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ROLE OF ANTI-MÜLLERIAN HORMONE IN THE DIAGNOSIS OF POLYCYSTIC OVARY SYNDROME IN ADOLESCENCE

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Abstract

Background: Diagnosing polycystic ovary syndrome (PCOS) in adolescence is difficult because menstrual irregularity, acne, and polycystic ovarian morphology overlap with normal pubertal physiology. Anti-Müllerian hormone (AMH), a granulosa-cell product that is raised in PCOS, has been proposed as a simple blood test, but current international guidance advises against using it for diagnosis in adolescents. **Objective:** To evaluate the diagnostic accuracy of serum AMH for identifying PCOS in adolescent girls, to derive an optimal cutoff, and to examine how accuracy varies with age and body mass index. **Methods:** This hospital-based cross-sectional analytical study analyzed a simulated patient-level dataset of 200 females aged 13–19 years presenting with menstrual irregularity, features of hyperandrogenism, or suspected PCOS, classified as PCOS (n=100) or non-PCOS (n=100) using adolescent-specific criteria. Serum AMH (ng/mL) was compared between groups using the Mann–Whitney U test. Diagnostic accuracy was assessed by receiver operating characteristic (ROC) analysis with DeLong confidence intervals, the Youden index for the cutoff, and

Wilson intervals for sensitivity and specificity. AMH was compared with other markers, and its association with PCOS was adjusted for age and BMI by logistic regression. **Results:** Median AMH was 6.92 ng/mL (IQR 5.28–8.84) in the PCOS group and 3.71 ng/mL (IQR 2.91–4.77) in the non-PCOS group ($p<0.001$). The area under the ROC curve (AUC) was 0.860 (95% CI 0.808–0.912). The optimal cutoff was ⩾5.22 ng/mL (bootstrap 95% interval 4.75–5.95), giving sensitivity 78.0% (95% CI 68.9–85.0), specificity 82.0% (73.3–88.3), positive predictive value 81.3% and negative predictive value 78.8%, with 22 of 100 PCOS cases missed and 18 of 100 non-PCOS girls misclassified. AMH discriminated no better than total testosterone (AUC 0.883) or ovarian volume (AUC 0.862). Each 1 ng/mL rise in AMH was associated with higher odds of PCOS after adjustment for age and BMI (odds ratio 2.36, 95% CI 1.82–3.07). Accuracy was lowest at ages 13–15 years (AUC 0.758, 95% CI 0.620–0.896, 21 PCOS cases) and higher at 16–17 years (0.910) and 18–19 years (0.882). **Conclusion:** In this simulated cohort, AMH showed good but imperfect discrimination of PCOS in adolescents, with about one in five cases missed at the optimal cutoff and weaker performance in younger girls. AMH did not outperform simpler androgen and ultrasound markers. These findings are consistent with guidance that AMH should not be used as a stand-alone diagnostic test in adolescents and require confirmation in real, prospectively collected clinical data.

Keywords: Anti-Müllerian hormone; polycystic ovary syndrome; adolescent; diagnostic accuracy; ROC curve; hyperandrogenism.

Introduction

Polycystic ovary syndrome (PCOS) is the commonest endocrine disorder of reproductive-age females. In adults, it is diagnosed using the Rotterdam criteria, which require two of three features: oligo-ovulation or anovulation, clinical or biochemical hyperandrogenism, and polycystic ovarian morphology on ultrasound (1,2). Its prevalence in adolescent girls is estimated at between 6% and 18%, depending on the criteria and population studied (3).

Applying adult criteria to adolescents risks over-diagnosis. During the first years after menarche, irregular cycles are common because the hypothalamic–pituitary–ovarian axis is still maturing, acne is frequent, and ovaries are normally larger and contain more follicles than in adults (4–6). For this reason, adolescent-specific criteria require both irregular cycles, defined according to the time since menarche, and clinical or biochemical hyperandrogenism, after exclusion of other causes. Ovarian morphology is not used for diagnosis in this age group (2,3,7). Girls who meet only one criterion are considered at risk and are reassessed later (7).

