Research Paper

PCOS Across the Spectrum: Current Diagnostic Practices, Treatment Modalities, and Investigational Therapies

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ABSTRACT

Polycystic ovary syndrome (PCOS) is a heterogenous endocrine disorder that affects 6-20% of reproductive-age women and has widespread effects on human health, including the leading cause of female infertility and metabolic derangement. The objective of this review is to provide a comprehensive overview on the current status of PCOS diagnosis, treatment and innovative therapeutic options. The heterogeneity of PCOS makes clinical management difficult, as patients may have a variable combination of hyperandrogenism,ovulatory disfunction and polycystic ovarian morphology. Options for treatment include lifestyle modifications and hormonal therapies, as well as surgical options that are based on patient phenotype and reproductive goals. Novel insulin sensitizers, anti-inflammatory drugs, and targeted hormonal modulators are some emerging investigational therapies that have the potential to target the multiple contributors of PCOS. This review presents the available evidence on PCOS treatment from early, round-the-clock health intervention to a late and symptomatic condition as an effort to provide clinicians with a whole view over PCOS management, revealing the importance of individualized therapeutic approach and further research for new therapeutic means.

Keywords: Polycystic ovary syndrome, PCOS, hyperandrogenism, insulin resistance, reproductive endocrinology, metabolic syndrome

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INTRODUCTION

Polycystic ovary syndrome (PCOS) is one of the most common endocrine diseases in women of reproductive age, and a systematic review estimated global prevalence estimates between 6% to 20%, depending on the diagnostic criteria [1]. Stein and Leventhal (1935) reported that PCOS has transformed from being a purely gynecological disorder to one that is now considered a complex metabolic and reproductive dysfunction, with serious health implications beyond the reproductive age [2]. It is defined by a pattern of clinical findings and laboratory/test results, which may include hyperandrogenism, anovulation/oligo-ovulation, and polycystic ovarian morphology as seen on ultrasonography. Nevertheless, the varied phenotypic spectrum of PCOS only confuses things even more and still makes it a matter of discussion what should be considered as the best diagnostic criteria, along with issue of treatment. The multisystem nature of the disorder involves reproductive impairment, metabolic disorders, cardiovascular risk factors and psychological comorbidities that demand a tailored multidisciplinary approach. Figure 1 illustrated molecular graph of

Polycystic Ovary Syndome, a common hormonal problem in women.

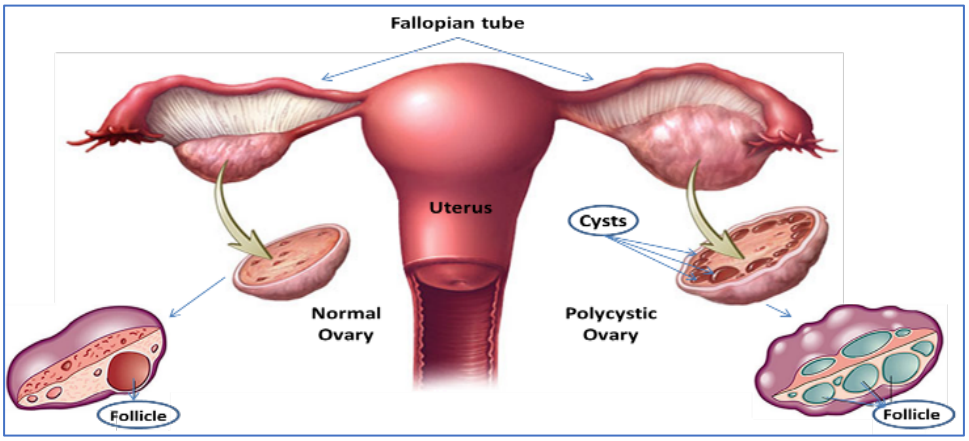

Figure 1. An illustrated diagram of polycystic ovary syndrome

New insights into the pathophysiology of PCOS have shown that it is a multifactorial complex disease, which combines both genetic susceptibility and environmental factors as well as derangement in some hormones. Insulin resistance is the underlying abnormality in about 65-70% of women with PCOS, and it seems to have a pivotal role in the pathogenesis of the syndrome and its reproductive and metabolic features [3]. This realization has led to novel therapeutic strategies and changed the treatment strategy from palliating symptoms to targeting the underlying metabolic abnormality.

