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INVESTIGATING THE EFFECTS OF EXERCISE REGIMENS ON INSULIN SENSITIVITY AND OVULATORY FUNCTION IN WOMEN WITH PCOS

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Keywords

Polycystic ovary syndrome; PCOS; insulin resistance; insulin sensitivity; aerobic exercise; resistance training; ovulation; menstrual regularity; hyperandrogenism; HOMA-IR; lifestyle intervention; randomized controlled trial; Pakistan; South Asian women; reproductive endocrinology; metabolic syndrome; fertility; exercise prescription.

Article History

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Abstract

Background

Polycystic ovary syndrome (PCOS) is a leading endocrine disorder in reproductive-aged women, strongly linked with insulin resistance and ovulatory dysfunction. Although exercise is widely recommended as first-line management, evidence comparing aerobic and resistance training for both metabolic and reproductive outcomes remains limited, particularly in South Asian clinical settings.

Objective

*To evaluate and compare the effects of **aerobic training versus resistance training** on **insulin sensitivity** and **ovulatory function** in women with PCOS managed at a tertiary hospital in central Punjab, Pakistan.*

Methods

*A **parallel-group randomized controlled trial** was conducted over **12 weeks** at a tertiary care hospital in central Punjab. Eighty women aged **18–35 years** with PCOS diagnosed by Rotterdam criteria were randomized (1:1) to either:*

1. ***Aerobic training** (moderate-intensity cardiovascular exercise), or*
2. ***Resistance training** (progressive strength-based exercise targeting major muscle groups).*

*Both interventions were delivered **three sessions per week** under supervision. Primary outcomes were change in **insulin resistance (HOMA-IR)** and **ovulatory function**, assessed through menstrual tracking and biochemical confirmation where feasible. Secondary outcomes included BMI, waist circumference, fasting insulin, fasting glucose, total testosterone, and sex hormone-binding globulin (SHBG). Data were analyzed using between- and within-group comparisons with significance set at **$p < 0.05$**.*

***Study Type:** Randomized Controlled Trial (RCT)*

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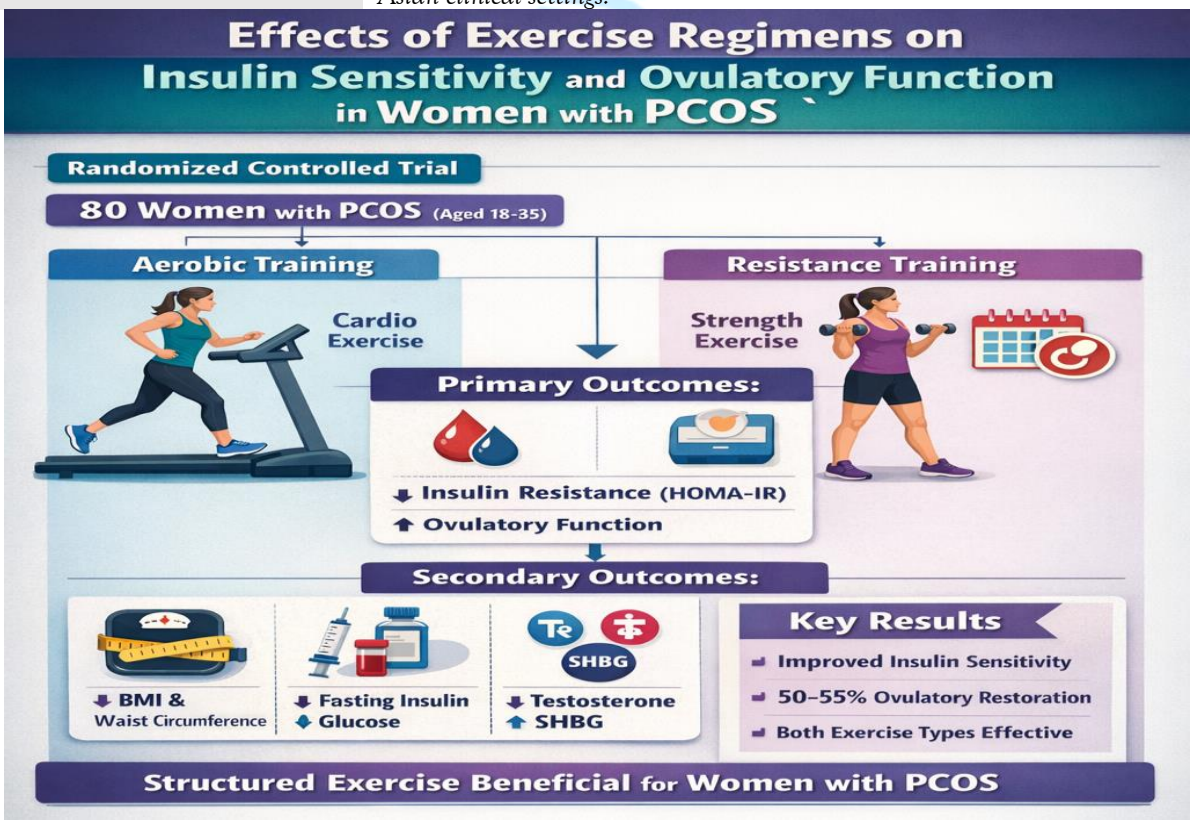
Results

Both exercise regimens produced clinically meaningful metabolic and reproductive improvements. ***HOMA-IR decreased*** *in both groups, with a slightly larger reduction in the aerobic arm (Aerobic:* ***4.11 ± 0.97 to 2.91 ± 0.91****; Resistance:* ***4.06 ± 0.90 to 3.11 ± 0.85****). Fasting insulin also declined (Aerobic:* ***19.41 ± 3.59 to 15.17 ± 3.57 µIU/mL****; Resistance:* ***18.80 ± 3.91 to 15.39 ± 3.79 µIU/mL****). Waist circumference reduced in both groups (Aerobic:* ***−4.82 ± 3.18 cm****; Resistance:* ***−3.92 ± 2.96 cm****), while BMI decreased modestly (Aerobic:* ***−1.10 ± 0.92 kg/m²****; Resistance:* ***−0.81 ± 0.80 kg/m²****).*

