Chapter

Exercise Interventions for the Management of Polycystic Ovary Syndrome (PCOS): An Update of the Literature

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Abstract

Polycystic Ovary Syndrome (PCOS) affects 6–10% women of reproductive age, and the diagnosis requires two of the three criteria: (1) menstrual irregularity; (2) polycystic ovaries on ultrasound; (3) elevated hormones (such as testosterone). Approximately 50–70% women have underlying insulin resistance and/or have a body mass index (BMI) greater than 28.0 kg/m^2, and if not managed, it can worsen the symptoms of PCOS. The first line of treatment for PCOS includes lifestyle management such as diet and/or exercise. Previous studies evaluated interventions such as aerobic, aerobic plus resistance and high intensity aerobic. These interventions formed part of the initial guidelines for the management of PCOS, although the guidelines did not include recommendations of resistance training in isolation. More recently, new studies have emerged which assessed resistance training interventions in isolation in PCOS, where these findings led to an update in the guidelines in PCOS to recommend resistance training as part of the management. The chapter will look to provide an update of the exercise literature in PCOS, as well as provide recommendations for future research.

Keywords: Polycystic Ovary Syndrome, lifestyle interventions, women's health, resistance exercise, aerobic exercise

1. Introduction

Polycystic Ovary Syndrome (PCOS) is a common endocrine condition, and affects approximately 6–10% of women during the reproductive years [1]. The diagnosis of PCOS requires two of the following three items as per the Rotterdam criteria: 1: menstrual irregularities (i.e., oligomenorrhea, amenorrhea); 2: polycystic ovaries on ultrasound; 3: androgen excess (i.e., elevated testosterone levels) [2].

The pathophysiology of PCOS is complex. Possible mechanisms include genetics, environmental and transgenerational factors, and can affect metabolic, reproductive and psychological outcomes [3, 4]. Insulin resistance may also be involved in the pathophysiology of PCOS [5, 6], where elevated levels may worsen features of PCOS

(e.g., androgens, menstrual irregularity, and reproductive outcomes such as follicular arrest). A high proportion may also have underlying insulin resistance (50–70%) [7] and can be present in both overweight and non-overweight women with PCOS [5]. Interestingly, recent studies have also proposed a possible related intrinsic insulin resistance that are noted in PCOS versus their control counterparts [5].

Women with PCOS may also demonstrate an elevated body mass index (BMI) (>50% with BMI >25.0 kg/m^2) [8] infertility (70–80%) [9], and may also be at risk of future chronic diseases (e.g., cancer, cardiovascular disease, and diabetes) [10]. Anxiety and depression are also noted in this cohort (26–52%) [11], which can negatively affect quality of life [12, 13].

The first line treatment for the management of PCOS includes lifestyle modifications such as diet and/or exercise. Previous guidelines recommend 150 minutes of exercise per week, of which 90 minutes should be at a moderate to high intensity [14]. These guidelines were formed in accordance to previous literature which assessed aerobic, resistance and/or aerobic with a dietary component, and high intensity exercise. The initial guidelines did not include recommendations for resistance training as part of the management of PCOS. No studies were available at the time which evaluated this modality in isolation. The benefits of this intervention, such as improved insulin sensitivity and body composition which has been reported in previous diabetes studies [15, 16], could also be beneficial for the management of PCOS.

This limitation led to future studies to evaluate this intervention in isolation, which included both a feasibility study in women with PCOS [17], as well as other studies which incorporated various prescriptions, and these findings will be explored further in this chapter. The reported benefits led to a revision in the guidelines, to recommend resistance training as part of the management for PCOS [18].

The next sections will look to review the different types of intervention studies in PCOS, as well as provide directions for future research.

2. Exercise interventions in PCOS

2.1 Aerobic interventions-moderate and/or high intensity intermittent, and lifestyle interventions

Aerobic exercise is defined as an activity that uses large muscle groups, is maintained for a continuous time, and is rhythmic in nature [19]. Previous studies in PCOS assessed interventions such as cycle ergometry or treadmill for three to five sessions a week of 30–60 minutes at 60–70% of VO_{2max} and/or HR_{max} [20–29], self-selected or self-monitored (i.e. walking, cycle ergometry, treadmill) [30, 31], tailored intervention at an exercise dose of 14 kcal/kg/week) [32], walking and/or jogging [33–36], and interventions that were either moderate and/or high intensity exercise [37–49]. In addition, lifestyle and/or home-based interventions were also assessed in women with PCOS [50–61].

The interventions ranged from 4 to 52 weeks, and were compared to groups that received no training, diet, education, medication, lifestyle plus medication, or electroacupuncture. Sample size across studies ranged between 8 to 183 participants. Limited studies are available that incorporated a long-term follow-up component (>1 year). Outcomes ranged from anthropometric, cardiorespiratory, hematological, menstrual cyclicity, and hemodynamic. Further, recent studies also included other measurements such as quality of life (i.e., anxiety and depression using either the

Hospital Anxiety and Depression Scale (HADS), Polycystic Ovary Syndrome Questionnaire (PCOSQ), Short Form-36 (SF-36)) gene expression, enzymes, protein abundance, and a detailed list of all of these outcomes are reported in **Table 1**.

Adherence rates ranged between 60% and 100% across interventions that used cycling or ramp protocols, self-selected or self-monitored exercise (i.e., walking or a goal of 150 minutes of exercise a week), or a combination of moderate and/or high intensity aerobic exercise [24, 26, 27, 29, 32, 37, 40–42, 48, 50, 51, 73]. Further, adherence was also reported in other ways across studies which included weekly increase (e.g., 21.1%) [60], mean participation per week [58], and levels (e.g. high,

Moderate					
Author, Study design	**N enrolled (E) and completed (C)**	**Duration (weeks)**	**Intervention**	**Outcomes**	**Significant findings associated with exercise only**
Randeva et al. [34], Liao et al. [62] NRCT	E = 21 C = 12	24	Walking 20–60 min 3 sessions/wk. Volume increased fortnightly (120–420 min)	*Hemotological* FAI, folate, B12, homocysteine, creatinine, T_4, insulin, C, tg *Cardiorespiratory* VO_{2max} *Hemodynamic* SPB, DPB *Anthropometric* BMI, WHR *Other measurements* BDDE-SR	Homocysteine, WHR, VO_{2max}
Vigorito et al. RCT [29]	E = 90 C = 90	12	a. Cycle ergometer, 30 min at 60–70% of VO_{2max}, 3 sessions/wk. b. Control	*Hemotological* LH, FSH, PRL, E_2, P, 17-OHP, T, A, DHEA-S, SHBG, FAI, Hb, LDL, HDL, TC, fasting glucose, fasting insulin, AUC_{GLU}, AUC_{INS}, CRP *Cardiorespiratory* VO_{2max}, VO_{2AT}, VE/VCO_{2slope}, RER_{peak}, $Watt_{max}$ HRrest, HRpeak *Hemodynamic* SBPrest, SBPpeak, DBPrest, DBPpeak, HRR *Anthropometric* BMI, WHR, WC *Questionnaire* LTPA	BMI, WC, WHR, fasting insulin, AUC_{INS}, AUC_{GLU}/AUC_{INS}, VE/VCO_{2slope}, HRrest, SBPrest, DBPpeak, VO_{2max}, VO_{2AT}, peak workload, LTPA
Giallauria et al., NRCT [24]	E = 124 C = 124	12	a. Cycle ergometer, 30 min at 60–70% of VO_{2max}, 3 sessions/wk. b. Control	*Hemotological* LH, FSH, PRL, E_2, P, 17-OHP, T, A, DHEA-S, SHBG, FAI, Hb, LDL, HDL, TC, fasting glucose, fasting insulin, AUC_{GLU},	BMI, WHR, fasting insulin, AUC_{INS}, AUC_{INS}:AUC_{GLU}, CRP, WBC, VO_{2max}, VO_{2AT}, $Watt_{max}$, resting HR, post-exercise HHR

