

Original Article

Diagnostic value of transvaginal three-dimensional ultrasonography combined with superb microvascular imaging for endometrial polyps

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Abstract: Aims: To evaluate the diagnostic value of transvaginal three-dimensional ultrasonography combined with superb microvascular imaging (SMI) for the preoperative detection of endometrial polyps, and to determine whether multimodal integration improves detection yield, diagnostic confidence, or recognition of diagnostically challenging lesions compared to morphology-based imaging alone. Methods: In this retrospective observational study, we reviewed 203 consecutive patients with suspected endometrial polyps who underwent evaluation at the Central Hospital of China Railway 17th Bureau Group Co., Ltd. between July 2025 and January 2026. All patients underwent conventional ultrasonography, transvaginal three-dimensional ultrasonography (3D-TVS), and SMI before hysteroscopic pathologic confirmation, which was used as the reference standard. Diagnostic performance was compared among different imaging strategies, including 3D-TVS alone, SMI alone, conventional ultrasonography combined with SMI, and 3D-TVS combined with SMI. The primary endpoint was preoperative detection yield of endometrial polyps. Results: Compared to conventional ultrasonography, 3D-TVS alone did not significantly improve the overall preoperative detection rate of endometrial polyps, whereas SMI alone significantly increased detection rate ($P<0.05$). The addition of SMI significantly improved detection when combined with conventional ultrasonography or 3D-TVS (both $P<0.001$), with 3D-TVS + SMI showing the highest overall diagnostic performance. Conventional ultrasonography and 3D-TVS more readily detected larger, solitary, pedunculated lesions with well-defined margins, whereas missed lesions were more frequently characterized by small size, multiplicity, sessile morphology, lower uterine segment location, intrauterine device use/history, heterogeneous endometrium, or acoustic artifacts (all $P<0.05$). SMI-based recognition was strongly associated with the presence of intralesional blood flow, central feeding vessels, branching vascular patterns, continuous vascular pedicles, and higher microvascular indices (all $P<0.001$). Multivariable analysis identified lesion size <15 mm, sessile morphology, acoustic artifact, absence of vascular pedicles, low microvascular density, and failure of coronal plane reconstruction as independent predictors of missed diagnosis (all $P<0.05$). Conclusion: Transvaginal 3D ultrasonography combined with SMI significantly improves the preoperative detection of endometrial polyps, particularly for diagnostically challenging lesions.

Keywords: Endometrial polyps, transvaginal three-dimensional ultrasonography, superb microvascular imaging, diagnostic value, ultrasound diagnosis

Introduction

Endometrial polyps are focal lesions of the uterine cavity and are among the most common causes of abnormal uterine bleeding, infertility, and incidental findings on gynecologic imaging [1, 2]. Although the majority of polyps are benign, they may have important clinical implications due to their potential to cause chronic symptoms, impair reproductive functions, and, in a small proportion of patients,

undergo premalignant or malignant transformation. Accurate preoperative diagnosis of endometrial polyps is thus critical for risk stratification, personalized treatment planning, and prevention of missed diagnosis as well as unnecessary invasive procedures.

Transvaginal ultrasonography (TVUS) is the initial imaging modality of choice for evaluating intrauterine lesions due to its accessibility, noninvasiveness, and diagnostic accuracy [3].

Nevertheless, conventional two-dimensional ultrasonography (2D-US) may have limited ability to differentiate endometrial polyps from other endometrial pathologies, especially sub-mucosal fibroids, endometrial hyperplasia, and focal endometrial thickening, which may exhibit overlapping morphologic features [4-6]. Transvaginal three-dimensional ultrasonography (3D-TVS) provides multiplanar reconstruction and more comprehensive visualization of lesion contours, endometrial-myometrial relationships, and intracavitary architecture, thereby offering more detailed structural information for improved lesion characterization compared with conventional ultrasonography [7].

Superb microvascular imaging (SMI), a relatively novel ultrasound technique, enables visualization of low-velocity microvascular blood flow while suppressing motion artifacts [8, 9]. However, the incremental diagnostic utility of combining 3D-TVS with SMI for endometrial polyp detection has not been fully established, and limited evidence is available regarding whether this integrated imaging approach can offer better diagnostic performance compared to conventional imaging strategies.

A better understanding of the clinical utility of this multimodal imaging approach is especially important, given the increasing emphasis on accurate, minimally invasive, and reproducible diagnostic strategies in gynecologic practice. Thus, this study aimed to evaluate the diagnostic value of 3D-TVS coupled with SMI for the preoperative detection of endometrial polyps.

Patients and methods

Study design

This retrospective observational study was conducted at the Central Hospital of China Railway 17th Bureau Group Co., Ltd. We retrospectively reviewed the clinical records of patients who presented to our hospital between July 2025 and January 2026 with suspected endometrial polyps. A total of 203 eligible patients were included in the final analysis. All participants underwent 3D-TVS and SMI, followed by hysteroscopy with histopathologic examination, which served as the gold standard reference for diagnosis.

Hysteroscopic evaluation of endometrial polyps was performed according to a standardized

protocol, including assessment of lesion size, morphology, stalk characteristics, and intracavitary protrusion by experienced gynecologists. Histopathologic classification was established based on criteria, including endometrial polyp subtype, the presence of endometrial hyperplasia, and cellular atypia, ensuring reproducibility across cases. The diagnostic performance of 3D-TVS, SMI, and their combination was compared to histopathological outcome.

Inclusion criteria: (1) patients with suspected endometrial polyps based on relevant symptoms or examination findings; (2) availability of complete clinical records; and (3) suitability for both imaging examinations and hysteroscopic pathological evaluation. Exclusion criteria: (1) no history of sexual activity; (2) coexisting malignant tumors; (3) pregnancy or lactation; and (4) cognitive impairment or inability to cooperate with examinations.

This study was approved by the Ethics Committee of the Central Hospital of China Railway 17th Bureau Group Co., Ltd. and was conducted in accordance with the principles of the Declaration of Helsinki.

Data collection

Baseline variables included age, body mass index (BMI), menopausal status, gravidity, parity, presenting symptoms, and relevant gynecologic and medical history, including abnormal uterine bleeding, infertility, previous miscarriage or abortion, cesarean section, endometrial curettage, intrauterine devices (IUD) use or previous IUD placement, hypertension, and diabetes mellitus.