Anti-Müllerian hormone is produced by granulosa cells of preantral and small antral follicles. Serum AMH is typically raised in PCOS, which has been attributed to an excess of small antral follicles and to increased AMH production per granulosa cell (8–10). Because it is measured in a simple blood sample and does not require imaging, AMH has attracted interest as an alternative to ultrasound. In adults, a meta-analysis found that AMH had useful, though heterogeneous, accuracy for PCOS (11), and the 2023 international guideline introduced AMH as an option for defining polycystic ovarian morphology in adults (2).

In adolescents, the case is less clear. AMH levels change through puberty and vary with age, and the assays and cutoffs used differ between laboratories (12–14). Studies in adolescents have reported higher AMH in girls with PCOS, but also elevated AMH in girls with oligomenorrhea without hyperandrogenism and in those with polycystic ovarian morphology and regular cycles, which limits specificity (15–17). A recent systematic review and meta-analysis reported lower pooled accuracy in adolescents than in adults (18). The 2023 guideline therefore does not recommend AMH or ultrasound for diagnosing PCOS in adolescents (2,7).

Because evidence in adolescents remains limited, further data on how well AMH separates adolescents with and without PCOS, and on which patient characteristics modify its performance, remain useful. The objectives of this study were to determine the diagnostic accuracy of serum AMH for PCOS in adolescents, to derive an optimal cutoff, to compare AMH with other biochemical and ultrasound markers, and to assess accuracy across age and BMI strata.

Materials and Methods

Study design and data source

This was a hospital-based cross-sectional analytical (diagnostic accuracy) study. The analysis used a simulated patient-level dataset of 200 adolescent females, with one record per participant and no missing values in the primary variables. The dataset was fixed at 100 participants per group by design. All analyses and all tables, figures, and text below use this single dataset of 200 participants. The report follows the STARD 2015 reporting guideline for diagnostic accuracy studies where applicable (19).

Participants

The modeled population comprised females aged 13–19 years presenting with menstrual irregularity, clinical or biochemical features of hyperandrogenism, or suspected PCOS. Participants were classified into a PCOS group (n=100) and a non-PCOS group (n=100) according to adolescent-specific diagnostic criteria, which require both irregular menstrual cycles (defined by time since menarche) and clinical or

biochemical hyperandrogenism, with other causes excluded (2,3,7). The group allocation was the reference standard. AMH and ovarian ultrasound morphology were not used to assign group.

Variables and measurements

The index test was serum AMH, recorded in ng/mL. The dataset does not specify the assay platform, which in a real study must be stated, because values differ between assay generations (14). Other recorded variables were age, body mass index (BMI), age at menarche, years since menarche, menstrual pattern (regular, infrequent, persistent irregular, or amenorrhea), hirsutism (present or absent), acne (mild/absent or moderate/severe), luteinizing hormone (LH), follicle-stimulating hormone (FSH), LH:FSH ratio, total testosterone (ng/dL), ovarian volume (mL), and ultrasound finding (multifollicular morphology, no polycystic morphology, or not performed; ultrasound was not performed in 22 participants).

Statistical analysis

Continuous variables were summarized as mean ± standard deviation (SD) and, for AMH, also as median and interquartile range (IQR). Because AMH and several other variables were not normally distributed, groups were compared using the Mann–Whitney U test, and categorical variables using the chi-square test. Associations between AMH and other variables were assessed using Spearman correlation, overall and within each group. Diagnostic performance of AMH was assessed with a ROC curve. The AUC and its 95% confidence interval were calculated using the DeLong method (20). The optimal cutoff was the value that maximized the Youden index (sensitivity + specificity − 1) (21), with a participant classified as test-positive if AMH was at or above the cutoff. Sensitivity, specificity, positive and negative predictive values (PPV, NPV), and accuracy were reported with Wilson 95% confidence intervals, and likelihood ratios were derived. Uncertainty around the cutoff was assessed with 2,000 bootstrap resamples. AUCs of other markers were calculated in the same way.

