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Assessing the clinical diagnostic value of anti-Müllerian hormone in polycystic ovarian syndrome and its correlation with clinical and metabolism indicators

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Abstract

Background This study investigated the association between Anti-Müllerian Hormone (AMH) and relevant metabolic parameters and assessed its predictive value in the clinical diagnosis of polycystic ovarian syndrome (PCOS).

Methods A total of 421 women aged 20–37 years were allocated to the PCOS ($n=168$) and control ($n=253$) groups, and their metabolic and hormonal parameters were compared. Spearman correlation analysis was conducted to investigate associations, binary logistic regression was used to determine PCOS risk factors, and receiver operating characteristic (ROC) curves were generated to evaluate the predictive value of AMH in diagnosing PCOS.

Results The PCOS group demonstrated significantly higher blood lipid, luteinizing hormone (LH), and AMH levels than the control group. Glucose and lipid metabolism and hormonal disorders in the PCOS group were more significant than in the control group among individuals with and without obesity. LH, TSTO, and AMH were identified as independent risk factors for PCOS. AMH along with LH, and antral follicle count demonstrated a high predictive value for diagnosing PCOS.

Conclusion AMH exhibited robust diagnostic use for identifying PCOS and could be considered a marker for screening PCOS to improve PCOS diagnostic accuracy. Attention should be paid to the effect of glucose and lipid metabolism on the hormonal and related parameters of PCOS populations.

Keywords PCOS, AMH, Clinical diagnosis, Metabolism

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Introduction

Polycystic ovary syndrome (PCOS) is a prevalent endocrine disorder that primarily affect women of childbearing age and is characterized by a combination of ovulatory dysfunction, hyperandrogenism, oligomenorrhea and polycystic ovarian morphology. Its global incidence varies between around 5–10% [1]. The etiology of PCOS is multifactorial, involving genetic, endocrine, and reproductive factors and infertility [2]. Notably, approximately 50% of PCOS women are also obese and obesity exacerbates PCOS symptoms [3]. While obesity is not a prerequisite for PCOS development, clinical observations suggest that patients with PCOS, especially those who are obese often present with more pronounced symptoms, such as menstrual irregularities, infertility and miscarriages, posing challenges for clinical diagnosis and treatment [4]. Granulosa cells in preantral and small antral follicles produce anti-Müllerian hormone (AMH), a glycoprotein that belongs to the transforming growth factor-β family. In contrast to estradiol (E2) and follicle-stimulating hormone (FSH), AMH provides a superior assessment of ovarian reserve function and is unaffected by menstrual cycle fluctuations [5]. Therefore, it is important to evaluate the ovarian reservoir capacity and the primordial follicle count. As we all known, female age and accurate assessment of ovarian reserve capacity are critical to assess women's reproductive capacity [6]. AMH and antral follicle count (AFC) are used to assess the ovarian reserve of infertility women and their response to stimulate in assisted reproductive technology (ART) [5, 7]. AMH < 1.1 ng/ml and AFC < 5–7 indicate diminished ovarian reserve (DOR) [8]. However, patients with PCOS infertility caused by anovulation, characterized by an increase in the number of AFC and an increase in ovarian reserve capacity, the decline of fertility in PCOS patients may be delayed. Therefore, it is difficult to calculate the aging of the ovary for the PCOS [9]. However, in patients with PCOS, AMH showed a high level, but it is not clear exactly the specific role of AMH in the pathogenesis of PCOS [10]. Currently, there is no international consensus on AMH diagnostic criteria for PCOS, underscoring the importance of tailored diagnostic approaches for Chinese women and the assessment of intervention outcomes during treatment.

Currently, some controversies arise regarding the clinical applications of AMH. Its levels are associated with insulin resistance and androgen levels. Various factors that influence the function of granulosa cells, such as obesity and metabolic factors, can affect AMH production [11, 12]. AMH is a sensitive serum marker in patients with PCOS, but many factors affect it, and the exact threshold has not been determined and standardized [13]. Notably, studies on hormonal and related parameters associated with PCOS, particularity those with obesity, are lacking. Early PCOS diagnosis plays a pivotal role in its clinical assessment, and patient treatment and prognosis [14]. Therefore, our study assessed the diagnostic efficacy of AMH in different subgroups of PCOS patients and the correlation between AMH and metabolic and hormone parameters was analyzed to assess. We wish to provide a basis for therapeutic interventions in PCOS.

Materials and methods

Study design

This study recruited 168 women diagnosed with PCOS and included 253 women as the control group by clinicians in the reproductive medicine center at Sichuan Maternal and Child Health Hospital from January 2021 to September 2023. Inclusion criteria for the PCOS group included women aged 20–37 years meeting the Rotterdam diagnostic criteria for PCOS, with at least two of the following: oligomenorrhea or amenorrhea, hyperandrogenism or clinical manifestations of hyperandrogenism, and sonographic evidence of polycystic ovarian morphology [15]. The control group comprised females aged 20–37 years with normal menstrual cycles, without ovulatory disturbances, normal basal hormone levels, and polycystic ovarian morphology in both ovaries. The exclusion criteria were (1) endocrine diseases that affect reproductive function; (2) patients with other diseases that cause hyperandrogenemia and ovulation dysfunction; and (3) use of hormone therapy in the past 3 months. Following the characteristics of the population [16], a body mass index (BMI) of ≥24 is defined as overweight or obese, and a BMI of ≥18.5 to < 24 is defined as normal for the diagnosis of obesity at childbearing age according to the BMI.

