

Original Research

Fitness Assessments of Women with Polycystic Ovary Syndrome: A Prospective Process Feasibility Study

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Abstract

Background: Fitness is a marker of physiological and mental health. The purpose of this pilot study was to assess the feasibility of processes to recruit women with polycystic ovary syndrome (PCOS) during the Covid pandemic and collect their health and fitness data. Additionally, the data was used to explore possible associations between anthropometrics, PCOS biomarkers, health-related quality-of-life (HRQoL), and depressive symptoms with that of fitness and self-reported physical activity levels among women with PCOS. **Methods:** A convenience sample of women with PCOS ($n = 15$) were recruited via flyers and the snowball method. Participants completed surveys, anthropometrics, a dual energy x-ray absorptiometry scan, blood work, and a fitness assessment. Data were statistically analyzed using Spearman correlations. **Results:** Feasibility measures of recruitment and retention rates were 83% and 100%, respectively. Fidelity measurement for process averaged 97%. Participants (age $25.9 (\pm 6.2)$, mostly White (80%), single (60%), and employed full-time (67%)) were categorized as obese (body mass index (BMI) $32.2 \text{ kg/m}^2 \pm 8.3$, percent bodyfat $41.1\% \pm 8.1$) with ≤ 1 comorbidity. Most participants were not regularly physically active and had high free testosterone levels ($7.6 \text{ pg/mL} \pm 4.3$), elevated high-density lipoprotein ($63.2 \text{ mg/dL} \pm 12.9$), fair cardiovascular capacity, and below average muscular strength/endurance. The following statistically significant and strong associations were found: (1) VO_2 max with percent bodyfat (-0.59 ; $p = 0.02$), sex hormone binding globulin (0.73 ; $p = 0.00$), HRQoL (0.72 ; $p = 0.00$), and depressive symptoms (-0.67 ; $p = 0.00$), (2) abdominal strength with BMI (-0.66 ; $p = 0.01$) and high density lipoprotein (HDL) (0.59 ; $p = 0.02$), (3) physical activity level with percent bodyfat (-0.72 ; $p = 0.00$), and (4) resistance training with low density lipoprotein (LDL) (-0.52 ; $p = 0.05$). **Conclusions:** Collecting health and fitness data from women with PCOS is a feasible research approach. Randomized controlled trials in which health and fitness data are collected from women with PCOS are needed to confirm possible associations between fitness and PCOS clinical features and is in the planning process.

Keywords: polycystic ovary syndrome; fitness testing; fitness; anthropometrics; biomarkers; aerobic capacity; muscular endurance

1. Introduction

Polycystic ovary syndrome (PCOS), the most common chronic endocrinopathy among women, has a prevalence that ranges between 15 and 20% [1]. Common signs/symptoms include subfertility, insulin resistance, dyslipidemia, hirsutism, and lethargy, placing women with PCOS at risk for comorbid conditions such as diabetes, cardiovascular disease, reproductive cancers, and depression and resulting in reduced health-related quality-of-life (HRQoL) [2]. Unfortunately, a PCOS diagnosis is often missed or delayed, as its presentation can widely vary, thus affecting treatment recommendations [3].

According to Rotterdam criteria, PCOS is diagnosed when two of three characteristics exist: clinical or biochemical hyperandrogenism, ovulatory dysfunction, and/or ultrasound evidence of polycystic ovaries [4]. Using all possible combinations, this heterogeneous condition produces four phenotypes. For example, some women with PCOS

may be obese, others lean and some women with PCOS may have hirsutism, while others may not. Such differences in physical presentation confound PCOS diagnosis and treatment. However, the risk for comorbid conditions holds constant regardless of phenotype due to factors such as central adiposity (affecting 50% of women) and dyslipidemia (affecting 70% of women), which are both independent of total bodyfat percentage [3,5].

Lifestyle changes, such as exercise, are recommended as first-line treatment by the Endocrine Society Clinical Practice Guidelines for PCOS [4]. However, research indicates that less than 60% of women with PCOS engage in regular physical activity [5] and more than 25% are sedentary [6]. Fitness (the sum attributes of cardiorespiratory capacity, muscular strength and endurance, and flexibility), is a marker of physical and mental health and people who are fit have lower mortality from any cause as compared to those who are not fit [7]. To date, there are



no research studies about fitness as an indicator of PCOS clinical features and health risk. As such, we conducted a pilot study to assess the feasibility of processes to recruit women with polycystic ovary syndrome (PCOS) and collect their health and fitness data. Additionally, the data was used to explore possible associations between anthropometrics, PCOS biomarkers, health-related quality-of-life (HRQoL), and depressive symptoms with that of fitness and self-reported physical activity levels among women with PCOS.

Theoretical Model

A theoretical PCOS physiological model guided this study (Fig. 1, Ref. [8]). PCOS is multifactorial, as genetic alterations, epigenetic modifications, and environmental factors contribute to development or worsening of the clinical manifestations [8]. Genetic origin of PCOS is confirmed by a hereditary factor observed in first-degree relatives, as women who have mothers or sisters with PCOS are at increased risk (35–40%) of developing the condition [9]. In addition to a genetic basis, epigenetic alterations (e.g., DNA methylation, noncoding RNA regulation) play a central role in PCOS outcomes, including phenotypic difference, by dynamically and reversibly controlling gene expression during childhood and into adulthood [8]. Environmental factors (e.g., nutrition, physical activity, smoking) combined with genetic predisposition can change the epigenome landscape leading to (epi)genetic susceptibility for developing PCOS throughout life [8].

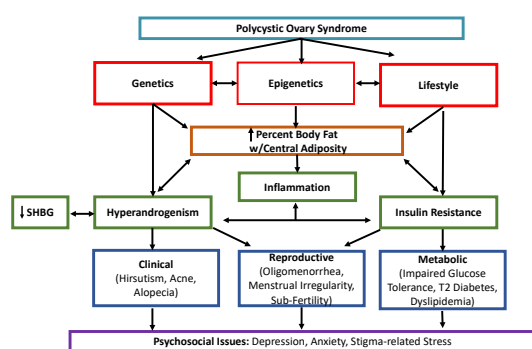


Fig. 1. Adapted (with permission) physiological model of polycystic ovary syndrome [8]. This model illustrates the interrelationships and outcomes of etiological factors and PCOS symptoms.