The association between AMH and PCOS was examined by logistic regression, crude and adjusted for BMI and age. Subgroup AUCs were calculated for age groups (13–15, 16–17, and 18–19 years), BMI (<25 and ⩾25 kg/m^2), and participants with irregular cycles only. Analyses were done in Python (SciPy and scikit-learn). A two-sided p-value <0.05 was considered statistically significant. No adjustment for multiple comparisons was made, and subgroup and secondary analyses are exploratory. PPV and NPV depend on prevalence and, because the groups were fixed at 50% each, they do not estimate predictive values in clinical practice.

Ethical considerations

Because the dataset is simulated and contains no real participant information, ethical approval and informed consent were not applicable. A study of real patients would require institutional ethics approval and consent or assent.

Results

Participant characteristics

The study included 200 adolescents with a mean age of 16.3 ± 1.6 years (range 13–19). Participants in the PCOS group were older (16.7 ± 1.4 vs 15.9 ± 1.6 years, p<0.001), had a higher BMI (26.7 ± 4.4 vs 23.7 ± 3.9 kg/m^2, p<0.001), and were further from menarche (4.3 ± 1.5 vs 3.4 ± 1.6 years, p<0.001), while age at menarche was similar (p=0.26). Cycles were regular in 62 non-PCOS girls and in only 2 girls with PCOS. Hirsutism was present in 73 girls with PCOS and 12 without, and moderate-to-severe acne in 63 and 18, respectively. LH, LH: FSH ratio, total testosterone, and ovarian volume were higher in the PCOS group, whereas FSH did not differ (Table 1). Among 178 participants who had an ultrasound, multifollicular morphology was found in 56 of 92 with PCOS (60.9%) and 16 of 86 without (18.6%).

Table 1. Characteristics of the 200 Participants by Group (Simulated Data)

Characteristic	PCOS (n=100)	Non-PCOS (n=100)	p-value
Age, years, mean ± SD	16.7 ± 1.4	15.9 ± 1.6	<0.001
BMI, kg/m^2, mean ± SD	26.7 ± 4.4	23.7 ± 3.9	<0.001
Age at menarche, years	12.4 ± 0.8	12.5 ± 0.8	0.26
Years since menarche	4.3 ± 1.5	3.4 ± 1.6	<0.001
Menstrual pattern, n			<0.001
Regular cycles	2	62	
Infrequent cycles	45	22	
Persistent irregular cycles	44	13	
Amenorrhea	9	3	
Hirsutism present, n	73	12	<0.001
Moderate/severe acne, n	63	18	<0.001
LH, mIU/mL	10.4 ± 2.9	6.3 ± 2.3	<0.001

Characteristic	PCOS (n=100)	Non-PCOS (n=100)	p-value
FSH, mIU/mL	5.5 ± 1.3	5.7 ± 1.6	0.34
LH: FSH ratio	2.00 ± 0.83	1.25 ± 0.69	<0.001
Total testosterone, ng/dL	61.5 ± 19.1	33.0 ± 13.9	<0.001
Ovarian volume, mL	11.2 ± 2.6	7.5 ± 2.4	<0.001
Multifollicular morphology on ultrasound*	56/92 (60.9%)	16/86 (18.6%)	<0.001
Serum AMH, ng/mL, mean ± SD	7.32 ± 3.05	3.97 ± 1.56	<0.001
Serum AMH, ng/mL, median (IQR)	6.92 (5.28–8.84)	3.71 (2.91–4.77)	<0.001

Diagnostic accuracy of AMH

The ROC analysis gave an AUC of 0.860 (95% CI 0.808–0.912; p<0.001 against 0.5), indicating good discrimination (Figure 3). The Youden index was maximal (0.60) at an AMH of ⩾5.22 ng/mL. At this cutoff, 78 of 100 girls with PCOS and 82 of 100 without PCOS were classified correctly. Sensitivity was 78.0% (95% CI 68.9–85.0%) and specificity 82.0% (95% CI 73.3–88.3%). PPV was 81.3% (72.3–87.8%), NPV 78.8% (70.0–85.6%), accuracy 80.0% (73.9–84.9%), positive likelihood ratio 4.33, and negative likelihood ratio 0.27. Twenty-two girls with PCOS had an AMH below the cutoff and 18 without PCOS were at or above it (Table 2). The bootstrap median cutoff was 5.27 ng/mL with a 95% interval of 4.75–5.95 ng/mL, so the exact threshold is imprecise.