Ethical approval

All procedures and protocols were approved by the Ethics Committee of the Sichuan Maternal and Child Health Hospital (Approval No.2021–002), and informed consent was obtained from all participating subjects.

Laboratory tests

All venous blood samples were drawn using vacuum pipettes after 12-hours fasting period. Serum samples were collected into standard gel separation tubes for subsequent biochemical analysis. All collected samples were processed within 1 hour of collection. Fasting blood glucose (FPG), triglycerides (TG), total cholesterol (TC), low-density lipoprotein (LDL-C), and high-density lipoprotein (HDL-C) were assessed by standard laboratory techniques using Hitachi automatic analyzer (Hitachi 008AS automatic analyzer, Tokyo, Japan). Estradiol (E2),

testosterone (TSTO), prolactin (PRL), progesterone (P), follicular stimulating hormones (FSH), and luteinizing hormone (LH) were quantified using standard laboratory techniques with a Mindray CL8000i automatic analyzer (Mindray, China). The concentrations of serum Anti-Müllerian Hormone (AMH) were determined ELISA kits (Kangrunbio, China). The intra-batch and inter-batch standard deviation coefficients were < 6.25% and < 8.30%, respectively.

Statistical analysis

Data analyses were performed using SPSS 22.0 (IBM, Chicago, USA). Normally, distributed data are presented as mean ± standard deviation, while non-normally distributed data expressed as median (interquartile range [IQR]). Depending on the data's distribution, group comparisons were conducted using either a t-test or the Mann-Whitney U test. Spearman correlation coefficients were calculated to assess the association between PCOS and AMH. Receiver operating characteristic (ROC) analysis were performed to establish the optimal cutoff values, and the sensitivity and specificity of each parameter in diagnosing PCOS were determined. Multivariate logistic regression was conducted to identify risk factors contributing PCOS development. A significance level of $P < 0.05$ was considered for determining statistical significance.

Table 1 Baseline data of the 421 assessed women

Variables	PCOS (n = 168)	Control (*n* = 253)	*P-value*
Age (years))	29.29 ± 3.57	29.50 ± 3.67	*0.561*
Infertility age (years)	2.00 (1.00, 4.00)	2.00 (1.50, 4.00)	*0.221*
BMI(kg/m^2)	22.85 ± 2.84	21.63 ± 2.69	*< 0.001*
FPG (mmol/L)	5.01 ± 0.49	4.91 ± 0.37	*0.655*
Insulin (μIU/ml)	10.06 ± 5.57	8.42 ± 4.89	*0.020*
HDL (mmol/L)	1.42 (1.19, 1.66)	1.51 (1.29, 1.73)	*0.537*
LDL (mmol/L)	2.51 (2.15, 2.98)	2.29 (1.94, 2.65)	*< 0.001*
TC (mmol/L)	4.59 ± 0.85	4.39 ± 0.75	*< 0001*
TG (mmol/L)	1.09 (0.79, 1.66)	0.80 (0.62, 1.12)	*< 0.001*
E2 (pg/ml)	35.44 (27.78, 44.99)	36.23 (28.40, 45.37)	*0.311*
LH (mIU/ml)	9.17 ± 5.26	4.99 ± 2.04	*< 0.001*
FSH (mIU/ml)	6.25 ± 1.59	6.41 ± 1.49	*0.293*
P (ng/ml)	0.47 ± 0.19	0.47 ± 0.19	*0.971*
PRL (μIU/ml)	318.00 (224.32, 417.33)	323.30 (257.85, 431.60)	*0.471*
TSTO (ng/ml)	0.37 (0.25, 0.51)	0.24 (0.18, 0.32)	*0.049*
AMH (ng/ml)	8.39 (6.22,12.08)	3.22 (2.07, 4.66)	*< 0.001*
AFC	28.00 (24.00, 36.00)	16.00 (12.00, 20.00)	*< 0.001*

FPG fasting blood glucose, *HDL* high-density lipoprotein, *LDL* low-density lipoprotein, *TC* total cholesterol, *TG* triglyceride, *E2* Estradiol, *LH* luteinizing hormone, *FSH* follicular stimulating hormone, *P* progesterone, *PRL* prolactin, *TSTO* testosterone, *AMH* anti-Müllerian Hormone, *AFC* antral follicle count

Results

Study population

Table 1 presents the demographic information of the 421 women in the study, aged 20–37 years. The cohort comprised 168 individuals in the PCOS group and 253 in the control group. Comparative analysis showed no significant differences in age or infertility duration between the two groups. However, the PCOS group demonstrated significant higher BMI and AFC level than the control group. Additionally, the PCOS group display higher insulin levels, indicative of possible insulin resistance. Furthermore, the PCOS group exhibited significantly higher levels of LDL, TC and TG in their blood lipids compared to the control group (Table 1). A comparison of hormone indicators revealed that LH, TSTO and AMH levels were significantly higher in the PCOS group (Table 1).