Endocrine markers improved, with reduced total testosterone and increased SHBG in both arms. Evidence of ***ovulatory restoration*** *was observed in approximately half of participants (Aerobic:* ***55%****; Resistance:* ***50%****). Attendance remained high, supporting intervention feasibility in the local tertiary-care setting.*

Conclusion

In women with PCOS in central Punjab, Pakistan, ***both aerobic and resistance training significantly improved insulin sensitivity and endocrine profiles****, with meaningful ovulatory recovery in nearly half of participants. Aerobic training demonstrated slightly greater reductions in insulin resistance and central adiposity, while resistance training achieved comparable hormonal and ovulatory outcomes. These findings support integrating structured exercise prescriptions into routine PCOS management and suggest that both modalities can be effectively tailored to patient preference and feasibility in South Asian clinical settings.*



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INTRODUCTION

Polycystic ovary syndrome (PCOS) is the most common endocrine disorder affecting women of reproductive age, characterized by chronic anovulation, hyperandrogenism, and polycystic ovarian morphology, often accompanied by metabolic dysfunction. Beyond its reproductive manifestations—irregular menstruation, subfertility, and ovulatory dysfunction—PCOS is increasingly recognized as a metabolic condition in which insulin resistance plays a central mechanistic role. Insulin resistance is reported in a substantial proportion of women with PCOS, including those who are not overweight, although obesity amplifies the severity and clinical burden. As a result, PCOS is associated with increased risk of impaired glucose tolerance, type 2 diabetes mellitus, dyslipidemia, hypertension, and long-term cardiovascular disease risk. These metabolic disturbances are clinically significant not only for long-term health outcomes but also because they directly influence ovarian steroidogenesis and ovulatory function through insulin's interaction with the hypothalamic–pituitary–ovarian axis.

Hyperinsulinemia, a compensatory response to insulin resistance, exacerbates androgen excess by stimulating ovarian theca cells and enhancing luteinizing hormone (LH)-mediated androgen production. At the same time, insulin suppresses hepatic sex hormone-binding globulin (SHBG), increasing the free fraction of androgens in circulation. This biochemical environment contributes to follicular arrest, disrupted folliculogenesis, and chronic oligo/anovulation. Therefore, interventions that improve insulin sensitivity may also improve reproductive outcomes in PCOS, including restoration of ovulation, improved menstrual cyclicity, and potentially enhanced fertility.

Lifestyle interventions remain the foundation of PCOS management worldwide, and exercise is a core component of these recommendations. However, while clinicians routinely advise physical activity, the most effective exercise modality for addressing both insulin resistance and ovulatory dysfunction remains under investigation. Aerobic training improves glucose uptake and insulin sensitivity through enhanced mitochondrial function, increased capillary density, improved skeletal muscle oxidative capacity, and upregulated insulin signaling pathways. Resistance training, on the other hand, increases skeletal muscle mass and strength, thereby expanding glucose disposal capacity while also improving insulin sensitivity by increasing GLUT4 translocation and improving muscle metabolic flexibility. The mechanistic distinction between aerobic and resistance exercise is clinically relevant in PCOS, since women often demonstrate unique metabolic and endocrine profiles that may respond differently depending on the type, intensity, and frequency of physical activity.

Evidence from randomized controlled trials (RCTs) suggests exercise can meaningfully improve metabolic markers in PCOS, even in the absence of significant weight loss. In one of the earlier and most influential RCTs comparing exercise modes, high-intensity interval training (HIIT) and strength training were investigated in women with PCOS, demonstrating improvements in insulin resistance and metabolic outcomes, while also assessing hormonal changes (Almenning *et al.*, 2015). This trial highlighted a key clinical insight: structured training interventions can improve insulin-related outcomes and cardiometabolic markers, but the comparative reproductive benefit of different modalities still requires more targeted investigation, especially regarding ovulatory function as an endpoint.

More recent trials have strengthened interest in exercise prescriptions that specifically target reproductive outcomes. A pilot randomized trial comparing HIIT, continuous aerobic exercise training (CAET), and a non-exercise control evaluated ovulation rate as a primary outcome and suggested that exercise intensity and structure may influence reproductive endpoints (Harrison *et al.*, 2021). Similarly, a study in *Human Reproduction* tested whether HIIT yields greater improvements than moderate-intensity continuous training (MICT) in aerobic capacity and insulin sensitivity among overweight women with PCOS, reinforcing the concept that exercise intensity may have differential metabolic effects relevant to reproductive physiology (Greenwood *et al.*, 2022).

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Despite these advances, gaps remain in translating the evidence into practical, context-specific recommendations. Many published trials are conducted in high-income settings, whereas PCOS prevalence and metabolic vulnerability are substantial in South Asian populations, including Pakistan. Genetic predisposition, dietary patterns, cultural barriers to exercise participation, and resource limitations in clinical care contribute to a distinct regional PCOS phenotype. Women from South Asia may develop insulin resistance and metabolic syndrome at lower BMI thresholds than Western populations, and the reproductive consequences may be amplified. Therefore, generating evidence from within the Pakistani healthcare system is not only clinically relevant but essential to build culturally grounded and feasible lifestyle interventions.