Pathologic and lesion-related findings included endometrial thickness, maximum polyp diameter, number of lesions, gross morphology, anatomic location, and histopathologic subtype. Imaging examinations were performed using a GE Voluson E10 ultrasound system equipped with a RIC5-9-D transvaginal 3D probe. The SMI parameters were standardized as follows: frequency, 5-9 MHz; velocity scale, 2.0 cm/s; gain, 45%; dynamic range, 65; and frame rate, 20 fps. All ultrasound examinations were performed by two experienced sonographers, each with more than 5 years of experience in gynecologic ultrasound. Image interpretation was independently performed by two radiologists who were blinded to clinical and pathological

information. Interobserver agreement for key imaging variables, including lesion detection and vascular characteristics, was assessed using Cohen's Kappa coefficient, with values ranging from 0.82 to 0.91, indicating excellent reproducibility.

For conventional ultrasonography, detection ability and morphologic features such as boundary delineation, echogenicity, pedicle sign, and concomitant uterine abnormalities were recorded. For 3D-TVS, volumetric and spatial features, including polyp volume, longitudinal-to-transverse diameter ratio, intracavitary protrusion, coronal plane reconstruction, visualization of the endometrial basal layer, stalk characteristics, cavity distortion, and imaging artifacts, were documented. For SMI, microvascular characteristics were evaluated, including intralesional flow, central feeding vessel, branching vascular architecture, vascular pedicle continuity, punctate flow, avascular areas, microvascular density, flow grade, branching number, and penetration depth.

Detection results were recorded for each modality individually and in combination, focusing on incremental diagnostic yield for challenging subgroups, including small lesions, multiple polyps, sessile lesions, lower uterine segment lesions, IUD-related cases, heterogeneous endometrium, pedicle sign-negative lesions, and lesions affected by imaging artifacts. Variables potentially associated with missed diagnoses using the combined 3D-TVS + SMI strategy were further identified for subsequent univariate, multivariate, and subset analyses.

Outcome measure

The primary outcome was the preoperative detection rate of endometrial polyps across different imaging strategies, with particular emphasis on the incremental diagnostic value of adding SMI or 3D-TVS to conventional ultrasonography, as well as the overall diagnostic performance of the combined 3D-TVS + SMI strategy. A lesion was considered successfully detected when the imaging modality accurately identified the presence of an endometrial polyp, with confirmation by postoperative histopathologic examination. Secondary outcomes included: (1) modality-specific detection characteristics based on conventional morphologic characteristics, 3D-spatial features, and SMI-

derived microvascular characteristics; and (2) subgroup-specific detection performance according to lesion size, number, morphology, attachment pattern, anatomic location, pathologic subtype, and potential imaging interference factors.

Collectively, these outcome measures were designed to evaluate not only the overall diagnostic performance of each imaging modality, but also the specific clinical and imaging conditions under which multimodal integration may provide the greatest benefit for endometrial polyp detection.

Statistical analysis

All statistical analyses were performed to compare the diagnostic performance of different imaging modalities and to identify factors associated with lesion recognition and missed diagnosis. Continuous variables were expressed as mean $\pm$ standard deviation (SD) or median (interquartile range), according to data distribution, and were compared using the independent-samples t-test or Mann-Whitney U test, as appropriate. Categorical variables were summarized as frequencies and percentages and were compared using the chi-square test or Fisher's exact test, as appropriate. Because each patient underwent all imaging examinations, comparisons of overall and subgroup-specific preoperative detection rates among paired diagnostic modalities (conventional ultrasonography, 3D-TVS, SMI, conventional ultrasonography + SMI, and 3D-TVS + SMI) were performed using the McNemar test for paired binary outcomes. This analysis was specifically used to evaluate the incremental diagnostic value of adding SMI to conventional ultrasonography or 3D-TVS.

Exploratory analyses were performed to identify modality-specific imaging features associated with lesion detection. Variables considered clinically relevant or showing statistical significance by univariate analyses were entered into logistic regression models to identify independent factors associated with missed diagnosis using the combined 3D-TVS + SMI strategy, with results reported as odds ratios (ORs) and 95% confidence intervals (CIs).

Prespecified subgroup analyses were further performed according to age, menopausal sta-

Table 1. Baseline characteristics of included patients with pathologically confirmed endometrial polyps

Variable	Total (n=203)
Age (years)	41.97 ± 8.14
BMI (kg/m ²)	23.54 ± 3.18
Premenopausal (n, %)	157 (77.3)
Postmenopausal (n, %)	46 (22.7)
Abnormal uterine bleeding (n, %)	129 (63.5)
Infertility history (n, %)	38 (18.7)
History of miscarriage/abortion (n, %)	71 (35.0)
IUD use/history (n, %)	52 (25.6)
Prior endometrial curettage (n, %)	44 (21.7)
Prior cesarean section (n, %)	39 (19.2)
Hypertension (n, %)	31 (15.3)
Diabetes mellitus (n, %)	18 (8.9)
Endometrial thickness (mm)	12.72 ± 3.69
Single polyp on pathology (n, %)	136 (67.0)
Multiple polyps on pathology (n, %)	67 (33.0)
Polyp maximal diameter (mm)	16.07 ± 6.04
Pedunculated polyps (n, %)	121 (59.6)
Sessile polyps (n, %)	82 (40.4)

Notes: BMI, body mass index; IUD, Intrauterine device.

tus, lesion size, lesion number, morphology, anatomical location, pathologic subtype, and the presence of IUD-related or intrauterine cavity-related interference to evaluate the consistency of the diagnostic benefit of combined imaging across clinically relevant strata. All tests were two-sided, and a *P* value <0.05 was considered significant.

Results

Baseline clinical and pathologic characteristics of patients with pathologically confirmed endometrial polyps

In this cohort of 203 patients with pathologically confirmed endometrial polyps, the mean age was 41.97 ± 8.14 years, and the mean BMI was 23.54 ± 3.18 kg/m². Most patients were premenopausal (157/203, 77.3%), whereas 46 (22.7%) were postmenopausal. The median gravidity and parity were 2 (IQR, 1-3) and 1 (IQR, 0-2), respectively. Abnormal uterine bleeding was the most common presenting symptom, occurring in 129 patients (63.5%), followed by a history of miscarriage or abortion (71 patients, 35.0%), IUD use or previous IUD

use (52 patients, 25.6%), prior endometrial curettage (44 patients, 21.7%), infertility history (38 patients, 18.7%), and prior cesarean section (39 patients, 19.2%). Regarding comorbidities, hypertension, and diabetes mellitus were documented in 31 (15.3%) and 18 (8.9%) patients, respectively. Pathologic evaluation further showed a mean endometrial thickness of 12.72 ± 3.69 mm and a mean maximal polyp diameter of 16.07 ± 6.04 mm. Single polyps were more common than multiple lesions (136 [67.0%] vs. 67 [33.0%]), and pedunculated lesions were more frequent than sessile lesions (121 [59.6%] vs. 82 [40.4%]) (**Table 1**).

