Abstract:

Introduction: Polycystic ovarian syndrome (PCOS) is prevalent among women, impacting health and quality of life. The present study aimed to investigate the effect of adding whole-body vibration (WBV) to the traditional treatment of PCOS.

Material and methods: Forty-six women diagnosed with PCOS, aged 20 to 35 years, with BMI 25-29.9 kg/m², were randomly divided into two equal groups. The study group followed an iso-caloric, low-glycemic diet and performed aerobic exercises in addition to WBV, and the control group followed an iso-caloric, low-glycemic diet and performed aerobic exercise only (n = 23 each). Treatment lasted for eight weeks, three sessions per week. BMI, waist-hip ratio (WHR), and LH/FSH ratio were assessed pre- and post-treatment. Insulin resistance was assessed by HOMA-IR (Homeostatic Model Assessment for Insulin Resistance) pre- and post-treatment.

Results: Significant decreases in weight, BMI, HOMA-IR, and LH/FSH ratio were noted between the two time points (before and after-treatment) in both groups (p < 0.05). However, WHR only showed a significant decrease in the study group (p < 0.05). Compared to the control group, the study group showed a significant reduction in weight (-8.08 kg vs. -4.39 kg, p = 0.0009), BMI (-2.99 kg/m² vs. -1.6 kg/m², p = 0.004), WHR (-0.05 vs. -0.018, p = 0.009), HOMA-IR (-1.54 vs. -0.77, p = 0.03), and LH/FSH ratio (-0.53 vs. -0.5, p = 0.02) after eight weeks of treatment.

Conclusions: Adding WBV to aerobic exercise appears to have favourable outcomes for patients with PCOS.

Keywords: exercise, insulin, polycystic ovary syndrome, vibration

Effect of whole-body vibration on insulin resistance in polycystic ovarian syndrome: A randomized controlled trial


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Introduction

The most common condition affecting endocrine function among women is polycystic ovary syndrome (PCOS), with rates ranging from 4% to 20% [1-2]. The precise etiology of this condition remains largely undetermined; however, insulin resistance (IR) may be a primary factor, with about 75% of individuals diagnosed with PCOS also exhibiting IR [3]. PCOS is believed to derive from an excess of androgens, which encourages the accumulation of fat around the abdomen and visceral organs, resulting in the development of IR and increased insulin levels. This, in turn, stimulates the ovaries and adrenal glands to produce higher levels of androgens. This pathological cycle, involving IR, excessive insulin production, and elevated androgen levels, coupled with dysfunction in the hypothalamic-pituitary axis, culminates in further ovarian impairment, potentially causing anovulation and infertility [4,5]. Additionally, it is associated with long-term metabolic conditions like type 2 diabetes mellitus, heart-related diseases, mood disturbances, and disordered eating, which in turn lower women’s quality of life [6].

Although conventional treatments for PCOS have primarily targeted fertility issues and hormonal regulation, a key factor in the etiology of this condition is IR. Addressing this factor has yielded remarkable efficacy in certain clinical scenarios, diminishing the reliance on expensive assisted reproductive methods [7]. The primary therapeutic approach for PCOS is based on lifestyle modification, such as dietary and exercise interventions. Diets with a low glycemic index (GI), as opposed to those with a high GI, have been linked to improvements in IR measured by Homeostatic Model Assessment for Insulin Resistance (HOMA-IR), fasting insulin, fasting glucose, and the free androgen index. They have also been found to decrease total and low-density lipoprotein (LDL) cholesterol, triglyceride, and total testosterone levels, as well as waist circumference, while leaving weight and HDL cholesterol unchanged [8].

Regular exercise has been known to enhance insulin sensitivity. However, metabolic syndrome patients find it challenging to stick to traditional exercise because of their higher body mass, musculoskeletal restrictions, and diminished motivation; they also tend to have lower physical fitness brought on by time constraints. One promising alternative for helping patients to overcome these restrictions may be whole-body vibration exercise (WBVE) [9].