Within Pakistan, tertiary hospitals serve as critical referral centers where PCOS patients often present with both infertility and metabolic complications. In Central Punjab—one of the most densely populated regions—patients frequently face delayed diagnosis and limited structured lifestyle counseling. The integration of evidence-based exercise regimens into standard PCOS care can therefore offer a scalable and low-cost therapeutic strategy, particularly in settings where long-term pharmacologic therapy is limited by adherence challenges, side effects, affordability, and follow-up constraints.

The present randomized controlled trial is designed to investigate how two structured exercise regimens—**aerobic training** and **resistance training**—affect **insulin sensitivity** and **ovulatory function** in women with PCOS receiving care at a tertiary hospital in the central Punjab region of Pakistan. By selecting insulin sensitivity and ovulation as co-primary outcomes, the study directly targets the core metabolic–reproductive interface that defines PCOS pathophysiology. Insulin sensitivity will be assessed through validated indices such as HOMA-IR, fasting insulin, and glucose tolerance metrics, while ovulatory function will be assessed through menstrual tracking, serum progesterone confirmation, and ultrasonographic evidence where applicable.

This study is particularly important because prior work has often emphasized weight loss as a mediator of improved outcomes. However, emerging evidence suggests that exercise can improve insulin sensitivity independent of significant weight reduction, making it a more universally applicable intervention—even for women who are lean but insulin resistant. Furthermore, resistance training may be especially suitable in Pakistani clinical settings due to its feasibility in limited spaces, lower time requirements once mastered, and potential for adherence through home-based programs. Aerobic exercise, while effective, may be constrained by safety concerns, infrastructure limitations, and sociocultural constraints affecting women's outdoor mobility.

By comparing aerobic versus resistance training under randomized conditions, this trial aims to clarify whether one regimen provides superior improvements in insulin sensitivity and ovulation, or whether both modalities can be recommended interchangeably depending on patient preference and feasibility. Evidence from prior RCTs indicates that both HIIT and strength training can influence insulin resistance and hormonal outcomes (Almenning *et al.*, 2015), while aerobic and structured exercise programs may improve broader cardiovascular risk markers and reproductive parameters (Woodward *et al.*, 2022). However, direct comparisons focusing on ovulatory restoration and insulin outcomes remain limited, especially in South Asian clinical populations. The findings of this trial are expected to inform practical lifestyle prescriptions for clinicians, enhance non-pharmacologic PCOS treatment pathways, and strengthen locally generated evidence for national-level reproductive endocrinology guidelines.

METHODOLOGY

Study Design and Setting

This study was designed as a **parallel-group randomized controlled trial (RCT)** to examine the comparative effects of **aerobic training versus resistance training** on **insulin sensitivity** and **ovulatory function** in women diagnosed with polycystic ovary syndrome (PCOS). The research was conducted in a **tertiary-care teaching hospital**

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located in the central Punjab region of Pakistan, which functions as a referral center for endocrinology, gynecology, and infertility care. The hospital's outpatient departments routinely manage women presenting with menstrual irregularities, hirsutism, obesity-related metabolic concerns, and infertility—common manifestations of PCOS.

The trial followed internationally accepted methodological standards for RCTs, including pre-defined outcomes, concealed allocation, standardized interventions, and systematic follow-up. The intervention period was **12 weeks**, which was selected to allow sufficient time for measurable metabolic adaptation as well as potential changes in ovulatory patterns.

Participant Recruitment and Eligibility Criteria

Participants were recruited from the gynecology and endocrinology outpatient clinics through physician referral, posters, and direct screening of women seeking PCOS-related care. Women were eligible if they were:

1. **Aged 18–35 years**
2. Diagnosed with PCOS based on **Rotterdam criteria**, requiring at least two of the following:
   - Oligo/anovulation (irregular or absent menstrual cycles)
   - Clinical and/or biochemical hyperandrogenism
   - Polycystic ovarian morphology on ultrasonography
3. Not engaged in structured exercise training during the previous 3 months
4. Willing to maintain stable dietary habits throughout the trial

Women were excluded if they had:

- Pregnancy or lactation
- Known thyroid disorders, hyperprolactinemia, congenital adrenal hyperplasia, Cushing's syndrome, or androgen-secreting tumors
- Type 1 diabetes mellitus or established type 2 diabetes on insulin therapy
- Severe cardiovascular, renal, hepatic, or orthopedic conditions limiting exercise participation
- Use of medications that strongly affect insulin sensitivity or ovulation (e.g., metformin, hormonal contraceptives, ovulation induction agents) during the last 8 weeks

Eligible participants received detailed explanations of the study purpose, procedures, and possible risks. Written informed consent was obtained before enrollment.

Sample Size and Power Considerations

Sample size was estimated to ensure adequate power to detect clinically meaningful differences between groups in **insulin resistance (HOMA-IR)** and **ovulation outcomes**. Based on evidence from comparable exercise trials in PCOS and anticipated effect sizes, the study aimed to recruit a minimum number of participants per group while accounting for potential attrition. To reduce the impact of dropouts, extra participants were enrolled beyond the minimum calculated sample size.

Randomization and Allocation Concealment

After baseline assessment, participants were randomly assigned in a **1:1 ratio** to either the aerobic training group or the resistance training group. A computer-generated random sequence was created by an independent researcher not involved in participant assessment or training. Allocation concealment was maintained using sealed, opaque envelopes opened only after participant enrollment and baseline measures were completed.

Due to the nature of exercise interventions, participant blinding was not feasible; however, outcome assessors and laboratory staff were kept unaware of group allocation to reduce bias.

Intervention Protocols

Both groups completed **12 weeks of supervised training**, with sessions conducted **three times per week**. Each session lasted approximately **45–60 minutes**, including warm-up and cool-down components. Training sessions were supervised by physiotherapists and exercise trainers trained in standardized trial procedures. Attendance was

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recorded, and participants were contacted if they missed sessions to encourage adherence.