Obesity is a common characteristic of women with PCOS, and affects clinical manifestations such as hyperandrogenism, insulin resistance, and dyslipidemia [4]. Visceral fat, bodyfat located within the abdominal cavity, is a storage site for circulating androgen. Androgen is also present in plasma as free or unbound testosterone [4]. Further, hyperinsulinemia due to insulin resistance also contributes to excess androgen, as hyperinsulinemia decreases

the total amount of sex hormone binding globulin (SHBG) [10], a glycoprotein that binds with androgen. Androgen is also produced in excess by the adrenal glands in most women with PCOS [4].

2. Materials and Methods

2.1 Study Overview

The investigator's apriori target goal for sample size was based on a small effect size and $p < 0.05$ [11], as well limited resources. A convenience sample of participants ($n = 15$) was recruited into this single-arm process feasibility study using flyers and the snowball method during the summer months of 2021 on a university campus (~35,000 students) in the southeastern United States and amidst the Covid pandemic. Inclusion criteria were women aged 18–42 with a medically confirmed PCOS diagnosis. Exclusion criteria were medically induced menopause, cardiovascular disease, orthopedic injury, and pregnancy. Exclusion criteria were identified during telephone or email prescreening using the Physical Activity Readiness Questionnaire. When participants met requirements and provided medical confirmation of a PCOS diagnosis via secured email, they were scheduled an appointment at a university-based clinical exercise research center. Upon arrival at the research center, the study purpose, benefits, and risks were explained to potential participants, and their questions were answered. After informed consent, the following measures were obtained: anthropometrics, venipuncture for laboratory panel, questionnaires, dual energy x-ray absorptiometry (DEXA), estimated oxygen consumption, muscular fitness, and flexibility. Participants received a \$50 gift card as an incentive. Research protocols were approved by the university's Institutional Review Board (Pro00106153).

2.2 Feasibility Measures

Feasibility measures included recruitment and retention rates and participant feedback. The recruitment rate was calculated by dividing the total number of participants who entered the study by the number of participants who answered the call for participants, and then multiplying by 100%. The retention rate was calculated by dividing by the number of participants completing all phases of the study by the number of participants entering the study, and then multiplying by 100%. Fidelity to process was measured using an apriori checklist, with results calculated by dividing the number of missed steps by the number of defined actions and multiplying by 100%. At the end of each fitness assessment, participants were asked three open-ended questions to obtain their feedback about the research process. A future full-scale study will be based on the feasibility of this pilot trial.

2.3 Anthropometrics

Anthropometric measurements included height (measured to nearest 0.1 cm using a wall-mounted stadiometer),

weight (measured twice and to nearest 0.1 kg using an electronic scale), and waist and hip circumferences (measured twice to nearest 0.1 cm using a measuring tape). Body mass index (BMI) was calculated with the formula $[BMI = \text{weight (kg)}/\text{height (m)}^2]$. Waist-to-hip ratio was determined by dividing waist circumference by hip girth. Percent bodyfat and lean muscle mass were determined using the Lunar fan-beam dual energy x-ray absorptiometry (DEXA) scanner (GE Healthcare model 8743, GE Healthcare, Waukesha, WI, USA). DEXA is spectral imaging involving less than two days' exposure to natural background radiation, with demonstrated reliability of an intraclass correlation of $R = 0.99$ [12].

2.4 Laboratory-Derived Data

After fasting for at least eight hours before the appointment, participants received venipuncture for a laboratory panel including free testosterone, SHBG, and lipid profile. Trained personnel followed standard protocol for venipuncture to collect approximately 10 mL of blood. The specimens were processed at Lexington Medical Center (West Columbia, SC, USA). Results were confidentially sent to the principal investigator's university office. Free testosterone is used to diagnose androgen excess not due to other rare disorders [3]. SHBG is a PCOS and insulin resistance biomarker [10]. A lipid profile was collected to assess for dyslipidemia.

2.5 Questionnaire-Derived Data

2.5.1 Demographics

The demographic questionnaire included age, race, educational attainment, marital status, number of children, employment, insurance, geographic residence, and comorbid conditions.

2.5.2 Health-Related Quality-of-Life

PCOS-specific HRQoL was measured using the Polycystic Ovary Syndrome Questionnaire (PCOSQ-50). The PCOSQ-50 has been reported to have a construct validity of 0.92 and test-retest reliability of 0.91 [13]. It includes 50 items in six domains: psychosocial/emotional, fertility, sexual function, obesity/menstrual disorders, hirsutism, and coping. Answers are given on a 5-point Likert scale ranging from 1 = always (worst condition) to 5 = never (best condition). A score for each domain was calculated as the sum of all answered items in the domain divided by the number of answered items. The total PCOSQ-50 score was calculated as the sum of all answered items divided by the number of answered items. Lower scores indicate poor HRQoL [13].

2.5.3 Physical Activity Level

The Rapid Assessment of Physical Activity (RAPA) was used to determine participants' physical activity levels. The RAPA includes seven yes/no questions. The sum of "yes" responses indicates physical activity frequency,

and intensity. The second section of the RAPA includes questions about the performance of resistance training and flexibility exercise. The RAPA has been reported to have good sensitivity (100%) and specificity (75%) for determining physical activity level [14]. Positive and negative predictive value for determining physical activity levels were 94.4% and 100% respectively [14].

2.5.4 Depressive Symptoms

The Personal Health Questionnaire (PHQ-8) was used to assess prevalence and severity of depressive symptoms occurring within the past two weeks. The scale consists of 8 items with a 4-point rating ranging from 0 (not at all) to 3 (nearly every day). A score of ≥ 10 indicates major depression and ≥ 20 indicates severe major depression [15]. Construct validity was reported at 0.75 and internal reliability was reported at 0.81 [15]. Given the sensitive nature of the questions and the overall purpose of the screening, local and national mental health resources were provided. The resources were verbally mentioned during the informed consent and provided in writing before the depressive symptoms survey.