Correlation analysis between hormone and metabolism indicators and PCOS

PCOS was positively correlated with several parameters, including FPG (r = 0.113, $P = 0.020$), insulin (r = 0.189, $P < 0.001$), BMI (r = 0.230, $P < 0.001$), AMH (r = 0.628, $P < 0.001$), LH (r = 0.474, $P < 0.001$), TSTO (r = 0.381, $P < 0.001$) and AFC (r = 0.656, $P < 0.001$). Additionally, PCOS displayed positive correlations with LDL (r = 0.195, $P < 0.001$), TC (r = 0.126, $P = 0.010$), and TG (r = 0.283, $P < 0.001$) but showed a negative correlation with HDL (r = − 0.127, $P < 0.001$). Furthermore, AMH exhibited positive correlation with LH (r = 0.460, $P < 0.001$), TSTO (r = 0.323, $P < 0.001$), AFC (r = 0.737, $P < 0.001$), LDL (r = 0.159, $P = 0.001$), TC (r = 0.125, $P = 0.010$) and TG (r = 0.167, $P = 0.001$) but demonstrated a negative correlation with FSH (r = − 0.131, $P < 0.001$).

Independent factors predicting PCOS with hormone and metabolism indicators

After adjusting for age, the independent risk factors for PCOS were predicted using a logistic regression model, which revealed BMI, LH, TSTO, AMH, AFC and TG as independent risk factors for PCOS (Table 2).

Predictive value of AMH and other indicators for PCOS

Parameters with significant differences between the PCOS and control groups were screened, and ROC curve analysis was performed to determine their efficiency in predicting PCOS. ROC analysis results revealed that AMH exhibited the most robust predictive value, with an area under the curve (AUC) of 0.888, sensitivity of 83.93% and specificity of 80.63% (Table 3, Fig. 1). The predictive value was higher than TSTO (AUC = 0.725), LH (AUC = 0.779), and AFC (AUC = 0.887). Interestingly,

Table 2 Comparison of markers of independent risk factors for PCOS

Variables	OR	95%CI	*P*
BMI	6.201	1.034–1.325	*0.013*
FBG	0.254	0.563–2.644	*0.614*
Insulin	0.545	0.963–1.087	*0.460*
LH	23.725	1.218–1.587	*< 0.001*
TSTO	14.155	10.255–1620.438	*< 0.001*
AMH	18.338	1.158–1.482	*< 0.001*
AFC	23.142	1.084–1.210	*< 0.001*
TG	15.803	1.609–4.060	*< 0.001*

BMI body mass index, *FPG* fasting blood glucose, *LH* luteinizing hormone, *TSTO* testosterone, *AMH* anti-Müllerian Hormone, *AFC* antral follicle count, *TG* triglyceride

the combined diagnostic value of AMH and AFC (AUC = 0.913) is higher than that of AMH and LH (AUC = 0.901) (Table 3, Fig. 1).

Comparison of basic and hormone indexes in individual with obesity

To assess the differences in hormone and metabolic parameters among individuals with obesity (BMI ≥ 24), we conducted subgroup analyses between obese PCOS and obese control groups. We observed that levels of LH and AMH in the obese PCOS group were significantly higher ($P < 0.05$, Table 4). And the number of AFC in obese PCOS group was higher than that in obese control group ($P < 0.05$, Table 4). However, there were no

Table 3 Comparison of predictive values of AMH and other indicators of PCOS

Variables	AUC	Sensitivity (%)	Specificity (%)	Cut off value	95% CI	*P-value*
LH	0.779	61.90	81.82	6.52	0.737–0.818	*< 0.001*
TSTO	0.725	60.10	78.70	0.33	0.680–0.767	*<0.001*
AMH	0.888	83.93	80.63	5.06	0.854–0.916	*< 0.001*
AFC	0.887	79.76	82.61	22	0.852–0.915	*< 0.001*
AMH + LH	0.901	78.57	86.56	0.4	0.869–0.928	*< 0.001*
AMH + AFC	0.913	91.67	77.08	0.26	0.881–0.938	*< 0.001*

LH luteinizing hormone, *TSTO* testosterone, *AMH* anti-Müllerian Hormone, *AFC* antral follicle count