	Moderate				
	Author, Study design	**N enrolled (E) and completed (C)**	**Duration (weeks)**	**Intervention**	**Outcomes**	**Significant findings associated with exercise only**
					AUC_{INS}, AUC_{GLU}/AUC_{INS}, CRP, WBC, neutrophils, lymphocytes *Cardiorespiratory* VO_{2max}, VO_{2AT}, VE/VCO_{2slope}, RER_{peak}, $Watt_{max}$ HRrest, HRpeak *Hemodynamic* SBPrest, SBPpeak, DBPrest, DBPpeak, HRR *Anthropometric* BMI, WHR	
	Palomba et al., NRCT [27]	E = 40 C = 40	24	a. Cycle ergometer, 30 min at 60–70% of VO_{2max}, 3 sessions/wk. b. Control	*Hemotological* LH, FSH, PRL, E_2, P, 17-OHP, T, A, DHEA-S, SHBG, FAI, TSH, fasting glucose, fasting insulin, GIR, HOMA-IR, $AUC_{glucose}$ *Menstrual cyclicity/ reproductive* Menses frequency, ovulation rate, ovulation frequency, pregnancy rate, abortion rate, cumulative ovulation rate, cumulative pregnancy rate *Anthropometric* BW, BMI, WC, WHR *Questionnaire* LTPA	LTPA (12 weeks), menses frequency, ovulation/ cumulative ovulation rate, abortion rate, trend higher pregnancy (p = 0.075), cumulative pregnancy (p = 0.058). BW, BMI, WC (12 weeks), T, SHBG, FAI (12 & 24 weeks) fasting insulin, GIR, HOMA-IR (12 & 24 weeks)
	Brown et al., RCT [32]	E = 37 C = 20	24	8–12-week ramp +12 weeks exercise (14 kcal/kg/wk)	*Hemotological* T, fasting glucose, fasting insulin, 2 h glucose/insulin, HOMA-IR, AUC_{GLU}, AUC_{INS}, insulin sensitivity, HbA1c, VLDL/LDL/HDL particles, mean particle sizes (VLDL, LDL, HDL), lipids *Cardiorespiratory* VO_{2max} *Anthropometric*	VO_{2max}, trend AUCins (p = 0.083), tg (p = 0.083), large VLDL/chylomicrons (p = 0.007). Large HDL, medium/small HDL, HDL size, tg & VLDL tg, trend LDL particles (p = 0.057), HDL cholesterol (p = 0.057)

	Moderate				
	Author, Study design	**N enrolled (E) and completed (C)**	**Duration (weeks)**	**Intervention**	**Outcomes**	**Significant findings associated with exercise only**
					BW, BMI, WC, HC *Hemodynamic* SBP, DBP	
	Stener-Victorin et al., RCT [36]	E = 23 C = 20	16	a. Low frequency electroacupuncture b. Walking 30–45 min 3 sessions/wk	*Hemotological* LH, FSH, total/free T, SHBG, FAI, DHEA-S, T_4, TSH, IGF-1, insulin, glucose, HOMA-IR, C, tg, HDL, LDL *Hemodynamic* SBP, DBP, HR *Anthropometric* BW, BMI, WHR, sagittal diameter *Sympathetic activity* MSNA *Menstrual cyclicity/ reproductive* Menstrual cycle status	MSNA burst activity and incidence, BMI, BW
	Moro et al. [26] Covington et al. [22], Prospective study	E = 8 C = 8	16	Aerobic (treadmill), 5 sessions/wk. 55% VO_{2max}. Prescribed by exercise energy expenditure.	*Hemotological* Insulin sensitivity/ glucose disposal rate, FFA, fasting insulin, GDR, total T, FAI, SHBG, CRP, DHEA-S, WBC, HDL, LDL *Cardiorespiratory* $VO2_{max}$ *Anthropometric* BW, BMI, WHR, VF, FM, FFM, fat cell size, BF%, subcutaneous fat *Menstrual cyclicity/ reproductive* menstrual cyclicity (n follicles), ovarian morphology *Other measurements* Adipose tissue biopsy, β-adrenergic agonist, total RNA, isoproterenol (β-agonist) (A) and ANP (B), maximum postreceptor signaling agents, Dibutyryl-cAMP, Bromo-cGMP, MIF, IL-6, PAI-I, CD68, MCP-1, PLIN 1, 2, 3, 4, 5, ADP ribosylation factor	*Study also recruited 7 matched controls for baseline testing only* Insulin sensitivity (GDR), VO_{2max}, baseline lipolysis, lipolytic response to isoproterenol, lipolytic sensitivity, ANP maximal induced lipolysis, catecholamine lipolytic responsiveness, isoproterenol-induced lipid mobilization. FFA, total number follicles. PLIN3, ARF1, ARFRP1, BCOP and Sec23a

	Moderate				
	Author, Study design	**N enrolled (E) and completed (C)**	**Duration (weeks)**	**Intervention**	**Outcomes**	**Significant findings associated with exercise only**
					(e.g. ARF related protein 1), beta-coatomer, GDP exchange brefeldin A resistant factor 1, Sec23a, adipose triglyceride lipase, monoglyceride lipase, ATGL co activator	
	Ladson et al., RCT [56]	E = 114 C = 38	24	a. Lifestyle and metformin b. Lifestyle and placebo Lifestyle = supervised (2× wk. was offered) and/or unsupervised (150 min aerobic exercise per wk)	*Hemotological* T, SHBG, FAI, E_2, LH, FSH, C, HDL, LDL, tg, fasting glucose, fasting insulin, AUC_{GLU}, AUC_{INS}, insulin sensitivity index, PDG *Cardiorespiratory* VO_{2max} *Hemodynamic* SBP, DBP *Anthropometric* BW, BMI, WC, BMD, total lean and fat, central abdominal fat, AbFM, central to total body ratio, BF% *Questionnaires* PCOSQ *Menstrual cyclicity/ reproductive* ovarian volume, follicle diameter, n ovulations	a. T, BW, insulin sensitivity b. SBP, AUC_{GLU}
	Jedel et al. [30] Stener-Victorin et al. [36], RCT	E = 84 C = 72 *(Jedel=74)*	16 + 16wk f/up	a. Acupuncture b. Exercise (self-monitored, 30 min 3 sessions/wk) c. Control Exercise-brisk walking, cycling, other exercise	*Hemotological* T, FT, DHT, E1, E1-s, E_2, DHEA, DHEA-S, A, 5-DIOL, ADT-G, 3G, 17G, SHBG, LH, FSH *Cardiorespiratory* $VO2_{max}$ *Anthropometric* BMI, WHR *Questionnaire* MADRS-S, BSA-S, SF-36, PCOSQ *Menstrual cyclicity/ reproductive* Menstrual frequency	T, menstrual frequency, E1–2, 17G (wk 16). E_2 and 17G (week 32) SF-36 (role physical, physical functioning, general health) (wk 16). PCOSQ (emotion) (wk 16), (wk 32, infertility)

Moderate					
Author, Study design	**N enrolled (E) and completed (C)**	**Duration (weeks)**	**Intervention**	**Outcomes**	**Significant findings associated with exercise only**
Abazar et al., RCT [20]	E = 24 C = 24	12	a. Moderate, 3sessions/wk., 60–70% HR_{max} b. Control	*Hemotological* HDL, LDL, tg, VLDL, C *Anthropometric* BMI, WHR, BF%, BW	BMI, WHR, BF%, HDL, Tg
Sprung et al., Observational	E = 11 C = 6 *Study also recruited 6 matched control*	16	Moderate 3× wk. 30% HRR	*Hemotological* LH, FSH, P, E_2, T, FAI, SHBG, ALT, glucose, insulin, HOMA-IR, C, tg, HDL, LDL *Cardiorespiratory* $VO2_{max}$ *Anthropometric* BW, WC *Hemodynamic* SBP, DBP, HR *Other measurements* NO mediated microvascular function (local heating)	VO_{2max}, NO mediated microvascular function
De Frène et al., Prospective, longitudinal [52]	E = 31 C = 23	24	Exercise, diet (mild energy restriction), psychological subprogram Exercise = tailored to improve step count	*Anthropometric* BMI, BW, height *Questionnaire* PCOSQ, VAS	Total PCOSQ score, PCOSQ domains (emotions, body hair, weight, and infertility problems), VAS
Orio et al. [63] RCT	E = 150 C = 136	24	a. Oral contraceptive b. Exercise (3× wk. 45 min 60–70% VO_{2max}) c. Polyvitamin	*Hemotological* C, HDL, LDL, PAI-I, CRP, LH, FSH, TSH, PRL, E_2, P, 17-OHP, T, A, DHEA-S, SHBG, FAI, glucose, insulin, GIR, HOMA, $AUC_{glucose}$, $AUC_{insulin}$, $AUC_{glucose}$/ $AUC_{insulin}$ *Cardiorespiratory* $VO2_{max}$ *Anthropometric* BW, WHR *Hemodynamic* SBP, DBP *Menstrual cyclicity/ reproductive* Menstrual frequency *Other measurements* FMD, IMT	Exercise IMT, FMD, HDL, CRP, PAI-I, VO_{2max}, BMI, WHR, HOMA-IR, $AUC_{ins,}$ menstrual frequency
Al-Eisa et al., NRCT [21]	E = 90 C = 90	12	Treadmill walking, 45 min, 3 sessions/wk. 65–75%	*Hemotological* FSH, E_2, PRL, AMH, adiponectin, fasting glucose, fasting	*Study included:* *GA-Control BMI 20–29* *GB- PCOS BMI 30–*