The clinical relevance of PCOS goes beyond short-term reproductive issues. Throughout their lifespan, women with PCOS are at an elevated risk for type 2 Diabetes mellitus, cardiovascular disease endometrial cancer, and mood disorders [4]. Early identification and management is essential for maximizing short-term reproductive health and long-term future health.

CURRENT DIAGNOSTIC PRACTICES

Historical Evolution of Diagnostic Criteria

PCOS diagnosis has changed greatly since it was first described. NIH consensuses criteria, published in 1990, mandated both hyperandrogenism and chronic anovulation with the exclusion of other androgen excess disorders [5]. This was the one too narrow, which did not cover all PCOS phenotypes and in particular those with no overt hyperandrogenism.

The Rotterdam criteria, defined by ESHRE and the ASRM in 2003, added polycystic ovarian morphology as a third criterion to broaden the diagnosis [6]. According to these criteria, the diagnosis of PCOS is given when two out of three aspects are found: oligo-ovulation or anovulation, androgen excess either clinically or biochemically, polycystic ovaries on ultrasound; once other etiologies are excluded.

The Androgen Excess and PCOS Society (AE-PCOS) criteria were published in 2006 and stressed the importance of hyperandrogenism as a requirement, linking it with ovulatory or polycystic ovarian morphology [7]. This concept underscores the society's belief that androgen excess is the core characteristic of PCOS.

Contemporary Diagnostic Approaches

Current PCOS criteria (Rotterdam) are the most widely used globally because they are inclusive and internationally accepted. Nevertheless, this broadened definition has resulted in the identification of separate PCOS phenotypes with different clinical implications. These comprise (i) hyperandrogenism, ovulatory dysfunction and polycystic ovarian morphology (classic PCOS); (ii) hyperandrogenism and ovulatory dysfunction in the absence of polycystic ovarian morphology; (iii) hyperandrogenism and polycystic ovarian morphology with regular menstrual cycles; or, these may fulfill at least 2 of the following criteria: (iv) ovulatory dysfunction and polycystic ovarian morphology without concurrent evidence of hyperandrogenemia. Diagnosis criteria and phenotype classification of PCOS are displayed in table 1.

Table 1: PCOS Diagnostic Criteria and Phenotype Classification

Criteria	NIH (1990)	Rotterdam (2003)	AE-PCOS (2006)
Requirements	Hyperandrogenism + Anovulation	Hyperandrogenism, Anovulation, PCO morphology	Hyperandrogenism + (Anovulation OR PCO)
Advantages	High specificity, metabolic focus	Most inclusive, international acceptance	Emphasizes androgen excess
Limitations	Too restrictive, misses cases	May include questionable cases	Less inclusive than Rotterdam

CLINICAL ASSESSMENT COMPONENTS

Hyperandrogenism Evaluation

Clinical evaluation of hyperandrogenism involves determining hirsutism by scoring the modified Ferriman-Gallwey system, with a score ≥8 representing objective evidence of hirsutism in most ethnic groups [8]. Other signs include acne, androgenic alopecia, virilization if severe. Biochemical hyperandrogenism is most often evaluated by determination of total testosterone, free testosterone, or the free androgen index; however laboratory- and assay-specific reference ranges differ substantially.

Ovulatory Function Assessment

Assessment of ovulatory dysfunction includes obtaining a comprehensive menstrual history which has oligomenorrhea as cycle length >35 days and amenorrhea as the absence of menses for >90 days. Biochemical confirmation can consist of measurement of mid-luteal progesterone or serial luteinizing hormone surge testing. The evaluation should take into account the possibility of transient causes for anovulation such as stress, weight changes, or medication use.