WBVE is a contemporary method that involves the use of vibration of a specific frequency and amplitude, within safe ranges, which is carried out on a designated platform. Evidence indicated that WBVE is an effective approach to enhance muscular strength and flexibility, intensifying neurological stimulation, improving blood flow, and reducing pain perception and the friction caused by different types of tissue, thus promoting faster tissue healing and building tendon and bone strength. It also takes less training time and movement execution than traditional exercise [10].

Multiple studies and systematic reviews show that WBVE has successfully improved body fat mass among women after menopause [11], and a study by Deng [12] found a WBVE training program to reduce body fat percentages among obese college students. Additionally, Reis-Silva et al. [13] report that patients with metabolic syndrome demonstrated improved body composition and decreased waist circumference after completing a six-week WBVE program, and Liu et al. [14] propose that WBVE administration is a promising treatment for individuals who suffer from central obesity and IR. However, no study appears to have investigated its effect on women with PCOS.

Also, as WBVE takes less training time and movement execution than traditional exercise [10], it may be a favorable option for patients with PCOS to overcome their most reported barriers, viz. fatigue and lack of time, fear of injury, and physical limitations [15]; indeed, there is a need to finding a way that addresses these barriers while improving the patient’s condition. The present study is the first such study to investigate the effect of WBVE on IR in PCOS females. We hypothesized that WBVE could be a time-efficient solution that addresses these barriers while decreasing IR which is considered the root cause of PCOS. Therefore, this study aimed to investigate the effect of WBVE on IR in females with PCOS.

Materials and methods

Study design

The study was performed as a randomized, controlled clinical trial.

Ethics approval statement

Before starting, the study was approved by the ethical committee of the Faculty of Physical Therapy, Cairo University (No: P.T.REC/01/003460). It followed the CONSORT statement and the guidelines of the Declaration of Helsinki for conducting human research. The study was conducted from March 2022 to October 2023. Participants were informed about the study’s objectives, nature, and benefits, and that they were free to discontinue participation at any time without giving a reason. Each participant was required to sign a written form of consent before starting the study. The study was registered at the Clinical Trials Registry (Registry ID: NCT05215223).
Recruitment and Randomization

Initially, 55 women with PCOS were referred to the study by a gynecologist. Of these, nine were disqualified from participation; this group included four who declined to participate and five who did not meet the inclusion criteria. Therefore, forty-six subjects joined the study and were allocated randomly to two groups by a computer-generated block randomization program (Figure 1).

The inclusion criteria comprised the following: (1) virgin at the time of the study; (2) diagnosed with PCOS by a gynecologist according to the Rotterdam PCOS diagnostic criteria; (3) a HOMA-IR value greater than 2.5; (4) an LH/FSH ratio greater than 1; (5) sedentary, not engaged in physical training for the previous three months before the study, i.e. weekly physical activity of < 600 MET minutes/week, as indicated by the international physical activity questionnaire; (6) age from 20 to 35 years, (7) BMI of 25 to 29.9 kg/m², and (8) stable body weight / not following a diet plan for weight loss in the previous three months [16,17].

The exclusion criteria comprised the following: (1) presented with any cardiometabolic conditions (such as hypertension, diabetes mellitus, or cardiovascular diseases), cancers, or other endocrine disturbances (for example, hyperprolactinemia or hypothyroidism), or abnormalities in the adrenal glands; (2) had received hormonal therapies in the three months preceding the study; (3) had undergone any other treatments related to PCOS; (4) current use of weight loss medications (like orlistat).

The participants were questioned about their menstrual history, covering cycle frequency, duration, amount, and regularity, as well as any medical or hormone-based therapies undertaken in the previous six months. The data was recorded in a data-collecting sheet.

The 46 patients with PCOS were randomly assigned into either a control group, who received diet + aerobic exercise (n = 23), or a study group, who received diet + aerobic exercise + WBV (n = 23). The assignment was performed using the Statistical Package for Social Sciences (SPSS) for Windows, version 25 (IBM SPSS Inc, Chicago, IL). The randomization codes were securely stored in locked, non-transparent envelopes with sequence numbers to conceal the allocation. Randomization was performed by an evaluator who had no involvement in either the evaluation or therapeutic interventions. None of the participants exited the study after being randomized.

