ORIGINAL RESEARCH ARTICLE

Multimodal hysterosalpingo-contrast sonography in the assessment of fallopian tubal patency: A retrospective study

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Abstract

Tubal factor infertility accounts for 25–35% of female infertility cases, requiring accurate fallopian tubal patency assessment for diagnosis and treatment. Traditional hysterosalpingography (HSG) carries radiation and allergy risks, while laparoscopic chromopertubation, the gold standard, is invasive and expensive. Multimodal hysterosalpingo-contrast sonography (HyCoSy) provides a radiation-free alternative. This retrospective study at Shenzhen Maternity and Child Healthcare Hospital, a tertiary maternity hospital in southern China (January 2019–December 2024) evaluated HyCoSy's diagnostic accuracy against laparoscopy in 62 infertile women (121 tubes, including three with unilateral salpingectomy). All underwent HyCoSy followed by laparoscopy within three months. Sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), Kappa coefficient, and area under the curve (AUC) were calculated using laparoscopy as reference. HyCoSy identified 90 obstructed and 31 patent tubes, versus 79 obstructed and 42 patent by laparoscopy, yielding sensitivity of 98.8%, specificity of 73.2%, PPV of 87.8%, NPV of 96.8%, and AUC of 0.86 (95% CI: 0.775–0.944). Agreement was substantial (Kappa = 0.72, P < 0.001). Misdiagnoses (n=12) mainly arose from venous reflux, pelvic adhesions, uterine malposition, or pain-induced spasm. Multimodal HyCoSy demonstrates high accuracy and substantial agreement with laparoscopy, positioning it as a promising non-invasive tool for tubal patency evaluation in infertility workup.. *(Afr J Reprod Health 2026; 30 [6]:115-124).*

Keywords: Hysterosalpingo-contrast sonography (HyCoSy); Multimodal ultrasound; Tubal patency; Female infertility; Diagnostic accuracy

Résumé

L'infertilité tubaire représente 25 à 35 % des cas d'infertilité féminine, nécessitant une évaluation précise de la perméabilité des trompes de Fallope pour le diagnostic et le traitement. L'hystérosalpingographie (HSG) traditionnelle comporte des risques d'irradiation et d'allergie, tandis que la chromopertubation laparoscopique, technique de référence, est invasive et coûteuse. L'hystérosalpingographie par contraste (HyCoSy) multimodale offre une alternative sans irradiation. Cette étude rétrospective menée à l'hôpital de maternité et de soins infantiles de Shenzhen, un centre hospitalier universitaire du sud de la Chine (janvier 2019 – décembre 2024), a évalué la précision diagnostique de l'HyCoSy par rapport à la laparoscopie chez 62 femmes infertiles (121 trompes, dont trois ayant subi une salpingectomie unilatérale). Toutes les patientes ont bénéficié d'une HyCoSy, suivie d'une laparoscopie dans les trois mois suivants. La sensibilité, la spécificité, la valeur prédictive positive (VPP), la valeur prédictive négative (VPN), le coefficient Kappa et l'aire sous la courbe (AUC) ont été calculés en utilisant la laparoscopie comme référence. L'hystérosonographie (HyCoSy) a identifié 90 trompes obstruées et 31 perméables, contre 79 obstruées et 42 perméables par laparoscopie, ce qui donne une sensibilité de 98,8 %, une spécificité de 73,2 %, une VPP de 87,8 %, une VPN de 96,8 % et une AUC de 0,86 (IC à 95 % : 0,775–0,944). La concordance était substantielle (Kappa = 0,72, p < 0,001). Les erreurs de diagnostic (n = 12) étaient principalement dues à un reflux veineux, des adhérences pelviennes, une malposition utérine ou des spasmes induits par la douleur. L'hystéroscopie multimodale HyCoSy démontre une grande précision et une concordance substantielle avec la laparoscopie, ce qui la positionne comme un outil non invasif prometteur pour l'évaluation de la perméabilité tubaire dans le cadre du bilan d'infertilité. *(Afr J Reprod Health 2026; 30 [6]: 115-124).*

Mots-clés: Hystérosalpingographie par contraste (HyCoSy) ; Échographie multimodale ; Perméabilité tubaire ; Infertilité féminine ; Précision diagnostique.