2.6 Fitness Testing

2.6.1 Modified Bruce Treadmill Test

The modified Bruce treadmill test was used to estimate maximal oxygen consumption (VO_2 max) or cardiorespiratory fitness, as this measure is related to functional capacity and serves as a strong independent predictor of all-cause and disease-specific mortality [5]. The modified version was chosen to ensure safety and comfort when assessing sedentary or physically inactive participants and due to availability and cost of a more direct measure. After a prolonged warm-up (6 minutes), the protocol is divided into 3-minute stages, each with a faster speed and steeper grade. The participant's heart rate and perceived exertion were monitored throughout the test. The final score was calculated using the total time spent in working phases with the formula $[(4.38 \times T) - 3.9 = VO_2 \text{ max}]$. The estimated VO_2 max was then compared to gender- and age-based normative data. The modified Bruce treadmill test was chosen as the safest alternative for sedentary participants. For the modified Bruce treadmill test, a Pearson product moment correlation coefficient between predicted and measured VO_2 max of 0.94 for women without cardiac conditions ($n = 5509$) [16]. The average predicted error was $-0.6 \text{ mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ for the general equation [16].

2.6.2 Modified Push-Up Test

Using the American College of Sports Medicine (ACSM) protocol, the modified push-up test was used to estimate upper body muscular fitness. This test was chosen as a safer alternative than one-rep-max tests for sedentary or physically inactive participants and due to the availability of normative data. The test involves performing push-ups

in a modified position (knees bent with lower legs in contact with the mat). The score is the total number of modified push-ups performed with proper form in one minute. The score was compared to gender- and age-based normative data. The norm-referenced test-retest reliability estimate using intraclass correlations from one-way analysis of variance (ANOVA) was $R = 0.99$ [16].

2.6.3 Curl-Up Test

Using ACSM protocol, the curl-up test was used to estimate abdominal muscular fitness. This test was chosen as a safer alternative than one-rep-max tests for sedentary or physically inactive participants and due to the availability of normative data. In a supine position, the participant repetitively lifts and lowers the upper body to a metronome set at 40 beats/minute. The score is the number of curl-ups performed with proper form to cadence. The score was compared to gender- and age-based normative data. Psychometric findings included high test-retest reliability ($r = 0.98$), moderately high inter-apparatus reliability ($r = 0.71$), and moderately high inter-tester reliability ($r = 0.76$) [16].

2.6.4 Sit-and-Reach Test

Using ACSM protocol, the sit-and-reach test was used to assess hamstring flexibility. The test was chosen because it assesses the flexibility of several muscle groups with one movement and due to the availability of normative data. This measure was chosen because hamstring flexibility is related to low back and knee joint health. Participants sat against a wall with feet placed at the 15-inch mark on a measuring tape. Keeping knees straight and feet plantarflexed, participants reached forward with both hands. The score was the farthest distance reached of three trials. The score was compared to gender- and age-based normative data. The sit-and-reach test has shown a moderate mean criterion-related validity for estimating hamstring extensibility ($r = 0.46$ – 0.67) [16].

2.7 Statistical Analyses

Analyses were conducted using IBM SPSS Statistics for Windows, version 27.0 (IBM Corp., Armonk, NY, USA). Descriptive statistics (frequencies or mean $\pm$ standard deviations) were computed for each measure. Given the small sample, assumptions of normality were not met. Thus, Spearman correlations were conducted. The data that support the findings of this study are available from the corresponding author upon reasonable request.

3. Results

The feasibility of conducting health and fitness assessments of women with PCOS was measured using recruitment and retention rates and participant feedback. Eighteen women answered the call for participants, with 15 meeting eligibility requirements for a recruitment rate of 83%. Fifteen women entered the study and successfully completed

all phases for a retention rate of 100% (Fig. 2). Using a level of confidence at 95%, the margin of error for recruitment was 2%. Anything between 0.61% and 1.00% (0.81 ± 0.2) would accurately describe the PCOS population on the university's campus.

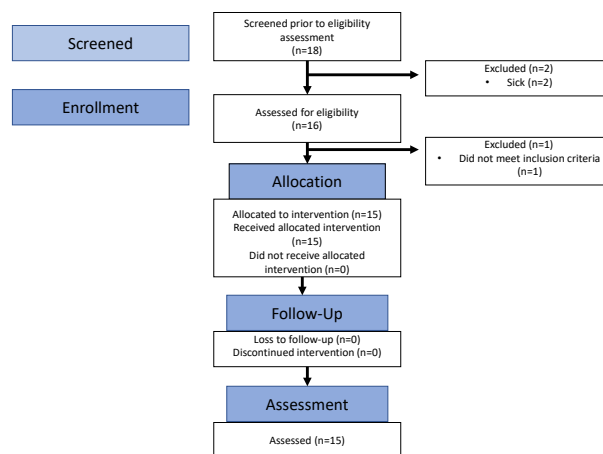


Fig. 2. Consort flow diagram of recruitment and retention.

The process for each participant progressed as planned and there were no adverse events. Fidelity to process was 96%. All participants expressed satisfaction with the study and seven participants (47%) requested their laboratory and fitness results. Participant feedback was positive, and no recommendations were made for improving the process.

Participants ($n = 15$) were $25.9 (\pm 6.2)$ years of age and mostly White (80%). Almost half (47%) had ≥ 1 comorbid conditions. Characteristics of the study sample are listed in Table 1. Phenotypically, the women were obese (BMI $32.2 \text{ kg/m}^2 \pm 8.3$, bodyfat $41.1\% \pm 8.1$) with high levels of free testosterone ($7.6 \text{ pg/mL} \pm 4.3$) (Table 2). Many (53%) of the women reported regular physically activity, but not for the recommended 150 minutes/week of moderate-to-vigorous activity. Six (40%) participants reported performing resistance training. Nine (60%) participants reported performing flexibility exercises. Table 3 presents clinical ranges, means ($\pm$ standard deviation (SD)) of the total population (*i.e.*, reference group), a descriptor of sample means for each study characteristic, and the percent of the sample at risk for a poor health outcome based on that characteristic. Participants reported a neutral HRQoL total (3.3 ± 0.7) with low scores in the obesity/menstrual and hirsutism domains. The sample mean for depressive symptoms indicated few depressive symptoms; however, four (27%) participants scored high (≥ 10), indicating major depression [15] (Table 2). Correlational analyses yielded nine statistically significant ($p < 0.05$) associations and seven associations with large effect sizes that approached statistical significance ($p = 0.05$ – 0.15) (Table 4).