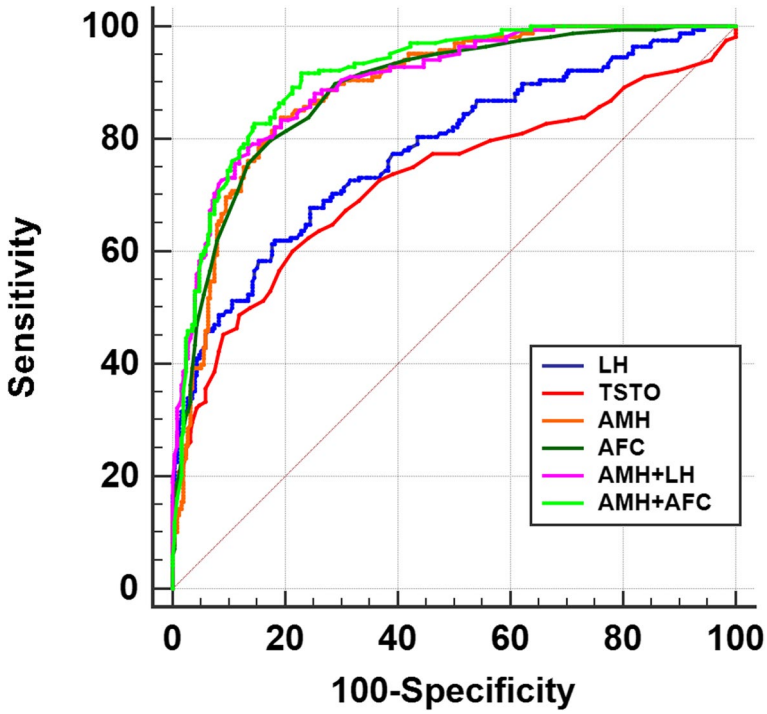

Fig. 1 ROC curves of the predictors of PCOS of hormone indicators and AFC. LH, luteinizing hormone; TSTO, testosterone; AMH, anti-Müllerian Hormone; AFC, antral follicle count

Table 4 Comparison of general data in the obese population

Variables	Obese PCOS ($n=67$)	Obese control ($n=48$)	*P-value*
Age (years)	29.74 ± 3.74	28.17 ± 3.78	*0.402*
Infertility age (years)	2.00 (1.00, 4.00)	3.00 (1.00, 3.00)	*0.732*
BMI(kg/m^2)	25.71 ± 0.92	25.87 ± 1.67	*0.505*
FPG (mmol/L)	5.07 ± 0.51	4.92 ± 0.47	*0.065*
Insulin (μIU/ml)	11.21 ± 6.55	11.31 ± 6.09	*0.861*
HDL (mmol/L)	1.48 (1.19, 1.67)	1.37 (1.22, 1.48)	*0.124*
LDL (mmol/L)	2.51 (2.03, 3.03)	2.50 (2.22, 2.94)	*0.989*
TC (mmol/L)	4.67 ± 0.98	4.51 ± 0.69	*0.241*
TG (mmol/L)	1.15 (0.87, 1.86)	1.03 (0.75, 1.58)	*0.244*
E2 (pg/ml)	35.00 (27.27, 41.65)	32.99 (26.12, 44.28)	*0.514*
LH (mIU/ml)	8.18 ± 4.57	4.57 ± 2.21	*< 0.001*
FSH (mIU/ml)	6.09 ± 1.29	6.33 ± 1.52	*0.379*
P (ng/ml)	0.47 ± 0.19	0.42 ± 0.16	*0.188*
PRL (μIU/ml)	311.00 (209.80, 396.12)	312.20 (256.65, 398.39)	*0.408*
TSTO (ng/ml)	0.34 (0.19, 0.43)	0.26 (0.20, 0.37)	*0.115*
AMH (ng/ml)	7.98 (5.07, 10.35)	2.85 (2.01, 4.51)	*< 0.001*
AFC	26.00 (23.00, 30.00)	17.50 (12.00, 21.00)	*< 0.001*

FPG fasting blood glucose, *HDL*, high-density lipoprotein, *LDL* low-density lipoprotein, *TC* total cholesterol, *TG* triglyceride, *E2* Estradiol, *LH* luteinizing, *FSH* follicular stimulating hormone, *P* progesterone, *PRL* prolactin hormone, *TSTO* testosterone, *AMH* anti-Müllerian Hormone, *AFC* antral follicle count

significant differences in BMI, FPG, blood lipid, E2, FSH, P, PRL and TSTO between the two groups ($P>0.05$, Table 4).

Predictive value of hormone-related indicators for PCOS with obesity

ROC curve analysis was conducted to investigate the predictive efficacy of PCOS in obese individuals. Among the individuals with obesity, AMH was found to be the most effective diagnostic parameter for PCOS (AUC = 0.879), with a sensitivity of 73.13%, specificity of 89.58%, and cut off value of 5.63 (Table 5, Fig. 2). In contrast, TSTO demonstrated a lower diagnostic capacity for PCOS (AUC = 0.587), whereas LH exhibited a certain diagnostic value for PCOS (AUC = 0.771). Remarkably, the combined diagnostic use of AMH, LH and AFC increased PCOS diagnostic accuracy. The diagnostic capacity of AMH and LH was 0.893 and that of AMH and AFC was 0.897 (Table 5, Fig. 2).

