg)/height (m^2), which is a well-established measure of general adiposity. It was measured on the standard anatomical sites at the waist and hip with non-elastic tape to give credible indices of central fat distribution with inter-rater reliability (ICC > 0.95). Body composition was measured using bioelectrical impedance analysis (BIA, Tanita MC-980MA, Japan), which is a non-invasive, valid and reliable technique of estimating fat mass, lean mass and body fat percentage where the correlation

coefficients were found to be greater than 0.9 compared to that of dual-energy X-ray absorptiometry (DXA) (27, 28). The evaluation was also carried out at baseline, 12 weeks and the end of the 24-week intervention.

Physical Fitness Assessment

Two key indicators that were used to assess physical fitness included cardiorespiratory fitness and muscular strength. The cardiorespiratory fitness was measured by using maximal oxygen uptake (VO_2 max), which was estimated indirectly using a submaximal treadmill test based on the modified Bruce protocol, which is a valid and reliable means of measuring aerobic capacity in both clinical and exercise environments (31).

Muscular strength was assessed by estimating the one-repetition maximum (1RM)

For both the leg press and the chest press exercises based on the standardized prediction equations that were obtained through the multiple-repetition testing (32, 33). The assessments were conducted at baseline, 12 weeks and following the 24 weeks of intervention to follow the improvements in aerobic endurance and muscular performance that can be attributed to the exercise and lifestyle program.

Statistical Analysis

All statistical analyses were conducted using IBM SPSS Statistics version 28 (IBM Corp., Armonk, NY, USA) to evaluate changes across multiple outcome variables at three time points: baseline (pre-intervention), mid-intervention (12 weeks), and post-intervention (24 weeks). The primary variables of assessment included insulin resistance (HOMA-IR), reproductive function (menstrual regularity and ovulation status), hormonal profile (serum total testosterone, DHEAS, SHBG, and Free Androgen Index), anthropometric and body composition measures (body weight, BMI, waist-to-hip ratio, fat mass, lean mass, and body fat percentage), lipid profile (total cholesterol, HDL-C, LDL-C, and triglycerides), and physical fitness indicators (VO^2 max and 1RM for leg and chest press). Data were expressed as mean ± standard deviation (SD) for continuous variables and frequency (%) for categorical variables. The Shapiro–Wilk test was used to confirm data normality, and between-group baseline comparisons were performed using independent t-tests or chi-square tests. A two-way mixed-model repeated-measures ANOVA (time × group) assessed changes within and between groups over the study period, followed by Bonferroni-adjusted post hoc tests for pairwise comparisons. Effect sizes were calculated using partial eta squared (η^2), categorized as small (0.01–0.06), medium (0.06–0.14), or large (>0.14). Statistical significance was set at $p < 0.05$.

Results

Participant Characteristics

The enrolment of participants was done randomly, and 66 women were selected as the intervention group (n = 33) or the control group (n = 33). Every participant underwent baseline testing, and 59 (89.4 0) of them completed the 24-week intervention period, and any missing data was handled using an intention-to-treat methodology with the last observation carried forward strategy. The baseline showed no statistically significant differences between groups in terms of age, anthropometric indices, hormonal profile, insulin resistance, lipid parameters, or physical fitness ($p>0.05$) Table1.

Metabolic and Hormonal Parameters

Table 2 summarizes the changes in metabolic and hormonal outcomes across time points. A significant time × group interaction was found for HOMA-IR ($p < 0.001$, $\eta^2 = 0.26$), indicating greater improvement in insulin sensitivity in the intervention group compared with the control group. Mean HOMA-IR values declined progressively from baseline (4.82 ± 1.25) to 24 weeks (2.45 ± 0.87) in the intervention group, while only minimal reduction occurred in controls. In the same manner, serum total testosterone and the Free Androgen Index (FAI) had a statistically significant decrease throughout the intervention ($p<0.001$), whereas sex hormone-binding globulin (SHBG) levels increased at the same time. These hormonal changes are also reflective of more improved androgen control, as the effect sizes ($\eta^2 = 0.20$-024) are large, thus supporting the beneficial impacts of the exercises and dietary modification programme.