Polycystic Ovarian Morphology

The ultrasound evaluation of polycystic ovarian morphology has developed with the improvement in technology. At present, definition of polycystic ovaries include ≥20 follicles in the size range 2-9 mm in any one ovary or increased ovarian volume >10 mL [9]. Anti-Müllerian hormone (AMH) is a promising biomarker in relation to polycystic ovarian morphology, and the cut-off levels are still matters of argument.

Diagnostic Challenges and Considerations

Several reasons contribute to difficulty in diagnosing PCOS. Diagnosis in adolescence Adolescents continue to be challenging with regard to diagnosis, because normal pubertal changes can give the appearance of PCOS. The pediatric Endocrine Society recommends cautious consideration of adult criteria in adolescents, focusing on persistence of symptoms beyond normal pubertal time lines [10]. Use of hormonal contraceptives has an important effect on diagnostic accuracy, because they inhibit ovarian androgen production and lead to a regular cycle. A three month washout period is advised for the purpose of diagnostic evaluation, but it may not always be practical clinically.

The ethnicity-related differences in PCOS spectrum mandates ethnic - specific diagnostic approach. For example, South Asian women with PCOS show more severe metabolic dysfunction than white counterparts while not differing in reproductive characteristics [11].

TREATMENT MODALITIES

Lifestyle Interventions

Lifestyle intervention is the cornerstone of PCOS therapy with evidence to its benefit in several clinical areas. Even moderate weight loss (5-10% of initial body weight) can lead to substantial improvements in reproductive, metabolic and psychological features of overweight and obese women with PCOS [12].

Dietary Approaches

There are many dietary approaches that have been successful in the treatment of PCOS. Low-Glycemic index diets enhance insulin sensitivity, and reduce hyperandrogenism by lowering postprandial glucose peaks [13]. The Mediterranean dietary pattern, which is high in anti-inflammatory foods and good fats, has demonstrated advantages for both cardiovascular risk factors and reproductive outcomes [14].

Intermittent fasting regimes, such as time restricted feeding and alternate day fasting appear to be efficacious strategies for weight loss and metabolic improvement in

PCOS. Yet, strict follow-up is necessary to avoid impact on infertility [15].

Exercise Interventions

Insulin sensitivity, abdominal adiposity and reproductive function in PCOS are improved not only through weight loss but also via exercise training. There is a positive effect of both aerobic exercise as well as resistance training, but the combination may result in higher effects [16]. Among these, high-intensity interval training (HIIT) has emerged as the most potent for beneficially modulating metabolism in time-efficient manner.

PHARMACOLOGICAL INTERVENTIONS

Insulin Sensitizers

Metformin is still the insulin sensitizer most frequently prescribed for PCOS, and has been shown effective in improving metabolic profiles, as well as menstrual pattern and ovulation rates. Doses vary from 1500 to 2000 mg per day, with extendedrelease formulations achieving better gastrointestinal tolerance [17]. Due to metformin's cardiovascular benefits and possible benefit in pregnancy outcomes, for so many women it was an attractive first-line choice. Inositol derivates, particularly myo-inositol and D-chiro-inositol, have emerged as insulin sensitizers, which are well-tolerated compared to metformin. Clinical trials show an increased ovulation rate, improved hormonal profile as well as metabolites after inositol supplementation [18].

Hormonal Therapies

Combined oral contraceptives (COCs) were found to be an effective treatment of hyperandrogenic symptoms and for primary prevention of endometrial overgrowth in women who are not pregnant. Formulations with anti-androgenic progestins as cyproterone acetate, drospirenone and dienogest have been shown to provide a further advantage for hirsutism and acne therapy [19]. Hormonal agents Other than the above-mentioned, (i) Anti-androgens: Spironolactone, flutamide and finasteride bind to androgen receptor directly or inhibits 5α-reductase activity. Antiandrogen using the agent: spironolactone.

A reasonable dose for hirsutism is 100-200 mg/day; contraceptive precautions are necessary because of possible feminization of male fetuses.

Ovulation Induction

Pregnancy induction is the main clinical endpoint for ovulating women. Clomiphene citrate is still the first line drug due to ovulation rates of 70-80% and pregnancy rates of 30%-40%, if successful [20]. With several randomized trials showing better ovulation and pregnancy rates compared with clomiphene, letrozole has gained popularity as the agent of choice in the first line therapy [21].