Table 1. Descriptive statistics of study sample (n = 15).

Characteristics	Frequency (%) or Mean $\pm$ SD
Age	25.9 $\pm$ 6.2
Ethnicity	
African American or black	0% (0)
Hispanic, Latino/a, or Spanish	13.3% (2)
White	80% (12)
Mix of two	6.7% (1)
Educational attainment	
High school or GED	13.3% (2)
Some college	26.7% (4)
Bachelors	33.3% (5)
Masters	26.7% (4)
Employment status	
Not working	13.3% (2)
Part time	20% (3)
Full time	66.7% (10)
Medical insurance	
Yes	100% (15)
Marital status	
Single	60% (9)
Married or partnership	40% (6)

GED, general educational development; SD, standard deviation.

4. Discussion

4.1 Feasibility

According to a review of funded and published randomized controlled trials, successful recruitment is $\geq 75\%$ and successful retention is $\geq 80\%$ [17]. Using these criteria, collecting health and fitness information from women with PCOS is a feasible research approach. According to participant feedback, women with PCOS are seeking answers about their condition and are eager to participate in future PCOS research including this assessment protocols used in this study.

4.2 VO_2 Max

VO_2 max is an indicator of long-term morbidity and mortality and has been recommended by the American Heart Association to be regularly assessed and used as a clinical vital sign [5]. The finding that participants in this study had only “fair” VO_2 max was alarming, as VO_2 max gradually decreases 1–2% per year at ≥ 26 years [18]. The mean age of this sample was 25.9 ($\pm$ 6.2) years. The mean VO_2 max was lower than the VO_2 max reported for apparently healthy women in the same age group [18]. As with the general population, the participants did not meet recommended physical activity guidelines [18]. However, exercise studies implementing moderate-to-vigorous aerobic exercise have demonstrated that obese women with PCOS can increase VO_2 max at the same rate as obese women without PCOS [19–22]. More research is necessary to delineate factors associated with decreased VO_2 max among women with PCOS at baseline.

4.2.1 Percent Bodyfat

Consistent with studies in other populations, VO_2 max had a strong negative relationship with percent bodyfat ($R = -0.59$, $p = 0.02$). Debate exists about the causal direction between VO_2 max and body composition. Findings from a cross-sectional study by Maciejczyk and colleagues [23] suggested that high body mass, independent of cause (high lean mass or high bodyfat percentage) decreases VO_2 max relative to total body mass. Whereas a prospective randomized trial conducted by Skrypnik and colleagues [24] concluded that exercise increases VO_2 max, which affects body composition. These studies included obese women, but not women diagnosed with PCOS.

4.2.2 Lean Muscle Mass

VO_2 max had a small, positive association with lean muscle mass ($R = 0.09$, $p < 0.001$). Studies among the general population reveal that higher lean muscle mass contributes to metabolic capacity, which can elevate cardiorespiratory fitness dependent on total bodyfat percentage [25]. A study among women with PCOS revealed that women had lower cardiovascular capacity and muscular endurance than women without PCOS. The authors hypothesized that metabolic and hormonal factors specific to PCOS (e.g., central obesity, insulin resistance) may affect muscle function in women with PCOS [26].

4.2.3 Sex Hormone Binding Globulin (SHBG)

VO_2 max had a strong, positive association with SHBG ($R = 0.73$, $p < 0.001$). SHBG production is regulated by androgens (decrease), estrogens (increase), and insulin (decrease). The participants in this study presented with low levels of SHBG, which is often related to hyperandrogenism (also present in the participants in this study). The association between physical activity or cardiovascular fitness might be mediated, in part, through androgens; however, this has only been studied in men [27]. Findings from a systematic review about exercise effects on hormones suggest that SHBG was largely unaffected by aerobic exercise but increased with either the isolated use of resistance training or the combination of cardiovascular and resistance exercise [28]. Additionally, women with PCOS who exercised at vigorous intensities had higher levels of SHBG than women who exercised at lower intensities [28].

4.2.4 Health Related Quality of Life (HRQoL)

VO_2 max had a strong, positive relationship with HRQoL ($R = -0.72$, $p < 0.01$). Several studies have shown that women with PCOS have reduced HRQoL, especially in the psychosocial domain. However, only three randomized controlled exercise trials included HRQoL, all which revealed improved physical functioning, general health, social functioning, and mental health [29]. Therefore, by improving VO_2 max with exercise, women with PCOS may improve their HRQoL [30].

Table 2. Means and standard deviations of laboratory and fitness data compared to clinical guidelines (n = 15).

Variable	Reference values	Mean $\pm$ SD	Descriptor	Sample # at risk
Body mass index (BMI)	<18.5 (underweight)	32.2 $\pm$ 8.3	obese	12 (80%)
	18.5–24.9 (normal)			
	25–29.9 (overweight)			
	≥ 30 (obesity)			
Waist-to-hip ratio (WtH)	≤ 0.80 (low risk)	0.81 $\pm$ 0.1	moderate risk	7 (47%)
	0.81–0.84 (moderate risk)			
	≥ 0.85 (high risk)			
Percent bodyfat	21–32%	41.1 $\pm$ 8.1	obese	14 (93%)
Lean muscle mass	≥ 93.1 lb	98.07 $\pm$ 15.1	low	7 (47%)
Free testosterone	0.7–3.6 pg/mL	7.6 $\pm$ 4.3	high	11 (73%)
Sex hormone binding globulin (SHBG)	18–144 nmol/L	23.0 $\pm$ 12.9	normal	6 (40%)
High density lipoprotein (HDL)	40–59 mg/dL	63.2 $\pm$ 12.9	high	3 (20%)
Low density lipoprotein (LDL)	<100 mg/dL	91.0 $\pm$ 24.0	normal	5 (33%)
Triglycerides (TGs)	<150 mg/dL	93.0 $\pm$ 32.0	normal	1 (7%)
VO ₂ max (mL/mg/min)	Based on age	36.8 $\pm$ 10.6	fair	5 (33%)
Upper body muscular endurance	Based on age	15.4 $\pm$ 4.0	Below average	7 (47%)
Abdominal muscular endurance	Based on age	21.3 $\pm$ 18.2	Below average	12 (80%)
Flexibility (inches)	Based on age	18.8 $\pm$ 2.8	average	6 (40%)

Table 3. Means and standard deviations of HRQoL and depressive symptoms (n = 15).