Table 1. Baseline Characteristics of Participants.

Variable	Intervention Group (n = 33)	Control Group (n = 33)	p-value
Age (years)	28.6 ± 4.8	29.1 ± 5.2	0.74
BMI (kg/m²)	31.4 ± 3.2	31.0 ± 3.5	0.65
Waist–Hip Ratio	0.89 ± 0.05	0.88 ± 0.06	0.58
HOMA-IR	4.82 ± 1.25	4.77 ± 1.31	0.88
Total Testosterone (ng/mL)	0.78 ± 0.24	0.80 ± 0.23	0.79
SHBG (nmol/L)	38.5 ± 7.9	39.2 ± 8.3	0.72
FAI	2.06 ± 0.48	2.03 ± 0.51	0.83
Total Cholesterol (mg/dL)	205.4 ± 28.1	207.6 ± 30.4	0.79
VO^2 max (mL/kg/min)	29.8 ± 4.2	30.1 ± 4.5	0.83

— Data are presented as mean ± standard deviation (SD).

— Independent samples t-test was used to compare baseline characteristics between the intervention and control groups.

— Abbreviations: BMI = Body Mass Index; HOMA-IR = Homeostatic Model Assessment of Insulin Resistance; SHBG = Sex Hormone–Binding Globulin; FAI = Free Androgen Index; VO^2 max = Maximal Oxygen Uptake.

— $p < 0.05$ was considered statistically significant.

— Data are presented as mean ± standard deviation (SD).

Table 2. Changes in Metabolic and Hormonal Parameters Over Time.

Variable	Time	Intervention	Control	Time (p)	Group (p)	Time × Group (p)	η^2 (Effect Size)
HOMA-IR	Baseline	4.82 ± 1.25	4.77 ± 1.31	<0.001	0.004	<0.001	0.26
	12 weeks	3.29 ± 0.98	4.42 ± 1.20				
	24 weeks	2.45 ± 0.87	4.10 ± 1.15				
Total Testosterone (ng/mL)	Baseline	0.78 ± 0.24	0.80 ± 0.23	<0.001	0.031	<0.001	0.22
	12 weeks	0.62 ± 0.18	0.75 ± 0.20				
	24 weeks	0.54 ± 0.15	0.72 ± 0.19				
SHBG (nmol/L)	Baseline	38.5 ± 7.9	39.2 ± 8.3	<0.001	0.040	<0.001	0.20
	12 weeks	45.8 ± 8.0	40.3 ± 8.4				
	24 weeks	51.6 ± 8.8	41.2 ± 8.6				
FAI	Baseline	2.06 ± 0.48	2.03 ± 0.51	<0.001	0.021	<0.001	0.24
	12 weeks	1.46 ± 0.42	1.91 ± 0.46				
	24 weeks	1.12 ± 0.38	1.84 ± 0.45				

- Data are presented as mean ± standard deviation (SD).
- Statistical analysis was performed using two-way mixed-model ANOVA
- η^2 (eta-squared) represents the effect size, where 0.01 = small, 0.06 = medium, and ≥0.14 = large effect.
- Abbreviations: HOMA-IR = Homeostatic Model Assessment of Insulin Resistance; SHBG = Sex Hormone–Binding Globulin; FAI = Free Androgen Index.
- P< 0.05 was considered statistically significant.

Anthropometric and Body Composition Change

The 24-week intervention resulted in significant changes in body weight, body fat percentage, and BMI Table 3. The time interaction with groups was statistically significant on all the parameters measured ($p < 0.001$) with significant effect sizes ($\eta\eta^2 =$ 0.23-0.28). Intervention group members reported an average weight loss of 7.4 kg and a 5.8% decrease in body fat percentage, but the control group had had a small change. Waist and hip circumference alterations reflected these trends, which showed positive change in total and central adiposity. These findings highlight the cumulative impact of dietary control combined with exercise on weight management, in addition to the effects of exercise alone.