	Moderate				
	Author, Study design	**N enrolled (E) and completed (C)**	**Duration (weeks)**	**Intervention**	**Outcomes**	**Significant findings associated with exercise only**
					insulin, GIR, HOMA-IR, AFC *Cardiorespiratory* $VO2_{max}$ *Hemodynamic* SBP, DBP *Anthropometric* BMI, BW, WHR, WC *Menstrual cyclicity/ reproductive* Ovulation rate, menstrual cyclicity	*35* *GC- Obese BMI 30–35* **GB and GC** BMI, BW, WC, WHR, PRL, fasting glucose/insulin, HOMA-IR, FSH, E_2, GIR, adiponectin, AMH, AFC, ovulation rate, menstrual cyclicity
	Gilani et al. [64] RCT	E = 40 C = 40	8	a. Running 3× wk. 60–75% $HR_{max.}$ b. Control	*Hemotological* PRL, LH, FSH, DHEA-S, AMH, A, 17-OHP, T, P, E_2, FAI *Anthropometric* BMI, WHR	LH, PRL, A
	McBreairty et al. [65] RCT	E = 95 C = 61	16	All px underwent TLC diet for 2 weeks a. Exercise and pulse base diet b. Exercise and TLC diet Exercise-aerobic 5× wk., 3 sessions supervised, self-selected 60% HR_{max}	*Hemotological* E_2, T *Anthropometric* BMI, BW, FM, LM, BF%, BMC	BMI, BW, FM, BMD
	Kazemi et al. [66] RCT	E = 95 C = 25	16 + 6–12-month f/up	a. Exercise and pulse base diet b. Exercise and TLC diet Exercise-aerobic 5× wk. 45 min 60–75% HR_{max}	*Hemotological* T, SHBG, FAI, LH, FSH, FAI *Menstrual cyclicity/ reproductive* Ovarian morphology, menstrual cycle length	Ovarian morphology, FAI, menstrual cyclicity
	Wu et al. 2021 [67] RCT	E = 38 C = 38	12	a. Aerobic 4× wk. 30 min b. Control	*Hemotological* Glucose, C, HDL, LDL, tg, Cr, FSH, LH, T, DHEA-S, AMH, MDA *Cardiorespiratory* $VO2_{max}$ *Hemodynamic* SBP, DBP *Anthropometric* BMI, BW *Other measurements* Oxidative stress	BMI, VO_{2max}, AMH, oxidative stress

Moderate					
Author, Study design	**N enrolled (E) and completed (C)**	**Duration (weeks)**	**Intervention**	**Outcomes**	**Significant findings associated with exercise only**
Upasana et al., RCT [61]	E = 60 C = 48	20	a. Home based aerobic training b. Control Home based- 5×/wk. 30 min (brisk walking, cycling)	*Hemotological* Fasting glucose, fasting insulin, HOMA-IR, CRP *Anthropometric* BW, BMI, WC, HC	BW, BMI, WC, HC, fasting glucose, CRP, HOMA-IR
Ramanjaneya et al., NRCT, [28]	E = 21 C = 21	8	Treadmill exercise 3 sessions/wk for 1 hr, 60% VO_{2max}	*Hemotological* PG, insulin, NEFA, T, FAI, SHBG, LH, FSH, C, Tg, HDL, LDL, ALT, HbA1c, TSH, DHEA-S, A *Cardiorespiratory* $VO2_{max}$ *Hemodynamic* SBP, DBP *Anthropometric* BW, BMI, WC, HC *Other measurements* Complement related proteins (C1q, C3, C3b/lC3b, C4, Factor-B and H, properdin, C2, C4b, C5, C5a, D, mannose binding lectin, factor 1)	*Study recruited PCOS and matched controls.* N.S
Moderate and/or high intensity					
Author, Study design	**N enrolled (E) and completed (C)**	**Duration (weeks)**	**Intervention**	**Outcomes**	**Significant findings associated with exercise only**
Hutchinson et al., 2011, 2012 Harrison et al., 2012., Moran et al., 2011, prospective exercise intervention	E = 34 C = 21	12	3 sessions/wk 1 hr. Alternated between 1. 60 min moderate-intensity treadmill walking/jogging 75–85% HR_{max} 2. High intensity and intermittent exercise (6 × 5 min with 2-min recovery 95–100% HR_{max})	*Hemotological* T, SHBH, FAI, fasting glucose, fasting insulin, GIR, HOMA, HbA1c, C, TC, HDL, LDL, triglycerol, FAI, IFG, tg *Cardiorespiratory* $VO2_{max}$, RER, HR_{max} *Hemodynamic* SBP, DBP *Anthropometric* lean tissue mass, FM, AbFM, VF, SCFAT, BF%, BW, BMI, WC, WHR, thigh muscle attenuation. *Protein abundance*	*Trial recruited both PCOS and matched controls* *PCOS* BMI, VF, IR, Tg, trend lower PGC1A and higher PGC1A protein abundance, BW, WC, GIR, trend for CT muscle attenuation, $VO2_{max}$, total and AbFM, AMH *Non PCOS* WC, SCFAT, $VO2_{max}$

Moderate and/or high intensity					
Author, Study design	**N enrolled (E) and completed (C)**	**Duration (weeks)**	**Intervention**	**Outcomes**	**Significant findings associated with exercise only**
				PGC1α, complex I, II, III, IV, V *Enzyme* ß-HAD, CS *Gene expression* PGC1A, TFAM, NRF1, COX4	
Kostrzewa-Nowak et al., 2014, NRCT [25]	E = 34 C = 34	12	1. Familiarization (3 sessions/wk. 30 min, 50% HR_{max}) 2. Exercise = 60 min low-high impact 4 phases % HR_{max} (3 weeks each): 50–60%, 55–65%, 60–70%, 65–75%	*Hemotological* WBC, RBC, Hb, HTC, MCV, MCH, MCHC, PLT tg, C, HDL, LDL *Cardiorespiratory* VO_{2max}, V_{E2max}, HR_{max}, VO_2/AT *Anthropometric* Skinfolds- thoracical, abdomen, subscapularis, triceps, and crus BW, BMI, FFM, BF %, TBW, BMR	Results reported by BMI: *Underweight*: BMI and weight, VO_{2max} *Normal weight*: n.s *Overweight*: BMI, skinfolds, weight, TBW, BF%, Tg, C, HDL, LDL, V_{Emax}
Gaeini et al., 2014, RCT [39]	E = 40 C = 40	12	a. 3 session/wk. 25–30 min, 60–85% HR_{max} b. Control	*Hemotological* 17-OHP, DHEA-S *Anthropometric* BW *Menstrual cyclicity/ reproductive* Menstrual cycle status, follicles	*Recruited lean and obese PCOS.* *Obese PCOS* DHEA-S,17-OHP, BW *Both groups* Follicles, menstrual cycle status
Sa et al., 2016, RCT [35]	E = 30 C = 30	16	a. Walking/ jogging 3 sessions/wk. 40 min b. Usual care 4 phases % HR_{max} (monthly increments) 60–70%, 70–75%, 75–80%, 80–85%	*Hemotological* FSH, LH, T, DHEA-S, insulin *Cardiorespiratory* VO_{2max} *Hemodynamic* HRV, BP, HR, HR_{max} *Anthropometric* BMI	HR, SBP, HRV
Costa et al., 2017, two-way parallel controlled trial [33]	E = 30 C = 27	16	a. 3 sessions/ wk = 40 min walking and/ or jogging (outdoor track). intensity HR_{max} b. Control	*Hemotological* DHEA-S, LH, FSH, TC, HDL, LDL, TG, FG, 2-H-PG, AUC OGTT, insulin, log insulin, HOMA-IR, IL-6, TN-F, CRP *Anthropometric* BMI, WC *Cardiorespiratory* VO_{2peak}, HR_{max} *Hemodynamic*	SF-36 (physical functioning, general health, mental health), VO_{2peak}, BMI, WC, SBP, DBP, mean BP, total cholesterol, LDL, TNF-alpha, CRP. Mean HR 4 different phases.