Variable	Mean $\pm$ SD
HRQoL total	3.3 $\pm$ 0.7
Psychosocial/emotional	3.2 $\pm$ 0.7
Fertility	3.9 $\pm$ 0.9
Sexual function	3.3 $\pm$ 0.9
Obesity/menstrual	3.1 $\pm$ 0.9
Hirsutism	3.1 $\pm$ 1.4
Coping	3.4 $\pm$ 0.8
Depressive symptoms total	7.3 $\pm$ 5.3

HRQoL, health-related quality-of-life; SD, standard deviation.

4.2.5 Depressive Symptoms

VO₂ max had a strong, negative association with depressive symptoms ($R = -0.67$, $p = 0.01$). VO₂ max as a predictor of depressive symptoms has not been extensively studied among the general population and not at all among women with PCOS. In a cross-sectional study of women without PCOS (aged 26–43) who did not meet physical activity guidelines, VO₂ max was found to be the only physiologic characteristic (as compared to bodyfat percentage, autonomic indices, and physical activity levels) to independently predict depressive symptom scores [31].

4.3 Abdominal Strength

Study participants had “below average” muscular fitness for age, a risk factor for musculoskeletal injuries and osteoarthritis due to poor posture and instability [32]. Evidence suggests that obese individuals have reduced maximum muscle strength relative to body mass compared to

non-obese persons [33]. In this study, the three participants with a “normal” BMI scored average to above average on both muscular fitness tests. The two participants with the highest BMIs and percent bodyfat levels were unable to perform the curl-up test and scored poorly on the push-up test. More research is necessary to determine if bodyfat percentage is related to muscle activation and/or muscle morphology, such as muscle volume and architecture [34].

4.3.1 Body Mass Index (BMI)

The relationship between abdominal fitness and obesity indices among women in general is not well studied. A cross-sectional study of healthy men and women aged 18–30 found that women had lower abdominal strength due to anatomical differences and higher bodyfat mass [35]. Findings from another cross-sectional study indicated that obesity had a significant negative impact on core muscular endurance among young adult men, regardless of which obesity measure was assessed [36]; however, a prospective study comparing normal-weight women with PCOS (phenotype D) to women without PCOS, using obesity indices, revealed that women with PCOS had lower muscle endurance than the control group of normal-weight women [30]. The researchers hypothesized that factors such as insulin resistance and visceral adiposity may damage muscle function in women with PCOS by slowing protein synthesis [26].

4.3.2 Lean Muscle Mass

Women with PCOS and increased levels of lean muscle mass demonstrated strong and significant performance with abdominal strength. However, less than half of the women had normal to elevated lean muscle mass. This

Table 4. Bivariate analysis of anthropometrics, PCOS biomarkers, HRQoL, and depressive symptoms with fitness variables (n = 15).

Variable	VO ₂ Max		Strength 1 (upper)		Strength 2 (abdominal)		Flexibility		RAPA 1 (PA level)		RAPA 2 (RT)	
	R	p	R	p	R	p	R	p	R	p	R	p
BMI	-0.49	0.07	-0.29	0.29	-0.66	0.01	0.40	0.14	-0.63	0.12	-0.06	0.82
% Bodyfat	-0.59	0.02	-0.44	0.10	-0.61	0.12	0.22	0.43	-0.72	0.00	-0.09	0.74
LMM	0.09	0.01	0.20	0.01	0.69	0.01	-0.91	0.01	1.21	0.01	0.51	0.01
WtH	-0.06	0.83	-0.05	0.86	-0.28	0.32	0.15	0.60	-0.47	0.08	0.25	0.36
Test _F	0.39	0.16	0.04	0.89	-0.23	0.39	0.07	0.82	0.02	0.95	-0.17	0.54
SHBG	0.73	0.00	0.26	0.34	0.33	0.23	-0.00	0.99	0.20	0.47	0.10	0.74
HDL	0.16	0.57	0.14	0.63	0.59	0.02	-0.48	0.07	-0.02	0.95	-0.46	0.08
LDL	-0.03	0.91	0.12	0.67	-0.20	0.49	0.08	0.77	0.33	0.23	-0.52	0.05
TGs	-0.43	0.11	-0.11	0.69	-0.14	0.62	0.09	0.75	-0.47	0.08	-0.17	0.54
HRQoL	0.72	0.00	0.36	0.19	0.36	0.62	-0.42	0.12	0.28	0.32	0.13	0.66
DepSx	-0.67	0.00	-0.31	0.25	-0.20	0.48	-0.06	0.84	-0.39	0.15	-0.49	0.06

BMI, body mass index; LMM, lean muscle mass; SHBG, sex hormone binding globulin; R, Pearson correlation; DepSx, depressive symptoms; HDL, high density lipoprotein; PCOS, polycystic ovary syndrome; HRQoL, health-related quality of life; LDL, low density protein; PA, physical activity; RT, resistance training; Test_F, free testosterone; TGs, triglycerides; VO₂ max, maximum oxygen volume; WtH, waist-to-hip ratio.

finding indicates that increased lean muscle mass can yield greater core strength, thus providing evidence for resistance training as a component of physical fitness. Resistance training studies for women with PCOS have resulted in improved strength measures, although core strength was not directly measured [37,38].

4.3.3 High Density Lipoprotein (HDL)

Contrary to other research [39], the women in this study had high HDL, a protective factor for cardiovascular disease. The finding of high HDL was counter-intuitive, given the fair VO₂ max and high bodyfat percentages. The high HDL may be due to unique characteristics of this small sample. More research is needed with a larger sample.

4.4 Physical Activity Level

Physical activity level had strong negative associations with percent bodyfat among the women with PCOS in this pilot study. Physical activity is defined as any bodily movement produced by skeletal muscles that requires energy expenditure [40], and thus includes all types of exercise.

Percent Bodyfat

The strong negative association between physical activity level and percent bodyfat is consistent with the literature. Many studies have revealed that performing regular aerobic exercise, especially of vigorous intensity, decreases bodyfat percentage over time [41]. This was true among women with and without PCOS [42]. Performing other modalities of physical activity, such as resistance training, also reduces percent bodyfat over time, especially at higher intensities and in presence of greater lean mass [43].