Comparison of basic and hormone indicators in individuals with no obesity

We observed no significant differences in age, years of infertility, BMI, FPG or TC levels in patients between the nonobese PCOS and nonobese control groups ($P>0.05$, Table 6). However, nonobese PCOS group exhibited significantly elevated insulin, LDL and TG levels compared with those with the control group, and the HDL level was significantly decreased ($P<0.05$, Table 6). The hormone levels of LH, TSTO and AMH in the PCOS subgroup were significantly higher than those in the control group. Concurrently, the number of AFCs in nonobese PCOS group was significantly higher than that in the nonobese control group ($P<0.05$, Table 6).

Table 5 Comparison of predictive value of hormones and AFC to PCOS in individuals with obesity

Variables	AUC	Sensitivity (%)	Specificity (%)	Cut off value	95% CI	*P*
LH	0.771	64.18	83.33	6.01	0.684–0.844	*<0.001*
TSTO	0.587	34.33	87.50	0.4	0.491–0.678	*0.101*
AMH	0.879	73.13	89.58	5.63	0.805–0.932	*<0.001*
AFC	0.855	79.10	83.33	21	0.779–0.915	*<0.001*
AMH + LH	0.893	89.55	75.00	0.42	0.811–0.936	<0.001
AMH + AFC	0.897	86.57	79.17	0.44	0.881–0.938	<0.001

LH luteinizing hormone, *TSTO* testosterone, *AMH* anti-Müllerian Hormone, *AFC* antral follicle count

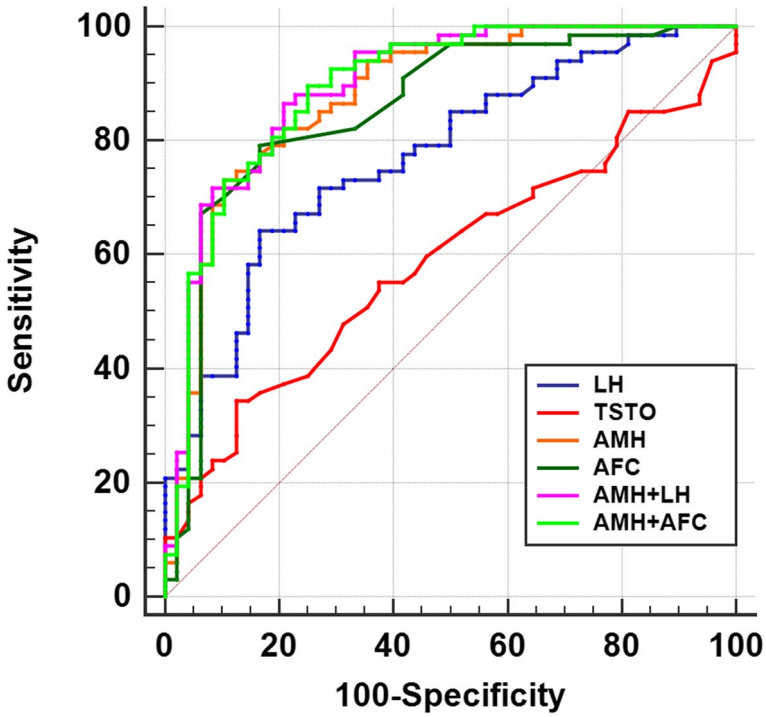

Fig. 2 ROC curves of the predictors of hormone indicators and AFC for PCOS in the population with obesity. LH, luteinizing hormone; TSTO, testosterone; AMH, anti-Müllerian Hormone; AFC, antral follicle count

Table 6 Comparison of general data in individuals with no obesity

Variables	Non-obese PCOS ($n=101$)	Non-obese control ($n=205$)	*P-value*
Age (years)	28.98 ± 3.46	29.58 ± 3.65	*0.169*
Infertility age (years)	2.00 (2.00, 4.00)	2.00 (1.75, 4.00)	*0.972*
BMI(kg/m^2)	20.96 ± 1.95	20.64 ± 1.75	*0.147*
FPG (mmol/L)	4.95 ± 0.41	4.92 ± 0.35	*0.421*
Insulin (μIU/ml)	8.42 ± 4.89	7.74 ± 4.32	*0.011*
HDL (mmol/L)	1.40 (1.21, 1.66)	1.58 (1.34, 1.77)	*< 0.001*
LDL (mmol/L)	2.49 (2.19, 2.93)	2.23 (1.88, 2.57)	*< 0.001*
TC (mmol/L)	4.53 ± 0.75	4.35 ± 0.76	*0.057*
TG (mmol/L)	1.03 (0.75, 1.62)	0.76 (0.60, 1.03)	*< 0.001*
E2 (pg/ml)	35.77 (28.44, 46.54)	36.51 (29.20, 45.53)	*0.652*
LH (mIU/ml)	9.82 ± 5.59	5.09 ± 1.88	*< 0.001*
FSH (mIU/ml)	6.35 ± 1.76	6.43 ± 1.49	*0.682*
P (ng/ml)	0.47 ± 0.19	0.48 ± 0.19	*0.674*
PRL (μIU/ml)	337.09 (238.35, 443.85)	327.00 (258.65, 433.45)	*0.697*
TSTO (ng/ml)	0.42 (0.29, 0.54)	0.23 (0.17, 0.31)	*< 0.001*
AMH (ng/ml)	9.16 (6.92, 13.02)	3.35 (2.10, 4.77)	*< 0.001*
AFC	30.00 (24.00, 38.00)	16.00 (12.00, 20.00)	*< 0.001*