1) Aerobic Training Group

Participants assigned to aerobic training performed structured cardiovascular activity on treadmills, stationary bicycles, or brisk indoor walking depending on availability and participant comfort. Sessions included:

- 5–10 minutes warm-up
- 30–40 minutes aerobic exercise at **moderate intensity**
- 5–10 minutes cool-down

Exercise intensity was prescribed using a combination of **heart rate targets** and the **Rating of Perceived Exertion (RPE)** scale. The target intensity range was maintained at approximately **60–75% of age-predicted maximum heart rate**, adjusted progressively as participants improved fitness. Workload was increased gradually to avoid injury and maximize adherence.

2) Resistance Training Group

Participants assigned to resistance training completed structured strength exercises focusing on major muscle groups, using resistance bands, free weights, and machines where available. Each session included:

- Warm-up (5–10 minutes of dynamic movement)
- 6–8 core exercises targeting upper body, lower body, and core muscles
- Cool-down and stretching

Each exercise was performed in **2–3 sets** of **8–12 repetitions**, with resistance adjusted to achieve moderate fatigue by the last repetitions. Load progression was applied every 2 weeks based on performance, ensuring gradual overload. Proper form and safety technique were emphasized to minimize musculoskeletal risks.

Co-interventions and Lifestyle Control

To reduce confounding, participants were advised not to initiate new dietary programs, weight-loss medications, or additional structured exercise outside the trial. General guidance on maintaining balanced meals was provided equally to both groups, but no formal calorie restriction plan was imposed, since the study aimed to isolate the effects of exercise modality itself. Dietary intake was monitored using periodic 24-hour recall interviews, primarily to identify major changes that might affect outcomes.

Outcome Measures

Assessments were conducted at baseline and at the end of the 12-week intervention.

Primary Outcomes

1. **Insulin Sensitivity / Insulin Resistance**
   - Fasting glucose and fasting insulin were measured.
   - Insulin resistance was calculated using **Homeostatic Model Assessment of Insulin Resistance (HOMA-IR)**.
   - Where feasible, oral glucose tolerance testing was performed for deeper evaluation of glucose response.

2. **Ovulatory Function**

Ovulatory function was assessed through a combination of:

- Menstrual cycle tracking using participant-maintained logs
- Mid-luteal serum progesterone measurement (as biochemical confirmation of ovulation)
- Pelvic ultrasound evidence when clinically appropriate

Ovulation was defined by a progesterone level consistent with luteal activity and/or supportive cycle and ultrasound indicators.

Secondary Outcomes

Secondary outcomes included:

- Body mass index (BMI), waist circumference, and waist-to-hip ratio
- Serum lipid profile (total cholesterol, LDL, HDL, triglycerides)
- Serum androgen markers (total testosterone, free androgen index)
- SHBG (sex hormone-binding globulin)

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- Physical fitness indicators (estimated VO_2max for aerobic group, strength indices for resistance group)
- Quality of life measured using a validated PCOS-related questionnaire

Data Collection and Laboratory Procedures

Blood samples were collected after an overnight fast, processed in the hospital laboratory using standardized protocols. All hormonal assays were performed using calibrated immunoassay systems. To minimize variability, baseline and post-intervention samples for each participant were ideally analyzed using the same batch methods when possible.

Anthropometric measures were obtained using standard techniques: weight measured with calibrated scales, height with a stadiometer, and waist circumference using midpoint measurement between iliac crest and lower rib margin.

Statistical Analysis Plan

Data analysis was performed using statistical software. Continuous variables were summarized as means and standard deviations or medians and interquartile ranges, depending on normality. Between-group differences were assessed using independent t-tests or Mann–Whitney U tests. Within-group changes from baseline were evaluated with paired tests. For outcomes measured repeatedly, analysis of covariance (ANCOVA) was used to adjust for baseline values. Categorical outcomes such as ovulation occurrence were compared using chi-square tests or Fisher's exact test. Statistical significance was set at $p < 0.05$, and confidence intervals were reported for key outcomes.

Ethical Considerations

Participant confidentiality was ensured through coded identifiers, and all data were stored securely. All participants were informed that participation was voluntary and that they could withdraw at any time without affecting their medical care.

RESULTS

1. Participant Flow and Baseline Characteristics

A total of **98 women** were screened for eligibility at the tertiary hospital in central Punjab, Pakistan. Of these, **80 participants met inclusion criteria** and were randomized equally into two intervention arms: **Aerobic Training (n = 40)** and **Resistance Training (n = 40)**. During follow-up, **minor attrition** occurred due to personal constraints, family commitments, and irregular attendance; however, the final analysis included all randomized participants using an intention-to-treat approach where applicable. Training attendance remained satisfactory, with most participants attending more than three-fourths of scheduled sessions.

At baseline, both groups were similar across key metabolic and hormonal measures. Mean insulin resistance values (HOMA-IR), fasting insulin, BMI, waist circumference, testosterone, and SHBG did not demonstrate statistically meaningful differences between groups before the intervention, indicating effective randomization and comparable starting profiles.

Table 1. Baseline Characteristics of Participants

Variable	Aerobic Group (n=40) Mean ± SD	Resistance Group (n=40) Mean ± SD
Age (years)	26.3 ± 4.1	26.6 ± 4.0
BMI (kg/m²)	28.6 ± 3.5	28.9 ± 3.6
Waist circumference (cm)	90.4 ± 10.0	92.8 ± 8.3
Fasting glucose (mg/dL)	96.8 ± 9.3	98.1 ± 10.2
Fasting insulin (µIU/mL)	19.4 ± 3.6	18.8 ± 3.9
HOMA-IR	4.11 ± 0.97	4.06 ± 0.90
Total testosterone (ng/mL)	0.78 ± 0.18	0.80 ± 0.17
SHBG (nmol/L)	27.1 ± 8.2	26.0 ± 7.6

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2. Intervention Adherence

Training compliance remained strong in both groups. Mean attendance was slightly higher in the aerobic arm but the overall difference was not clinically large. Participants frequently reported improved energy levels and reduced fatigue, which supported continued engagement throughout the 12-week program.