4.5 Resistance Training Level

The performance of resistance training, as determined by RAPA, had a strong negative relationship with low density lipoprotein (LDL).

4.5.1 Low Density Lipoprotein (LDL)

The negative association between resistance training and LDL is supported by the scientific literature. Research findings of a systematic review revealed that LDL decreased with resistance training, especially when the resistance training involved either an increased volume of movement (*i.e.*, an increased numbers of sets and/or repetitions) or a larger load (*i.e.*, weight lifted X repetitions X number of sets). All studies examining the differential effects of exercise types showed that resistance training had a greater impact on LDL (decrease) than either fewer sets or the isolated use of aerobic activity [44]. Other researchers reported that as little as one hour per week of high-volume resistance training, independent of aerobic activity, conferred a 40–70% lower risk for cardiovascular disease [45].

4.5.2 Flexibility

While increased lean muscle mass was inversely related to flexibility, we argue that those with lean muscle mass would also benefit from flexibility training, of which less than half participated. Fitness for anyone involves a holistic approach of cardiovascular, strength, and flexibility training [46]. Despite debate [47], these authors hypothesize that full range of motion, provided by flexibility training, enables strength gains from resistance exercise.

4.6 Limitations

This pilot study was conducted to assess the feasibility of conducting health and fitness assessments of women with PCOS. Possible associations between anthropometrics, PCOS biomarkers, HRQoL, and depressive symptoms among women with PCOS with that of fitness and self-reported physical activity levels were also explored. The study involved a convenience sample, thus minimizing external validity. The sample was small; however, there were several strong statistically significant associations between participants' fitness levels and their biopsychosocial characteristics. A glucose tolerance test was not included in this study due to cost. However, an SHBG level, a marker of insulin resistance, and consequently, a predictor of diabetes was included [3]. Indirect fitness measures may result in less precision; however, indirect measures were chosen as safer alternatives for those women with PCOS who were sedentary or not regularly physically active. Self-report measures of physical activity can lack accuracy. Digital wearable devices will be considered in future studies. Lastly, information about medication-use was not collected and may have confounded results.

4.7 Strengths

This pilot study had several strengths. Recruitment and process procedures flowed such that 15 women with PCOS were recruited within three summer months on a college campus during the Covid-19 pandemic when remote learning was mandated. The participants provided a medically confirmed PCOS diagnosis. Anthropometrics were precisely measured by trained professionals using established protocols and body composition was determined with DEXA, a gold standard for total body composition assessment [12]. The list of PCOS biomarkers was not exhaustive but representative, and it allowed for exploration of associations between fitness and health indicators. Biomarkers measured that specifically reflected the unique physiologic challenges of women with PCOS included free testosterone, SHBG (a marker of insulin resistance), and total lipid panel.

5. Recommendations

Randomized controlled trials in which health and fitness data are collected from women with PCOS are needed to confirm possible associations between fitness and PCOS clinical features. As such, the authors are currently planning to pilot a two-armed randomized controlled trial of an exercise intervention for women with PCOS to establish proof-of-concept [48]. We will incorporate the processes of health and fitness testing within the future study to compare pre-post results and between- and within-group differences between the intervention and control groups, while also assessing health and fitness as secondary outcomes.

6. Conclusions

In summary, the research team's processes for recruitment and collection of health and fitness data from women with PCOS met feasibility parameters. Given the small sample size of this process feasibility study, the authors recognize the opportunities to expand recruitment efforts (e.g., social media and referral networks) and the battery of biomarkers (e.g., fasting serum glucose). Data from fitness assessments may help identify PCOS clinical features, and thus help reveal possible health risks among women with PCOS. Research evidence, although limited at this time, supports associations between fitness and health outcomes in other populations. The scientific literature also includes evidence that most types of physical activity confer hormonal or metabolic benefit when performed regularly and at higher intensities. This study supported current research and added associations between fitness indices and health outcomes not yet explored.

Abbreviations

ACSM, American College of Sports Medicine; BMI, body mass index; DepSx, depressive symptoms; DEXA, dual energy x-ray absorptiometry; HDL, high density lipoprotein; HRQoL, health-related quality of life; LDL, low density lipoprotein; PCOS, polycystic ovary syndrome; PA, physical activity; PHQ-8, personal health questionnaire; RAPA, rapid assessment of physical activity; RT, resistance training; SHBG, sex hormone binding globulin; Test_T, free testosterone; TGs, triglycerides; VO₂ max, maximum oxygen volume; WtH, waist-to-hip ratio.

Availability of Data and Materials

The dataset for this process feasibility study can be found via Open Science Framework at https://osf.io/8skdy/?view_only=67bee5c0dc4547df9cdac185fc71c425.

Author Contributions

PJW conceived of the study idea. PJW and CFC designed the research study. PJW performed the research. PJW and MDW performed data analysis. PJW, CFC, RMD, MDW, and BMP worked together to interpret data. CFC and BMP provided supervision. PJW drafted the manuscript. CFC, RMD, MDW, and BMP provided revisions to the manuscript. PJW, CFC, RMD, MDW, and BMP gave final approval of the final version to be published. All authors agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Ethics Approval and Consent to Participate

Research protocols were approved by the University of South Carolina's (USC) Institutional Review Board (Pro00106153). Written informed consent was obtained from each participant after explaining the study's purpose, risk, and benefits.

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Conflict of Interest

The authors declare no conflict of interest.