Overall preoperative detection of endometrial polyps by different imaging modalities

As shown in **Table 2**, 3D-TVS alone did not improve the preoperative detection of endometrial polyps compared to conventional ultrasound (63/203, 31.0% vs. 68/203, 33.5%; McNemar test, *P*=0.516). In contrast, SMI alone significantly improved lesion detection rate compared to conventional ultrasonography (89/203, 43.8% vs. 68/203, 33.5%; *P*=0.004). Furthermore, combining SMI with conventional ultrasound significantly improved the detection rate (104/203, 51.2%; *P*<0.001). The combined 3D-TVS + SMI modality achieved the highest detection rate among all evaluated modalities (117/203, 57.6%; *P*<0.001 vs. conventional ultrasound).

These findings indicate that the major incremental improvement was associated with the incorporation of vascular information from SMI, whereas 3D-TVS appeared to provide additional value primarily when combined with SMI rather than as a standalone modality.

Morphologic characteristics associated with conventional ultrasound detection

Regarding morphologic features associated with lesion recognition by conventional ultrasound, detected lesions were associated with significantly greater endometrial thickness and larger maximal polyp diameter compared to missed lesions (both *P*<0.001).

Conventional ultrasound showed a higher detection rate for solitary polyps than multiple polyps (*P*=0.001) and for pedunculated lesions than for sessile lesions (*P*=0.002). Regarding

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Table 2. Overall preoperative detection rate by different imaging modalities

Imaging modality	Positive diagnosis of EP, n (%)	Missed diagnosis, n (%)	95% CI of detection rate	McNemar vs. conventional US	P value
Conventional ultrasound (2D TVUS/US)	68 (33.5)	135 (66.5)	27.0-40.0	-	-
Transvaginal three-dimensional ultrasonography (3D-TVS)	63 (31.0)	140 (69.0)	24.6-37.4	0.42	0.516
SMI alone	89 (43.8)	114 (56.2)	37.0-50.6	8.31	0.004
Conventional US + SMI	104 (51.2)	99 (48.8)	44.3-58.1	17.62	<0.001
3D-TVS + SMI	117 (57.6)	86 (42.4)	50.8-64.4	24.53	<0.001

Notes: EP, endometrial polyps; 3D-TVS, transvaginal three-dimensional ultrasonography; SMI, superb microvascular imaging; BMI, body mass index; IUD, intrauterine device.

Table 3. Morphologic characteristics associated with conventional ultrasound detection

Factor	Detected by conventional US (n=68)	Missed by conventional US (n=135)	Statistic	P value
Age (years)	39.09 ± 10.03	40.65 ± 8.67	t=1.149	0.252
Endometrial thickness (mm)	14.47 ± 3.51	12.53 ± 3.64	t=3.618	<0.001
Maximal polyp diameter (mm)	20.56 ± 6.70	13.87 ± 5.04	t=7.957	<0.001
Single polyp (n, %)	56 (82.4)	80 (59.3)	$\chi^2=10.907$	0.001
Multiple polyps (n, %)	12 (17.6)	55 (40.7)	$\chi^2=10.907$	0.001
Pedunculated morphology (n, %)	51 (75.0)	70 (51.9)	$\chi^2=10.064$	0.002
Sessile morphology (n, %)	17 (25.0)	65 (48.1)	$\chi^2=10.064$	0.002
Fundal lesion (n, %)	29 (42.6)	31 (23.0)	$\chi^2=8.416$	0.004
Lower uterine segment lesion (n, %)	7 (10.3)	28 (20.7)	$\chi^2=3.459$	0.063
Clear lesion boundary (n, %)	46 (67.6)	42 (31.1)	$\chi^2=24.581$	<0.001
Homogeneous echogenicity (n, %)	39 (57.4)	44 (32.6)	$\chi^2=11.471$	0.001
Visible pedicle sign (n, %)	31 (45.6)	19 (14.1)	$\chi^2=24.193$	<0.001
Coexisting IUD (n, %)	9 (13.2)	43 (31.9)	$\chi^2=8.225$	0.004
Coexisting adenomyosis/fibroids (n, %)	14 (20.6)	46 (34.1)	$\chi^2=3.950$	0.047

Notes: US, ultrasonography; IUD, intrauterine device.

anatomical location and sonographic characteristics, fundal lesions were more likely to be detected ($P=0.004$), whereas lower uterine segment lesions were not significantly associated with detection rate ($P=0.063$).

Detected lesions more frequently exhibited a clear boundary ($P<0.001$), homogeneous echogenicity ($P=0.001$), and a visible pedicle sign ($P<0.001$), which were associated with improved lesion recognition on conventional ultrasonography. In contrast, IUD use/previous IUD placement and concomitant adenomyosis/uterine fibroids were significantly more frequent among missed cases, suggesting that cavity interference and background uterine pathology may adversely affect lesion visualization ($P=0.004$ and $P=0.047$, respectively) (Table 3).

Three-dimensional ultrasonographic characteristics associated with 3D-TVS detection

Successful detection was associated with larger lesion size and volume, including larger polyp volume and maximal diameter (both $P<0.001$). In addition, detected lesions exhibited more prominent spatial configuration, including higher longitudinal-to-transverse diameter ratios and greater intracavitary protrusion ratios (both $P<0.001$). The detected group also showed a higher frequency of technically optimal and diagnostically informative 3D features, including successful coronal plane reconstruction ($P<0.001$), clear visualization of the endometrial basal layer ($P<0.001$), and direct visualization of the polyp stalk on 3D images ($P<0.001$). Morphologically, pedunculated lesions were significantly more likely to be detect-

Table 4. Three-dimensional ultrasonographic characteristics associated with 3D-TVS detection