Lipid Profile and Physiological Fitness.

Table 4 shows that total cholesterol, low-density lipoprotein cholesterol, and triglyceride concentrations decreased significantly over time in both groups; however, the interaction between time and group was statistically significant in the intervention group ($p < 0.001$). Only in the intervention group was there a significant increase in high-density lipoprotein cholesterol ($p < 0.001$, $\eta^2 =$ 0.21).which indicated the possible improvement of lipid-metabolic processes. In physical fitness, maximal oxygen uptake and muscular strength increased in both cohorts, but the magnitude of increase was significantly higher in the intervention group (VO^2 max: +5.8 mL/kg/min; 1RM leg press: +19.3 kg). These findings support the hypothesis that the dietary control combined with structured physical activities had better cardiometabolic and fitness benefits compared to exercise alone.

Outcomes of Reproductive Functions.

Reproductive outcomes are presented in Table 5, demonstrating no significant baseline differences between groups in menstrual irregularities or ovulation rates ($p > 0.05$), while after 24 weeks the intervention group showed significantly greater improvements in menstrual regularity (2.1 ± 1.0 to 5.0 ± 1.2 menses) and ovulation rate (24.2% to 78.8%) compared with the control group (2.9 ± 1.1 menses and 39.4% ovulation), with large effect sizes ($p < 0.001$; $\eta^2 =$ 0.21-0.23), indicating a substantial enhancement in reproductive function attributable to the combined lifestyle intervention.

Table 3. Anthropometric and Body Composition Changes.

Variable	Time	Intervention	Control	Time (p)	Group (p)	Time × Group (p)	η^2
Body Weight (kg)	Baseline	81.5 ± 7.8	80.8 ± 8.1	<0.001	0.012	<0.001	0.28
	12 weeks	77.3 ± 7.0	80.2 ± 7.9				
	24 weeks	74.1 ± 6.5	79.5 ± 7.8				
BMI (kg/m²)	Baseline	31.4 ± 3.2	31.0 ± 3.5	<0.001	0.018	<0.001	0.23
	12 weeks	29.8 ± 3.1	30.9 ± 3.4				
	24 weeks	28.7 ± 3.0	30.9 ± 3.3				
Body Fat %	Baseline	38.9 ± 4.6	38.5 ± 4.9	<0.001	0.009	<0.001	0.27
	12 weeks	35.8 ± 4.1	38.2 ± 4.8				
	24 weeks	33.1 ± 3.9	37.9 ± 4.7				

- Data are expressed as mean ± standard deviation (SD).
- Two-way mixed-model ANOVA was applied to assess the main effects of time (baseline, 12 weeks, and 24 weeks), group (intervention vs. control), and their interaction (time × group) on body composition parameters.
- η^2 (eta-squared) denotes effect size
- Abbreviations: BMI = Body Mass Index.
- $p < 0.05$ was considered statistically significant.

Table 4. Lipid and Fitness Outcomes.

Variable	Time	Intervention	Control	Time (p)	Group (p)	Time × Group (p)	η^2
Total Cholesterol (mg/dL)	Baseline	205.4 ± 28.1	207.6 ± 30.4	<0.001	0.045	<0.001	0.19
	12 weeks	192.3 ± 26.5	206.0 ± 29.7				
	24 weeks	182.5 ± 25.3	203.2 ± 28.7				
HDL-C (mg/dL)	Baseline	42.6 ± 5.8	42.3 ± 6.0	<0.001	0.031	<0.001	0.21
	12 weeks	46.3 ± 6.0	42.7 ± 6.1				
	24 weeks	49.8 ± 6.2	43.2 ± 6.1				
LDL-C (mg/dL)	Baseline	132.7 ± 23.5	133.9 ± 24.0	<0.001	0.038	<0.001	0.20
	12 weeks	121.6 ± 22.8	132.5 ± 23.8				
	24 weeks	113.4 ± 22.0	130.8 ± 23.6				
VO^2 max (mL/kg/min)	Baseline	29.8 ± 4.2	30.1 ± 4.5	<0.001	0.008	<0.001	0.29
	12 weeks	33.2 ± 4.6	30.8 ± 4.4				
	24 weeks	35.6 ± 4.8	31.8 ± 4.3				
1RM Leg Press (kg)	Baseline	78.5 ± 12.4	79.2 ± 13.1	<0.001	0.010	<0.001	0.25
	12 weeks	89.1 ± 13.0	81.5 ± 13.3				
	24 weeks	97.8 ± 13.6	83.4 ± 13.2				