FPG fasting blood glucose, *HDL* high-density lipoprotein, *LDL* low-density lipoprotein, *TC* total cholesterol, *TG* triglyceride, *E2* Estradiol, *LH* luteinizing hormone, *FSH* follicle stimulating hormone, *P* progesterone, *PRL* prolactin, *TSTO* testosterone, *AMH* anti-Müllerian Hormone, *AFC* antral follicle count

Predictive value of hormone indicators for PCOS in individuals with no obesity

In contrast to the results in obese individuals, it appears that AMH and hormone indicators had better predictive value nonobese individuals (BMI < 24). AMH exhibited the highest diagnostic value (AUC = 0.903)

among LH, TSTO and AMH, (Table 7, Fig. 3). Both LH (AUC = 0.804) and TSTO (AUC = 0.796) demonstrated diagnostic utility for PCOS in individuals with no obesity. The diagnosis of PCOS frequently requires a comprehensive evaluation that includes AMH, LH and AFC in clinical practice. Accordingly, a combined diagnosis involving AMH and LH demonstrated an improved predictive value (AUC = 0.916) and AMH and AFC showed the highest predictive value (AUC = 0.927) (Table 7, Fig. 3).

Comparison of hormone indicators in obese and non-obese patients with PCOS

Patients with PCOS were stratified into subgroups based on their BMI. The PCOS subgroup with obesity demonstrated notable increases in FBG levels and metabolism indicators, insulin and TG ($P < 0.05$, Table 8). In contrast, the LH, TSTO, AMH and AFC levels in the obese PCOS group were significantly decreased compared with those in the nonobese PCOS group ($P < 0.05$, Table 8).

Discussion

PCOS ranks among the most prevalent endocrine and metabolic disorders. Its etiology is believed to be multifactorial, with prior research suggesting that insulin resistance and hyperandrogenemia can be considered as its primary causative factors [17]. Additionally, some PCOS patients presented with obesity, which complicated the diagnosis process, as many clinical indicators used for PCOS diagnosis might have been influenced by various factors [18]. While AMH is less susceptible to the

Table 7 Comparison of the predictive value of hormones and AFC for PCOS in individuals with no obesity

Variables	AUC	Sensitivity (%)	Specificity (%)	Cut off value	95% CI	*P*
LH	0.804	53.47	92.68	7.96	0.755–0.847	*<0.001*
TSTO	0.796	66.34	81.95	0.33	0.747–0.840	*<0.001*
AMH	0.903	89.11	80.00	5.06	0.864–0.934	*<0.001*
AFC	0.855	91.09	74.15	19	0.860–0.931	*<0.001*
AMH + LH	0.916	86.14	85.85	0.30	0.879–0.944	<0.001
AMH + AFC	0.927	84.16	89.76	0.36	0.892–0.953	<0.001

LH luteinizing hormone, *TSTO* testosterone, *AMH* anti-Müllerian Hormone, *AFC* antral follicle count

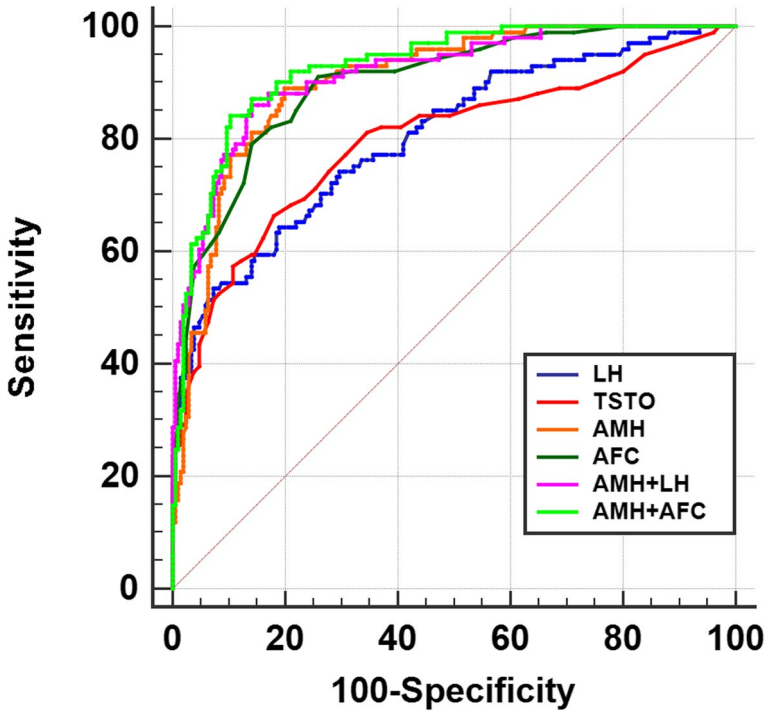

Fig. 3 ROC curves of the predictive value of hormone indicators and AFC for PCOS with individuals with no obesity. LH, luteinizing hormone; TSTO, testosterone; AMH, anti-Müllerian Hormone; AFC, antral follicle count