Introduction

Tubal factor infertility accounts for approximately 25–35% of female infertility cases worldwide, underscoring the critical need for accurate assessment of fallopian tubal patency in clinical evaluations.[1] This determination not only pinpoints etiology but also guides treatment strategies, such as in vitro fertilization or tubal surgery. Conventional modalities like hysterosalpingography (HSG) and laparoscopic chromopertubation remain staples, yet their drawbacks are well-recognized: HSG exposes patients to ionizing radiation and risks iodine allergy, with false-positive rates up to 30% due to spasm or debris;[2] laparoscopy, the gold standard, is invasive, costly, and less acceptable for routine screening.[3]

Transvaginal hysterosalpingo-contrast sonography (HyCoSy) has emerged as a safer alternative, offering radiation-free, outpatient-based imaging with good tolerability.[4] Advances have evolved it from basic 2D real-time contrast flow monitoring to 3D volumetric reconstruction for precise luminal detailing and 4D dynamic capture of tubal peristalsis.[5,6] Although 2D HyCoSy suffices for many cases, it may overlook subtle interstitial obstructions; integrating 3D/4D modes in multimodal protocols enhances diagnostic yield by providing complementary anatomical and functional insights.[7,8] Meta-analyses confirm HyCoSy's overall efficacy (pooled sensitivity ~93%), but evidence for multimodal approaches is largely from small, single-center studies lacking laparoscopic corroboration.[8] International guidelines, such as those from the American Society for Reproductive Medicine (ASRM), advocate its use yet highlight the need for robust validation in diverse cohorts.[9]

In this context, we conducted a retrospective analysis of 62 infertile women undergoing multimodal HyCoSy, using laparoscopic chromopertubation as the reference. Our primary aim was to evaluate its diagnostic accuracy of multimodal HyCoSy —an integrated approach combining 2D real-time flow monitoring, 3D volumetric reconstruction, and 4D dynamic imaging, as recommended by national guidelines for comprehensive tubal assessment for tubal patency,[7] while exploring misdiagnosis factors to inform clinical optimization and provide real-world evidence for broader adoption in infertility management

Methods

Study population

This retrospective study was conducted at Shenzhen Maternity and Child Healthcare Hospital, a tertiary maternity facility in Shenzhen, a coastal metropolis in southern China's Guangdong Province characterized by a subtropical climate and rapid urbanization. As one of China's most economically prosperous cities (per capita GDP > USD 25,000), it features advanced healthcare infrastructure supporting comprehensive infertility assessments for a large and diverse patient population. Initially, we evaluated 78 consecutive women who underwent multimodal HyCoSy for infertility assessment at this hospital between January 2019 and December 2024. After applying exclusion criteria, 16 women were excluded due to prior tubal ligation with reanastomosis (n=7), incomplete ultrasound imaging data (n=5), or insufficient laparoscopic surgical documentation (n=4). Thus, the final cohort consisted of 62 women, all of whom completed both multimodal HyCoSy and laparoscopic chromopertubation within a three-month period. In our group of patients, these procedures were typically carried out as part of routine infertility care—most often through combined hysterolaparoscopy to explore unexplained infertility, or as a follow-up check when ultrasound raised concerns about tubal blockage. This approach mirrors the practical steps outlined in the Expert consensus on the whole-process management of tubal factor infertility in China (2023 Edition), reflecting common clinical indications in our infertility population and minimizing potential selection bias.[10]

Participants ranged in age from 22 to 41 years (mean, 31.0 ± 4.6 years), with infertility durations of 12 to 45 months. Complete medical histories, imaging data, and surgical reports were available for all included cases. Notably, three patients had a history of unilateral salpingectomy due to prior ectopic pregnancy or severe tubal pathology, resulting in 121 fallopian tubes assessed. These cases were retained, as the remaining tubes met inclusion criteria, ensuring data integrity

without introducing selection bias. The participant flowchart is presented in Figure 1.

***Inclusion criteria*:** Fallopian tubal patency assessed by multimodal HyCoSy; laparoscopic chromopertubation performed within three months ofHyCoSy.

***Exclusion criteria*:** presence of pelvic malignancy; prior tubal ligation; incomplete imaging data; insufficient laparoscopic surgical documentation.

