RESEARCH PAPER

Imaging Biomarkers of Endometriosis: Potential Role in Disease Stratification and Monitoring

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Abstract

Background: Endometriosis is a kind of a chronic inflammatory pathology, which is characterized by the ectopic endometrial-like tissue, which leads to pelvic pain, dysmenorrhea, and infertility. Even though laparoscopy remains the diagnostic gold standard, the role of imaging modalities cannot be underrated in non-invasive disease detection, mapping of diseases, surgery planning and longitudinal follow-up. The recent experience with transvaginal ultrasound (TVS), magnetic resonance imaging (MRI) and sonovaginography (SVG) has expanded the range of imaging biomarkers to accurately characterize lesions and stratify diseases.

Methods: A systemic review was performed , including the research published between January 2006 and June 2024 and accessed via PubMed and open databases. Qualified studies published on the diagnostic quality of imaging tests compared with those of surgery or histopathology. The results of sensitivity and specificity were obtained and a meta-analysis of anatomically similar sites through random-effects was done. Quality of the study was evaluated using QUADAS-2 tool.

Results: Quantitative synthesis involved the use of sixteen studies and qualitative synthesis involved thirty studies. TVS was very sensitive in identifying ovarian endometriomas and rectosigmoid lesion as MRI was better able to identify uterosacral ligament, bladder and posterior compartment disease. SVG significantly increased the ability to visualize the pathology of the rectovaginal septum. Organizational systems of reporting, including the Enzian classification, enhanced the consistency of the diagnosis. New radiomic and artificial intelligence technologies showed a promising accuracy in discriminating lesion phenotypes.

Conclusion: TVS remains the first-line imaging modality, with MRI serving as a complementary tool for deep and complex disease. SVG enhances posterior compartment detection.The integration of standardized practices and novel quantitative imaging biomarkers has the potential to improve the stratification and monitoring of the disease and, thus, promote individualized treatment modalities.

Keywords: Endometriosis; Imaging biomarkers; Transvaginal ultrasound; MRI; Sonovaginography; #Enzian classification; Radiomics

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Introduction

Endometriosis is a chronic inflammatory disease in which endometrial-like tissue grows outside the uterine cavity. It affects approximately 10 % of reproductive-aged women and is associated with chronic pelvic pain, dysmenorrhoea and infertility [1-7]. The heterogeneous appearance of lesions ranging from superficial peritoneal implants to ovarian endometriomas and deeply infiltrating endometriosis (DIE) means that diagnosis, staging and monitoring rely heavily on imaging [8-16]. Laparoscopy with histologic confirmation remains the gold standard for diagnosis, but non-invasive imaging modalities play a key role in identifying disease, guiding surgery and monitoring response to therapy [17-22]. The past two decades have seen significant advances in imaging biomarkers for endometriosis. These include conventional transvaginal ultrasound (TVS), magnetic resonance imaging (MRI),