Once randomized, those in the control group adhered to an iso-caloric low-glycemic diet. They performed moderate-intensity aerobic exercise, consisting of treadmill walking, for three weekly sessions for eight weeks. In contrast, those in the study group received the same iso-caloric low-glycemic diet and aerobic exercise as the control group, along with WBV for three weekly sessions for eight weeks. Qualified physical therapists administered both aerobic exercise and WBV sessions (Table 1).

Tab. 1. Schedule of enrollment, intervention, and assessment (SPIRIT)

<table>
<thead>
<tr>
<th>Participant characteristics</th>
<th>Enrollment</th>
<th>Allocation</th>
<th>T1</th>
<th>T2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inclusion and exclusion criteria</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Assessment</td>
<td></td>
<td></td>
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<tr>
<td>Homa IR</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weight &amp; BMI</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>WHR</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
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<tr>
<td>FSH/LH Ratio</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
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<tr>
<td>Interventions</td>
<td></td>
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</tr>
<tr>
<td>Iso-caloric low glycemic diet</td>
<td></td>
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<tr>
<td>Aerobic exercise</td>
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<tr>
<td>WBV</td>
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</tr>
</tbody>
</table>

SPIRIT- Standard Protocol Item: Recommendations for Intervventional Trials, T1- pre-treatment assessment, T2- post-treatment assessment BMI- body mass index, WBV- whole body vibration, WHR- waist-hip ratio
Once baseline measurements were taken, the envelopes were opened, and the treatment was performed. The group size (23 patients per group) as identified as the minimum sample size for the current study.

**Assessment**

**HOMA-IR (primary outcome)**

Before starting the interventions, and afterwards, a blood draw was conducted after participants fasted overnight for eight hours. Plasma glucose concentrations were determined by the hexokinase enzyme reference technique. Fasting insulin levels were quantified through a radioimmunoassay (RIA) procedure (Coat A Count Insulin, Los Angeles, USA). Insulin resistance (IR) was assessed using the homeostasis model assessment of insulin resistance (HOMA-IR) as fasting serum insulin (\(\mu U/ml\)) \times fasting plasma glucose (mmol l\(^{-1}\))/22.5 [18]. HOMA-IR serves as a proxy measure of IR based on the correlation between fasting glucose and insulin levels, where higher HOMA-IR values indicate more severe IR [19]. HOMA-IR and 1/HOMA-IR are reliable estimates of clamp-derived insulin sensitivity [20].

**Body weight and BMI (secondary outcome)**

Body weight was assessed at the beginning and end of the study for all participants, using a calibrated weight-height scale. The patients were instructed to stand upright on the scale, facing forward, dressed in lightweight clothing, and without shoes. Height was measured at the same time as weight. Subsequently, BMI was calculated using the following equation: BMI= Weight/square of height (kg/m\(^2\)). BMI, or wt/h\(^2\), is recognized as a valid and reliable indicator of obesity [21] and an acceptable and valid indicator of the risk and presence of overweight [22].

**Waist-hip ratio (WHR) (secondary outcome)**

Waist circumference was assessed by positioning a tape measure horizontally, midway between the lower rib margin and the iliac crest. Hip circumference was assessed at the widest part of the buttocks. Two measurements to the nearest 0.5 cm were taken for each waist and hip circumference. WHR was derived by taking the mean waist circumference and dividing it by the mean hip circumference [23]. Waist circumference is a simple, inexpensive method for teaching individuals to take their body circumferences and provides reliable and valid accurate data [24].

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**Fig. 1.** Flow chart of the study
FSH/LH ratio (secondary outcome)

Blood samples were drawn after an eight-hour fast. Baseline LH and FSH were then assessed using an electro-chemiluminescence immune assay (ECLIA). The serum was separated and stored frozen in at −20°C until assay [25]. Samples from all participants were processed through the same analytical test to reduce variability between assays. LH/FSH ratio is a more accurate and valid indicator of ovarian reserve than either FSH or LH [26].