Ultrasound equipment and HyCoSy procedure

Ultrasound examinations were performed using Samsung W80A and Hera W10 systems equipped with a transvaginal probe (EV3-10B, 3.0–10.0 MHz). Standard contrast-enhanced ultrasound imaging software packages equipped on the systems were used for all examinations. No specific software modifications or dedicated presets for SonoVue were required. All procedures were performed by certified gynecologists with over five years of specialized experience in reproductive ultrasonography, skilled in integrating 2D, 3D, and 4D imaging modalities.[7, 11]The contrast agent was SonoVue (Bracco, Italy; 59 mg/vial).This choice was based on its established safety profile, widespread availability in our institution, and prior evidence supporting its efficacy for tubal patency assessment,[12] despite being an off-label application; no adverse events were observed in our cohort, consistent with reported literature.[7, 11].Examinations were scheduled 5–7 days after menstruation. Pre-procedural assessments included vaginal secretion testing, complete blood count, coagulation profile, and infection screening. Vaginal infection screening (cervical/vaginal swabs for chlamydia/gonorrhoea) was performed within 3 days prior to assessment; any identified infections were fully treated and confirmed cleared via immediate follow-up to preclude procedural complications.[7] Written informed consent was obtained from each patient.SonoVue (59 mg/vial) was reconstituted with 5 ml saline for initial preparation. For 4D HyCoSy, 2.5 ml of this suspension was diluted with 17.5 ml saline to achieve continuous intracavitary flow.

Multimodal HyCoSy procedure

The multimodal HyCoSy examination began with conventional transvaginal ultrasound to evaluate the uterus, adnexa, and rectouterine pouch. The probe was carefully angled to obtain clear views of the uterine cornua and ovaries.Following aseptic preparation, a sterile disposable uterine cavity catheter (Disposable Uterine Angiography Catheter, F12; Suzhou Huahao Medical Devices Co., Ltd., Suzhou, China) was inserted into the uterine cavity. This catheter ensured stable positioning and prevented leakage during contrast administration. To confirm proper placement and stability, 1.5–3.0 mL of 0.9% saline was gently injected.

Four-dimensional HyCoSy was then performed using settings of Tis <0.1, Tib <0.1, and MI = 0.11. Transverse planes of the uterus that included both cornua and ovaries were scanned while a diluted contrast agent was slowly injected to produce continuous intracavitary flow. Dynamic images were recorded, and peritubal contrast dispersion was observed in real time.

Immediately afterward, three-dimensional HyCoSy was conducted using the same imaging parameters. If both fallopian tubes could not be visualized in a single acquisition, separate acquisitions were performed for each side.

Finally, the system was switched to two-dimensional mode for targeted tracking of contrast flow from the uterine cornua through the tubes to the fimbrial ends. Particular attention was paid to peritubal spillage and the characteristic ring-shaped enhancement around the ovaries.

Image interpretation

All images were independently interpreted by two senior sonographers with at least 10 years of experience, who were blinded to the laparoscopic findings. Fallopian tubes were classified as patent or obstructed.[7,11] Any disagreements were resolved through consensus discussion with a third experienced reviewer.Tubal patency was defined by smooth contrast passage with low injection resistance, continuous tubular enhancement, free fimbrial spillage, and good peritoneal dispersion of contrast. In contrast, obstruction was diagnosed when there was high injection resistance, contrast reflux into the uterus, incomplete tubular

visualization, absence of fimbrial spillage, and poor or absent pelvic dispersion.In cases of diagnostic discrepancy between HyCoSy and laparoscopy, retrospective review of the imaging data and laparoscopic reports was performed to identify potential contributing factors, such as venous intravasation or pelvic adhesions.

Laparoscopic chromopertubation

All patients underwent laparoscopic chromopertubation with methylene blue within three months after multimodal HyCoSy. Findings from laparoscopic chromopertubation served as the diagnostic reference standard.

Statistical analysis

Statistical analyses were conducted using SPSS version 26.0. Categorical variables were expressed as n (%), and comparisons were performed using the χ^2 test. Diagnostic accuracy of multimodal HyCoSy was evaluated using sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV). Receiver operating characteristic (ROC) curves were generated, and agreement with laparoscopic chromopertubation was assessed using Kappa statistics. A *P*-value <0.05 was considered statistically significant.

Ethical approval

This retrospective study was conducted in accordance with the Declaration of Helsinki. The study protocol, including the waiver of informed consent for this specific retrospective data analysis, was reviewed and approved by the Ethics Committee of Shenzhen Maternity and Child Healthcare Hospital (Approval No. SFYLS[2025]039).

Results

Patient characteristics

A total of 62 women were included, with 121 fallopian tubes assessed. Three patients had a history of prior unilateral salpingectomy due to conditions such as ectopic pregnancy or severe tubal pathology, resulting in 121 evaluable tubes. The mean age was 31.0 ± 4.6 years (range: 22–41 years). Of the cohort, 41(66.1%) had primary infertility, and 21(33.9%) had secondary infertility, with detailed characteristics summarized in Table 1. All participants completed multimodal HyCoSy between days 5–7 of the menstrual cycle, followed by laparoscopic chromopertubation within three months. No procedure-related complications, such as infection, allergic reactions, or significant pain requiring intervention, were recorded for either HyCoSy or laparoscopic procedures in this cohort.