- Data are presented as mean ± standard deviation (SD).
- Two-way mixed-model ANOVA was conducted to examine the main effects of time (baseline, 12 weeks, and 24 weeks), group (intervention vs. control), and their interaction (time × group) on cardiometabolic and fitness variables.
- η^2 (eta-squared) indicates the effect size
- Abbreviations: HDL-C = High-Density Lipoprotein Cholesterol; LDL-C = Low-Density Lipoprotein Cholesterol; VO^2 max = Maximal Oxygen Uptake; 1RM = One-Repetition Maximum.
- P< 0.05 was considered statistically significant.

Table 5. Reproductive Function Outcomes Across Time.

Variable	Time	Intervention Group	Control Group	Time (p)	Group (p)	Time × Group (p)	η^2
Menstrual Regularity (number)	Baseline	2.1 ± 1.0	2.2 ± 1.1	<0.001	0.018	<0.001	0.23
	12 weeks	3.4 ± 1.1	2.5 ± 1.0				
	24 weeks	5.0 ± 1.2	2.9 ± 1.1				
Ovulation Rate	Baseline	24.2% (8/33)	27.3% (9/33)	<0.001	0.027	<0.001	0.21
	12 weeks	54.5% (18/33)	33.3% (11/33)				
	24 weeks	78.8% (26/33)	39.4% (13/33)				

- Data are presented as mean ± standard deviation (SD) for continuous variables and as percentage (n/total) for categorical variables.
- Two-way mixed-model ANOVA was used to assess the main effects of time (baseline, 12 weeks, and 24 weeks), group (intervention vs. control), and their interaction (time × group) on menstrual and ovulatory outcomes.
- η^2 (eta-squared) represents the effect size
- $p < 0.05$ was considered statistically significant.

Discussion

The current research examined the impacts of 24 weeks of supervised lifestyle change, which involves organized exercise and personalized dietary counseling, on women with insulin resistance on metabolic, hormonal, anthropometric, reproductive, and physical fitness data. The results revealed that this combined method led to significant gains in all spheres in comparison to the control group that exercised. This intervention notably decreased insulin resistance, in this case in the form of HOMA-IR, which verifies that a combination of physical activity and diet changes are synergistic with regard to glucose regulation. These findings are in line with the findings of other researchers who found out that a combination of caloric restriction and regular aerobic and resistance exercise is better than exercise alone in increasing the insulin sensitivity (34, 35). Similar improvements in insulin resistance and body weight have been reported in recent meta-analyses evaluating both lifestyle -based and pharmacological interventions, reinforcing the clinical relevance of targeting metabolic dysfunction in PCOS (36). The degree of HOMA-IR change in our cohort is clinically significant, moving the participants away from the insulin-resistant and close to normal range, and this could lower the risks of type 2 diabetes in the long-term (37).

There was an important decrease in total testosterone and free androgen index and an augmentation of SHBG in the intervention group. This hormonal change indicates better control of androgens, which is essential in ovulatory processes and reproductive wellness of insulin-resistant women with PCOS-like phenotypes. The results confirm the previous data that indicate that lifestyle changes have the potential to normalize hyperandrogenism through decreasing the peripheral insulin resistance that regulates estrogen production by the ovaries (38, 39).