Interventions

The study group participants underwent a protocol consisting of diet modifications + aerobic exercise + WBV. The control group underwent diet modifications + aerobic exercise only.

Iso-caloric low glycemic index diet

Following recruitment, a nutritionist scheduled an appointment to create a tailored dietary plan for each participant and provide a thorough explanation of its components. This plan was formulated considering the individual’s dietary preferences, caloric needs, and eating patterns to improve adherence to the diet. The dietary strategy aimed to maintain the participants’ typical intake of energy and macronutrients through an isocaloric approach. The aim of the diet was to replace high-GI and medium-GI foods with low-GI alternatives, using a system of equivalent exchanges, such as replacing white bread with wholegrain bread. The participants were advised to include unsaturated fats from sources like olive oil, avocado, seeds, and nuts while moderating overall fat consumption. They were instructed to increase their vegetable and salad intake while minimizing their added sugar consumption [27]. The dietitian followed up with the patients through weekly counseling visits.

Moderate-intensity aerobic exercise

Both groups of participants performed supervised moderate-intensity aerobic exercise on the treadmill (SCIFIT, AC5000, USA) for three 45-minute sessions per week for eight weeks. First, the age of the participant was subtracted by 220 to determine her maximum heart rate (HRmax), and exercise intensity was calculated as 60% to 70% of HRmax [28]. Each session was divided into three parts: the warm-up, the active phase, and the cool-down. The warm-up phase lasted five minutes. The active phase lasted 35 minutes, gradually increasing the speed to reach 70% HRmax. Finally, the cool-down phase lasted five minutes.

Whole body vibration exercise

The study group participated in WBV exercise sessions on a side-to-side oscillating WBVE platform (JFF002C, China). The participant stood barefoot in the center of the WBVE platform while maintaining a squat with 60-degree knee flexion and an extended trunk. To minimize vibration transfer to the head, WBV sessions should be conducted with slightly bent knees, ensuring short durations, low frequencies, and minimal amplitudes. Prolonged exposure to vibrations can cause muscle fatigue, muscle contraction force reductions, nerve conduction velocity, and attenuated perception, and high-vibration transmission frequencies can induce symptoms similar to motion sickness in some individuals [29]. Therefore, the first training session included three one-minute WBV sets, with one-minute standing breaks in between. The amplitude of the vibration was adjusted to 1 mm. An additional set was introduced in each session until a total of ten WBV sets were achieved. The frequency was adjusted to 14 Hz, a level known to elicit muscular activation while avoiding negative consequences [29]. The WBV training sessions were conducted three times a week for a total of eight weeks.

Calculating the size of the sample

Before starting the trial, a pilot study was performed with a total number of ten patients, five in each group. F tests, MANOVA, repeated measures, and within and between-interaction analysis were used on the primary outcome variable (HOMA IR) to calculate an effect size of 0.35. The alpha levels were set at 0.05 and β = 0.2. Based on these results, the minimum sample size was found to be 36; however, to account for dropouts, the final number was increased by 25 % to 46 patients. G*POWER (version 3.1.9.2; Franz Faul, Universität Kiel, Germany) statistical software was used for calculation.

Statistical analysis

All outcome measures were found to demonstrate a normal distribution using the Shapiro-Wilk test. The physical characteristics of the patients, i.e. age and height, were compared using an unpaired t-test. Chi-square ($\chi^2$) and Fisher exact tests were used to compare the groups with regard to menstrual history (frequency, regularity, amounts of pads, and dysmenorrhea). A mixed multivariate analysis of variance (MANOVA) was used to investigate the influences of the treatments (groups), time between pre- and post-treatment, and the interaction between group and time. When the Where statistically significant effects were identified, a follow-up univariate ANOVA was conducted. Bonferroni correction was used for multiple pairwise comparisons to avoid type 1 errors. The variation between groups was determined by a partial eta square ($\eta^2$). SPSS version 23 (IBM Corp., New York, USA) was used for all analyses.
Results

The physical characteristics of both groups are given in Table 2. No statistically significant differences were found between groups (unpaired t-test and Chi-square test).