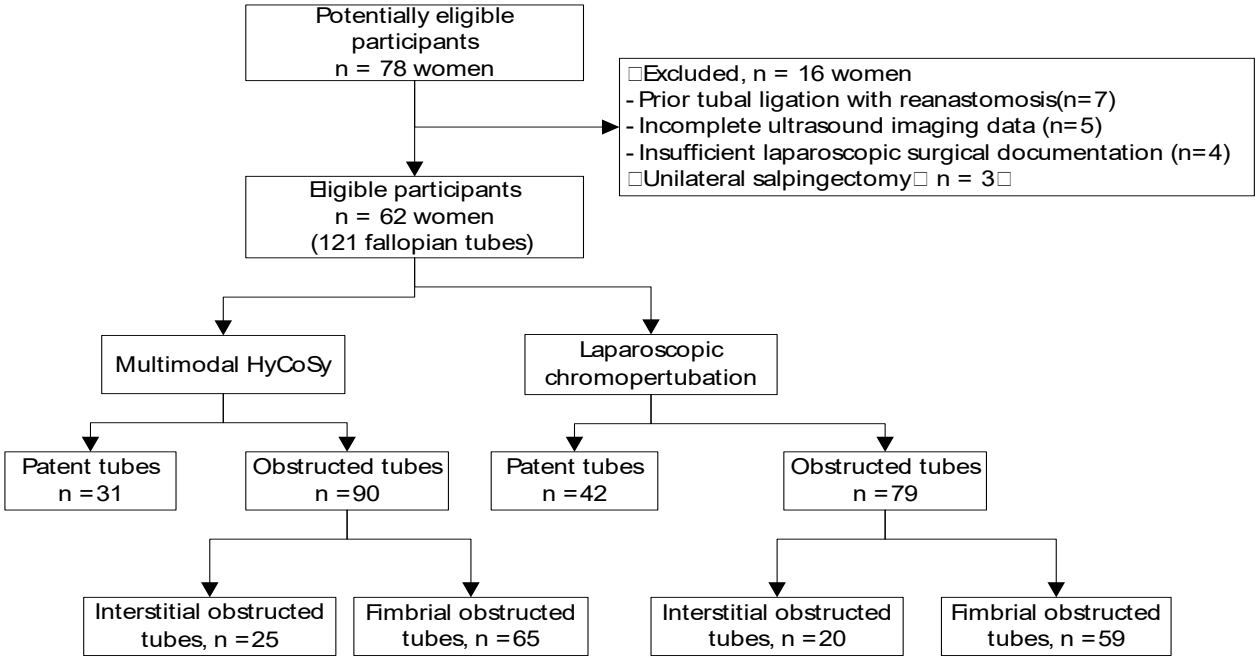
Findings of multimodal HyCoSy and laparoscopic chromopertubation

A total of 121 fallopian tubes were analyzed; diagnostic classifications by multimodal HyCoSy and laparoscopic chromopertubation are summarized below for direct comparison. Multimodal HyCoSy identified 31 patent tubes and 90 obstructed tubes (25 interstitial, 65 fimbrial), as illustrated in representative images (Figure 2A). In our multimodal protocol, 2D mode provided foundational flow tracking, but 3D/4D enhanced anatomical detailing(Figure 3); no isolated 2D cases were available for direct comparison, consistent with one-stop guidelines.[7] Differences in outcomes would require prospective studies separating modes.Laparoscopic chromopertubation, the reference standard, confirmed 42 patent tubes and 79 obstructed tubes (20 interstitial, 59 fimbrial; Figure 2B). Of the 31 tubes classified as patent by HyCoSy, 30 were confirmed patent, and 1 was identified as fimbrial obstruction by laparoscopy. Among the 25 interstitial obstructions identified by HyCoSy, 20 were confirmed, while 5 were patent. Similarly, of the 65 fimbrial obstructions, 59 were confirmed, and 6 were patent.

Patency and right fimbrial hydrops with obstruction.

Diagnostic performance

Using laparoscopic chromopertubation as the reference standard, multimodal HyCoSy demonstrated high diagnostic accuracy (Table 2). The overall agreement was substantial (Kappa = 0.72, $p < 0.001$). Sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) for detecting tubal obstruction were 98.8% (79/80; 95% CI: 92.98–99.97%), 73.2% (30/41; 95% CI: 57.12–85.27%), 87.8% (79/90; 95% CI: 79.10–93.29%), and 96.8% (30/31; 95% CI: 82.78–99.85%), respectively.