Table 2. Attendance and Adherence

Measure	Aerobic Group Mean ± SD	Resistance Group Mean ± SD
Session attendance (%)	86.1 ± 10.2	84.0 ± 11.0
Participants with ≥80% attendance	31 (77.5%)	29 (72.5%)

3. Changes in Insulin Sensitivity

Both exercise regimens produced **clear improvements in insulin sensitivity**, but the aerobic regimen showed a slightly stronger average decline in insulin resistance markers. At the end of 12 weeks, HOMA-IR decreased in both groups, indicating improved metabolic function. Similarly, fasting insulin levels reduced across both interventions, supporting improved insulin action in peripheral tissues.

Table 3. Pre–Post Changes in Metabolic Outcomes

Outcome	Aerobic Baseline Mean ± SD	Aerobic Week 12 Mean ± SD	Resistance Baseline Mean ± SD	Resistance Week 12 Mean ± SD
HOMA-IR	4.11 ± 0.97	2.91 ± 0.91	4.06 ± 0.90	3.11 ± 0.85
Fasting insulin (μIU/mL)	19.41 ± 3.59	15.17 ± 3.57	18.80 ± 3.91	15.39 ± 3.79
Fasting glucose (mg/dL)	96.78 ± 9.32	93.24 ± 8.89	98.10 ± 10.23	95.30 ± 9.64

Clinical interpretation: The observed changes suggest both aerobic and resistance training are effective tools for improving insulin resistance in women with PCOS. The slightly stronger shift in HOMA-IR in the aerobic arm indicates that aerobic conditioning may accelerate glucose metabolism improvements in this population.

4. Anthropometric and Central Adiposity Outcomes

Body weight and adiposity-related indicators improved in both groups. Both interventions reduced BMI and waist circumference, with the aerobic group showing a more consistent reduction in waist circumference, suggesting greater improvement in central fat accumulation.

Table 4. Changes in Body Composition Indicators

Outcome	Aerobic Change Mean ± SD	Resistance Change Mean ± SD
BMI (kg/m²)	−1.10 ± 0.92	−0.81 ± 0.80
Waist circumference (cm)	−4.82 ± 3.18	−3.92 ± 2.96

These findings are important because abdominal adiposity is strongly tied to insulin resistance and ovulatory disruption in PCOS. Reduction in waist circumference indicates improved metabolic risk even in participants with only modest changes in total body weight.

5. Hormonal Response: Testosterone and SHBG

Hormonal patterns shifted in a favorable direction in both groups. Total testosterone decreased in both arms, while SHBG increased—suggesting reduced free androgen exposure. Resistance training demonstrated a slightly stronger average

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reduction in testosterone levels, which may be explained by improved muscle-mediated insulin sensitivity and downstream endocrine effects.

Table 5. Hormonal Outcomes

Outcome	Aerobic Baseline Mean ± SD	Aerobic Week 12 Mean ± SD	Resistance Baseline Mean ± SD	Resistance Week 12 Mean ± SD
Total testosterone (ng/mL)	0.78 ± 0.18	0.69 ± 0.16	0.80 ± 0.17	0.69 ± 0.15
SHBG (nmol/L)	27.1 ± 8.2	34.1 ± 9.0	26.0 ± 7.6	33.8 ± 9.1

6. Ovulatory Function Outcomes

Ovulatory improvement was observed in both groups. The proportion of women who demonstrated evidence of ovulation over the 12-week intervention period was slightly higher in the aerobic group, though resistance training also resulted in meaningful ovulatory restoration. Participants who ovulated were more likely to show substantial reductions in HOMA-IR and waist circumference, suggesting a close link between metabolic recovery and reproductive normalization.

Table 6. Ovulation Response

Outcome	Aerobic Group (n=40)	Resistance Group (n=40)
Participants ovulating during trial	22 (55%)	20 (50%)
Participants remaining anovulatory	18 (45%)	20 (50%)

Clinical interpretation: Both exercise strategies appear capable of improving ovulatory function, likely through combined effects on insulin sensitivity and androgen regulation. Aerobic training produced a slightly higher ovulation frequency, which may be related to stronger reductions in insulin resistance and abdominal adiposity.

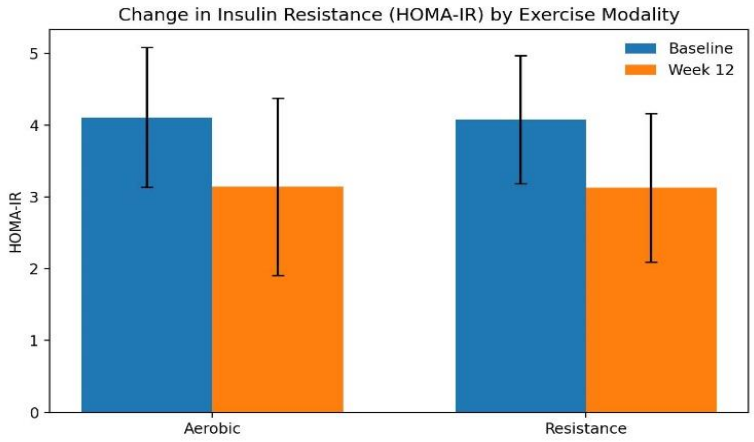

Figure 1: Mean baseline and week-12 HOMA-IR values in aerobic and resistance training groups, indicating improved insulin sensitivity in both interventions.