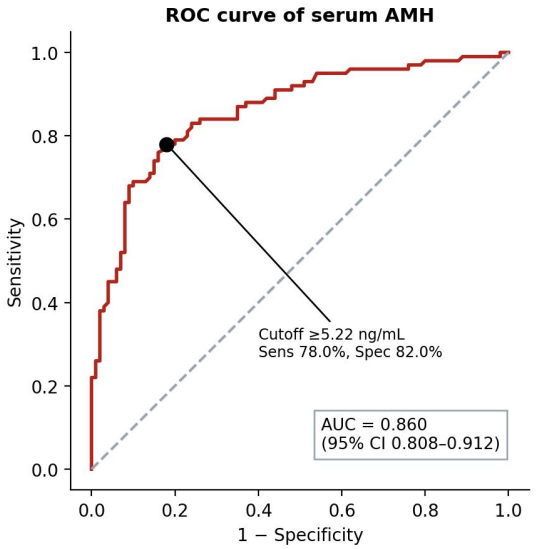


Figure 3. ROC curve for serum AMH in identifying PCOS (n=200).

Table 2. Diagnostic Performance of Serum AMH at the Youden Cutoff (⩾5.22 ng/mL)

Measure	Value (95% CI)
True positives / false negatives	78 / 22
False positives / true negatives	18 / 82
Sensitivity	78.0% (68.9–85.0)
Specificity	82.0% (73.3–88.3)
Positive predictive value*	81.3% (72.3–87.8)
Negative predictive value*	78.8% (70.0–85.6)
Accuracy	80.0% (73.9–84.9)
Positive likelihood ratio	4.33
Negative likelihood ratio	0.27
AUC	0.860 (0.808–0.912)

**Calculated at the fixed 50% group allocation and not generalizable to clinical prevalence.*

Table 3 shows how performance changes with the cutoff. Lowering the threshold to 4.0 ng/mL raised sensitivity to 89.0% but cut specificity to 57.0%, while a threshold of 6.0 ng/mL gave specificity of 92.0% but sensitivity of only 64.0% (Figure 4).

Table 3. Performance of Serum AMH at Selected Cutoffs (⩾ cutoff considered positive)

AMH cutoff (ng/mL)	Sensitivity	Specificity	PPV	NPV	Accuracy
4.0	89.0%	57.0%	67.4%	83.8%	73.0%
4.5	84.0%	72.0%	75.0%	81.8%	78.0%
5.0	79.0%	80.0%	79.8%	79.2%	79.5%
5.22 (Youden)	78.0%	82.0%	81.3%	78.8%	80.0%
5.5	72.0%	85.0%	82.8%	75.2%	78.5%
6.0	64.0%	92.0%	88.9%	71.9%	78.0%
7.0	48.0%	93.0%	87.3%	64.1%	70.5%

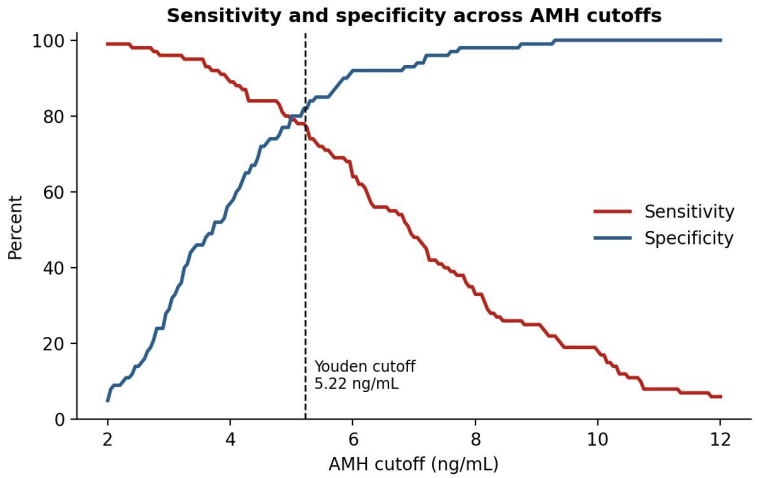


Figure 4. Sensitivity and specificity of AMH across candidate cutoffs.