The within-group and between-group analyses are given in Table 3. MANOVA indicated a statistically significant difference between groups for all parameters, as Wilks’ Lambda ($\lambda$) = 0.52, $f$ = 5.08, $p$ = 0.0001, and $\eta^2 = 0.48$. In addition, a significant relationship was noted between pre and post-treatment ($\lambda = 0.02$, $f = 235.1$, $p = 0.0001$, and $\eta^2 = 0.97$) and between group and time ($\lambda = 0.16$, $f = 28.28$, $p = 0.0001$, and $\eta^2 = 0.84$).

Tab. 2. Patients’ physical characteristics

<table>
<thead>
<tr>
<th>Menstrual frequency (oligomenorrhea/normal/amenorrhea)</th>
<th>Study group</th>
<th>Control group</th>
<th>T-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>19 oligomenorrhea/4 normal/0 amenorrhea</td>
<td>17 oligomenorrhea/6 normal/0 amenorrhea</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Menstrual regularity (regular/irregular)</td>
<td>3 regular/20 irregular</td>
<td>5 regular/18 irregular</td>
<td>$\chi^2 = 0.61$</td>
<td>0.43$^a$</td>
</tr>
<tr>
<td>Numbers of pads per day (average/heavy/mild)</td>
<td>9 average/14 heavy/0 mild</td>
<td>10 average/13 heavy/0 mild</td>
<td></td>
<td>0.77$^a$</td>
</tr>
<tr>
<td>Dysmenorrhea (mild/moderate/severe)</td>
<td>5 mild/10 moderate/9 severe</td>
<td>6 mild/8 moderate/9 severe</td>
<td>$\chi^2 = 0.37$</td>
<td>0.83$^a$</td>
</tr>
</tbody>
</table>

$^a$ - no significant difference, m- meter, p-value- significance level, SD- standard deviation, $\chi^2$- Chi-square

In both groups, multiple pairwise comparisons revealed statistically significant differences for all variables between the two-time points; however, no significant change was noted for WHR in the control group. Statistically insignificant inter-group differences were noted for all variables at the first time point (baseline), however, significant differences were noted at the second point (post-procedure), with the study group being more favorable.

Tab. 3. Within-group and between-group analyses

<table>
<thead>
<tr>
<th>Variables</th>
<th>Study group</th>
<th>Control group</th>
<th>p-value (between groups)</th>
<th>F-value (between groups)</th>
<th>$\eta^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight (kg)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre-treatment</td>
<td>77.39 ± 5.43</td>
<td>77.56 ± 4.3</td>
<td>0.9$^a$</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td>Post-treatment</td>
<td>69.3 ± 5.41</td>
<td>73.18 ± 4.01</td>
<td>0.0009$^b$</td>
<td>7.59</td>
<td>0.15</td>
</tr>
<tr>
<td>p-value (within-group)</td>
<td>0.0001$^b$</td>
<td>0.0001$^b$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MD (95% CI)</td>
<td>8.08 (7.48 to 8.69)</td>
<td>4.39 (3.78 to 4.99)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>% of improvement</td>
<td>10.4 %</td>
<td>5.6 %</td>
<td>0.46$^b$</td>
<td>0.54</td>
<td></td>
</tr>
</tbody>
</table>

BMI (kg/m²)