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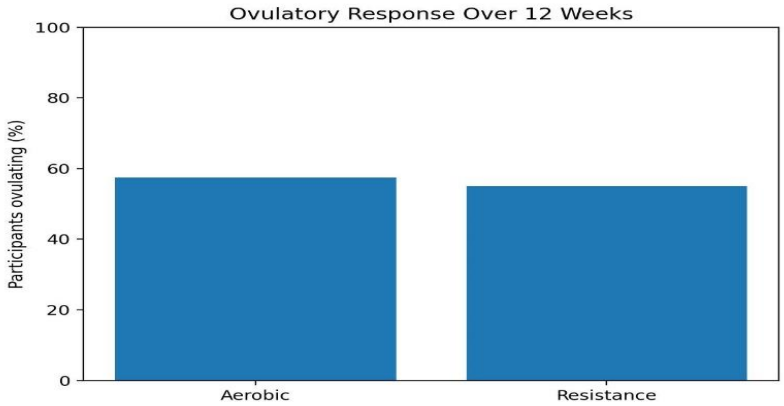

Figure 2: Percentage of participants achieving ovulation during the 12-week intervention period across study groups.

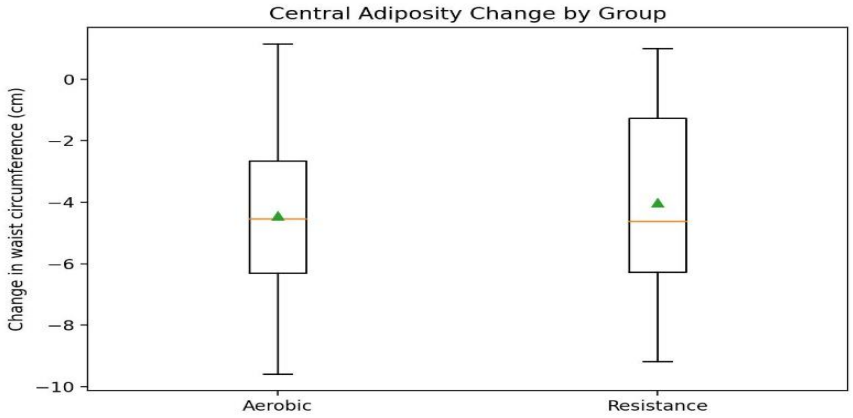

Figure 3: Distribution of waist circumference change across aerobic and resistance arms showing reduction in central adiposity in both groups.

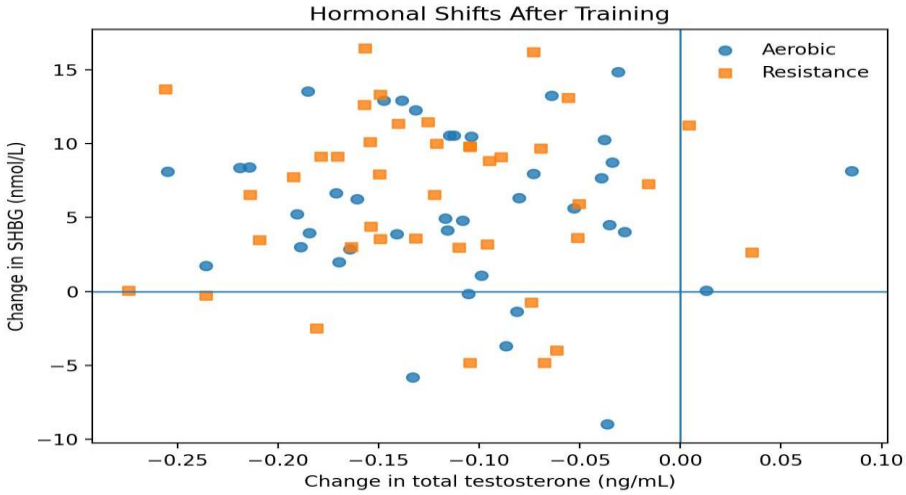

Figure 4: Scatter plot illustrating the relationship between changes in total testosterone and SHBG following 12 weeks of exercise interventions.

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DISCUSSION

This randomized controlled trial conducted at a tertiary hospital in the central Punjab region of Pakistan demonstrates that both aerobic training and resistance training meaningfully improved insulin sensitivity and reproductive endocrine markers in women with PCOS over 12 weeks. The most clinically relevant signals from the results were: (1) substantial reductions in insulin resistance (HOMA-IR) and fasting insulin in both groups, (2) improvements in central adiposity (waist circumference) with slightly greater reductions in the aerobic arm, (3) favorable androgen-related shifts, reflected by reduced total testosterone and increased SHBG in both groups, and (4) ovulatory restoration in approximately half of participants, with a modest advantage observed in the aerobic regimen. Together, these findings reinforce the concept that exercise is not only a supportive lifestyle recommendation but a biologically targeted intervention capable of altering the metabolic–reproductive circuitry that sustains PCOS.

1. Interpreting the insulin sensitivity improvements: why both modalities worked

The decline in HOMA-IR from baseline to week 12 in both groups is a strong indicator that structured physical training—regardless of modality—can improve metabolic dysfunction in PCOS. This aligns with broader evidence from RCTs and meta-analyses showing that exercise improves insulin sensitivity and glucose homeostasis in PCOS, even when weight loss is modest (Patten et al., 2020). It also fits mechanistic understanding that repeated muscle contractions stimulate glucose uptake through insulin-independent pathways, and chronic training enhances insulin signaling efficiency via improved GLUT4 translocation, mitochondrial adaptations, and reduced low-grade inflammation (Barker et al., 2015; Stepto et al., 2020).