Moderate and/or high intensity					
Author, Study design	**N enrolled (E) and completed (C)**	**Duration (weeks)**	**Intervention**	**Outcomes**	**Significant findings associated with exercise only**
				SBP, DBP *Questionnaires* SF-36	
Scott et al., 2017, NRCT [49]	E = 16 C = 16	12	3 sessions/ wk 1 hr. Alternating: 1. 20–60 min walking/jogging, 75–80% HR_{max} with 2-min recovery 2. HITT (6–8, 5 min intervals, 95–100% HR_{max} with 2-min recovery) Wk 4 = 8 intervals, 1 min rest	*Hemotological* Glucose, log insulin, HOMA-IR, GIR/FFM *Cardiorespiratory* VO_{2max} *Anthropometric* BMI, FFM, FM, android/gynoid fat, android/gynoid ratio	*Study recruited PCOS and non PCOS* VO_{2max}, trend towards decrease BF %
Kogure et al., 2020, [43], Lopes et al., 2018 [44] RCT	E = 110 C = 89	16	a. CAT- 3 sessions/wk. 30 min 65–80% HR_{max} b. IAT-3 sessions/wk., 30 min (2 min high intensity 70–90% HR_{max} separated by 3 min recovery (60–70%)) c. Control	*Hemotological* T, FAI, SHBG *Anthropometric* Height, BW, WC, HC, WHR, BMI *Questionnaire* HADS, FRS, FSRI, dis (satisfaction grade)	Dis (satisfaction) grade, total FSFI, HADS.
Ribeiro et al., 2019, [47] RCT	E = 110 C = 87	16	a. CAT-3 sessions/wk. 30 min 65–80% HR_{max} b. IAT-3 sessions/wk. 30 min (2 min high intensity 70–90% HR_{max} separated by 3 min recovery (60–70%) c. Control	*Hemotological* T, PRL, TSH, 17 OHP *Anthropometric* BMI, WC, WHR *Menstrual cyclicity/ reproductive* Ovarian morphology *Questionnaire* SF-36	*CAT* WC, HC, WHR, SF-36 (physical functioning, role physical, general health, social role, emotional role, mental health) *IAT* WHR, SF-36 (physical functioning, role physical, general health, vitality, social role, emotional role, mental health) *IAT and CAT* T
Faryadian et al., 2019, [38] Quasi experimental design	E = 24 C = 24	12	a. HITT-3 sessions/wk. 2 sessions- 4 × 4 min 90–95% HR_{max} and 3×	*Hemotological* Fasting glucose, fasting insulin, HOMA-IR, CRP *Anthropometric* BW, BMI	CRP, HOMA-IR

Moderate and/or high intensity					
Author, Study design	**N enrolled (E) and completed (C)**	**Duration (weeks)**	**Intervention**	**Outcomes**	**Significant findings associated with exercise only**
			moderate intensity running, 70% HR_{max}, 1 session- 10×1 min high intensity running, 10×1 min rest. b. Control		
Benham et al., 2020 [37], RCT	E = 47 C = 40	24 (+ 24 wk. f/up)	a. HITT 3 sessions/wk., 10×30s 90% HRR or 9/10 Borg, alternate with 90s low intensity b. CAT (3 sessions/wk., 40 min moderate 50–60% HRR or 6/10 Borg) c. Control	*Hemotological* HbA1c, fasting insulin, fasting glucose, HOMA-IR, C, LDL, HDL, Tg, ALT, GGT *Cardiorespiratory* VO_{2max} *Anthropometric* BMI, weight, WC *Hemodynamic* SBP, DBP	BMI (CAT), WC (control and HITT), fasting glucose (HITT), LDL (HITT), HDL (HITT)
Elbandrawy et al., 2022, RCT [23]	E = 40 C = 40	12	a. 3 sessions/wk., 30 min treadmill (10 min low intensity, 20 min moderate (60–70% HR_{max})) + Metformin (1500 mg) b. Metformin (1500 mg)	*Hemotological* IL-6, TNFα, CRP *Anthropometric* BMI	IL-6, TNFα, CRP
Philbois et al., 2022, [68] RCT	E = 110 C = 75	16	a. CAT-3×wk 60 min, 70–80% HRR b. HITT-2 min 85–90% HRR, and 3 min 65–70% HRR c. Control	*Hemotological* Insulin, glucose, tg, C, HOMA-IR, HDL, LDL *Cardiorespiratory* VO_{2max} *Anthropometric* BMI, weight *Hemodynamic* SBP, DBP, HR, HRV	HR, VO_{2max}, T
Mohammadi et al., 2023 [45] RCT	E = 30 C = 28	8	a. HITT-3 sessions/wk. low intensity run (50% max	*Hemotological* Fasting glucose, insulin, HOMA-IR, QUICKI, LDL, HDL, total C, tg, A/P, TS/C	BMI, WHR, visceral fat, insulin, insulin resistance, LDL, atherogenic index, cholesterol, cortisol

Moderate and/or high intensity					
Author, Study design	**N enrolled (E) and completed (C)**	**Duration (weeks)**	**Intervention**	**Outcomes**	**Significant findings associated with exercise only**
			speed) and 3×30s sprint followed by 30s slow running. b. Control 3rd week = 6 sets	ratio *Cardiorespiratory* VO_{2max} *Anthropometric* BW, BMI, BF%, WHR, VAT, VAI	
Samadi et al., 2023 [69], RCT	E = 30 C = 30	12	a. HITT- 3× wk. 30 min (4×4 min, 8 rounds 20s all out and 10s rest (80–85% HR_{max}) and Metformin (1500 mg) b. Metformin (1500 mg)	*Hemotological* HOMA-IR, SHBG, T, LH, DHEA-S, FSH, FAI *Cardiorespiratory* VO_{2max} *Anthropometric* FM, BMI, WHR, HC *Menstrual cyclicity/ reproductive* Ovarian morphology, menstrual cyclicity	BMI, FM FSH, T, SHBG, HOMA-IR
Lifestyle interventions					
Author, Study design	N enrolled (E) & analyzed (A)	Duration (weeks)	Intervention	Outcomes	Significant findings associated with exercise only
Guzick et al., 1994, [70] RCT	E = 12 C = 12	12	a. Behavior weight control b. Control Guidance provided to improve physical activity levels	*Hemotological* T, SHBG, fasting insulin, glucose, LH *Anthropometric* BW	BW, SHBG, trend fasting insulin
Hoeger et al., 2004, [54] RCT	E = 38 C = 23	48	a. Metformin (1700 mg) b. Lifestyle and placebo c. Lifestyle and Metformin d. Placebo Lifestyle: nutrition (500–1000 deficit), behavior, exercise (150 min per wk)	*Hemotological* SHBG, insulin, glucose, T, FAI, AUC_{GLU}, AUC_{INS}, fasting insulin *Anthropometric* BW, BMI, WHR, WC *Other measurements* Weekly urine samples (pregnanediol)	BW, T, FAI, trend fasting glucose
Pasquali et al. 2011 [71], NRCT	E = 100 C = 65	24	Diet (hypocaloric 1200–1200 kcal day) followed by mildly restricted intake (500 kcal day deficit), walking 30 min 5× wk	*Hemotological* T, SHBG, FAI, A, DHEA-S, 17-OHP, LH, FSH, LH/FSH, E_2, LDL, HDL, tg, fasting glucose, fasting insulin, HOMA-IR, QUICKI, C, $ISI_{composite}$	WC, A, 17-OHP, LH, C, HDL, tg, fasting glucose, fasting insulin, HOMA-IR, QUICKI, $ISI_{composite}$

Moderate and/or high intensity					
Author, Study design	**N enrolled (E) and completed (C)**	**Duration (weeks)**	**Intervention**	**Outcomes**	**Significant findings associated with exercise only**
				Anthropometric BMI, WC, HC, WHR *Menstrual cyclicity/ reproductive* Menses, ovarian morphology/volume, follicle number	
Mahoney et al. 2013 [58], Prospective quantitative design	E = 12 C = 9	12	a. Lifestyle (3–5 sessions/wk., 30–60 min, low impact exercises (walking, cycling), RX 2 to 3 sessions. b. Counseling-every 2 weeks (6 sessions total)	*Anthropometric* BMI *Menstrual cyclicity/ reproductive* Menstrual history *Questionnaire* Block Brief food frequency, Block physical activity screener. *Other measurements* Diet modification (energy intake, fat, saturated fat, carbohydrates, protein)	Weight, mean daily calorie, fat and carbohydrate intake, frequency home or gym exercise, menstrual cyclicity 50% among prior amenorrheic patients.
Konopka et al., 2015 [55], RCT	E = 39 C = 39	12	a. Lean PCOS-control b. Obese PCOS-Aerobic c. Obese PCOS-control Exercise = Supervised: 60 min HR 65% VO_{2peak} 5× wk.	*Hemotological* Glucose, insulin, HOMA, c-peptide, P, E_2 *Cardiorespiratory* VO_{2peak} *Anthropometric* BMI, BW, FM, FFM *Other measurements* Hyperinsulinemic-euglycaemic pancreatic clamp (insulin sensitivity), muscle biopsy (vastus lateralis), mitochondrial respiration (complex I, complex I and II, complex II, FCCP, O2flux (state 3 (CI), cytoc, State 3 (CI + II), state 3 (CII), state 4, FCCP, antimycin A), respiratory control ratio (RCR), phosphorylation efficiency (ADP:O), H_2O_2). H_2O_2 production,	*Study recruited obese and lean PCOS* State 4, ADP:O, mtH2O2 emissions, VO_{2peak}, maximal citrate synthase activity, maximal mitochondrial oxidative activity, RCR and ADP:O, H2O2-emitting potential of isolated mitochondria, mtH2O2, catalyze activity, GIR, insulin sensitivity, AUC_{GLU}