Factor	Detected by 3D-TVS (n=63)	Missed by 3D-TVS (n=140)	Statistic	P value
Lesion volume (cm ³)	2.60 ± 1.36	2.00 ± 0.66	t=4.234	<0.001
Maximal diameter (mm)	21.75 ± 7.89	16.62 ± 5.11	t=5.535	<0.001
Longitudinal/transverse ratio	1.37 ± 0.21	1.14 ± 0.22	t=7.248	<0.001
Intracavitary protrusion ratio (%)	73.95 ± 11.93	56.75 ± 13.11	t=8.887	<0.001
Coronal plane reconstruction success (n, %)	59 (93.7)	81 (57.9)	χ ² =26.008	<0.001
Clear endometrial basalis line (n, %)	48 (76.2)	58 (41.4)	χ ² =21.042	<0.001
Stalk visualized on 3D image (n, %)	35 (55.6)	17 (12.1)	χ ² =42.975	<0.001
Pedunculated morphology (n, %)	49 (77.8)	72 (51.4)	χ ² =12.529	<0.001
Sessile morphology (n, %)	14 (22.2)	68 (48.6)	χ ² =12.529	<0.001
Multiple polyps (n, %)	11 (17.5)	56 (40.0)	χ ² =9.983	0.002
Coexisting IUD (n, %)	8 (12.7)	44 (31.4)	χ ² =8.000	0.005
Cavity distortion/artifact (n, %)	10 (15.9)	53 (37.9)	χ ² =9.811	0.002
Endometrial heterogeneity (n, %)	18 (28.6)	67 (47.9)	χ ² =6.639	0.010

Notes: 3D-TVS, transvaginal three-dimensional ultrasonography; IUD, intrauterine device.

Table 5. SMI microvascular characteristics associated with lesion recognition

Factor	Detected by SMI (n=89)	Missed by SMI (n=114)	Statistic	P value
Detectable internal microflow (n, %)	89 (100.0)	21 (18.4)	χ ² =133.990	<0.001
Single central feeding vessel (n, %)	62 (69.7)	14 (12.3)	χ ² =70.263	<0.001
Branch-like vessel pattern (n, %)	54 (60.7)	22 (19.3)	χ ² =36.532	<0.001
Spotty/punctate flow (n, %)	18 (20.2)	33 (28.9)	χ ² =2.022	0.155
Avascular appearance (n, %)	0 (0)	49 (43.0)	χ ² =50.426	<0.001
Microvascular density index (%)	9.81 ± 3.01	5.14 ± 2.45	t=12.128	<0.001
Peak flow signal grade (0-3)	2.24 ± 0.64	1.04 ± 0.18	t=19.054	<0.001
Vessel branching count	2.89 ± 1.39	2.32 ± 1.09	t=3.256	0.001
Flow penetration depth (%)	60.58 ± 14.63	37.47 ± 12.23	t=12.251	<0.001
Vascular pedicle continuity (n, %)	58 (65.2)	16 (14.0)	χ ² =56.413	<0.001
Coexisting IUD (n, %)	12 (13.5)	40 (35.1)	χ ² =12.243	<0.001
Lesion size <10 mm (n, %)	9 (10.1)	38 (33.3)	χ ² =15.147	<0.001
Multiple polyps (n, %)	18 (20.2)	49 (43.0)	χ ² =11.707	0.001

Notes: SMI, superb microvascular imaging; IUD, intrauterine device.

ed by 3D-TVS ($P<0.001$), whereas missed lesions were more frequently associated with sessile morphology ($P<0.001$), multifocal lesions ($P=0.002$), IUD-related interference ($P=0.005$), cavity distortion or imaging artifacts ($P=0.002$), and heterogeneous endometrial background ($P=0.010$) (**Table 4**).

SMI microvascular characteristics associated with lesion recognition

Lesions detected by SMI were significantly more likely to exhibit intralesional blood flow, central feeding vessels, branching-like vascular patterns, and continuous vascular pedicles, whereas missed lesions were more often

characterized by absent vascular signals (all $P<0.001$). Quantitative SMI-derived vascular parameters, including microvascular density, flow grade, and penetration depth, were significantly higher in the detected group (all $P<0.001$). Vessel branching count also differed significantly between groups ($P=0.001$). In contrast, punctate or spotty flow patterns did not differ significantly between detected and missed groups ($P=0.156$). In addition, missed lesions were more frequently associated with potential detection-limiting factors, including IUD presence ($P<0.001$), lesion size <10 mm ($P<0.001$), and multiple polyps ($P=0.001$) (**Table 5**).

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Table 6. Incremental detection improvement after adding SMI

Factor	Conventional US	US + SMI	P value	3D-TVS	3D-TVS + SMI	P value
Overall detected cases (n, %)	68 (33.5)	104 (51.2)	<0.001	63 (31.0)	117 (57.6)	<0.001
Lesions <10 mm (n)	8	21	0.012	7	24	0.001
Multiple polyps (n)	12	28	0.008	11	31	0.001
Sessile lesions (n)	17	37	0.003	14	40	<0.001
IUD-associated cases (n)	9	21	0.023	8	24	0.003
Lower uterine segment lesions (n)	7	20	0.010	6	18	0.012
Heterogeneous endometrium (n)	15	36	0.002	13	39	<0.001
Non-pedunculated lesions (n)	17	37	0.003	14	40	<0.001
Pedicle sign-negative lesions (n)	10	32	<0.001	9	35	<0.001
Artifact-affected cases (n)	8	25	0.002	10	27	0.003

Notes: 3D-TVS, transvaginal three-dimensional ultrasonography; SMI, superb microvascular imaging; IUD, intrauterine device.

Incremental detection improvement after adding SMI

Compared to conventional ultrasonography alone, conventional ultrasonography combined with SMI significantly improved the overall detection rate of endometrial polyps ($P<0.001$). Significant improvements were also observed in several diagnostically challenging subgroups, including lesions <10 mm ($P=0.002$), multiple polyps ($P=0.001$), sessile lesions ($P<0.001$), IUD-associated lesions ($P=0.008$), lower uterine segment lesions ($P=0.021$), lesions with a heterogeneous endometrium ($P<0.001$), non-pedunculated lesions ($P<0.001$), pedicle sign-negative lesions ($P<0.001$), and artifact-affected lesions ($P<0.001$).

Similarly, adding SMI to 3D-TVS resulted in a further significant increase in the overall detection rate ($P<0.001$) and improved lesion detection across all predefined challenging subgroups, including small lesions ($P<0.001$), multiple polyps ($P<0.001$), sessile lesions ($P<0.001$), IUD-associated lesions ($P=0.003$), lower uterine segment lesions ($P=0.010$), heterogeneous endometrium ($P<0.001$), non-pedunculated lesions ($P<0.001$), pedicle sign-negative lesions ($P<0.001$), and artifact-affected lesions ($P<0.001$).