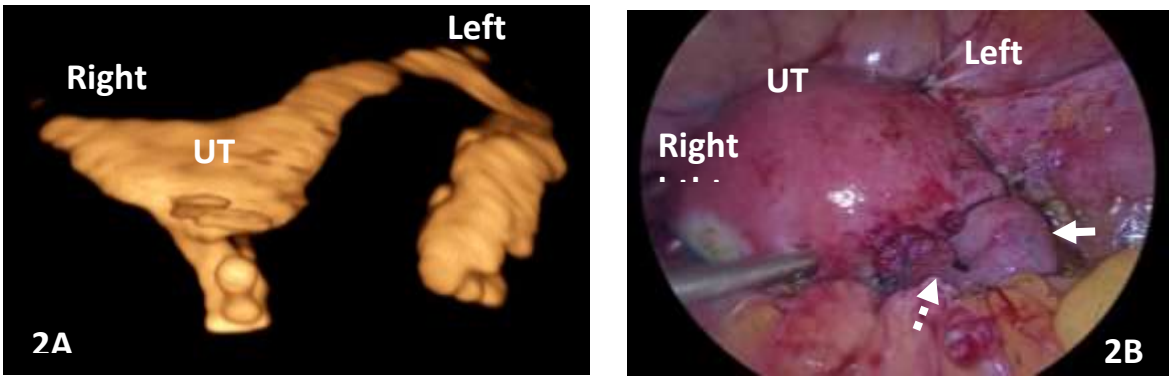


HyCoSy : multimodal hysterosalpingo-contrast sonography

Figure 1: Flowchart of the study

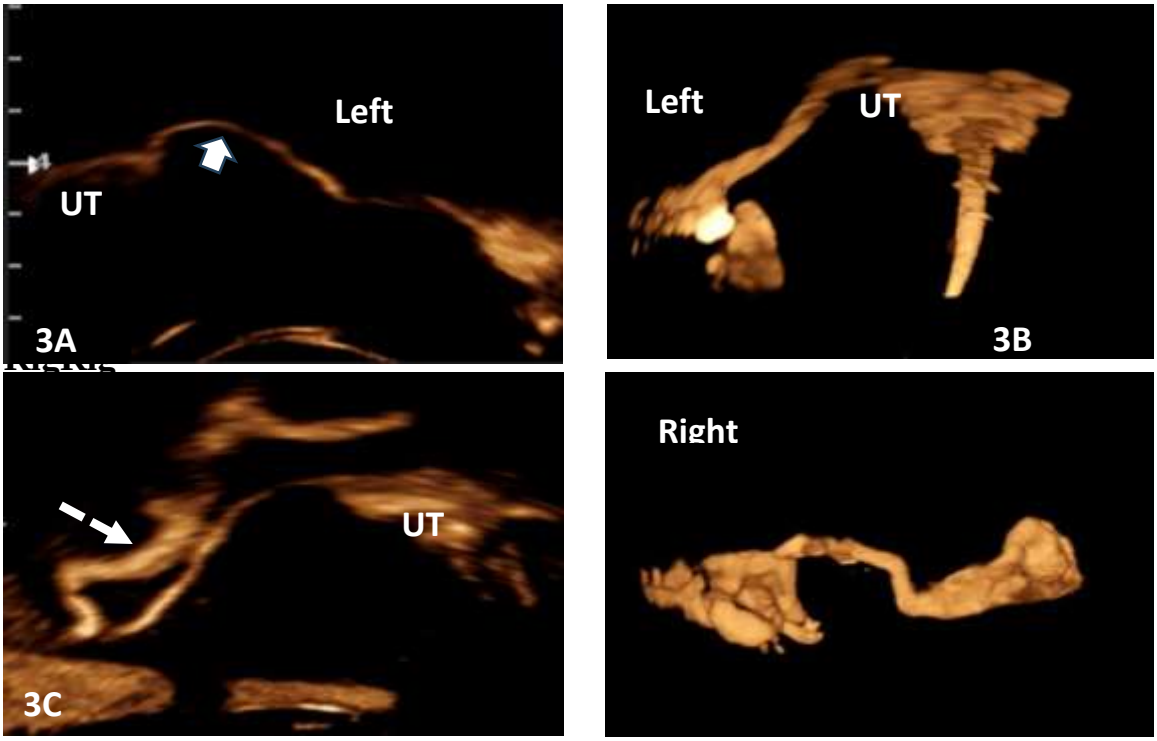
Table 1: Baseline characteristic of the study population(n=62)