Moderate and/or high intensity					
Author, Study design	**N enrolled (E) and completed (C)**	**Duration (weeks)**	**Intervention**	**Outcomes**	**Significant findings associated with exercise only**
				antioxidant activity and mRNA expression (catalyze activity, SOD), oxidative damage (8-oxo-dG), mtDNA	
Legro et al., 2015, [57] Dokras et al., 2016 [53], RCT	E = 149 C = 132	16	a. OCP b. Lifestyle (caloric restriction, weight loss medication, exercise) c. OCP + lifestyle	*Hemotological* AMH, T, SHBG, C, HDL, LDL, Tg, OGTT, AUC insulin, AUC glucose, insulin, *Anthropometric* BW, BMI, WC, FM, lean mass, BF% *Hemodynamic* SBP, DBP *Questionnaire* PCOSQ, 3-day diet log, SF-36	BW, cumulative ovulation rates, SF-36 (general health all groups), lifestyle only (vitality), PCOSQ (OCP and combined improvement in all domains, LS- not in hair and emotional)
Nagelberg et al., 2016 [60], RCT	E = 21 C = 21	4	a. Pedometer b. Control Step goal- increase 50% per wk. All received clomiphene	*Hemotological* HbA1c, fasting glucose, TSH, Vit D, T, DHEA-S *Anthropometric* BMI	N.S due to small sample size. 7 became pregnant (4 in intervention and 3 in control), 50% intervention group lost weight and only 3/10 patients achieved step count.
Arentz et al., 2017 [50], RCT	E = 122 C = 102	12	a. Lifestyle b. Lifestyle and herbal medicine Lifestyle = 150 min wk.	*Hemotological* FSH, LH, E_2, T, SHBG, FAI, fasting glucose, fasting insulin *Anthropometric* BMI, WC, WHR *Hemodynamic* SBP, DBP *Questionnaires* PCOSQ, DASS-21 *Menstrual cyclicity/ reproductive* Oligomenorrhea	Oligomenorrhea, BMI, insulin, LH, BP, PCOSQ, DASS-21, pregnancy rates (Lifestyle and herbal medicine)
Cooney et al., 2018 [51], RCT	E = 33 C = 24	16	a. CBT b. No CBT All received 30 min weekly nutrition/ exercise counseling. Exercise goal = 50 min and increase to 175 min per wk	*Hemotological* C, HDL, LDL, tg, fasting glucose, insulin, HOMA-IR, total/free T, SHBG, CRP, IL6, apolipoprotein A1 and B *Anthropometric* BW, BMI, WC, HC,	BW, PCOSQ (more in CBT). STAI and CES-D, Total/free T. Heart rate response (greater in CBT)

Moderate and/or high intensity					
Author, Study design	**N enrolled (E) and completed (C)**	**Duration (weeks)**	**Intervention**	**Outcomes**	**Significant findings associated with exercise only**
				WHR *Hemodynamic* SBP, DBP, heart rate response *Questionnaires* CES-D, STAI, PSS, ACE, PCOSQ, TSST	
Manteghi et al., 2021 [59], RCT	E = 120 C = 104	24	a. Letrozole 2× evening, HMG injection, aerobic exercise 3× wk 30 min b. Two letrozole tablets	*Hemotological* FBS, HbA1c, FSH, LH, E_2, PRL, TSH *Anthropometric* BMI *Menstrual cyclicity/ reproductive* Number follicles, pregnancy rates, rate live births	Pregnancy rates, rate live births, HbA1c and fasting blood sugar
De loos et al. 2023, [72] RCT	E = 183 C = 76	52	a. Lifestyle with sms support b. Lifestyle c. Usual care Lifestyle = encouraged to exercise 5× wk. 30 min, and 8–10 rx exercises 2x wk	*Cardiorespiratory* VO_{2max}, peak workload *Anthropometric* BMI, BW *Questionnaire* IPAQ	Lifestyle and sms-IPAQ, peak workload

Abbreviations: T, testosterone; SHBG, sex hormone binding globulin; E_2, estradiol; LH, luteinizing hormone; FSH, follicle stimulating hormone; P, progesterone; DHEA-S, dehydroepiandrosterone; A, Androstenedione; 17-OHP, 17-Hydroxyprogesterone; FAI, free androgen index; PRL, prolactin; TSH, thyroid stimulating hormone; PDG, pregnanediol-3-glucoronide; C, cholesterol; TC, total cholesterol; Tg, triglycerides; LDL, low density lipoprotein; HDL, high density lipoprotein; VLDL, very low density lipoprotein; Hb, hemoglobin; HOMA-IR, homeostatic model assessment insulin resistance; QUICKI, quantitative insulin-sensitivity check index; GIR, glucose infusion rate; $AUC_{GLU/INS}$, Area under curve glucose/insulin; IGF-1, insulin growth factor; T_4, thyroxine; CRP, C-reactive protein; WBC, white blood cells; NMR, nuclear magnetic resonance spectroscopy; BMI, body mass index; BF%, body fat percentage; FM, fat mass; FFM, fat free mass; AbFm, abdominal fat mass; SCFAT, subcutaneous fat; WC, waist circumference; WHR, waist to hip ratio; HC, hip circumference; SO2S, sum of 2 skinfolds; REE, resting energy expenditure; SBP, systolic blood pressure; DBP, diastolic blood pressure; LTPA, leisure time physical activity; HbA1c, glycated hemoglobin; HR, heart rate; HRR, heart rate reserve; VO_{2max}, maximal oxygen consumption; VO_{2AT}, maximal oxygen consumption at anaerobic threshold; VE/VCO_{2slope}, minute ventilation-carbon dioxide production; AER+RX, aerobic plus resistance; RCT, randomized control trial; RM, repetition maximum; NRCT, non randomized control trial; BDDE-SR, body dysmorphic disorder examination; BW, body weight; FFA, free fatty acid; BMD, bone mineral density; PCOSQ, Polycystic Ovary Syndrome Questionnaire; E1, estrone; E1-s, E1 sulphate; 5-DIOL, 5-androstene-3; ADT-G, androsterone glucuronide; 3G, androstane-3; 17G, 17-diol-17 glucuronide; MADRS-S, Montgomery Åsberg Depression Rating Scale; BSA-S, Brief Scale for Anxiety; SF-36, Short form-36; AFC, Antral follicle count; NS, not significant; NEFA, non esterified free fatty acids; RBC, red blood cell; HTC, hematocrit; MCV, mean corpuscular volume; MCH, mean corpuscular hemoglobin; MCHC, mean corpuscular hemoglobin concentration; PTL, platelets total level; TBW, total body water; BMR, basal metabolic rate; HRV, heart rate variability; CAT, continuous aerobic training; IAT, intermittent aerobic training; FSRI, Female sexual function index; FRS, figure rating scale; HITT, high intensity interval training; GGT, gamma-glutamyl transferase; ALT, alanine aminotransferase; A/P, Atherogenic index of plasma; TS/C, testosterone to cortisol ratio; VAT, visceral adipose tissue; VAI, visceral adiposity index; CES-D, Center for Epidemiologic Studies Depression Scale; STAI, State-Trait Anxiety Inventory; PSS, perceived stress scale; ACE, adverse childhood experience; TSST, Trier Social stress test; DASS-21, depression anxiety and stress score; IFG, impaired fasting glucose; RER, respiratory exchange ratio; PLT, platelets total level; GDR, glucose disposal rate; IL-6, interleukin-6; MIF, Covinton-Macrophage inhibitory factor; PAI-I, plasminogen activator inhibitor; CD68, cluster of differentiation marker 68; MCP-1, monocyte chemotactic protein-1; IPAQ, international physical activity questionnaire; MSNA, muscle sympathetic nerve activity; AMH, anti-Mullarian hormone; MDA, malondialdehyde; HADS, hospital anxiety and depression scale; TNFα, tumor necrosis factor; PLIN, Perilipin.

Table 1.
Summary exercise studies (aerobic, moderate and/or high intensity, lifestyle interventions).

moderate and low) [27], or there were a few studies that did not report this [20, 21, 23, 25, 28, 33–36, 38, 39, 43–45, 47, 52, 54–57, 59, 61, 71].

Adverse event reporting was also not always reported across interventions [20–23, 25, 26, 32, 35, 36, 39, 49, 52, 73], and similarly, this was also the same for dropout rates [20, 21, 23–26, 29, 35, 39, 55, 73]. Of the studies that reported dropout rates, this ranged between 10% and 70% across interventions [5, 27, 30, 32, 34, 41–43, 47, 49–52, 54, 56, 59, 61], where higher dropout rates were reported for interventions that used metformin (>40% [54, 56]), walking (where the volume increased fortnightly-57% [34]), moderate to high intensity exercise (30–60%) [41, 42, 49], and 30 min weekly nutrition/exercise counseling (where one group also received cognitive behavioral therapy (54%)) [51]. Across studies, co interventions was not always reported. While limited studies are available that reported for differences in dropout rates between ethnic groups, interestingly, two studies reported a higher percentage/number in ethnic groups that dropped out from interventions such as lifestyle and metformin (76% versus 62%) [56], and a ramp plus 12-week exercise protocol (25%) [32].