Comparison with other markers

Total testosterone (AUC 0.883, 95% CI 0.837–0.928), ovarian volume (0.862, 0.811–0.913), and LH (0.859, 0.808–0.911) discriminated PCOS from non-PCOS to a similar degree as AMH (0.860, 0.808–0.912). The LH:FSH ratio (0.795, 0.732–0.857) and BMI (0.700, 0.627–0.772) performed less well. The confidence intervals overlapped for AMH, testosterone, ovarian volume, and LH, and no formal comparison of AUCs was undertaken (Figure 5). AMH was only modestly related to ultrasound morphology: among the 178 participants with ultrasound, the AUC of AMH for multifollicular morphology was 0.619 (95% CI 0.534–0.703).

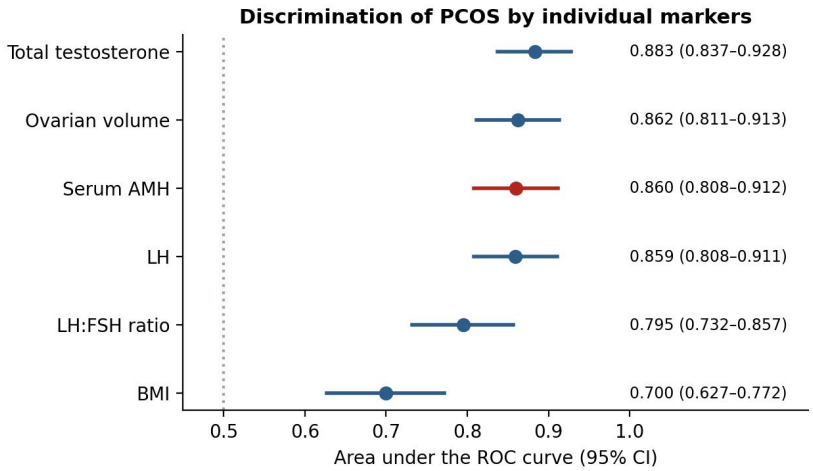


Figure 5. AUC (95% CI) of individual markers for identifying PCOS.

Correlations and adjusted association

Across all 200 participants, AMH correlated positively with total testosterone (Spearman rho 0.44), ovarian volume (0.41), LH (0.34), the LH:FSH ratio (0.29), and age (0.21; all $p<0.01$), and showed no significant correlation with BMI (0.10, $p=0.18$) or FSH (−0.05, $p=0.45$). These correlations were largely absent within groups: within the PCOS group, AMH was unrelated to testosterone (rho 0.05), LH (−0.17), and ovarian volume (−0.03), and was weakly correlated with age (rho 0.23, $p=0.02$); within the non-PCOS group, AMH showed a weak inverse correlation with BMI (rho −0.26, $p=0.009$) and no other significant correlation (Figure 6). The overall correlations therefore largely reflect the difference between groups.

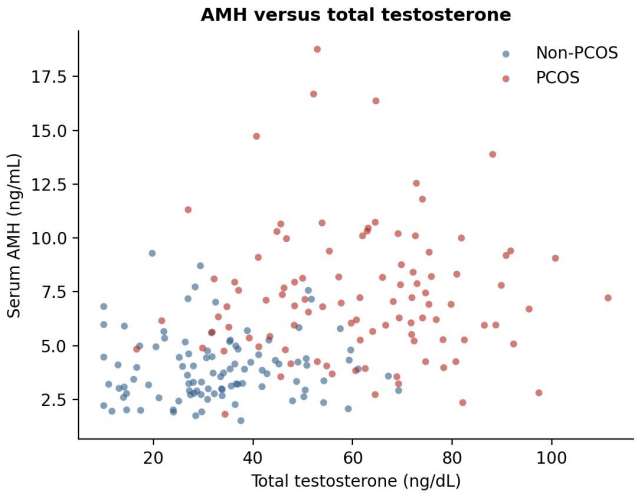


Figure 6. Serum AMH versus total testosterone by group.