Characteristic	Value
Age(years)	
Mean±SD	31.0±4.6
Range	22-41
Body Mass Index(kg/m^3)	
Mean±SD	23.0±2.2
Range	18-29
Infertility Type, n (%)	
Primary	41(66.1%)
Secondary	21(33.9%)
Infertility Duration(months)	
Mean±SD	21.9±7.9
Range	12-45
Prior Pelvic Surgery, n (%)	
None	41(66.1%)
Unilateral salpingectomy	3(4.8%)
Other (e.g. myomectomy, cystectomy)	18(29.0%)
Suspected Cause of Infertility, n (%)	
Tubal factor	45(72.6%)
Endometriosis	5(8.1%)
Ovulatory dysfunction	5(8.1%)
Unexplained	6(9.7%)
Parity, n (%)	
Nulliparous	44(71.0%)
Parous	18(29.0%)



(2A) Four-dimensional hysterosalpingo-contrast sonography (4D HyCoSy) image illustrating ampullary hydrosalpinx and fimbrial obstruction in the left fallopian tube. The image reveals localized dilation in the ampulla with absent contrast spillage at the fimbrial end and limited peritoneal dispersion, consistent with distal blockage.(2B) High-definition laparoscopic photograph of the same left fallopian tube, corroborating the ampullary hydrosalpinx and fimbrial obstruction. Visible is the swollen ampullary segment (solid arrows) with adhesions and no dye efflux (dotted arrows), matching the HyCoSy observations. Images from a representative case in the study cohort.

Figure 2: Multimodal HyCoSy and laparoscopic visualization of left fallopian tube ampullary hydrosalpinx with fimbrial obstruction



Transvaginal sonography (TVS) images illustrate bilateral tubal evaluation using 2D-HyCoSy (static views), 4D-HyCoSy (real-time dynamic sequences), and 3D-HyCoSy (volumetric rendering). (3A) TVS 2D-HyCoSy depicts uniform contrast filling of the left uterine horn, linear tubal progression (solid arrows), and free pelvic spillage, confirming patency.(3B) TVS 4D-HyCoSy validates real-time contrast flow and left tubal peristalsis, providing dynamic enhancement. (3C) TVS 2D-HyCoSy shows normal intrauterine filling but abrupt distal cutoff at the right fimbria with cystic dilatation (dotted arrows), indicative of hydrops and obstruction.(3D) TVS 3D-HyCoSy reconstructs volumetric irregularity at the right fimbria with pooling and absent distal flow (dotted arrows), offering a clearer three-dimensional view for improved anatomical assessment.

Figure 3: Multimodal HyCoSy in a patient with laparoscopically confirmed left tubal patency and right fimbrial hydrops with obstruction

Table 2: Accuracy of multimodal hycosy in detecting tubal patency with laparoscopic chromopertubation as reference (62 Patients, 121 Tubes)

	Obstructed tubes on laparoscopic chromotubation	Patent tubes on laparoscopic chromotubation	Total
Obstructed tubes on multimodal HyCoSy	79	11	90
Patent tubes on multimodal HyCoSy	1	30	31
Total	80	41	121

Data are presented as *n*

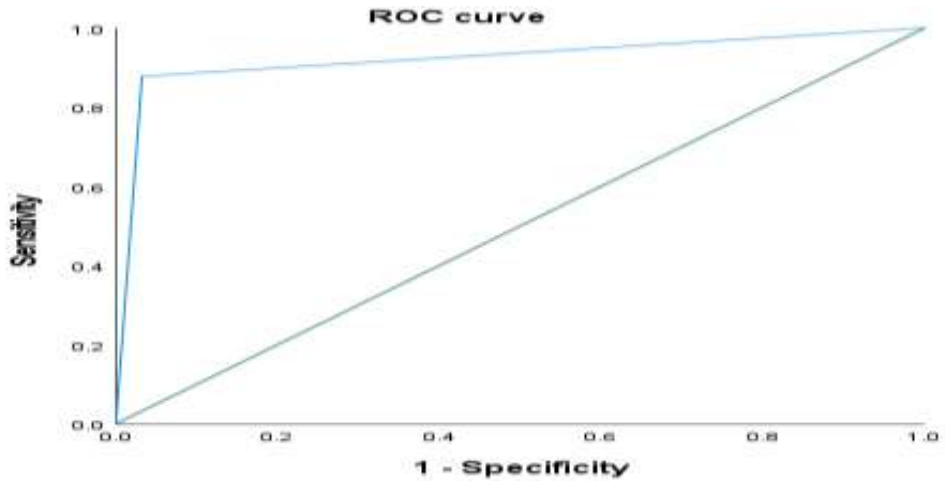


Figure 4: ROC curve of multimodal HyCoSy in detecting fallopian tubal obstruction