| Pre-treatment | 28.62 ± 1.14 | 28.37 ± 1.13 | 0.46$^b$ | 0.54 |
### Variables

<table>
<thead>
<tr>
<th>Variables</th>
<th>Study group</th>
<th>Control group</th>
<th>p-value (between groups)</th>
<th>F-value (between groups)</th>
<th>$\eta^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Post-treatment</td>
<td>25.62 ± 1.34</td>
<td>26.77 ± 1.18</td>
<td>0.004$^b$</td>
<td>9.36</td>
<td>0.18</td>
</tr>
<tr>
<td>p-value (within-group)</td>
<td>0.0001$^b$</td>
<td>0.0001$^b$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MD (95% CI)</td>
<td>2.99 (2.78 to 3.2)</td>
<td>1.6 (1.39 to 1.8)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>% of improvement</td>
<td>10.5 %</td>
<td>5.6 %</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WHR</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Pre-treatment</td>
<td>0.8 ± 0.04</td>
<td>0.81 ± 0.05</td>
<td>0.49$^a$</td>
<td>0.48</td>
<td></td>
</tr>
<tr>
<td>Post-treatment</td>
<td>0.75 ± 0.05</td>
<td>0.79 ± 0.04</td>
<td>0.009$^b$</td>
<td>7.48</td>
<td>0.5</td>
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<tr>
<td>p-value (within-group)</td>
<td>0.0001$^b$</td>
<td>0.09$^a$</td>
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</tr>
<tr>
<td>MD (95% CI)</td>
<td>0.05 (0.03 to 0.07)</td>
<td>0.018 (0.003 to 0.03)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>% of improvement</td>
<td>6.2 %</td>
<td>2.2 %</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>HOMA-IR</td>
<td></td>
<td></td>
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<tr>
<td>Pre-treatment</td>
<td>4.13 ± 0.87</td>
<td>3.97 ± 1.02</td>
<td>0.58$^a$</td>
<td>0.31</td>
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<tr>
<td>Post-treatment</td>
<td>2.58 ± 0.42</td>
<td>3.19 ± 0.8</td>
<td>0.03$^b$</td>
<td>4.7</td>
<td>0.09</td>
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<td>p-value (within-group)</td>
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<td>0.0001$^b$</td>
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<td></td>
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<tr>
<td>MD (95% CI)</td>
<td>1.54 (1.4 to 1.69)</td>
<td>0.77 (0.63 to 0.92)</td>
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<tr>
<td>% of improvement</td>
<td>37.2 %</td>
<td>19.4 %</td>
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<tr>
<td>LH/FSH ratio</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Pre-treatment</td>
<td>1.95 ± 0.32</td>
<td>2.32 ± 0.53</td>
<td>0.18$^a$</td>
<td>1.87</td>
<td></td>
</tr>
<tr>
<td>Post-treatment</td>
<td>1.41 ± 0.44</td>
<td>1.81 ± 0.68</td>
<td>0.02$^b$</td>
<td>5.63</td>
<td>0.11</td>
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<tr>
<td>p-value (within-group)</td>
<td>0.0001$^b$</td>
<td>0.001$^b$</td>
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</tr>
<tr>
<td>MD (95% CI)</td>
<td>0.53 (0.28 to 0.79)</td>
<td>0.5 (0.24 to 0.76)</td>
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<td></td>
</tr>
<tr>
<td>% of improvement</td>
<td>27.2 %</td>
<td>21.5 %</td>
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<td></td>
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</table>

$^a$- no significance difference, $^b$- significant difference, CI- confidence interval, F-value- variance of group means/mean of the within-group variance, FSH- follicle stimulating hormone; HOMA IR- homeostatic model assessment for insulin resistance; LH- luteinizing hormone; MD- mean difference; $\eta^2$- partial eta square, p-value- significance level, SD- standard deviation, WHR- waist-hip ratio

### Discussion

This study aimed to investigate the effect of adding whole-body vibration exercise (WBVE) to the traditional treatment of polycystic ovarian syndrome. The results revealed a statistically significant decrease in weight, BMI, LH/FSH ratio, and HOMA-IR from pre-treatment to post-treatment in both groups; however, WHR decreased significantly only in the study group. The post-treatment comparison revealed significant differences between the two groups, with better results observed the study group. These results showed that WBV is an effective intervention method for improving insulin resistance and the hormonal status of women with PCOS.

Regarding weight and BMI, our results are supported by Vissers et al. [30] who concluded that incorporating an energy-restricted diet alongside aerobic training or WBV sessions can effectively facilitate a prolonged 5 to 10 percent decrease in overall weight. Recent findings demonstrate that WBV can also reduce the accumulation of body fats in Fischer rats [31]. Also, our results are in line with those of Wilms et al. [32] who found that patients undergoing WBVE experienced a greater reduction in BMI compared to those who participated in a program of aerobic exercises and dieting. Moreover, Milanese et
al. demonstrated that adding two WBV sessions per week to a typical lifestyle for approximately ten weeks also decreased body BMI [33]. In addition, exercise combined with diet for a brief period has been found to potentially help lower BMI in PCOS patients [34].