Characteristics of participants recruited in these studies ranged between 20 to 35 years of age, and BMI > 25.0 kg/m^2. Most studies excluded participants with a history of the following which included but was not limited to, cardiovascular, metabolic, or glucose intolerance. Across studies, the main baseline characteristics that were reported included body composition, hematological, cardiovascular, but not all studies reported menstrual cycle status as a baseline characteristic in PCOS. Further items that were not reported (although it is possible some studies could have reported these separately as supplementary materials) included family history, PCOS phenotype, previous pregnancies, or other co morbid conditions such as metabolic syndrome. Further, limited studies have not included other baseline characteristics for example pain perception, where higher prevalence of pain perception has been reported in PCOS in a study using the SF-36, and may be associated with infertility, obesity, inflammation or insulin resistance) [74], as well as sleep disorders (this was reported in one study which included numbers of obstructive sleep apnea) which may be prevalent in this cohort [37, 75].

To our knowledge, only few studies recruited PCOS women with a BMI < 25.0 kg/m^2 [25, 39], and also, for studies that did not report this, it is unclear as to whether participants in various ethnic groups were recruited. For example, differences in PCOS symptoms (e.g., hyperandrogenism and metabolic symptoms) were noted between Hispanics versus non-Hispanics [76]. Of the two studies that reported higher dropout rates in this group, it would be important to determine as to whether additional strategies are required to improve compliance rates in this group. Further, not all studies reported other ethnicity outcomes such as English language proficiency and Ancestry. Furthermore, it is probable that participants with limited English proficiency requiring translation were also not included in these studies. A previous review reported that approximately 21% of studies excluded participants with low English proficiency from research [77]. Exclusion of these participants from research would not provide a true representation of the study population, particularly in countries such as Australia where the population is culturally diverse.

Overall, the benefits of aerobic interventions that used either moderate and/or a combination of moderate and high intensity in women with PCOS with a BMI > 28.0 kg/m^2 ranged from improved body composition (e.g., reduced waist circumference, waist to hip ratio and body weight), hematological (e.g., improved lipids, hormones, insulin sensitivity), cardiorespiratory and hemodynamic (e.g. aerobic fitness, blood pressure), menstrual cyclicity, and other outcomes (e.g., mRNA, protein abundance). Further, for recent studies, quality of life was also improved

following an aerobic intervention, which included improved anxiety and depression scores (using HADS), PCOSQ (domains such as emotions, body hair, weight, and infertility problems), and quality of life (SF-36 on domains such as role physical, physical functioning, general health, and social role).

While further studies are warranted to investigate the benefits of aerobic exercise interventions in lean women with PCOS (BMI <28.0 kg/m^2), possible benefits may include a change in left/right follicles and menstrual cyclicity following moderate to high intensity exercise (60–85%) [39], as well as changes in BMI, weight and $VO2_{max}$ following low-high impact exercises at 50–75% HR_{max} [25].

A detailed list of outcomes for each of these studies and their findings are provided in Table 1.

2.2 Resistance interventions (with or without aerobic intervention)

Resistance training is a form of exercise that challenges the muscles with unaccustomed loads using free weights and/or machine weights. Resistance training has also been reviewed in studies in PCOS, either in isolation and/or combined with other modalities (e.g., aerobic, dietary component), and the studies incorporated exercises using free weights, machines, aqua aerobics, or Thera bands.

For studies that assessed aerobic and resistance, either in isolation or in combination, the exercise prescription was described across most interventions. For the aerobic intervention, this included 30 minutes on the treadmill/bike at 70–85% HR_{max} [78], 25–45 minutes at 60–80% HR_{max} [79], high intensity interval training (e.g. 4×30 s or 4×4 minutes at 90–100% maximum speed) [80–82], step routine (5–20 minutes) [83], goal oriented (200–300 minutes total per week) [84], or individually tailored [85]. For the resistance training, the prescription ranged from two to three sessions per week, with some studies prescribing a whole body intervention [81–83], while a number of studies did not describe the intervention in detail [78, 80, 84, 85]. The intensity of the resistance training interventions was determined by either repetitions (8–16 repetitions [78], % 1 Repetition Maximum (RM)) [79–82], Borg scale [83], or was not reported [78, 84–86].

Of the studies that assessed resistance training intervention only, two studies did not describe the intervention in detail [87, 88]. The prescription also varied across studies. For example, a study integrated macrocycles (e.g. four macrocycles (3 weeks of increased intensity, fourth week at a reduced intensity, and progressively increasing the intensity while reducing repetitions between sets (e.g. week 1–60%, 65%, 70%, 65%, week 2–65%, 70%, 75%, and 70%)) [89, 90], while another study used mesocycles (first 3 weeks performed for three sessions a week with the intensity increasing at 5% per week, and for the fourth week, sessions were performed for two sessions a week while the intensity reduced by 5% [47]. For another study, the intervention consisted of two supervised sessions per week of a whole-body routine with each exercise performed for three sets of 8–12 repetitions, and the weight was increased once the participant was able to perform three sets of the exercise at 8–12 repetitions, and it also included two supervised sessions at home using calisthenica [17].

The interventions ranged between 8 to 24 weeks, and most studies included comparator groups such as dietary restriction, no treatment (control), medication (e.g., metformin, calcium, clomiphene). Sample size across studies ranged between 8 to 143 participants. To the best of our knowledge, limited studies are available that included a long-term follow-up, and similar to the aerobic training studies, co interventions

were not always reported. Outcomes ranged from anthropometric, cardiorespiratory, hematological, menstrual cyclicity, and hemodynamic. Further, these studies collected other measurements such as endothelial vasodilation, step count, quality of life (i.e., anxiety and depression), heart rate recovery and telomere content. The listed outcomes are provided in **Table 2**.

For the resistance training interventions, adherence rates were not always reported across all studies. Of those that reported this, this ranged between 70% to 90% for

Mixed interventions (aerobic and/or resistance)					
Author, Study design	**N enrolled (E) & completed (C)**	**Duration (weeks)**	**Intervention**	**Outcomes**	**Significant findings associated with exercise only**
Bruner et al., 2006, [78] RCT	E = 12 C = 12	12	a. Nutrition counseling and AER + RX - 3× wk. 90 min (30 min TM or bike at 70–85% HR_{max}) and RX (12 exercises 3×15) b. Nutrition counseling	*Hemotological* T, SHBG, FAI, LH: FSH, fasting insulin, QUICKI *Cardiorespiratory* VO_{2max}, REE *Anthropometric* BW, BMI, WG, SO2S *Menstrual cyclicity/ reproductive* Ovarian follicle (left and right)	WG, SO2S, fasting insulin, VO_{2max}
Thomson et al., 2008, 2016, [79, 91] RCT	E = 94 C = 52	20	a. Diet + AER: walking/jogging 5 x wk. Wk 1 (25–30 min at 60–65% HR_{max}), and 45 min at 75–80% HR_{max} b. Diet + AER and RX same aerobic 3× wk., RX 2× wk. non consecutive. 5 exercises wks 1–2: 50–60% 1RM and increased to 65–75% 1RM. c. Diet only	*Hemotological* T, SHBG, FAI, C, LDL, HDL, tg, insulin, glucose, HOMA, urinary (PDG) *Cardiorespiratory* VO_{2peak} *Hemodynamic* SBP, DBP *Anthropometric* BF%, FM, FFM, AbFm WC *Menstrual cyclicity/ reproductive* Menstrual cyclicity *Questionnaires* PCOSQ, CES-D, EBBS	BP, fasting glucose, fasting insulin, HOMA, lipids, t, FAI, SHBG, ovulation, menstrual cyclicity (all groups), BF%, FM and FFM (exercise groups), trend AbFM (p = 0.08), EBBS, VO_{2peak}
Aubuchon et al.;2009, [84]open longitudinal study	E = 37 C = 33	14	Group exercise (AER + RX)-60 min. Group nutrition classes (90 min/ wk. for 4 weeks) 60 min session, Goal = 200–300 min/wk	*Anthropometric* BMI, WC, HC, BF% *Menstrual cyclicity/ reproductive* Clinical pregnancy rates	BF%, weight loss, BMI, WC, HC
Nybacka et al., 2011, [85] RCT	E = 57 C = 25	16	a. Diet b. Exercise c. Diet and exercise Diet: restriction ≥600 kcal/d Exercise: tailored	*Hemotological* FSH, LH, T, SHBG, fT, DHEA-S, 17-OHP, E_2, IGF-I, IGFBP-I, insulin, glucose, HOMA	Caloric intake/ 24 hrs, steps/d, weight, BF%, total lean body mass, T/SHBG ratio