Receiver operating characteristic (ROC) analysis yielded an area under the curve (AUC) of 0.86 (95% CI: 0.775–0.944, $p < 0.05$; Figure 4). The misdiagnosis rate was 9.9% (12/121 tubes). No significant difference was observed in diagnostic accuracy between interstitial and fimbrial obstructions ($p > 0.05$).

Diagnostic accuracy of multimodal HyCoSy for detecting fallopian tubal patency in 62 patients (121 tubes), using laparoscopic chromopertubation as the reference standard. Sensitivity was 98.8% (79/80; 95% CI: 92.98–99.97%), specificity was 73.2% (30/41; 95% CI: 57.12–85.27%), positive predictive value was 87.8% (79/90; 95% CI: 79.10–93.29%), and negative predictive value was 96.8% (30/31; 95% CI: 82.78–99.85%). Agreement between the two methods was substantial (Kappa = 0.72, $p < 0.001$).

Receiver operating characteristic (ROC) curve of multimodal HyCoSy for detecting fallopian tubal obstruction, with laparoscopic chromopertubation as the reference standard.

The area under the curve (AUC) was 0.86 (95% CI: 0.775–0.944, $p < 0.05$), demonstrating good discriminative performance, with high sensitivity (98.8%) and acceptable specificity (73.2%).

Misdiagnosed cases

Of the 121 fallopian tubes, 109 (90.1%) were correctly classified by multimodal HyCoSy, while 12 (9.9%) were misdiagnosed across 10 patients. These included five patent tubes misclassified as interstitial obstruction, six as fimbrial obstruction, and one fimbrial obstruction misclassified as patent. Retrospective analysis identified venous reflux as the leading cause (5/12 cases, 41.7%), followed by pelvic adhesions (3/12, 25.0%), procedural pain inducing tubal spasm (2/12, 16.7%), and uterine malposition or suboptimal ovarian positioning (2/12, 16.7%). Overlaps occurred in two patients (e.g., venous reflux combined with adhesions). These findings underscore the multifactorial nature of diagnostic errors in HyCoSy.

Discussion

Diagnostic value of multimodal HyCoSy

Transvaginal HyCoSy has progressed from 2D imaging to advanced 3D and 4D techniques, offering detailed visualization of tubal anatomy and function.[5, 6] In our study, multimodal HyCoSy achieved a high sensitivity of 98.8% and substantial agreement with laparoscopic chromopertubation (Kappa = 0.72, $p < 0.001$), with an AUC of 0.86. By integrating real-time 2D flow tracking, 3D structural assessment, and 4D dynamic imaging, this approach outperforms single-mode protocols, enhanced by harmonic imaging for clearer peritoneal contrast.[13] Compared to Qu et al.'s meta-analysis (pooled sensitivity 93%, specificity 90%),[14] our higher sensitivity likely reflects multimodal synergy, though lower specificity (73.2%) suggests cohort-specific challenges.

Our findings build upon previous studies, such as Ludwin et al.'s foam-based HyCoSy and Zhou et al.'s 3D HyCoSy work,[5,6] but provide larger-scale data verified by laparoscopy from a Chinese center, in line with national guidelines.[7, 11] The high sensitivity of 98.8% highlights HyCoSy's strong diagnostic potential, although the relatively lower specificity of 73.2%—likely due to the high prevalence of tubal obstructions in our cohort—suggests that the test may be more prone to overdiagnosing marginal cases. This could explain the increased sensitivity, as the method is more likely to identify tubal obstructions than to miss them. The 9.9% misdiagnosis rate, points to areas that require further optimization, especially in minimizing false positives and improving diagnostic precision.