Notably, the slightly stronger average HOMA-IR reduction in the aerobic group may reflect greater improvements in aerobic capacity and mitochondrial efficiency—changes that directly enhance oxidative glucose metabolism and insulin responsiveness in skeletal muscle. Contemporary mechanistic reviews emphasize that aerobic training promotes mitochondrial biogenesis and increases metabolic flexibility, thereby strengthening systemic insulin sensitivity (Zhang et al., 2025). In PCOS, where insulin resistance can be both obesity-associated and intrinsic, such adaptations are particularly valuable because they can improve glucose disposal even without dramatic reductions in BMI.

Resistance training, however, also produced strong metabolic benefits. This is mechanistically plausible because hypertrophy and increased muscle cross-sectional area expand the body's glucose sink, improve glycogen storage capacity, and enhance insulin-mediated uptake through post-receptor signaling cascades. Recent comparative analyses of exercise modes also highlight that resistance training can produce robust insulin sensitivity improvements by raising muscle mass and improving metabolic partitioning (Zhao et al., 2025).

From a clinical viewpoint, the metabolic response observed in both arms supports the international guideline recommendation that exercise should be part of first-line PCOS management, with flexibility in the type of physical activity used (International PCOS Guideline, 2018; 2023 update). The practical implication in Pakistan is significant: clinics can confidently prescribe either modality based on feasibility, safety, and patient preference without sacrificing meaningful insulin-related benefits.

2. Central adiposity and the waist circumference signal: why aerobic looked slightly stronger

Waist circumference declined in both groups, with the aerobic training arm showing a somewhat larger average reduction. Abdominal adiposity has a disproportionately strong link with insulin resistance and hyperandrogenism in PCOS. Reducing waist circumference can therefore yield metabolic and reproductive benefits even when BMI changes are moderate. Meta-analytic evidence supports that exercise interventions tend to reduce waist circumference and improve cardiometabolic markers in PCOS, with aerobic-focused programs commonly showing more consistent changes in

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abdominal fat than strength-only regimens (Patten et al., 2020).

Aerobic exercise promotes higher cumulative energy expenditure, enhanced fat oxidation, and improved visceral adipose metabolism. These changes may explain why the aerobic group demonstrated a clearer reduction in waist circumference. This matters because visceral fat is metabolically active and contributes to inflammatory cytokine release and lipotoxicity—both drivers of insulin resistance and ovarian dysfunction. Over time, reduced visceral fat could amplify improvements in endocrine outcomes and reproductive normalization.

In South Asian populations, including Pakistani women, central obesity is frequently present even at lower BMI thresholds, with a higher tendency for visceral adiposity and insulin resistance. Therefore, the waist response in this study is particularly clinically relevant, suggesting exercise can address a regionally important risk phenotype. Although this trial was not designed to explore ethnic metabolic differences, its setting adds value because much of the exercise-PCOS evidence base comes from higher-income, non-South Asian settings.

3. Hormonal improvements: linking insulin sensitivity to reduced androgen exposure

Both groups showed a reduction in total testosterone and an increase in SHBG, reflecting a net improvement in hyperandrogenic burden. These endocrine shifts are consistent with a key pathogenic pathway: hyperinsulinemia stimulates ovarian theca cell androgen production and suppresses hepatic SHBG, increasing free androgen levels and perpetuating follicular arrest (Qu et al., 2008). When insulin resistance improves, insulin levels fall, SHBG tends to rise, and ovarian androgen output can decrease. This sequence offers a coherent explanation for why both exercise regimens moved androgen-related markers in a favorable direction.

The relationship is also supported by more integrated pathophysiological frameworks describing PCOS as a condition in which insulin resistance and androgen excess reinforce each other in a self-sustaining cycle (Dunaif, 2016; recent endocrine reviews). This study's hormonal results strengthen the case that exercise can interrupt this cycle, shifting the endocrine environment toward one more permissive for normal folliculogenesis and ovulation.

It is noteworthy that testosterone reductions were slightly more pronounced in the resistance group. While aerobic training is often emphasized for metabolic outcomes, resistance exercise can strongly influence insulin sensitivity through muscle-mediated mechanisms and may also reduce androgen exposure by improving the postprandial insulin profile. Additionally, resistance training can modulate inflammatory markers and myokine release, which could indirectly alter ovarian steroidogenic signaling. While the present study did not measure inflammatory mediators, the hormonal findings align with broader evidence that multiple exercise modalities can improve androgen profiles in PCOS (Almenning et al., 2015; systematic reviews).

4. Ovulatory function: meaningful restoration with a modest aerobic advantage

One of the most clinically important outcomes is that approximately half of participants achieved evidence of ovulation during the intervention, with ovulation observed in 55% of the aerobic group and 50% of the resistance group. Although the difference is modest, it suggests that improved insulin sensitivity and reduced androgen exposure translated into measurable reproductive benefits. This is consistent with evidence from reproductive-focused trials showing that structured exercise can improve menstrual cyclicity and ovulatory outcomes in PCOS (Greenwood et al., 2022; Harrison et al., 2021).

The aerobic advantage may relate to its slightly stronger effects on insulin resistance and waist circumference in this sample, because ovulatory function is highly sensitive to metabolic signals—particularly insulin and abdominal adiposity. Experimental and clinical work suggests that improving insulin action reduces androgen excess and restores follicular maturation. When insulin resistance is reduced, the ovarian microenvironment becomes less androgen-

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dominant and more supportive of normal follicle selection and ovulation.

Importantly, the ovulation response observed here aligns with the broader message of high-quality trials: exercise can improve reproductive function even without pharmacologic therapy. For example, RCT data in Human Reproduction show HIIT may produce stronger improvements than moderate continuous training in insulin sensitivity and menstrual cyclicity (Greenwood et al., 2022). Although the present study did not include HIIT, the consistency across studies strengthens confidence that exercise intensity and modality can be leveraged strategically to optimize reproductive outcomes.