In addition, the incorporation of SMI significantly increased diagnostic confidence scores in both imaging pathways (both $P<0.001$) (**Table 6**).

Influence of IUD-related factors and cavity interference on diagnostic yield

Lesions in women with current or previous IUD use were significantly more likely to be missed

by conventional ultrasonography, 3D-TVS, and SMI alone than those in patients without IUD-related factors (Conventional: $P=0.004$; 3D-TVS: $P=0.005$; SMI: $P<0.001$).

After modality integration, the association between IUD-related factors and missed diagnosis was substantially attenuated and no longer reached statistical significance for either conventional ultrasonography + SMI ($P=0.070$) or 3D-TVS + SMI ($P=0.052$).

Similarly, endometrial heterogeneity, acoustic shadowing/artifacts, and cavity contour distortion were significantly associated with missed diagnosis, with acoustic shadowing/artifacts showing the strongest association ($P<0.001$), followed by cavity contour distortion ($P<0.001$) and endometrial heterogeneity ($P=0.003$). Conversely, the presence of a visible pedicle sign and detectable microflow were both associated with a lower likelihood of missed diagnosis (Visible pedicle sign: $P=0.030$; Detectable microvascular flow: $P=0.001$). Although the final missed diagnosis rate remained numerically higher in patients with IUD-related factors, the difference did not reach statistical significance after combined imaging assessment ($P=0.052$) (**Table 7**).

Univariate analysis for factors associated with missed diagnosis by 3D-TVS + SMI

By univariate analysis, several lesion- and imaging-related characteristics were significantly associated with missed diagnosis using the combined 3D-TVS + SMI. Lesions size <15 mm was significantly associated with missed diagnosis (OR, 0.110; 95% CI, 0.056-0.214; $P<0.001$). Similarly, acoustic artifact (OR, 0.148; 95% CI, 0.076-0.288; $P<0.001$), low

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Table 7. Influence of IUD and cavity interference on diagnostic yield

Factor	IUD/history present (n=52)	No IUD/history (n=151)	OR (95% CI) for missed diagnosis	P value
Conventional US positive (n, %)	9 (17.3)	59 (39.1)	0.326 (0.148-0.719)	0.004
3D-TVS positive (n, %)	8 (15.4)	55 (36.4)	0.317 (0.139-0.723)	0.005
SMI positive (n, %)	12 (23.1)	77 (51.0)	0.288 (0.140-0.592)	<0.001
US + SMI positive (n, %)	21 (40.4)	83 (55.0)	0.555 (0.293-1.053)	0.070
3D-TVS + SMI positive (n, %)	24 (46.2)	93 (61.6)	0.535 (0.283-1.010)	0.052
Endometrial heterogeneity (n, %)	31 (59.6)	54 (35.8)	2.652 (1.390-5.060)	0.003
Acoustic shadow/artifact (n, %)	22 (42.3)	18 (11.9)	5.419 (2.590-11.337)	<0.001
Cavity contour distortion (n, %)	19 (36.5)	21 (13.9)	3.564 (1.720-7.387)	<0.001
Visible pedicle sign (n, %)	7 (13.5)	43 (28.5)	0.391 (0.163-0.934)	0.030
Detectable microflow (n, %)	18 (34.6)	92 (60.9)	0.340 (0.176-0.656)	0.001
Final combined detection failure (n, %)	28 (53.8)	58 (38.4)	1.871 (0.990-3.534)	0.052

Notes: 3D-TVS, transvaginal three-dimensional ultrasonography; SMI, superb microvascular imaging; BMI, body mass index; IUD, intrauterine device.

Table 8. Univariate analysis of factors associated with missed diagnosis by 3D-TVS + SMI

Variable	Detected (n=117)	Missed (n=86)	OR (95% CI)	P value
Age ≥45 years (n, %)	39 (33.3)	35 (40.7)	0.729 (0.409-1.297)	0.281
Postmenopausal status (n, %)	23 (19.7)	23 (26.7)	0.670 (0.346-1.297)	0.233
Abnormal uterine bleeding (n, %)	78 (66.7)	51 (59.3)	1.373 (0.771-2.444)	0.281
Maximal diameter <15 mm (n, %)	38 (32.5)	70 (81.4)	0.110 (0.056-0.214)	<0.001
Multiple polyps (n, %)	33 (28.2)	34 (39.5)	0.601 (0.333-1.085)	0.090
Sessile morphology (n, %)	40 (34.2)	42 (48.8)	0.544 (0.308-0.962)	0.036
Lower uterine segment location (n, %)	18 (15.4)	17 (19.8)	0.738 (0.355-1.532)	0.414
IUD/history (n, %)	24 (20.5)	28 (32.6)	0.535 (0.283-1.010)	0.052
Acoustic artifact (n, %)	17 (14.5)	46 (53.5)	0.148 (0.076-0.288)	<0.001
No visible vascular pedicle (n, %)	30 (25.6)	57 (66.3)	0.175 (0.095-0.323)	<0.001
Low microvascular density (<6%) (n, %)	21 (17.9)	49 (57.0)	0.165 (0.087-0.312)	<0.001
Coronal reconstruction failure (n, %)	22 (18.8)	41 (47.7)	0.254 (0.136-0.476)	<0.001

Notes: 3D-TVS, transvaginal three-dimensional ultrasonography; SMI, superb microvascular imaging; IUD, intrauterine device.

microvascular density <6% on SMI (OR, 0.165; 95% CI, 0.087-0.312; $P<0.001$), and absence of a visible vascular pedicle (OR, 0.175; 95% CI, 0.095-0.323; $P<0.001$) were significantly associated with missed diagnosis. Failure of coronal plane reconstruction was also significantly associated with diagnostic failure (OR, 0.254; 95% CI, 0.136-0.476; $P<0.001$), while sessile morphology showed a weaker but still significant association (OR, 0.544; 95% CI, 0.308-0.962; $P=0.036$). In contrast, age ≥45 years ($P=0.281$), postmenopausal status ($P=0.233$), abnormal uterine bleeding ($P=0.281$), multiple polyps ($P=0.090$), lower uterine segment location ($P=0.414$), and IUD-related factors ($P=0.052$) were not significantly associated with missed diagnosis in the univariate

model, although IUD-related factors showed a borderline trend (**Table 8**).