Analysis of misdiagnosed cases

The lower specificity (73.2%) compared to meta-analyses (90%) stems from our cohort's high obstruction prevalence (65.3%), which amplifies false positives, consistent with prevalence effects in diagnostic tests. [5,12,14,15] Of 12 misdiagnoses across 10 patients (Section 3.4), venous reflux was most common (41.7%, n=5), causing artifacts like non-opacification or false spillage; slow injection reduces this, as Jin et al. noted.[16] Pelvic adhesions (25.0%, n=3) mimicked obstruction in 30% of cases, as seen in one patient with laparoscopically confirmed ovaro-intestinal adhesions.[13,17] Uterine malposition or suboptimal ovarian positioning (16.7%, n=2) hindered visualization due to poor insonation angles,[18] while pain-induced spasms (16.7%, n=2) simulated blockages, often resolvable by reinjection.[19] Two patients had overlapping factors (e.g., reflux and adhesions), highlighting the need for meticulous technique and clinical correlation to avoid unnecessary interventions.

Methodological limitations and scope of application

Our retrospective, single-center design (n=62) limits generalizability, and referral biases may favor obstructed cases, inflating false positives. Operator variability and specific equipment (Samsung systems, SonoVue) may not translate universally,[16] and unmeasured factors like BMI or endometriosis severity could affect imaging.[20] However, our rigorous laparoscopic verification and multimodal protocol strengthen the evidence, addressing gaps in single-mode studies.[5, 6] Results are most applicable to Asian infertility cohorts but align with international standards.[9] Future multicenter RCTs should explore diverse platforms and cost-effectiveness.

Clinical practice and technical optimization

Multimodal HyCoSy offers a non-invasive, radiation-free alternative to HSG or laparoscopy, ideal for first-line tubal assessment due to its high sensitivity (98.8%) and patient tolerability. [3,4] We recommend optimizing via patient repositioning for malpositioned uteri, slow contrast injections to minimize reflux or spasms, and repeat imaging for ambiguous cases.[17,19] Suspected adhesions require laparoscopic confirmation.[18] Standardizing protocols per guidelines and improving training are critical.[7, 11] Emerging AI tools could enhance artifact detection and specificity.[21]

Multimodal HyCoSy offers enhanced diagnostic accuracy compared to traditional methods. The learning curve for multimodal HyCoSy may encompass an initial rapid improvement phase, a mid-stage consolidation plateau, and a late proficiency stabilization period;

this dynamic is modulated by operator experience, equipment integration, patient variables, and structured training, with multimodal fusion (2D/3D/4D) mitigating technical barriers to enhance reproducibility.[22]

In our study, procedures were performed by experienced gynecologists (>5 years in reproductive ultrasonography), thereby minimizing operator variability and bolstering diagnostic consistency. To optimize adoption, a phased training framework—encompassing theoretical instruction, simulation practice, supervised clinical application, and performance feedback—is recommended to accelerate skill mastery and ensure equitable clinical utility.However, in tropical and low-resource settings—for example, sub-Saharan Africa or Southeast Asia—multimodal HyCoSy's feasibility hinges on tackling local hurdles much like those in laparoscopy programs. Rosenbaum and Maine point out that low- and middle-income countries often grapple with equipment maintenance breakdowns, stemming from scarce skilled engineers and dwindling resources.[23]

High humidity and temperature only compound these woes, but HyCoSy sidesteps them by leaning on portable, rugged ultrasound systems that demand few consumables. Patient acceptability is further enhanced by its outpatient format and low out-of-pocket costs (~USD 50 per procedure), addressing economic barriers like lack of insurance coverage that impede invasive diagnostics.[23] With a moderate learning curve (20-30 cases for proficiency), HyCoSy offers a simpler, faster-to-implement alternative, potentially accelerating infertility screening in high-burden regions. Large-scale global trials will solidify HyCoSy's role in infertility care.

Conclusion

Our retrospective study demonstrates that multimodal HyCoSy is a reliable, non-invasive method for evaluating fallopian tubal patency in infertile women, integrating 2D, 3D, and 4D ultrasound for comprehensive real-time assessment of tubal morphology and function. With a sensitivity of 98.8% and substantial agreement with laparoscopic chromopertubation (Kappa = 0.72), this approach offers a promising radiation-free alternative to traditional invasive diagnostics, particularly as a first-line tool in infertility workups.While challenges such as venous reflux, adhesions, and procedural factors contribute to a 9.9% misdiagnosis rate, optimizing techniques and incorporating clinical context can mitigate these issues. Overall, multimodal HyCoSy advances clinical practice in integrated protocols by bridging gaps in single-mode imaging, as supported by expert consensus on one-stop assessment.[7] Larger multicenter prospective studies are essential to validate our findings, standardize protocols, and integrate AI for improved artifact detection and diagnostic consistency.[21]

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Competing interests

None declared.

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