Gonadotropin treatment should be used for clomiphene or letrozole nonresponders and monitored closely to avoid the occurrence of ovarian hyperstimulation syndrome and multiple pregnancies. Low-dose protocols such as 37.5–75 IU/day reduce the risk of side effects without compromising overall success rate.

SURGICAL INTERVENTIONS

Laparoscopic Ovarian Drilling

Laparoscopic ovarian drilling (LOD) provides a surgical option for clomiphene-resistant PCOS women. This is performed by making 4-10 drilled holes into each ovary with electrocautery or laser, which results in a decreased level of circulating androgens and re-establishment of ovulation rates. Although success rates of 60-80% for ovulation induction and 50-60% for pregnancy are already described [22]. The benefit of LOD is the risk of multiple pregnancy and less demand for intensive monitoring than gonadotropin therapy. Nevertheless, it is associated with adhesion formation and may compromise long-term ovarian function.

Bariatric Surgery

Bariatric surgery may be particularly beneficial with regard to metabolic, as well as reproductive, outcomes among severely obese women with PCOS (BMI ≥35 kg/m²). Robust effects on insulin sensitivity androgen excess and menstrual regularity have been reported after different procedures of bariatric surgery [23].

However, nutritional assessment and contraceptive planning are also necessary for perioperative issues.

INVESTIGATIONAL THERAPIES

Novel Insulin Sensitizers

GLP-1 Receptor Agonists

GLP-1 receptor agonists are a potential new therapeutic option for PCOS. These agents cause weight loss, enhance glycemic control and may have direct effects on ovarian activity. Liraglutide and exenatide have shown promising results for weight reduction and metabolic enhancement in PCOS patients, with studies still ongoing to determine reproductive success [24].

SGLT-2 Inhibitors

The sodium-glucose cotransporter-2 (SGLT-2) inhibitors have recently provided a new approach for enhancement of insulin sensitivity and weight loss through elevation of renal glucose excretion. Early experimentations have

shown a promising application for patients with PCOS, including those suffering from type 2 diabetes [25].

Anti-inflammatory Approaches

Statins

The use of statin provides cardiovascular protection and anti-inflammatory effects, addressing the chronic inflammatory status in PCOS. Atorvastatin and simvastatin have been shown to decrease level of androgens, regulate lipid profile, and lead to better reproductive result in combination with metformin [26].

Omega-3 Fatty Acids

Omega-3 fatty acid supplementation could decrease inflammation and metabolic indices in PCOS. Triglycerides [27] insulin sensitivity and hormonal profiles have been shown to benefit from docosahexaenoic acid (DHA) in eicosapentaenoic acids (EPA) supplemented with clinical studies.

Emerging Hormonal Modulators

Kisspeptin Analogs

Kisspeptin has important effects on regulating reproductive hormones, and synthetic analogs are being studied for the treatment of PCOS. These agents may enable normalization of reproductive axis function without the drawbacks associated with conventional ovulation induction regimens.

Selective Androgen Receptor Modulators

Selective androgen receptor modulators (SARMs) present the possibility of inducing site-specific antagonism of the AR with less collateral damage than that incurred by bluntly inhibiting androgens. First-in-human studies are evaluating potential utility for treatment of hyperandrogenic symptoms.