Multivariable logistic regression analysis of factors associated with missed diagnosis by 3D-TVS + SMI

In the multivariable logistic regression analysis, most baseline clinical and anatomic variables were not independently associated with missed diagnosis after adjustment, including age ≥45 years, postmenopausal status, multiple polyps, lower uterine segment location, and IUD-related factors (all $P>0.05$). In contrast, several lesion- and imaging-related features remained independently associated with missed diagnosis, including lesion size <15 mm, sessile mor-

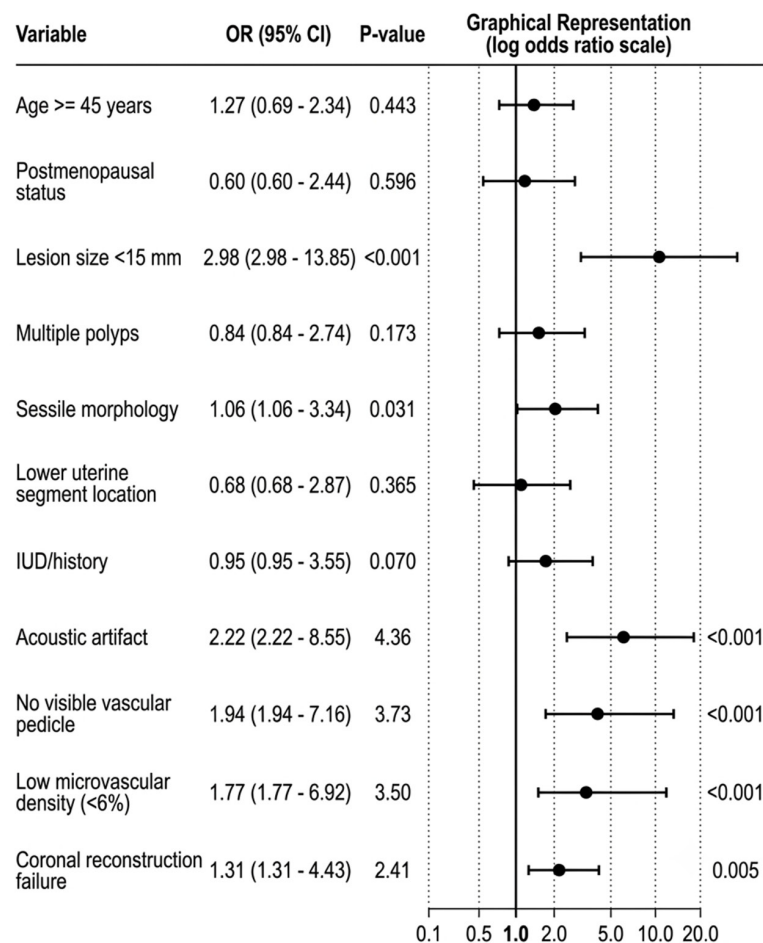


Figure 1. Multivariable logistic regression analysis of factors associated with missed diagnosis by 3D-TVS + SMI. Notes: 3D-TVS, transvaginal three-dimensional ultrasonography; SMI, superb microvascular imaging.

phology, acoustic artifacts, absence of a visible vascular pedicle, low SMI-derived microvascular density (<6%), and failure of coronal plane reconstruction (all $P<0.05$) (**Figure 1**).

Subgroup analyses of 3D-TVS + SMI detection

The combined 3D-TVS + SMI strategy significantly improved detection rates in both younger and older patients (<45 years, $P<0.001$; ≥ 45 years, $P=0.003$), as well as in both premenopausal and postmenopausal women ($P<0.001$ and $P=0.041$, respectively). The incremental benefit of the combined approach was also observed regardless of lesion number, with significant improvements for both single and multiple polyps (both $P<0.001$). The relative improvement was greater for multiple lesions than for solitary lesions (OR, 4.45 vs. 2.31). Similarly, detection was significantly improved

for both pedunculated and sessile polyps (both $P<0.001$), with a greater relative improvement observed in sessile lesions (OR, 3.64 vs. 2.40). Stratification by lesion size further demonstrated that the combined modality improved detection for both small and large lesions. However, the magnitude of improvement was substantially greater for lesions ≥ 15 mm (OR, 5.97; $P<0.001$) than for those <15 mm (OR, 1.80; $P=0.048$). Importantly, the combined approach also demonstrated improved detection in patients with and without IUD-related factors (both $P<0.001$), with a greater relative improvement observed in the IUD-related subgroup (OR, 4.10 vs. 2.50) (**Figure 2**).

Simplified clinical risk scoring system for predicting missed diagnosis of endometrial polyps using combined 3D-TVS and SMI

As shown in **Tables 9, 10**, six independent predictors identified by multivariable analysis were incorporated into the risk scoring system, including lesion size <15 mm, sessile morphology, acoustic artifacts, absence of a visible vascular pedicle, low SMI-derived microvascular density (<6%), and failure of coronal plane reconstruction, each assigned a weighted score according to its relative effect size.

The total score ranged from 0 to 13 points and was categorized into low-risk (0-3), moderate-risk (4-7), and high-risk (≥ 8) groups. These categories corresponded to routine ultrasound assessment, adjunctive 3D-TVS + SMI evaluation, and recommendation for hysteroscopic assessment or expert review, respectively. This scoring system integrates morphological and microvascular imaging features into a risk stratification tool for identifying patients at increased risk of diagnosis after combined 3D-TVS + SMI evaluation.