In logistic regression, each 1 ng/mL increase in AMH was associated with higher odds of PCOS (crude odds ratio 2.11, 95% CI 1.71–2.61). After adjustment for BMI and age the odds ratio was 2.36 (95% CI 1.82–3.07), with BMI also independently associated (odds ratio 1.26 per kg/m², 95% CI 1.13–1.40) and age not (odds ratio 1.14 per year, 95% CI 0.87–1.50; p=0.34). The AUC of the three-variable model was 0.898, compared with 0.860 for AMH alone; this is an apparent value from the same data and was not internally validated.

Subgroup analyses

Accuracy of AMH differed by age (Table 4, Figure 7). In girls aged 13–15 years (n=66; 21 with PCOS) the AUC was 0.758 (95% CI 0.620–0.896), with sensitivity of 66.7% and specificity of 80.0% at the overall cutoff. In girls aged 16–17 years (n=87; 49 with PCOS) the AUC was 0.910 (0.852–0.969), with sensitivity 79.6% and specificity 84.2%, and in those aged 18–19 years (n=47; 30 with PCOS) it was 0.882 (0.785–0.980), with sensitivity 83.3% and specificity 82.4%. The confidence intervals overlap, so the age difference is suggestive rather than established. AUCs were similar in girls with BMI <25 kg/m² (0.866) and ⩾25 kg/m² (0.882). Among the 136 girls with irregular cycles (98 with PCOS and 38 without), AMH remained higher in PCOS (7.35 ± 3.07 vs 4.12 ± 1.59 ng/mL, p<0.001) and the AUC was 0.841 (0.772–0.910). In non-PCOS girls, AMH was similar in those with irregular (4.12 ± 1.59 ng/mL) and regular cycles (3.88 ± 1.54 ng/mL).

Table 4. Diagnostic Accuracy of AMH in Subgroups

Subgroup	n (PCOS)	AUC (95% CI)	Sensitivity / Specificity at ⩾5.22 ng/mL
All participants	200 (100)	0.860 (0.808–0.912)	78.0% / 82.0%
Age 13–15 years	66 (21)	0.758 (0.620–0.896)	66.7% / 80.0%
Age 16–17 years	87 (49)	0.910 (0.852–0.969)	79.6% / 84.2%
Age 18–19 years	47 (30)	0.882 (0.785–0.980)	83.3% / 82.4%
BMI <25 kg/m²	98 (37)	0.866 (0.796–0.936)	—
BMI ⩾25 kg/m²	102 (63)	0.882 (0.817–0.948)	—
Irregular cycles only	136 (98)	0.841 (0.772–0.910)	—

Discussion

In this simulated cohort of 200 adolescents, serum AMH was clearly higher in girls with PCOS and discriminated PCOS from non-PCOS with an AUC of 0.86. At the optimal

cutoff of about 5.2 ng/mL, roughly one in five girls with PCOS was missed and a similar proportion of those without PCOS was falsely labelled positive. AMH was not better than total testosterone or ovarian volume, its accuracy appeared lower in the youngest girls, and the cutoff was imprecise.

Interpretation of AMH levels

The higher AMH in the PCOS group agrees with the established biology. Serum AMH reflects the number of small growing follicles and, in PCOS, also increased AMH secretion by granulosa cells, and it has been linked to the follicle excess and arrested follicular maturation that characterize the syndrome (8–10). The same studies explain why AMH is more informative about ovarian follicular status than about androgen excess, and in adolescents follicle numbers are physiologically high. This may explain why AMH in the present data was only weakly related to ultrasound morphology (AUC 0.619), even though AMH has been examined as a possible substitute for ultrasound description (22), and why its overall correlation with testosterone was not seen within either group. The overall correlations with testosterone, LH, and ovarian volume mainly reflected the contrast between groups, and should not be read as AMH tracking androgen excess within a patient group.