Intervention group participants showed marked reduction of their weight, BMI and waist to hip ratio and body fat percentage, with maintenance of the lean mass. These modifications bring out the cumulative advantages of nutritional restraint to the structured exercise. Lean mass retention in weight loss is also significant in the preservation of both the basal metabolic rate and functional capacity (40, 41). Central adiposity decreases also probably added to the

enhancement of insulin sensitivity and androgen profiles, which is in line with predetermined relationships between visceral fat, metabolic dysfunction, and reproductive health (42).

Another outcome of the combined intervention was the significant improvements in lipid profile, such as the decrease in the total cholesterol and LDL-C and the increase in HDL-C. These modifications are associated with an improved cardiometabolic health and are clinically applicable in the context of decreasing atherosclerotic risk in the long-term period (43). The small gains that were noted with the exercise-only group also lend credence to the argument that dietary intervention is essential in regulating the lipid metabolism.

The cardiorespiratory fitness assessed as VO^2 max showed significant evolution in the intervention group, and it was accompanied by the enhancement of muscular strength. These are improvements that are aligned with previous studies that have revealed that combined aerobic and resistance training increases cardiovascular efficiency and functional capacity, especially when coupled with weight loss and increased body composition (44, 45). The extent of change in the VO^2 max and 1RM is evidence of the possibility of lifestyle changes in enhancing metabolic and physical fitness.

It is interesting to note that the measures of menstrual regularity and ovulation rates in the intervention group improved significantly. The mean number of menses increased from 2.1 to 5.0 over six months, and ovulation occurred in nearly 79% of participants, compared with only 39% in the control group. The findings show that there is a close relationship between better metabolic health and reproductive performance. It is possible that the restoration of ovulatory cycles was through reductions in insulin resistance and androgen levels, which is also in line with findings that lifestyle changes can be used as the first-line treatment of reproductive dysfunction in women with metabolism disturbances (46, 47). Some of the mechanisms can be used to explain the observed improvements. Loss of weight lowers adipose-derived inflammatory cytokines and enhances insulin sensitivity, consequently decreasing the production of ovarian androgen. Modifications to aerobic exercise improve glucose assimilation and mitochondrial efficiency, whereas resistance exercise maintains lean mass, which also plays a role in metabolic control. These metabolic and hormonal changes are facilitated by dietary changes, such as low-caloric consumption and -glycemic index consumption of carbohydrates.

Our results support and generalize other previous studies in PCOS and insulin-resistant women. As an example, Moran et al. (2003) have shown that lifestyle intervention can improve ovulation and androgen profiles, and Bacchi et al. (2013) have shown that the combination of diet and exercise interventions have similar metabolic and lipid changes. The current research focuses on the cumulative impact of diet, since exercise per se provided statistically significant but significantly less impressive results (39, 45). These findings support the need to consider lifestyle interventions as an entire approach to insulin resistance, hyperandrogenism, and reproductive dysfunction management. To achieve the best metabolic, hormonal and reproductive outcomes, clinicians need to focus on structured programs incorporating exercise as well as customized dietary counseling. The cardiovascular and musculoskeletal health could also have some long-term benefits, which may be concluded due to the improvements in fitness and body composition.

The strengths of this study are the randomized controlled study, the monitored interventions, and the overall evaluation of the metabolic, hormonal, anthropometric, fitness, and reproductive aspects. The limitations are the moderate size of the sample and the use of HOMA-IR as a surrogate of insulin sensitivity instead of the gold-standard clamp studies. Moreover, the improvements should be evaluated with longer-term follow-up. The next area of research is to determine the sustainability of these benefits over time and to determine whether such interventions can be effective in other populations, such as adolescents or women with known PCOS. The mechanism of action through which metabolic improvements and reproductive restoration are connected to each other can also be studied further.

Conclusion

The 24 weeks of supervised lifestyle intervention that incorporated supervised physical exercise and personalized nutritional advice produced remarkable changes in metabolic parameters, body composition, endocrine regulation, physical fitness, and reproductive outcomes in women with insulin resistance and related polycystic ovary syndrome (PCOS). The findings highlight the superiority of combined lifestyle changes as a main treatment method to meet metabolic and reproductive dysfunctions.

Conflict of Interests

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

Data Sharing Statement

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

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