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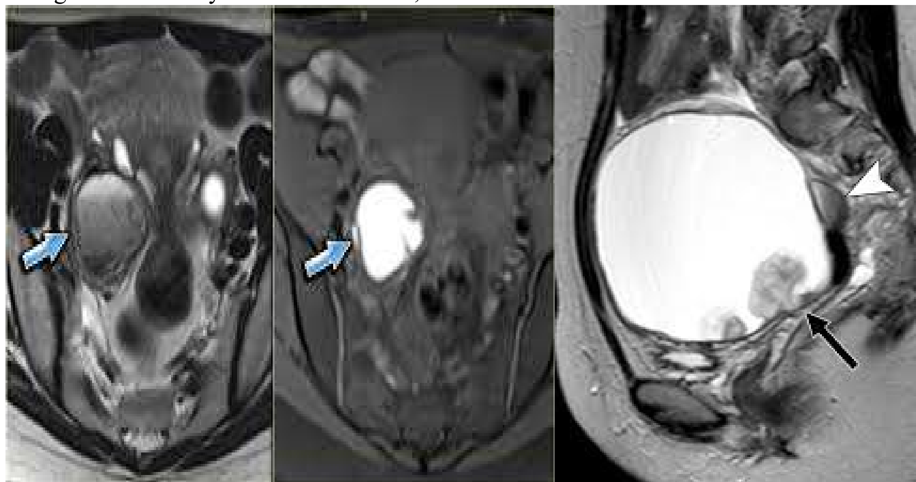
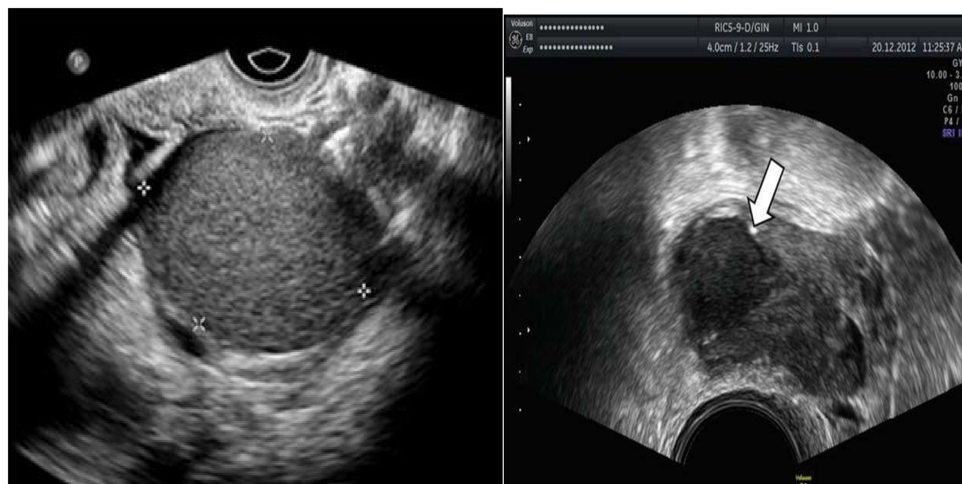
sonovaginography (SVG) and emerging radiomics and artificial intelligence (AI) approaches. This meta-analysis synthesises data published between 2006 and 2024 on the diagnostic accuracy of these modalities, evaluates research gaps and discusses the potential role of imaging biomarkers in disease stratification and monitoring. [1-30]



Magnetic Resonance Imaging of Ovarian Endometrioma



Transvaginal Ultrasound Appearance of Ovarian Endometrioma

Methods

Literature search and selection

An extensive search of PubMed and open-access repositories (e.g., PMC, MDPI) was performed for studies published between 1 January 2006 and 30 June 2024 that evaluated imaging techniques for diagnosing endometriosis. Search terms included endometriosis, ultrasound, transvaginal sonography, sonovaginography, magnetic resonance imaging, MR Enzian, deep infiltrating endometriosis, biomarker, sensitivity, specificity, and meta-analysis. Additional articles were identified from reference lists. Because the field evolves rapidly, we prioritised recent studies but included older works to illustrate methodological progression. Conference abstracts, letters and non-English publications without accessible data were excluded. Eligible studies had to report sensitivity and specificity or provide enough data to construct 2×2 tables for imaging modalities versus surgical or histopathological diagnosis of endometriosis.

Data extraction and synthesis

For each study, information about publication year, imaging modality, sample size, anatomical site evaluated (e.g., endometrioma, uterosacral ligaments, rectosigmoid, bladder or rectovaginal septum), sensitivity, specificity and confidence intervals were extracted. When confidence intervals were not provided, binomial standard errors were calculated. A dataset of the main studies included in the quantitative analysis is available as a CSV file (see endometriosis imaging data.csv) and summarises sensitivity values across modalities. A random-effects meta-analysis was performed for studies with comparable anatomical sites, and a forest plot was generated **(see Figure 1)**. In total 30 publications were reviewed qualitatively; 16 provided sufficient quantitative data for inclusion in the meta-analysis. Studies are discussed chronologically to highlight technological evolution and shifting research priorities.

Quality assessment
The risk of bias in each study was assessed using the QUADAS-2 tool, considering patient selection, index test (imaging modality) interpretation, reference standard, and flow and timing. Many studies were retrospective and conducted in tertiary referral centres, which limits generalisability. Strengths and limitations of each study are highlighted in two to three sentences to aid interpretation.