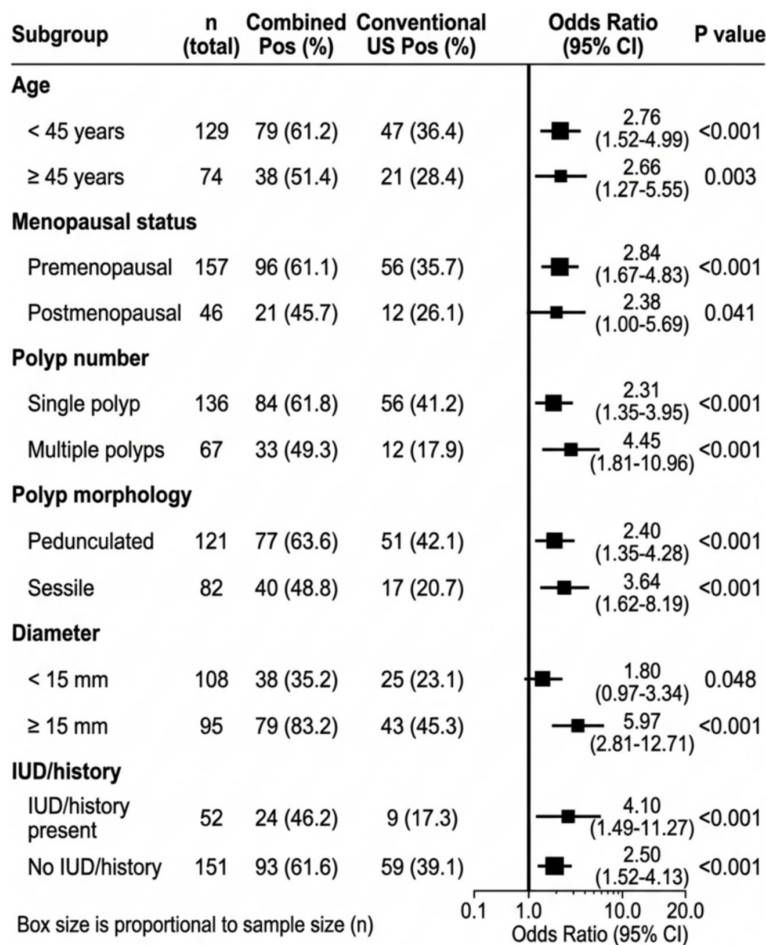


Figure 2. Subgroup analyses of 3D-TVS + SMI detection. Notes: 3D-TVS, transvaginal three-dimensional ultrasonography; SMI, superb microvascular imaging.

Discussion

Our study demonstrated that the combination of 3D-TVS and SMI achieved the highest preoperative detection rate for endometrial polyps among the evaluated imaging strategies. Although 3D-TVS alone did not significantly improve overall detection rate compared to conventional ultrasonography, the addition of SMI markedly improved lesion detection both when combined with conventional ultrasonography and when applied alongside 3D-TVS. Notably, 3D-TVS + SMI provided greater diagnostic benefit than conventional ultrasonography in clinically challenging settings, including small lesions, multiple polyps, sessile morphology, lower uterine segment lesions, IUD use, and imaging artifacts. Furthermore, based on independent predictors identified by multi-variable analysis, a simplified clinical risk scor-

ing system was developed to facilitate risk stratification and support individualized diagnostic decision-making. These findings highlight the primary contribution of this study: integrating spatial morphologic information from 3D-TVS with microvascular data from SMI may provide additional diagnostic value beyond morphology-based assessment alone and may help overcome limitations associated with conventional sonographic detection of endometrial polyps.

The overall preoperative detection showed no significant difference between 3D-TVS and conventional ultrasonography, despite the theoretical advantages of 3D reconstruction and coronal-plane imaging. Some prior studies have proposed that 3D ultrasonography can better delineates endometrial cavity architecture, lesion attachment, and intracavitary protrusion, particularly in focal endometrial lesions [10, 11]. However, the incremental diagnostic value of 3D imaging has not been

consistently demonstrated across studies, presumably due to variations in lesion conspicuity, image acquisition quality, and the success of coronal plane reconstruction. Our findings further clarify this issue by showing that 3D-TVS may be most effective for detecting larger, pedunculated, and spatially prominent lesions, whereas its performance may be limited in sessile, multifocal, and artifact-affected lesions. This observation is biologically plausible because 3D-TVS primarily improves geometric representation and spatial delineation rather than tissue-specific contrast. Therefore, when lesion margins are indistinct or the surrounding endometrial background is heterogeneous, enhanced spatial visualization alone may be insufficient to overcome limitations in lesion conspicuity. Clinically, these findings suggest that overreliance on 3D-TVS for endometrial polyp screening should be avoided, and its

Table 9. Simplified clinical risk scoring system for predicting missed diagnosis of endometrial polyps using combined 3D-TVS and SMI

Risk factor	Definition (Imaging/Clinical feature)	Adjusted OR (from study)	Assigned score
Lesion size <15 mm	Maximal diameter <15 mm on ultrasound	2.98	3
Sessile morphology	Broad-based lesion without stalk	1.84	2
Acoustic artifact	Shadowing/distortion affecting cavity visualization	2.22	3
Absence of vascular pedicle	No central feeding vessel on SMI	1.94	2
Low microvascular density (<6%)	Reduced vascular signal on SMI quantitative index	1.77	2
Failed coronal reconstruction	Inability to obtain diagnostic 3D coronal plane	1.31	1

Table 10. Total risk score interpretation

Total score	Risk level	Clinical implication
0-3	Low risk	Routine conventional US sufficient
4-7	Moderate risk	Recommend add 3D-TVS + SMI
≥8	High risk	Strong indication for hysteroscopy or expert review

interpretation should be integrated with additional imaging information, particularly for diagnostically challenging cases.

SMI demonstrated superior lesion detection capability compared to morphology-based assessment alone, highlighting the diagnostic value of microvascular evaluation in endometrial polyp assessment. Previous studies have shown that vascular-oriented ultrasound methods, including Doppler-based evaluation of feeding vessels, may assist in differentiating endometrial polyps from diffuse endometrial thickening and other intracavitary abnormalities [12-15]. Our observations extend these observations by demonstrating that the SMI-derived vascular signals, especially intralesional flow, central feeding vessels, branching vascular architecture, continuous vascular pedicles, and increased microvascular density, were significantly correlated with successful lesion detection. This finding may reflect the underlying biological characteristics of endometrial polyps, as most endometrial polyps, particularly glandular and fibroglandular subtypes, contain organized fibrovascular cores that may remain detectable even when lesion margins are poorly defined on grayscale or 3D imaging. Clinically, these results suggest that vascular-targeted imaging may help identify lesions that are inconspicuous on structural evaluation alone, specifically in the presence of endometrial heterogeneity or intrauterine cavity interference. Also, the absence of significant

discriminatory value of punctate or spotty patterns suggests that not all vascular signal provide equivalent diagnostic information, and that interpretation of SMI findings should emphasize vascular patterns rather than simple flow presence.