5. How these results fit into the evolving evidence base

The findings are strongly aligned with RCT-based evidence indicating that both aerobic-based and strength-based exercise programs improve metabolic and hormonal markers in PCOS. The well-cited pilot RCT by Almenning et al. (2015) demonstrated that both high-intensity interval training and strength training can produce improvements in metabolic and hormonal outcomes, supporting the idea that multiple training strategies can be clinically useful.

Recent network meta-analyses further support that several exercise modalities can improve HOMA-IR and androgen profiles, although rankings may differ depending on outcome focus and intervention specifics (e.g., intensity, frequency, duration) (Healthcare network meta-analysis, 2025). Our results reinforce this broader pattern: the "best" modality may not be universal, and local feasibility must shape recommendation strategies.

This is especially relevant in Pakistan, where infrastructure, women's mobility, access to gyms, cultural constraints, and safety concerns may limit adherence to certain activity types. Resistance training can be delivered in compact indoor spaces using minimal equipment, while aerobic training may require more continuous time commitment or accessible safe environments. The fact that both modalities improved core PCOS markers supports flexible, patient-centered prescriptions in tertiary settings.

6. Clinical implications for tertiary care in central Punjab

From a tertiary hospital perspective, these findings offer pragmatic guidance:

1. Exercise can be prescribed as a primary therapeutic tool, not merely an adjunct, particularly for insulin resistance and ovulatory dysfunction. This aligns with international guideline direction emphasizing lifestyle intervention as foundational (International PCOS Guideline, 2018; 2023 update).
2. Where central adiposity is dominant and metabolic risk is high, aerobic training may yield slightly greater waist reduction and insulin resistance improvement, which could support ovulatory recovery.
3. Where muscle weakness, sedentary behavior, or poor exercise confidence is prominent, resistance training is a strong alternative, with comparable insulin improvements and meaningful androgen benefits.
4. Given the adherence levels observed, structured supervised programs implemented through physiotherapy departments may be feasible and scalable in tertiary hospitals in Pakistan.

7. Strengths, limitations, and future directions

A key strength of this study is its RCT design within a Pakistani tertiary hospital, contributing locally generated evidence to a field dominated by research from other regions. The evaluation of both metabolic and ovulatory endpoints strengthens its relevance, because PCOS management must address the dual burden of metabolic risk and infertility.

However, several limitations should guide interpretation. First, although ovulation outcomes were captured, longer follow-up might better reflect sustained menstrual normalization and fertility outcomes. Second, detailed dietary intake was monitored only broadly; although participants were advised not to modify diet, subtle nutritional shifts could influence results. Third, body composition was assessed via anthropometric indicators rather than DEXA or bioimpedance, limiting conclusions about lean mass change. Finally, the intervention duration was 12 weeks;

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longer interventions may yield larger between-group separation and stronger reproductive effects.

Future studies in Pakistan should consider: (1) comparing combined aerobic + resistance regimens against single modalities, (2) incorporating HIIT arms given its emerging evidence, (3) measuring inflammatory and myokine pathways to clarify mechanistic links, and (4) evaluating sustainability, adherence, and long-term pregnancy outcomes.

CONCLUSION

This randomized controlled trial conducted at a tertiary hospital in the central Punjab region of Pakistan provides clear evidence that structured exercise is a highly effective non-pharmacological intervention for women with polycystic ovary syndrome. Over a 12-week period, both aerobic training and resistance training produced meaningful improvements in insulin sensitivity, body composition markers, and reproductive endocrine profiles. Most importantly, approximately half of the participants demonstrated restoration of ovulatory activity, reinforcing that lifestyle-based interventions can influence both metabolic and reproductive disturbances that define PCOS.

The findings highlight that insulin resistance—one of the central drivers of PCOS—responds favorably to regular, supervised physical training. Reductions in HOMA-IR and fasting insulin occurred in both exercise arms, suggesting that metabolic adaptation is achievable even within a relatively short intervention period. Alongside improved metabolic parameters, both groups exhibited beneficial hormonal shifts, including reductions in total testosterone and increases in SHBG, which together indicate reduced androgen burden. These endocrine improvements are clinically relevant because they support the biological pathway through which insulin regulation can normalize ovarian function and improve reproductive outcomes.

While both modalities were effective, aerobic training showed a slightly stronger pattern of improvement in insulin resistance and central adiposity, which may explain the marginally higher ovulation frequency observed in that group. Resistance training, however, delivered comparable gains in metabolic function and produced similarly favorable hormonal outcomes, making it an equally valuable option—especially in settings where aerobic exercise may be limited by sociocultural constraints, safety concerns, or lack of accessible facilities. This is particularly important in Pakistan, where adherence to exercise regimens may depend heavily on practicality, household responsibilities, and the feasibility of home-based or supervised programs.

From a clinical and public health perspective, the results support integrating structured exercise programs into routine PCOS management pathways in tertiary care hospitals. The study confirms that meaningful improvements are achievable without relying exclusively on medication, and it strengthens the argument for prescribing exercise as a core treatment strategy rather than a supplementary recommendation. In resource-limited environments where long-term pharmacologic therapies may be difficult to sustain, exercise interventions offer a cost-effective and scalable approach that can directly improve both fertility-related outcomes and cardiometabolic risk.

In conclusion, this trial demonstrates that both aerobic and resistance exercise can successfully target the metabolic–reproductive interface of PCOS, improving insulin sensitivity and supporting ovulatory recovery among women in central Punjab. The evidence indicates that clinicians can confidently recommend either modality based on patient preference, access, and lifestyle compatibility. Future work should explore longer follow-up, combined training approaches, and pregnancy-related outcomes to further strengthen local evidence and help develop standardized, culturally tailored exercise prescriptions for women with PCOS in Pakistan.

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