Table 8 Comparison of general data for PCOS according to BMI

Variables	Obese PCOS (*n* = 67)	Non-obese PCOS (n = 101)	*P-value*
Age (years)	29.76 ± 3.71	28.98 ± 3.46	*0.166*
Infertility age (years)	2.00 (1.00, 4.00)	2.00 (2.00, 4.00)	*0.596*
BMI(Kg/m^2)	25.71 ± 0.92	20.96 ± 1.95	*< 0.001*
FPG (mmol/L)	5.11 ± 0.57	4.95 ± 0.41	*0.036*
Insulin (μIU/ml)	10.06 ± 5.57	8.42 ± 4.89	*0.020*
HDL (mmol/L)	1.50 (1.19, 1.69)	1.40 (1.21, 1.66)	*0.457*
LDL (mmol/L)	2.51 (2.04, 3.08)	2.49 (2.19, 2.93)	*0.887*
TC (mmol/L)	4.67 ± 0.98	4.53 ± 0.75	*0.324*
TG (mmol/L)	1.15 (0.87, 1.86)	1.03 (0.75, 1.62)	*0.034*
E2 (pg/ml)	35.00 (27.27, 41.65)	35.77 (28.44, 46.54)	*0.642*
LH (mIU/ml)	8.18 ± 4.57	9.82 ± 5.59	*0.048*
FSH (mIU/ml)	6.09 ± 1.29	6.35 ± 1.76	*0.321*
P (ng/ml)	0.47 ± 0.19	0.47 ± 0.19	*0.934*
PRL (μIU/ml)	311.00 (209.80, 396.12)	337.09 (238.35, 443.85)	*0.248*
TSTO (ng/ml)	0.34 (0.19, 0.43)	0.42 (0.29, 0.54)	*0.004*
AMH (ng/ml)	7.98 (5.07, 10.35)	9.16 (6.92, 13.02)	*0.007*
AFC	26.00 (23.00, 30.00)	30.00 (24.00, 38.00)	0.024

FPG fasting blood glucose, *HDL* high-density lipoprotein, *LDL* low-density lipoprotein, *TC* total cholesterol, *TG* triglyceride, *E2* Estradiol, *LH* luteinizing hormone, *FSH* follicle stimulating hormone, *P* progesterone, *PRL* prolactin, *TSTO* testosterone, *AMH* anti-Müllerian Hormone, *AFC* antral follicle count

influence of external factors, making it an ideal marker for assessing PCOS and monitoring ovarian reserve function. Noteworthy, following the diagnostic criteria outlined in the Rotterdam criteria, certain researchers have reported elevated AMH levels exclusively in patients with type A PCOS, but not significantly increases in obese patients with type B PCOS [5, 19]. Therefore, PCOS diagnosis should simultaneously consider the effects of both body weight and metabolic patterns [20].

In patients with PCOS, the key clinical symptoms involve disruptions glucose and lipid metabolism along with hormonal abnormalities [21]. Therefore, systematically assessing the impact and correlation of relevant indicators on PCOS and AMH levels is essential. First, we analyzed fundamental metabolic and hormone-related parameters associated with PCOS. After excluding age and years of infertility as potential confounders, patients with PCOS demonstrated significantly higher body weight and insulin levels, exhibiting characteristics of obesity and insulin resistance, consistent with previous research [22]. Simultaneously, lipid metabolism indicators, including LDL, TC, and TG, were significantly increased. The significance of lipid metabolism in PCOS is frequently underestimated, and literature on this topic is limited; however, its impact on patients with PCOS is substantial [23]. PCOS displayed a significant positive correlation with TC, TG, and LDL levels. Our results indicated TG as an independent risk factor for PCOS. Previous studies considered LDL as the standard of PCOS metabolic syndrome, and lipid metabolism disorder is an important influencing factor of PCOS [24]. Hyperandrogenemia, insulin resistance, obesity, and dyslipidemia are all potential influencing factors contributing to PCOS metabolic syndrome and are the results of interaction; However, the precise mechanisms of interaction remain unclear [25]. Therefore, assessing the glucose metabolism and hormonal and lipid profiles of patients with PCOS is essential, and, when necessary, interventions should be aimed at mitigating risk factors associated with PCOS progression [26].