Table 2: PCOS: Category, Treatment with Dosing, Effency and its side effect

Category	Treatment	Indication	Dosing	Efficacy	Key Side Effects
Lifestyle	Diet + Exercise	All PCOS patients	5-10% weight loss target	High	Requires adherence
Insulin Sensitizers	Metformin	Metabolic dysfunction	1500-2000 mg/day	Moderate-High	GI intolerance (30%)
	Inositol	Insulin resistance	2-4 g/day	Moderate	Minimal
Hormonal	Combined OCs	Hyperandrogenism, cycles	Standard cycling	High for symptoms	VTE risk, mood changes
	Spironolactone	Hirsutism, acne	100-200 mg/day	High (6-12 months)	Hyperkalemia, teratogenic
Ovulation Induction	Letrozole	Anovulatory infertility	2.5-7.5 mg (days 3-7)	80-85% ovulation	Minimal
	Clomiphene	Anovulatory infertility	50-150 mg (days 3-7)	70-80% ovulation	Multiple pregnancy (8%)
Surgical Investigational	Ovarian Drilling	Clomiphene-resistant	4-10 punctures/ovary	60-80% ovulation	Adhesions
	GLP-1 Agonists	Obesity + PCOS	1.2-3.0 mg SC daily	High for weight loss	GI effects, cost

Table 2.Polycystic Ovary Syndrome (PCOS) categories, treatment options, dosages, response, and side effect summary. This organized data assists in clinical decision making and improves patients' comprehension of their choices.

Treatments for PCOS according to clinical objectives are illustrated in Table 3, where first- and second-line options of therapy offered to women depend on the patient's predominant aspect: menstrual irregularity, infertility or metabolic issues.

Table 3: Treatment Selection by Clinical Goal

Clinical Scenario	First-Line	Second-Line	Monitoring
Weight Management	Lifestyle + Metformin	GLP-1 agonists	Weight, HbA1c, lipids
Infertility	Letrozole	Gonadotropins	Ovulation tracking
Hirsutism/Acne	Combined OCs + Spironolactone	Finasteride	Ferriman-Gallwey score
Metabolic Issues	Lifestyle + Metformin	Statins, Inositol	Glucose, lipids

COMPLEMENTARY AND ALTERNATIVE MEDICINE

Herbal Therapies

There are some herbs that appear to be potentially effective for PCOS. This anti-androgenic effect of spearmint tea has been shown to be associated with suppression of 5α-reductase activity [28]. Patients may experience increased insulin sensitivity and cyclicity with cinnamon supplementation.

Acupuncture

Acupuncture has become recognized as an adjuvant treatment for PCOS, with studies demonstrating improved ovulation rates, hormonal status and quality of life indexes. Neuroendocrine modulation and enhanced insulin sensitivity are probably involved [29].

FUTURE SCOPE AND PERSONALIZED MEDICINE

Personalized treatment according to type of patient's phenotype, susceptibility genetic background and metabolic condition represents the future for PCOS treatment. Pharmacogenomic investigations have recently started to unveil genetic influences on treatment response, raising the possibility of more personalized therapy choice. Artificial intelligence and machine learning tools have the ability to access complex patterns from clinical, biochemical, and imaging data, which may aid in improved diagnostic accuracy and selection of therapy. Establish the use of wearables and continuous glucose monitoring for real-time feedback on lifestyle intervention quality. Understanding the developmental origins of PCOS could ultimately result in prevention strategies aimed at vulnerable populations during windows of reproductive development. Elucidating the impact of environmental factors, such as endocrine disruptors and dietary components, may help to inform public health strategies for the prevention of PCOS.

CONCLUSION

PCOS is a complex and diverse disorder which needs tailored treatment that target the reproductive and metabolic aspects of the disease. Diagnosis approaches are imperfect, but at present they provide a scaffold for detecting the affected woman, and aid in therapeutic decisions. Treatment strategies include evidence-based lifestyle interventions and established pharmacolotherapy as well as potential investigational approaches addressing new pathophysiological pathways. The evolving knowledge of PCOS etiopathogenesis remains to promote drug discovery, with insulin sensitizers, anti-inflammatory drugs and hormonal modulators emerging as interesting candidates. However, the heterogeneity of PCOS requires further exploration of how personalized treatment approaches may be developed taking into account specific phenotypes and genetics in concomitance with patient preferences. It is anticipated that emerging paradigms of PCOS care will involve precision medicine frameworks, novel therapeutic targets and holistic models of care that cover the multisystem and transgenerational consequences of this highly common disorder. The ongoing connectivity between the researchers, clinicians and patients would be beneficial for better strategies to further this field of PCOS research towards managing millions of women facing with PCOS around the globe.

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