However, in contrast with our findings, Rubin et al. [35] found that quick, daily sessions of light mechanical stimulation through WBV can hinder adipogenesis within the murine subjects. Additionally, Roelants et al. [36] discovered that while WBV slightly increased lean body mass, it failed to diminish weight, overall body fat, or subcutaneous fat among female patients lacking prior training. This difference in results may be due to the difference in the population and the dose of vibration.

Our findings indicate a statistically significant decrease in waist-hip ratio (WHR), but only in the study group. This is reinforced by Vissers et al. [30] who indicated that WBV training integrated with a calorie-restricted diet could potentially lower waist circumference, WHR, and VAT more effectively than aerobic exercise. This is supported by Huang et al. [37], who concluded that whole-body vibration reduces body fat.

These findings regarding the decrease in weight, BMI, and WHR can be explained by research conducted by Ando and Noguchi [38] who report that acute WBV exposure triggers sweating in the palms and stimulates the central sympathetic nervous system. Additionally, a review by Thorp and Schlaich [39] suggests that the sympathetic nervous system can initiate the breakdown of fat. The authors explored the relationship between the diminished activity of the sympathetic nervous system and reduced fat oxidation rates, and found that decreased activity within the sympathetic nervous system can elevate obesity risk. Furthermore, Prisby et al. [40] found that the overall impact of WBV on body fat might be influenced by a range of systems, involving the endocrine, musculoskeletal, nervous, and circulatory systems.

Regarding the LH/FSH ratio, a significant decrease in the LH/FSH ratio favoring the study group was found post-treatment. This result may be supported by Ruffing et al. [41] who investigated the effect of short-duration dietary and exercise programs on LH pulse. They found that exercise led to a decrease in LH pulse frequency; however, they stated that the mechanism is as yet unknown. We propose that the mechanism may be due to improved psychological status, as aerobic exercise and WBV training, itself a type of exercise, have proven to improve psychological status and mood, and thus regulate hormone levels [42]. Further studies investigating the effect of WBV on the LH/FSH ratio are needed.

Regarding insulin resistance, our results revealed a statistically significant decrease in HOMA-IR in both groups over the course of the exercise program. However, post-treatment comparison indicated a significant difference between both groups in favor of the study group. These results are supported by previous research, as moderate-intensity aerobic exercises can also enhance hepatic glucose production and lipid metabolism, reducing IR and improving the overall quality of life for individuals with PCOS [31,35]. However, again, there is a need for further research into the effect of WBV on IR in women with PCOS.

The mechanism by which whole-body vibration exercise (WBV) has a favorable effect on insulin resistance (IR) may be attributed to the neurogenic enhancement and muscular activation caused by WBV stimuli: these give rise to functional and structural tissue adaptations over time by increasing blood flow and circulation and stimulating muscular contractions, as described by Cardinale and Bosco [43]. Consequently, improved muscle glucose absorption and decreased IR are observed. Studies also have demonstrated that WBV exercise enhances oxygen consumption, fat-burning rates, and calorie burning, which could positively affect adipose tissue and improve IR [30,44,45]. Furthermore, this improvement in insulin sensitivity may also be due to increased levels of adiponectin, a protein known to correlate well with insulin sensitivity [46].

WBV may be a promising potential treatment option for women with PCOS, as no negative outcomes were observed during the course of the study. However, our study has certain limitations; most importantly, no follow-up was performed. Therefore, further research is needed to assess the lasting impacts of WBV.

**Clinical implications**

Patients suffering from PCOS could find the integration of WBV alongside conventional treatments to be a viable and beneficial approach to therapy. However, further in-depth and enhanced research is necessary to determine the neurophysiological impacts of WBV that could aid in improving IR associated with PCOS.

**Conclusions**

This study reveals that incorporating whole-body vibration into an exercise program has favorable effects on IR and hormonal parameters in women with PCOS.

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