References

- [1] Greenwood EA, Pasch LA, Cedars MI, Legro RS, Eisenberg E, Huddleston HG, *et al.* Insulin resistance is associated with depression risk in polycystic ovary syndrome. *Fertility and Sterility*. 2018; 110: 27–34.
- [2] Behboodi Moghadam Z, Fereidooni B, Saffari M, Montazeri A. Measures of health-related quality of life in PCOS women: a systematic review. *International Journal of Women's Health*. 2018; 10: 397–408.
- [3] Dunaif A (Producer). From distraction to traction: Redefining PCOS as a major metabolic disorder [Webinar]. 2016. Available at: https://education.questdiagnostics.com/presentations/from-distraction-to-traction-redefining-polycystic-ovary-syndrome-pcos-as-a-major-metabolic-disorder?presentation_id=370 (Accessed: 3 September 2022).
- [4] Legro RS, Arslanian SA, Ehrmann DA, Hoeger KM, Murad MH, Pasquali R, *et al.* Diagnosis and treatment of polycystic ovary syndrome: an Endocrine Society clinical practice guideline. *The Journal of Clinical Endocrinology and Metabolism*. 2013; 98: 4565–4592.
- [5] Lamb JD, Johnstone EB, Rousseau J, Jones CL, Pasch LA, Cedars MI, *et al.* Physical activity in women with polycystic ovary syndrome: prevalence, predictors, and positive health associations. *American Journal of Obstetrics and Gynecology*. 2011; 204: 352.e1–352.e6.
- [6] Moran LJ, Ranasinha S, Zoungas S, McNaughton SA, Brown WJ, Teede HJ. The contribution of diet, physical activity and sedentary behaviour to body mass index in women with and without polycystic ovary syndrome. *Human Reproduction*. 2013; 28: 2276–2283.
- [7] Strasser B, Burtcher M. Survival of the fittest: VO₂max, a key predictor of longevity? *Frontiers in Bioscience-Landmark*. 2018; 23: 1505–1516.
- [8] Hiam D, Moreno-Asso A, Teede HJ, Laven JSE, Stepto NK, Moran LJ, *et al.* The Genetics of Polycystic Ovary Syndrome: An Overview of Candidate Gene Systematic Reviews and Genome-Wide Association Studies. *Journal of Clinical Medicine*. 2019; 8: 1606.
- [9] Kahsar-Miller MD, Nixon C, Boots LR, Go RC, Azziz R. Prevalence of polycystic ovary syndrome (PCOS) in first-degree relatives of patients with PCOS. *Fertility and Sterility*. 2001; 75: 53–58.
- [10] Qu X, Donnelly R. Sex Hormone-Binding Globulin (SHBG) as an Early Biomarker and Therapeutic Target in Polycystic Ovary Syndrome. *International Journal of Molecular Sciences*. 2020; 21: 8191.
- [11] Bell ML, Whitehead AL, Julious SA. Guidance for using pilot studies to inform the design of intervention trials with continuous outcomes. *Clinical Epidemiology*. 2018; 10: 153–157.
- [12] Kutáč P, Bunc V, Sigmund M. Whole-body dual-energy X-ray absorptiometry demonstrates better reliability than segmental body composition analysis in college-aged students. *PLoS ONE*. 2019; 14: e0215599.
- [13] Nasiri-Amiri F, Ramezani Tehrani F, Simbar M, Montazeri A, Mohammadpour RA. The Polycystic Ovary Syndrome Health-Related Quality-of-Life Questionnaire: Confirmatory Factor Analysis. *International Journal of Endocrinology and Metabolism*. 2018; 16: e12400.
- [14] Topolski TD, LoGerfo J, Patrick DL, Williams B, Walwick J, Patrick MB. The Rapid Assessment of Physical Activity (RAPA) among older adults. *Preventing Chronic Disease*. 2006. Available at: http://www.cdc.gov/pcd/issues/2006/oct/06_0001.htm (Accessed: 3 September 2022).
- [15] Kroenke K, Strine TW, Spitzer RL, Williams JBW, Berry JT, Mokdad AH. The PHQ-8 as a measure of current depression in the general population. *Journal of Affective Disorders*. 2009; 114: 163–173.
- [16] American College of Sports Medicine. Guidelines for Exercise Testing and Prescription. 10th edn. Wolter Klower: Philadelphia, USA. 2018.
- [17] Walters SJ, Bonacho Dos Anjos Henriques-Cadby I, Bortolami O, Flight L, Hind D, Jacques RM, *et al.* Recruitment and retention of participants in randomised controlled trials: a review of trials funded and published by the United Kingdom Health Technology Assessment Programme. *BMJ Open*. 2017; 7: e015276.
- [18] Bara CLBP, Alves DL, Ruy-Barbosa MA, Palumbo DDP, Sotomaior B, da Silva L, *et al.* Changes in the cardiorespiratory fitness of men and women in various age groups. *Journal of Exercise Physiology*. 2019; 22: 1–10.
- [19] Harrison CL, Stepto NK, Hutchison SK, Teede HJ. The impact of intensified exercise training on insulin resistance and fitness in overweight and obese women with and without polycystic ovary syndrome. *Clinical Endocrinology*. 2012; 76: 351–357.
- [20] Almenning I, Rieber-Mohn A, Lundgren KM, Shetelig Løvvik T, Garnæs KK, Moholdt T. Effects of High Intensity Interval Training and Strength Training on Metabolic, Cardiovascular and Hormonal Outcomes in Women with Polycystic Ovary Syndrome: A Pilot Study. *PLoS ONE*. 2015; 10: e0138793.
- [21] Benham JL, Booth JE, Corenblum B, Doucette S, Friedenreich CM, Rabi DM, *et al.* Exercise training and reproductive outcomes in women with polycystic ovary syndrome: A pilot randomized controlled trial. *Clinical Endocrinology*. 2021; 95: 332–343.
- [22] Costa EC, DE Sá JCF, Stepto NK, Costa IBB, Farias-Junior LF, Moreira SDNT, *et al.* Aerobic Training Improves Quality of Life in Women with Polycystic Ovary Syndrome. *Medicine and Science in Sports and Exercise*. 2018; 50: 1357–1366.
- [23] Maciejczyk M, Więcek M, Szymura J, Szyguła Z, Wiecha S, Cempla J. The influence of increased body fat or lean body mass on aerobic performance. *PLoS ONE*. 2014; 9: e95797.
- [24] Skrypnik D, Bogdański P, Mądry E, Karolkiewicz J, Ratajczak M, Kryściak J, *et al.* Effects of Endurance and Endurance Strength Training on Body Composition and Physical Capacity in Women with Abdominal Obesity. *Obesity Facts*. 2015; 8: 175–187.
- [25] Ebaditabar M, Imani H, Babaei N, Davarzani S, Shab-Bidar S. Maximal oxygen consumption is positively associated with rest-