In most patients with PCOS, the increase in AMH levels may be attributed to follicular excess [27]. Furthermore, higher serum AMH levels are correlated with ovulation disturbance and hyperandrogenemia, indicating the potential involvement of AMH in the disturbance of follicle formation in PCOS [28]. Our study corroborated these results by confirming significantly elevated AMH, LH, and TSTO levels in patients with PCOS, all of which were determined as independent risk factors for PCOS. AMH demonstrated a positive correlation with LH and TSTO, thereby confirming the effect of the disorder of the above indicators on PCOS and a close interrelationship among AMH, LH, TSTO, and PCOS [29]. This intricate connection might be attributed the hyperinsulinemia and insulin resistance often observed in PCOS, which can stimulate TSTO production. Simultaneously, hormonal dysregulation can inhibit follicular growth and development, leading to increased AMH secretion. In

turn, elevated AMH levels induce GnRH-mediated LH pulsation and secretion, further enhancing the release of ovarian androgens from the follicular membrane, thereby establishing a positive feedback loop that promotes the polycystic ovarian morphology [30]. Conversely, the high AMH of PCOS affects follicular growth by inhibiting the expression of aromatase-dependent LH receptor, which reduces the sensitivity of follicles to FSH, causing anovulation [31, 32].

In PCOS patients, obesity is prevalent, which has associated with a PCOS, incidence rate of 25.6% among obese women [33]. Obesity can lead to abnormal secretion of adipose-related factors, resulting in notable differences in serum hormone levels and related metabolic indicators compared to non-obese PCOS patients. Thus, addressing the issue of obese PCOS is of paramount concern in clinical practice [34]. Based on the above theoretical basis, we comprehensively compared patients with PCOS with and without obesity to investigate the potential for individualized diagnosis and treatment strategies. Our findings revealed that in obese women, only two hormone indicators, LH and AMH, were significantly higher levels in the PCOS group, with no substantial changes observed in lipid and glucose metabolism indicators. Conversely, in non-obese individuals, the PCOS group exhibited not only elevated levels of metabolic indicators such as insulin, LDL and TG but also higher levels of hormone indicators, including LH, TSTO and AMH. Noteworthy, the results may not align entirely with results obtained when comparing PCOS populations [1]. We also revealed that even in PCOS, individuals with no obesity demonstrated higher levels of hormone metabolism disorders, whereas individuals with obesity exhibited more significant lipid metabolism disorders. This is consistent with previous literature reports [35]. Considering the interplay between obesity and these clinical indicators, PCOS with obesity may be more easily diagnosed clinically, thereby potential overshadowing the metabolic issues frequently encountered lean PCOS cases [21].

The current diagnostic criteria for PCOS clinical practice are inconsistent. The Rotterdam criteria define PCOS based on hyperandrogenemia and the presence of polycystic ovary [15]. Previous studies revealed that the actual prevalence of PCOS might be much higher than what is clinically diagnosed [36]. In the Rotterdam standard of PCOS in 2023, the diagnostic value is affirmed. However, the cut-off value is not defined and clearly distinguished among different subgroup [37]. Previous studies revealed a close correlation between AMH and AFC and that AMH is expected to be used as a marker of ovarian reserve [38]. Its diagnostic value has been limited because of controversies regarding optimal thresholds of clinical sensitivity and specificity [39, 40]. According to different clinical manifestations, PCOS exists in patients with and without obesity, and the AMH level in patients with and without obesity is also different. Therefore, separately evaluating the diagnostic value of AMH is necessary. Herein, we evaluated the diagnostic value of PCOS using AMH, hormones, and AFC in clinical practice. Our study revealed that AMH exhibited a higher predictive value for PCOS in both individuals with and without obesity. The diagnostic cut-off values of AMH in individuals with and without obesity are 5.63 and 5.06, respectively. Combining AMH with LH and AFC for diagnosis significantly improved the diagnostic accuracy, with increased sensitivity and specificity.

Our study reveals that AMH helps in guiding diagnosis and treatment to some extent. Hormones and glucose and lipid metabolism disorders are important factors, considering the influence factors of AMH. Our present study has clarified the correlation of AMH and metabolism and hormones in individuals with PCOS with and without obesity to a certain content, but more in-depth and large-sample studies are required to further explore the exact regulatory mechanism.

Conclusion

Our study demonstrates the clinical diagnostic value of AMH in identifying PCOS by analyzing the correlation between PCOS-related clinical metabolic indicators, hormone levels and AMH. Among PCOS patients, hyperandrogenemia and hyperlipidemia were identified as the primary manifestations, particularly in obese patients. Meanwhile, consideration the close relationship between AMH and obesity related to the disorders of glucose and metabolism, close attention should be paid to the clinical intervention and treatment of PCOS. However, due to the limitations in sample size, we could not conduct an in-depth investigation into the specific mechanisms underlying the relationship between AMH and PCOS, which could be a focus of further research efforts.

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Authors' contributions
L.W., M.L., W.L. and J.Z. participated in the study design and drafted the article. X.Y. and R.L performed the analysis. F.Y., D.X., Y.G. and M.Z. reviewed the final article and made appropriate corrections and suggestions to improve it. All authors approve the version to be published. All authors reviewed the manuscript.

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Availability of data and materials
The data that support the findings of this study are available from the corresponding author upon reasonable request.

Declarations

Competing interests
The authors declare no competing interests.

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