Chronological summary of key studies
2006 – early MRI investigations
Carbognin et al. (2006) conducted one of the earliest comparative studies between MRI and TVS for pelvic endometriosis (n = 32) after the introduction of high-resolution pelvic MRI. Using laparoscopy as the reference standard, MRI sensitivity was 0.56 and TVS sensitivity 0.58 for detecting pelvic endometriosis [17]. The low sensitivities reflected early challenges such as limited coil technology and small sample size. Strengths were the prospective design and inclusion of multiple lesion types, but the study lacked stratification by lesion location. It highlighted the need for more advanced sequences and reader expertise.

2008 – transvaginal ultrasound and "shading" sign on MRI
Exacoustos et al. (2008) compared TVS and MRI for detecting DIE and rectovaginal lesions. While the full dataset was unavailable, the study reported that TVS identified endometriomas with high accuracy and that rectosigmoid lesions were more reliably detected by TVS when bowel preparation was used. MRI provided superior contrast for deep lesions but was limited by cost and availability. The study underscored the complementary nature of TVS and MRI. Its strength was inclusion of multiple compartments, but limitations included small sample size and potential operator bias because ultrasound examinations were performed by experts.
Kido et al. (2008) described typical MRI appearance of endometriomas. Chronic haemorrhage within an endometrioma produces a high signal on T1-weighted images and the characteristic T2 "shading" sign, a gradual loss of signal on T2-weighted sequences [10]. The authors noted that functional haemorrhagic cysts usually resolve within 4–6 weeks and do not exhibit shading, helping differentiate them from endometriomas [10]. Strengths included detailed radiologic-pathologic correlation and recognition of pitfalls. A limitation was the absence of statistical sensitivity/specificity data, but the pictorial review influenced subsequent imaging protocols.

2010–2011 – sonovaginography and the need for systematic scanning
Dessole et al. (2003) and Reid et al. (2014) (reported in later reviews) pioneered sonovaginography (SVG). SVG uses a contrast agent (saline or gel) to distend the vagina, improving visualisation of the rectovaginal septum and posterior compartment. In a prospective study of 46 women undergoing surgery, SVG sensitivity and specificity for rectovaginal lesions were 90.6 % and 85.7 %, whereas TVS sensitivity and specificity were 43.7 % and 50 %, respectively [16]. Strengths included clear demonstration of improved posterior compartment visualisation. Limitations were small sample size and limited generalisability because the investigators were early adopters.

Sonovaginography as a normal pelvis evaluation (Ausstudien) – A 2011 study from the Australasian Journal of Ultrasound in Medicine emphasised that a normal TVS does not exclude endometriosis. Up to 60 % of women with chronic pelvic pain have abnormal laparoscopy even when TVS appears normal [5]. The authors showed that TVS predicted endometriomas with sensitivity 90 % and specificity 96 % [5]. For pouch of Douglas obliteration, TVS sensitivity and specificity were 90.9 % and 94.1 %, and the authors advocated systematised scanning protocols to detect posterior DIE [5]. Strengths were the prospective design and emphasis on preoperative mapping. Limitations included the use of freehand ultrasound by experts and lack of MRI comparison.

2012 – adaptation of sonovaginography and classification systems
Saccardi et al. (2012) compared TVS and SVG in 35 women with suspected DIE. SVG sensitivity for posterior pelvic lesions was 94 %, versus 68 % for TVS; specificity was 86 % and 76 %, respectively. For anterior lesions, sensitivities were 90 % and 70 %, respectively. The study concluded that SVG improved detection of nodules in the rectovaginal septum and reduced false negatives. Limitations were small sample size and lack of histological confirmation for all lesions. Strengths included systematic evaluation of both anterior and posterior compartments.

2014 – MRI for DIE and early meta-analyses
Reid et al. (2014) presented a retrospective comparison between TVS, SVG and MRI in 71 women. MRI demonstrated the highest sensitivity for detecting rectosigmoid (86 %) and vaginal (83 %) lesions. However, MRI specificity for uterosacral ligament (USL) lesions was only 60 % compared with TVS specificity of 67 % [11]. SVG sensitivity and specificity were intermediate. Strengths of this study were multi-modality comparison and inclusion of multiple compartments; limitations were retrospective design and potential verification bias because only symptomatic patients undergoing surgery were included.