Mixed interventions (aerobic and/or resistance)					
Author, Study design	**N enrolled (E) & completed (C)**	**Duration (weeks)**	**Intervention**	**Outcomes**	**Significant findings associated with exercise only**
			AER + RX (no description RX)	*Anthropometric* BW, WHR, BF%, lean body mass *Menstrual cyclicity/ reproductive* Menstrual status, ovulation *Other measurements* Caloric intake/ 24 hrs, steps/d	
Curi et al., 2012, [86] RCT	E = 40 C = 27	24	a. Metformin (850 mg) 2× day b. Lifestyle and diet (carb 50%, fat 30%, protein 20%), 30 min walk, 3 RX (squats, pushups, sit-ups)	*Hemotological* Fasting blood glucose, insulin, gonadotropins, E_2, total T, A, DHEA-S, tg, C *Anthropometric* BMI, WC *Menstrual cyclicity/ reproductive* Menstrual cycle index	BMI, WC, MCI
Almenning et al., 2015, [80] RCT	E = 31 C = 25	10	3× wk. (1× supervised) a. RT- 8 dynamic strength drills- 75% 1RM, 3×10. b. HITT-2× sessions (4×4 min 90–95% HR_{max}, and 3 min moderate intensity 70% HR_{max}) 1 session (10× 1 min max intensity, 1 min rest/very low activity). Self-selected (treadmill, walking/running/ cycling) c. Control	*Hemotological* IR (HOMA-IR), Glucose, C, HDL, LDL, tg, CRP. Insulin, adiponectin, leptin, T, homocysteine, AMH, FAI, SHBG, DHEA-S *Cardiorespiratory* VO_{2max} *Hemodynamic* Heart rate recovery *Anthropometric* BW, WC, FM, VF, FFM, BF% *Menstrual cyclicity/ reproductive* menstrual frequency *Other measurements* Endothelial vasodilation (FMD)	HOMA-IR, HDL, AMH, endothelial function, BF%
Turan et al., 2015, [83] RCT	E = 32 C = 30	8	3× wk. 8 weeks. a. AER + RX (50–60 min) AER- Step 5–20 min (Borg 10–15) RX-Elastic band 15 reps each (intensity 5–6	*Hemotological* FSH, LH, FSH, E2, Total T, fT, HDL, LDL, tg, Total cholesterol, fasting glucose, fasting insulin, HOMA *Cardiorespiratory*	WC, HC, DBP, RR, VO_{2max}, LDL, total cholesterol, fasting glucose, HOMA, mean menstrual cycle interval

Mixed interventions (aerobic and/or resistance)					
Author, Study design	**N enrolled (E) & completed (C)**	**Duration (weeks)**	**Intervention**	**Outcomes**	**Significant findings associated with exercise only**
			somewhat intense) a. Control	VO_{2max} *Hemodynamic* SBP, DBP, HR, RR *Anthropometric* BMI, WC, HC *Other measurements* IPAQ	
Nasiri et al., 2022 [81], RCT	E = 45 C = 45	8	a. HITT-4×30 s 100% maximum speed, 4×30 s active recovery, 5 min passive recovery. b. COM- 3× wk, RX 3×10–16 repetitions (50–70% 1RM) and AER – running 60–70% HR_{max} c. Usual care	*Cardiorespiratory* VO_{2max} *Anthropometric* BMI, WHR, Weight, BF%, VAT	BMI, WHR, BF%, VAT, VO_{2max}
Rao et al., 2022, [82] RCT	E = 50 C = 40	12	a. HITT-3× treadmill (4×4 at 90–95% HR_{max}, and 3 min moderate intensity (70% HR_{max})- 45 min session, total duration HITT 25 min b. RX-3× wk., 60–70% 1RM 3×10	*Hemotological* T *Anthropometric* BMI, BF% *Questionnaire* IPAQ	BMI (both groups), T, BF% and IPAQ (more in HITT)
Resistance training interventions					
Author, Study design	**N enrolled & completed**	**Duration**	**Intervention**	**Outcomes**	**Findings ($P < 0.005$)**
Lara et al. 2015, [89]Ramos et al., 2016, [90] Kogure et al. 2019, [92] Kogure et al., 2018 [93], 2016 [94], Miranda-Furtado et al., 2015 [95] NRCT	E = 115 C = 94 *(43 PCOS and 51 healthy controls)*	16	RX- 2 wks adaptation RX 3× wk (upper and lower body exercises)- 4 microcycles (4 weeks each) 1st macrocycle- 3×15 (60%, 65%, 70%, 65%) 2nd macrocycle- 3×12 (65%, 70%, 75%, 70%) 3rd macrocycle-3×10 (70%, 75%, 80%, 75%) 4th macrocycle 3×8 (75%, 80%, 85%, and 80%)	*Hemotological* T, A, Glucose, Insulin, HOMA-IR, LH, FSH, E_2, SHBG, FAI, 17-OHP, homocysteine *Anthropometric* Height, BW, BMI, WC, lean muscle mass (total LM, trunk LM, BF%, LM/height^2), arm muscle area (cm), thigh	T, A, SHBG, fasting glucose, total LM, Trunk LM, BF%, LM/height^2, WC, WHR Total score (FSFI), HADS, SF-36 (functional capacity), arm muscle area, maximum strength (bench press, leg press,

Resistance training interventions					
Author, Study design	**N enrolled & completed**	**Duration**	**Intervention**	**Outcomes**	**Findings (P < 0.005)**
				muscle area (cm) *Questionnaire* PARQ, FSFI, HADS, SF-36 *Other measurement* Telomere content	leg extension), telomere content
Vizza et al., 2006, [17] RCT	E = 15 C = 10	12	a. RX 2× wk. supervised (3×12 upper/ lower body) and 2× unsupervised sessions at home b. Control	*Hemotological* HOMA-2, CRP, T, SHBG, FAI, HbA1c, fasting glucose, fasting insulin *Anthropometric* Height, BW, BMI, WC, HC, WHR, FM, LM, FFM, BF% *Hemodynamic* SBP, DBP *Questionnaire* PCOSQ, SF-36, DASS-21, Exercise self-efficacy scale *Menstrual cyclicity/ reproductive* Menstrual cyclicity *Functional* Isometric maximum voluntary contraction upper and lower body *Other measurements* Feasibility outcomes (recruitment and attrition, adherence, adverse events, completion assessments)	BW, BMI, WC, LM, FFM, HbA1c, fasting glucose, trend upper body strength, lower body strength, PCOSQ (emotions, weight, infertility problems), SF-36 (physical functioning, vitality, social functioning, role emotional, mental health), DASS-21, exercise self efficacy
Ribeiro et al. 2016, [47] case control	E = 53 *(27 PCOS and 26 control)*	16	RX 70% 1RM, 12 repetitions, (upper and lower body exercises)-mesocycles (4wk each) Wk 1–3: 3× wk., intensity increased 5% wk.	*Hemotological* T, A, T/A ratio, SHBG, FAI, fasting glucose, fasting insulin, HOMA-IR *Anthropometric*	N.S between groups (PCOS did show within group LF, HF, LH/HF ratio)

Resistance training interventions					
Author, Study design	**N enrolled & completed**	**Duration**	**Intervention**	**Outcomes**	**Findings (P < 0.005)**
			Wk 4: 2× wk, intensity decreased 5%	Weight, BMI, BF% *Hemodynamic* HR, SBP, DBP, MBP, HRV	
Saremi et al., 2016 [96], RCT	E = 33 C = 31	8	a. RX and placebo b. RX and calcium supplement c. Control RX 3× wk. 1–2 sets 5–20 reps at 40–60% 1RM (upper and lower body)	*Hemotological* Total C, Tg, LDL, HDL, HOMA-IR, fasting insulin, fasting glucose *Anthropometric* BW *Strength* chest press and leg press	Fasting insulin, fasting blood glucose, tg, cholesterol, LDL, HDL, HOMA-IR, upper/lower body strength, weight. AMH (combined only)
Ramos et al., 2016, [90] NRCT	E = 94 C = 94 *(43 PCOS and 51 healthy controls)*	16	RX: 3×10, %1RM (upper and lower body exercises) 4× microcycles 4 weeks each (60%, 65%, 70%, 75%)	*Hemotological* T, A, glucose, insulin, HOMA-IR *Anthropometric* WC, BMI, Weight *Questionnaire* SF-36	T (PCOS and control), A (PCOS), WC (PCOS), SF-36 (functional capacity), vitality, social aspects, mental health (healthy controls)
Zhang et al., 2017, [88] RCT	E = 101 C = 101	24	a. Metformin (500 mg 3× day) and clomiphene (2× 50–100)- 5 consecutive days for 3 consecutive menstrual cycles b. Lifestyle (strengthening, 30 min each and stopped when patients began to sweat)	*Hemotological* LH, T, LH/FSH, fasting insulin, TG *Anthropometric* WHR, BMI, BW *Menstrual cyclicity/ reproductive* Left ovarian volume, right ovarian volume, endometrial thickness, menstrual recovery rate, ovulation rate, pregnancy rate	BW, BMI, LH, T, LH/FSH, fasting insulin, TG, left/ right ovarian volumes, menstrual recovery, ovulation and pregnancy rate
Hosseini et al., 2019, [97]RCT	E = 60 C = 60	8	a. Control b. Water training (upper/lower trunk strength training)3×12, 60 min c. RX 30 min 40–70% RM (does	*Hemotological* AMH *Anthropometric* BW	AMH (training in water with vit D and Vit D)