Our study further found that the greatest diagnostic benefit was achieved when SMI was integrated with morphology-based imaging, particularly 3D-TVS. This aligns with the broader concept that multimodal imaging approaches may improve lesion characterization by combining complementary biological and structural information from different techniques [16]. Previous studies in gynecologic ultrasonography have suggested that morphologic and vascular characteristics can improve the evaluation of adnexal and endometrial lesions; however, evidence focusing on endometrial polyp detection remains limited [17]. Our results provide direct evidence that 3D-TVS + SMI not only improved overall detection rate but also enhanced recognition across a broad range of lesion configurations and pathologic subtypes. The underlying mechanism is likely complementary: 3D-TVS provides detailed information regarding of lesion morphology, attachment, and intracavitary orientation, whereas SMI reveals internal vascular patterns and feeding vessels. Their combination may reduce the likelihood that small or atypical lesions are overlooked or misinterpreted as nonspecific endometrial irregularities. Clinically, these findings

support the application of 3D-TVS + SMI as an integrated second-line imaging strategy when traditional ultrasonography provides inconclusive findings before hysteroscopic evaluation.

The incremental value of SMI was particularly evident in diagnostically challenging subgroups, including lesions <10 mm, multiple polyps, sessile lesions, lower uterine segment lesions, lesions without pedicle signs, and artifact-affected examinations. In these situations, conventional ultrasonography may have limited sensitivity, and diagnostic uncertainty may contribute to under-recognition of lesions or delayed hysteroscopic examination. Previous studies have revealed that small lesion size, broad-based attachment, and altered uterine cavity morphology are associated with reduced sonographic sensitivity for endometrial polyp detection [18-20]. Our findings corroborate these observations and further suggest that multimodal vascular assessment may partially improve lesion detection under unfavorable circumstances. One possible explanation is that small or sessile lesions may not produce sufficient geometric distortion of the endometrial contour for reliable identification on morphological imaging, whereas microvascular patterns may remain detectable using high-sensitivity flow imaging. Likewise, in lower uterine segment lesions or multifocal disease, structural overlap may obscure morphological features, while vascular mapping may provide additional information for localization of focal abnormalities. These findings have potential practice implications. Rather than accepting reduced sensitivity in diagnostically challenging subgroups, clinicians may improve preoperative assessment by integrating SMI into the imaging workflow of lesions with unfavorable morphologic characteristics.

We further observed that IUD-related factors, endometrial heterogeneity, cavity contour distortion, and particularly acoustic shadowing/artifact were associated with missed diagnosis in single-modality imaging pathways. However, the inverse association between IUD-related factors and detection was significantly attenuated after integration of multimodal imaging. Previous studies have shown that intracavitary lesions may be obscured by foreign bodies, coexisting fibroids, adenomyosis, or irregular endometrial backgrounds, which can generate

acoustic shadowing, reverberation artifacts, or competing echogenic interfaces [21, 22]. Our findings suggest that combined imaging may reduce, but not completely eliminate, these masking effects. When morphologic visualization is compromised by structural interference, additional vascular information from SMI may help preserve lesion conspicuity. Nevertheless, since missed diagnosis remained numerically higher in IUD-associated cases and acoustic artifact remained an independent predictor of missed diagnosis, these findings also highlight the limitations of advanced multimodal imaging under technically suboptimal conditions. Therefore, negative imaging findings in the presence of substantial artifacts or persistent clinical suspicion should be interpreted cautiously.

From the perspective of translational medicine, the present findings may have practical implications beyond simple diagnostic comparison, by providing insight into a more individualized preoperative imaging pathway for patients with suspected endometrial polyps. In particular, our results suggest that conventional ultrasonography may be used as the initial screening tool, whereas 3D-TVS combined with SMI may be particularly valuable in patients with inconclusive conventional ultrasound findings or those with imaging characteristics associated with missed diagnosis, including small lesions, sessile morphology, multiple polyps, lower uterine segment lesions, IUD-related interference, heterogeneous endometrium, and acoustic artifacts. Based on these observations, a clinical plan of action can be proposed: initial conventional transvaginal ultrasonography for baseline morphologic assessment, followed by targeted 3D-TVS to evaluate lesion contour, attachment, and intracavitary configuration, with subsequent SMI assessment of vascular characteristics when lesion conspicuity remains limited. Such an integrated strategy may improve preoperative risk stratification, assist in identifying patient who may benefit from further hysteroscopic evaluation, and reduce missed diagnosis in challenging cases. Although a formal predictive model was not constructed in the present study, the identified imaging predictors of missed diagnosis, including small lesion size, sessile morphology, acoustic artifact, absent vascular pedicle, low microvascular density,

and failed coronal reconstruction, provide an important basis for future development of standardized diagnostic algorithms or predictive models with improved translational applicability for routine gynecologic practice.

There are several limitations that should be acknowledged. First, in this single-center retrospective study, it was subject to selection bias related to patient enrollment and clinical decision-making patterns. These factors may limit the generalizability of our findings to other institutions with different patient populations, imaging workflows, and diagnostic practices. In addition, the inclusion of a selected population with clinically suspected endometrial polyps may have introduced spectrum bias, potentially overestimating diagnostic performance compared with an unselected screening population. Second, image acquisition and interpretation were influenced by operator-dependent factors, particularly for 3D-TVS coronal plane reconstruction and SMI-based vascular signal assessment, where operator experience and technical proficiency may affect image quality and lesion conspicuity. Moreover, variations in ultrasound system settings and imaging parameters across examinations may have contributed to heterogeneity in image interpretation. Although interobserver agreement was assessed, formal reproducibility validation involving different operators and external centers was not performed, which may limit the robustness and external validity of the findings. Therefore, the reported diagnostic performance should be interpreted with caution. Finally, although subgroup and regression analyses were conducted to strengthen internal inference, the relatively small sample size in certain subgroups may have reduced statistical power for specific pathologic or anatomic categories. Future prospective multicenter studies incorporating standardized imaging protocols, harmonized equipment settings, and comprehensive reproducibility assessment are warranted to validate and further extend these findings.

Conclusion

3D-TVS combined with SMI demonstrated improved preoperative diagnostic performance for endometrial polyps compared to morphology-based imaging alone. Beyond increasing overall lesion detection, this multimodal app-

roach may enhance recognition of diagnostically challenging lesions, particularly in situations where conventional ultrasonography has limited sensitivity. The 3D-TVS + SMI strategy provides a comprehensive imaging approach for preoperative assessment of endometrial polyps, with potential clinical value for patients with small, sessile, multifocal, or interference-affected lesions.

Disclosure of conflict of interest

None.

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