Comparison with published adolescent studies

The accuracy observed here is higher than the pooled estimates in the most recent meta-analysis, in which AMH had a sensitivity of 0.66 (95% CI 0.58–0.73) and specificity of 0.78 (0.71–0.83) across 11 adolescent studies, against 0.79 and 0.87 in adults (18). Earlier adolescent work gave mixed results. Hart and colleagues found AMH raised in girls with polycystic ovaries and PCOS, but concluded that in a general adolescent population it was not a reliable predictor of either (15). Park and colleagues reported that oligomenorrheic girls without hyperandrogenism had AMH concentrations as high as girls with PCOS (17), and Villarroel and colleagues found raised AMH in adolescents with polycystic ovarian morphology and regular cycles (16). Such findings show that elevated AMH is not specific to PCOS in this age group. The difference between our results and the pooled estimate probably reflects the design of the present dataset: groups were assigned to be well separated, the comparison group was balanced at 50%, and the cutoff was chosen on the same data used to estimate its performance, all of which tend to give optimistic accuracy. In real clinical populations, where girls with other causes of irregular cycles and with high-normal AMH are common, performance would be expected to be lower.

Age and physiological variation

AMH was less accurate at 13–15 years (AUC 0.758) than at 16–19 years (0.88–0.91), although the intervals overlapped and the youngest group had only 21 PCOS cases. A lower accuracy in younger adolescents would be plausible, because AMH concentrations in healthy girls change across childhood and puberty (12,13), and a single adult-derived cutoff may not apply across the whole 13–19 range. In addition, the PCOS group was on average older and further from menarche than the non-PCOS group, and AMH was weakly correlated with age within the PCOS group, so part of the AMH difference could be age-related; the adjusted odds ratio of 2.36 per ng/mL, with little change from the crude estimate, suggests that age and BMI explain only a small part of the association. Age-specific reference values and cutoffs would be needed before clinical use in this group.

Clinical implications

The 2023 international guideline defines adolescent PCOS by the combination of irregular cycles and hyperandrogenism, and advises against using AMH or ultrasound for diagnosis in this age group because of poor specificity and the overlap with normal puberty (2,7). The present results are compatible with this position: even in a favorable simulated setting, AMH misclassified about one in five girls, and it added little over testosterone, which is already part of the diagnostic criteria. A stand-alone AMH test would also be vulnerable to variation between assays (14). If AMH has a role, it would at most be as supporting information for girls who meet only one criterion and are followed as "at risk" (7), and this requires prospective testing in real cohorts. Studies should also report AMH alongside the reference standard components, so that its incremental value over testosterone and menstrual history can be shown.

Strengths and limitations

Strengths include the use of an a priori defined reference standard that did not include AMH, reporting of confidence intervals for all accuracy measures, and examination of age, BMI, and irregular-cycle subgroups. The most important limitation is that the data are simulated. They do not represent real patients, and the effect sizes, the cutoff, and the group separation cannot be treated as clinical evidence. Other limitations apply even to the analysis of a real study of this design: the groups were fixed at 100 each, so PPV and NPV are not generalizable; the cutoff was derived and evaluated in the same sample without external or cross-validation, which overestimates accuracy; the assay platform was not specified; the 13–15 and non-PCOS irregular-cycle subgroups are small; the model AUC of 0.898 is an apparent value; ultrasound was missing in 22 participants; and

no adjustment was made for multiple comparisons. Follow-up was absent, so nothing can be said about whether AMH predicts later PCOS in girls who are only at risk.

Conclusion

In this simulated dataset of 200 adolescents, serum AMH was higher in PCOS and showed good but imperfect discrimination (AUC 0.860; cutoff ⩾5.22 ng/mL; sensitivity 78.0%, specificity 82.0%). AMH was not superior to testosterone or ovarian volume, and its accuracy appeared lower in girls aged 13–15 years. These findings support the position that AMH should not replace the clinical criteria for diagnosing adolescent PCOS. Validation in real, prospectively collected data from adolescents, using a specified assay, age-specific cutoffs, and independent validation, is required before any conclusion about clinical use.

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