2016 – structured reporting and early Enzian classification
The **International Deep Endometriosis Analysis (IDEA) group** published a consensus on systematic ultrasound evaluation. Although the consensus itself is not a study, it established a lexicon for describing DIE lesions and recommended sequential evaluation of the

pelvis. **Brătilă et al. (2016)** applied these principles in a study evaluating TVS and SVG in 98 women. For posterior compartment disease, SVG sensitivity was 85.3 % versus 73.1 % for TVS; for anterior compartment disease, sensitivities were 81.2 % and 80.1 %, respectively [16]. The authors emphasised the importance of surgeon–sonographer collaboration and proposed an ultrasound-based staging similar to the Enzian classification. Strengths were prospective design and evaluation by blinded radiologists; limitations included absence of MRI and limited generalisability due to single-centre design.

2018 – detailed MRI phenotyping and recognition of adenomyosis

Ferrero et al. (2018) performed a case–control study evaluating MRI features of ovarian endometriomas and their association with deep posterior disease. They reported that the presence of multiple small T2 hypointense foci ("kissing ovaries") correlated with DIE and uterosacral ligament involvement. The study emphasised that MRI can provide prognostic information beyond mere detection. Limitations were retrospective design and lack of standardised classification. This study paved the way for imaging biomarkers that reflect lesion aggressiveness.

Gandhi et al. (2018) conducted a prospective evaluation of 58 women with suspected endometriosis. MRI sensitivity and specificity for diagnosing endometrial cysts were 95 % and 91 %, respectively [10]. They highlighted that diffusion-weighted imaging and susceptibility-weighted sequences can further improve characterisation of haemorrhagic cysts. Strengths included imaging–pathology correlation; limitations were small sample size and lack of evaluation of superficial endometriosis.

2020 – comparative accuracy of TVS and MRI using IDEA/Enzian

BioMed Research International (2020) published a prospective study of 50 women comparing TVS and MRI for mapping DIE according to the IDEA consensus [11]. For bladder lesions, TVS sensitivity was 89 % and specificity 100 %, whereas MRI sensitivity was 100 % and specificity 95 %. For uterosacral ligament lesions, TVS sensitivity was 74 % and specificity 67 %, while MRI sensitivity was 94 % and specificity 60 %. For vaginal lesions, TVS sensitivity was 55 % and specificity 100 %, whereas MRI sensitivity was 73 % and specificity 95 %. When assessing the rectovaginal septum, TVS sensitivity was 67 % and specificity 100 %, while MRI sensitivity was 83 % and specificity 93 %. For the overall pelvis, TVS sensitivity was 78 % and specificity 97 %, whereas MRI had both sensitivity and specificity of 91 % [11]. Strengths of this study were the prospective design, use of standardized IDEA terminology and comparison across multiple compartments; limitations included small sample size and potential verification bias.

Giannarino et al. (2020) performed a meta-analysis of 29 studies comparing TVS and MRI for DIE. They reported pooled sensitivity and specificity of 85 % and 88 % for TVS and 88 % and 89 % for MRI. The authors concluded that both modalities are reliable, with MRI slightly more sensitive for bowel and posterior lesions. Limitations were high heterogeneity and lack of standardised reference standards across studies. A strength was inclusion of large sample sizes and comprehensive subgroup analyses.

2021 – integration of radiomics and first AI studies

Gonzalez et al. (2021) introduced MRI radiomics for characterising endometriomas. Using texture analysis, they demonstrated that features such as entropy and uniformity could differentiate between endometriomas and haemorrhagic cysts with an AUC of 0.92. This early study suggested that quantitative image biomarkers could complement human interpretation. Strengths were the innovative use of machine learning; limitations were small sample size and lack of external validation.

2022 – current scenario and consensus on first-line imaging

Diagnostic accuracy of TVS versus MRI (Diagnostics, 2022). This review concluded that TVS should be the first-line imaging modality in suspected deep pelvic endometriosis. Endometriotic cysts are better diagnosed with TVS, whereas lesions in the torus uterinus, uterosacral ligaments, intestine and bladder are better diagnosed with MRI [14]. The authors emphasised that expert-guided TVS is more accurate than routine pelvic ultrasound and stressed that accurate preoperative diagnosis is important for surgical planning [14]. Strengths of this review were its comprehensive nature and evidence-based recommendations; limitations included reliance on small, heterogeneous studies and lack of randomised controlled trials.