- ing metabolic rate and better body composition profile. *Obesity Medicine*. 2021; 21: 100309.
- [26] Doğan H, Demir Çaltekin M. Does polycystic ovary syndrome with phenotype D affect the cardiovascular endurance, core endurance, body awareness, and the quality of life? A prospective, controlled study. *Turkish Journal of Obstetrics and Gynecology*. 2021; 18: 203–211.
- [27] Wang Z, Groen H, Cantineau AEP, van Elten TM, Karsten MDA, van Oers AM, *et al.* Effectiveness of a 6-Month Lifestyle Intervention on Diet, Physical Activity, Quality of Life, and Markers of Cardiometabolic Health in Women with PCOS and Obesity and Non-PCOS Obese Controls: One Size Fits All? *Nutrients*. 2021; 13: 3425.
- [28] Wolin KY, Colangelo LA, Liu K, Sternfeld B, Gapstur SM. Associations of androgens with physical activity and fitness in young black and white men: the CARDIA Male Hormone Study. *Preventive Medicine*. 2007; 44: 426–431.
- [29] Shele G, Genkil J, Speelman D. A Systematic Review of the Effects of Exercise on Hormones in Women with Polycystic Ovary Syndrome. *Journal of Functional Morphology and Kinesiology*. 2020; 5: 35.
- [30] Kite C, Lahart IM, Afzal I, Broom DR, Randeva H, Kyrou I, *et al.* Exercise, or exercise and diet for the management of polycystic ovary syndrome: a systematic review and meta-analysis. *Systematic Reviews*. 2019; 8: 51.
- [31] Tonello L, Oliveira-Silva I, Medeiros AR, Donato ANA, Schuch FB, Donath L, *et al.* Prediction of Depression Scores From Aerobic Fitness, Body Fatness, Physical Activity, and Vagal Indices in Non-exercising, Female Workers. *Frontiers in Psychiatry*. 2019; 10: 192.
- [32] Weiss EP, Jordan RC, Frese EM, Albert SG, Villareal DT. Effects of Weight Loss on Lean Mass, Strength, Bone, and Aerobic Capacity. *Medicine and Science in Sports and Exercise*. 2017; 49: 206–217.
- [33] Abdelmoula A, Martin V, Bouchant A, Walrand S, Lavet C, Taillardat M, *et al.* Knee extension strength in obese and nonobese male adolescents. *Applied Physiology, Nutrition, and Metabolism*. 2012; 37: 269–275.
- [34] Tomlinson DJ, Erskine RM, Morse CI, Winwood K, Onambélé-Pearson G. The impact of obesity on skeletal muscle strength and structure through adolescence to old age. *Biogerontology*. 2016; 17: 467–483.
- [35] Rasif H, Wang J. Negative correlation between core muscle function and body composition in young people aged 18-30 years. *International Journal of Sport, Exercise and Health Research*. 2017; 1: 49–53.
- [36] Mayer JM, Nuzzo JL, Chen R, Quillen WS, Verna JL, Miro R, *et al.* The impact of obesity on back and core muscular endurance in firefighters. *Journal of Obesity*. 2012; 2012: 729283.
- [37] Kogure GS, Silva RC, Miranda-Furtado CL, Ribeiro VB, Pedroso DCC, Melo AS, *et al.* Hyperandrogenism Enhances Muscle Strength After Progressive Resistance Training, Independent of Body Composition, in Women With Polycystic Ovary Syndrome. *Journal of Strength and Conditioning Research*. 2018; 32: 2642–2651.
- [38] Vizza L, Smith CA, Swaraj S, Agho K, Cheema BS. The feasibility of progressive resistance training in women with polycystic ovary syndrome: a pilot randomized controlled trial. *BMC Sports Science, Medicine & Rehabilitation*. 2016; 8: 14.
- [39] Kim JJ, Choi YM. Dyslipidemia in women with polycystic ovary syndrome. *Obstetrics & Gynecology Science*. 2013; 56: 137–142.
- [40] World Health Organization (2020) Physical activity. 2022. Available at: <https://www.who.int/news-room/fact-sheets/detail/physical-activity> (Accessed: 9 March 2022).
- [41] Mario FM, Graff SK, Spritzer PM. Habitual physical activity is associated with improved anthropometric and androgenic profile in PCOS: a cross-sectional study. *Journal of Endocrinological Investigation*. 2017; 40: 377–384.
- [42] Gordon BR, McDowell CP, Hallgren M, Meyer JD, Lyons M, Herring MP. Association of Efficacy of Resistance Exercise Training With Depressive Symptoms: Meta-analysis and Meta-regression Analysis of Randomized Clinical Trials. *JAMA Psychiatry*. 2018; 75: 566–576.
- [43] Wewege MA, Desai I, Honey C, Coorie B, Jones MD, Clifford BK, *et al.* The Effect of Resistance Training in Healthy Adults on Body Fat Percentage, Fat Mass and Visceral Fat: A Systematic Review and Meta-Analysis. *Sports Medicine*. 2022; 52: 287–300.
- [44] Mann S, Beedie C, Jimenez A. Differential effects of aerobic exercise, resistance training and combined exercise modalities on cholesterol and the lipid profile: review, synthesis and recommendations. *Sports Medicine*. 2014; 44: 211–221.
- [45] Liu Y, Lee D, Li Y, Zhu W, Zhang R, Sui X, *et al.* Associations of Resistance Exercise with Cardiovascular Disease Morbidity and Mortality. *Medicine and Science in Sports and Exercise*. 2019; 51: 499–508.
- [46] Garber CE, Blissmer B, Deschenes MR, Franklin BA, Lamonte MJ, Lee I, *et al.* American College of Sports Medicine position stand. Quantity and quality of exercise for developing and maintaining cardiorespiratory, musculoskeletal, and neuromotor fitness in apparently healthy adults: guidance for prescribing exercise. *Medicine and Science in Sports and Exercise*. 2011; 43: 1334–1359.
- [47] Nuzzo JL. The Case for Retiring Flexibility as a Major Component of Physical Fitness. *Sports Medicine*. 2020; 50: 853–870.
- [48] Czajkowski SM, Powell LH, Adler N, Naar-King S, Reynolds KD, Hunter CM, *et al.* From ideas to efficacy: The ORBIT model for developing behavioral treatments for chronic diseases. *Health Psychology*. 2015; 34: 971–982.