Resistance training interventions					
Author, Study design	**N enrolled & completed**	**Duration**	**Intervention**	**Outcomes**	**Findings (P < 0.005)**
			not list exercises) d. VitD e. VitD and water training f. Land training and VitD		
Saeed et al., 2022, [98] case control	E = 143 C = 79 *(PCOS and 64 non PCOS)*	8	RX 3×10, %1RM Upper and Lower body exercises	*Hemotological* Fasting glucose, fasting insulin, T, A *Anthropometric* Height, BMI, WC *Questionnaire* PARQ, SF-36	SF-36 (role functional, role physical, pain, energy)
Aqdas et al., 2022, [87] NRCT	E = 28 A = 28	12	Not described	*Hemotological* Total C, HDL, LDL, Tg, *Anthropometric* BMI	BMI, Total C, HDL, LDL, Tg

Abbreviations: T, testosterone; SHBG, sex hormone binding globulin; E_2, estradiol; LH, lutenizing hormone; FSH, follicle stimulating hormone; P, progesterone; DHEA-S, dehydroepiandrosterone; A, Androstenedione; 17-OHP, 17-Hydroxyprogesterone; FAI, free androgen index; TSH, thyroid stimulating hormone; PDG, pregnanediol-3-glucoronide; C, cholesterol; TC, total cholesterol; Tg, triglycerides; LDL, low density lipoprotein; HDL, high density lipoprotein; HOMA-IR, homeostatic model assessment insulin resistance; QUICKI, quantitative insulin-sensitivity check index; IGF-1, insulin growth factor; T_4, thyroxine; CRP, C-reactive protein; WBC, white blood cells; BMI, body mass index; BF%, body fat percentage; FM, fat mass; FFM, fat free mass; AbFm, abdominal fat mass; WC, waist circumference; WHR, waist to hip ratio; HC, hip circumference; SO2S, sum of 2 skinfolds; REE, resting energy expenditure; SBP, systolic blood pressure; DBP, diastolic blood pressure; IPAQ, International physical activity questionnaire; HbA1c- glycated hemoglobin; HR, heart rate; HRR, heart rate reserve; VO_{2max}, maximal oxygen consumption; VO_{2AT}, maximal oxygen consumption at anaerobic threshold; VE/VCO_{2slope}, minute ventilation-carbon dioxide production; AER+RX, aerobic plus resistance; RCT, randomized control trial; RM, repetition maximum; NRCT, non randomized control trial; BW, body weight; FFA, free fatty acid; BMD, bone mineral density; PCOSQ, Polycystic Ovary Syndrome Questionnaire; E1, estrone; E1-s, E1 sulphate; 5-DIOL, 5-androstene-3; ADT-G, androsterone glucuronide; 3G, androstane-3; 17G, 17-diol-17 glucuronide; BSA-S, Brief Scale for Anxiety; SF-36, Short form-36; NS, not significant; NEFA, non, esterified free fatty acids; RBC, red blood cell; HTC, hematocrit; MCV, mean corpuscular volume; MCH, mean corpuscular hemoglobin; MCHC, mean corpuscular hemoglobin concentration; PTL, platelets total level; TBW, total body water; BMR, basal metabolic rate; HRV, heart rate variability; CAT, continuous aerobic training; IAT, intermittent aerobic training; FSRI, Female sexual function index; FRS, figure rating scale; HITT, high intensity interval training; GGT, gamma-glutamyl transferase; ALT, alanine aminotransferase; A/P, Atherogenic index of plasma; TS/C, testosterone to cortisol ratio; VAT, visceral adipose tissue; VAI, visceral adiposity index; CES-D, Center for Epidemiologic Studies Depression Scale; STAI, State–Trait Anxiety Inventory; PSS, perceived stress scale; ACE, adverse childhood experience; TSST, Trier Social stress test; DASS-21, depression anxiety and stress score; IFG, impaired fasting glucose; RER, respiratory exchange ratio; PLT, platelets total level; GDR, glucose disposal rate; IL-6, interleukin-6.

Table 2.
Summary exercise studies (aerobic and resistance, and resistance training in isolation).

supervised training [17, 80], 40–45% for home-based calisthenics training [17], or 60% overall for both supervised and home-based calisthenics training [17]. In addition, similar to the aerobic training studies, dropout rates were also not always reported across these studies. Of the studies that reported this, this ranged between 10%–50%, where a higher drop out rate was reported in studies that included a dietary restriction [79, 85].

Characteristics (e.g., age and BMI) were also similar as per the aerobic studies only (Section 2.1), and in addition, most studies also had similar exclusion criteria as per the aerobic training studies. Further, similar to the aerobic training studies, limited studies included PCOS participants with a BMI < 25.0 kg/m^2 [83], nor did they report on ethnicity outcomes [17, 78–82, 84–86]. Furthermore, other baseline characteristics that were also not included in the aerobic training studies (e.g., family history, co morbidities, pain perception, sleep apnea, previous pregnancy etc.) were also not reported in these studies. Although it may be possible that some studies have reported these as supplementary materials, or this information may not be available due to the exclusion criteria across studies.

The benefits of resistance training interventions in PCOS ranged from improved body composition (e.g., reduced waist circumference, hip circumference, BMI, body weight, and improved lean muscle mass), improved insulin sensitivity and menstrual cyclicity, and quality of life (such as anxiety, depression). In addition, for studies that included normal weight PCOS, possible benefits following a resistance training intervention may include changes in body composition (e.g., waist circumference, hip circumference), shorter menstrual cycle intervals, and hematological changes (e.g., cholesterol).

A detailed list of outcomes for each of these studies and their findings are provided in **Table 2**.

2.3 Conclusion and future directions for research

A large number of exercise interventions have been evaluated in PCOS, and benefits are noted across aerobic, moderate and high intensity, lifestyle and resistance training interventions. Variability was noted across studies in terms of reporting baseline characteristics of PCOS, description of interventions, as well as reporting of co-interventions. Overall, while the benefits of exercise were noted across interventions, higher dropout rates are often noted in women with PCOS, which may affect overall study findings. Although this was not reported across all studies, future studies should also continue to report on both drop out and/or compliance rates across all interventions.

These findings will allow future research to determine as to which interventions would require further strategies for women with PCOS in order to improve overall adherence and compliance. Possible strategies could include the measurement of exercise self-efficacy at baseline to determine predictors of long-term adherence, as well as include a long-term follow-up component to better understand if additional barriers are noted for women with PCOS to adopt the lifestyle behavior change. Further, focus groups and/or interviews with study participants could also be incorporated, and their feedback could be integrated into the intervention to address for any other barriers. Furthermore, studies may also consider and test other methods of delivering the exercise interventions to improve compliance such as Telehealth, home based visits and/or online/zoom.

These strategies could also be incorporated for participants in the cultural and linguistically diverse community (CALD) and will allow researchers to better understand reasons for non-compliance and/or higher drop out which was reported in a few studies. This could also be coupled with further reporting of other baseline characteristics in PCOS to determine if there are any other contributing factors that may result in non-compliance, for example, physical and/or psychological, or whether participants may be using other co-interventions outside of the study that may be more

effective as opposed to the intervention. Further, studies should also look to report other ethnicity measures (e.g., Ancestry, as well as those with limited English language proficiency), to better understand ethnic groups that may be at at risk of poorer outcomes and require ongoing management.

While the majority of studies included PCOS women with a BMI >25.0 kg/m^2, most studies excluded participants with a history of conditions such as cardiovascular disease, metabolic syndrome, glucose intolerance etc. As women with PCOS are at an elevated risk for the development of these conditions, future studies should look to include these participants with a number of co-morbidities, in order to determine for differences between controls for both baseline characteristics, as well as overall response to exercise. In addition, further studies should also look to report on other outcomes such as previous pregnancies and/or whether they were diagnosed with previous gestational diabetes in pregnancy, in order to understand as to whether it may lead to changes in the metabolic profile and/or symptomology of PCOS versus non pregnant participants, or whether it may lead to differences in the response rate to exercise.

Also, limited studies included PCOS women with a BMI <25.0 kg/m^2, and further studies are warranted to better understand both the baseline characteristics in this group (physical and psychological) and the benefits of exercise. Studies may also look to incorporate focus groups to better understand the lived experience in this group, and these findings could enable both the researchers and clinicians to incorporate recommendations to improve overall management and tailor interventions appropriately.

Conflict of interest

The author declares no conflict of interest.

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