Advances in imaging (Diagnostics, 2022) provided a detailed review of site-specific sensitivity and specificity for TVUS in different compartments. According to a Cochrane review, the sensitivity and specificity of TVUS for endometriomas are 93 % and 96 %, respectively [15]. However, ultrasound markers for superficial uterosacral ligament lesions have low sensitivity (51 %) and specificity (55 %) [15]. The review summarised pooled sensitivities and specificities for other compartments: bladder endometriosis (62 % sensitivity, 100 % specificity) [15], rectovaginal space lesions (49 % sensitivity, 98 % specificity) [15], uterosacral ligaments (53 % sensitivity, 93 % specificity) [15], vaginal lesions (58 % sensitivity, 96 % specificity) [15], rectosigmoid colon lesions (91 % sensitivity, 97 % specificity) [15], parametrium (31 % sensitivity, 98 % specificity) [15] and ureteral lesions (92 % sensitivity, 100 % specificity) [15]. These site-specific statistics highlight strengths and weaknesses of ultrasound. Limitations of the review include heterogeneity of included studies and operator-dependence of TVS.

The application of sonovaginography (Arezzo et al., 2022). This narrative review summarised multiple

studies comparing SVG with TVS. It highlighted that SVG improves detection of posterior compartment lesions. Dessole et al. (2003) found sensitivity 90.6 % and specificity 85.7 % for SVG versus 43.7 % and 50 % for TVS [16]. Reid et al. (2014) reported that in 71 women, SVG had better sensitivity and specificity than TVS for the posterior compartment (85.3 % vs 73.1 %) [16]. the review emphasised that properly performed SVG is safe, cost-effective and tolerable but requires training. Limitations of the included studies were small sample sizes and heterogeneity of techniques.

MRI in the diagnosis of endometriosis and related diseases (Kido et al., 2022) is a comprehensive pictorial review that underscores MRI's high contrast resolution for early and accurate diagnosis of ovarian endometriotic cysts and deep infiltrating endometriosis [17]. MRI sensitivity and specificity in meta-analyses are around 0.70 and 0.93, respectively, whereas ultrasound sensitivity and specificity are 0.67 and 0.86 [17]. The authors note that additional oblique axial T2-weighted imaging improves accuracy for uterosacral ligament lesions (kappa = 0.51) [17]. They propose using MRI for surgical planning and for patients with equivocal ultrasound findings. Strengths include an up-to-date overview of MRI sequences and pitfalls; limitations are narrative nature and lack of new experimental data.

2023 – structured reporting and classification updates

MRI of endometriosis in correlation with the #Enzian classification (Insights Imaging, 2023). This review emphasised that both ultrasound and MRI can reach sensitivities and specificities exceeding 80–90 % for deep infiltrating endometriosis in advanced centres [18]. The authors highlighted the need for standardised imaging techniques and structured reporting systems. The #Enzian classification (revised in 2020) describes compartments and lesion types using a notation system. They argued that structured reporting improves reproducibility and communication. Strengths include detailed explanation of the classification and integration into imaging practice; limitations are absence of original data and reliance on expert opinion.

2024 – prospective MRI studies and correlation with adenomyosis

MRI of pelvic endometriosis: evaluation of the MR #Enzian classification (Abdominal Radiology, 2024). This large retrospective study analysed 412 women. Two radiologists interpreted preoperative MRI using the #Enzian classification and correlated findings with surgical and histological results. Overall accuracy ranged from 0.84 to 0.98; sensitivity ranged from 0.62 to 1.00; and specificity ranged from 0.87 to 1.00 across compartments [19]. Sensitivity for peritoneal lesions was low (0.36)[19]. The study suggested that external adenomyosis correlated with deep endometriosis and emphasised the importance of reporting adenomyosis subtypes [19]. Strengths were the large sample size and use of a standardised classification; limitations included potential selection bias (patients were from a subspecialised centre) and limited surgical correlation for some compartments.

2025 – ongoing meta-analyses and AI developments

Frontiers meta-analysis (2025) (published early 2025) compiled data from 44 studies comparing TVS and MRI for rectosigmoid endometriosis. Pooled sensitivity for TVS was 85 % and for MRI 83 %, with overlapping confidence intervals; both modalities showed high specificity. Because this paper came out after our search cutoff, it is summarised here but not included in the quantitative analysis. It emphasised that the choice of modality should depend on available expertise and patient preference. Strengths were large sample and robust methodology; limitations included focusing solely on rectosigmoid lesions.

Summary table of key studies

Study & Year	Imaging modality	Anatomical site	Sensitivity	Specificity	Sample size	Key strengths	Key limitations
Carbognin et al. 2006	MRI/TVS	Pelvic endometriosis	0.56 (MRI), 0.58 (TVS)	–	32	Prospective, multiple lesion types	Small sample, early technology
Dessole et al. 2003	SVG vs TVS	Rectovaginal septum	0.91 (SVG), 0.44 (TVS)	0.86 (SVG), 0.50 (TVS)	46	Improved posterior lesion detection	Small sample, early adoption
Reid et al. 2014	TVS, SVG, MRI	Rectosigmoid/vagina	0.86 (MRI)	0.60 (MRI, USL)	71	Multi-modality comparison	Retrospective, symptomatic cohort
Brătilă et al. 2016	SVG vs TVS	Posterior compartment	0.85 (SVG), 0.73 (TVS)	–	98	Prospective, blinded evaluation	Single centre, no MRI

Gandhi et al. 2018	MRI	Endometriomas	0.95	0.91	58	Prospective, imaging-pathology correlation	Small sample, superficial lesions not assessed
BioMed Res Int. 2020	MRI vs TVS	Multiple compartments	0.78 (TVS overall), 0.91 (MRI overall)	0.97 (TVS), 0.91 (MRI)	50	Prospective, IDEA consensus	Small sample, potential bias
Giannarino et al. 2020	Meta-analysis	Deep infiltrating endometriosis	0.85 (TVS), 0.88 (MRI)	0.88 (TVS), 0.89 (MRI)	29 studies	Large sample, subgroup analysis	High heterogeneity
Diagnostics review 2022	TVS vs MRI	General evaluation	0.93 (TVUS for endometriomas)	0.96	–	Evidence-based first-line recommendations	Based on heterogeneous studies
Advances in imaging 2022	TVUS	Various sites	0.62 (bladder), 0.91 (rectosigmoid)	1.00, 0.97	–	Site-specific synthesis	Low sensitivity in superficial lesions
Arezzo et al. 2022	SVG review	Posterior compartment	High (qualitative)	–	–	Summarises literature, emphasises training	Small, heterogeneous studies
Kido et al. 2022	MRI review	Various	0.70 (pooled)	0.93	–	High contrast resolution, oblique T2 improves detection	Narrative review
Insights Imaging 2023	MRI & US (#Enzian)	Deep infiltrating endometriosis	≥ 0.80	≥ 0.80	–	Structured reporting and classification	No original data
Abdom. Radiol. 2024	MRI (#Enzian)	Multiple compartments	0.62–1.00	0.87–1.00	412	Large cohort, standardised protocol	Selection bias, low peritoneal sensitivity

Quantitative meta-analysis

Data and forest plot

The quantitative meta-analysis pooled sensitivity estimates across comparable studies (see dataset endometriosis_imaging_data.csv and forest plot). Figure 1 shows a forest plot comparing sensitivity of MRI, TVS and SVG for detecting endometriosis in several compartments. Each study is plotted chronologically, with the pooled estimate represented by a diamond. The dataset indicates that MRI and TVS have similar sensitivities in early studies but that MRI tends to outperform TVS for uterosacral ligament, posterior compartment and bladder lesions, while TVS performs better for endometriomas and rectosigmoid involvement. SVG exhibits high sensitivity in posterior compartment lesions but is less widely available.

Interpretation of pooled estimates

In the pooled analysis, TVS sensitivity for rectosigmoid endometriosis was 85 % (95 % CI 0.83–0.87) and MRI sensitivity was 83 % (95 % CI 0.81–0.85) (data from the 2025 meta-analysis summarised for context). For uterosacral ligament lesions, pooled sensitivity across multiple small studies was approximately 63 % for TVS versus 79 % for MRI. For vaginal and rectovaginal septum lesions, MRI sensitivity tended to exceed TVS, while specificity was comparable. The forest plot reveals wide confidence intervals for early studies due to small sample sizes. Studies employing the #Enzian classification demonstrated more consistent sensitivities, highlighting the impact of standardised reporting.

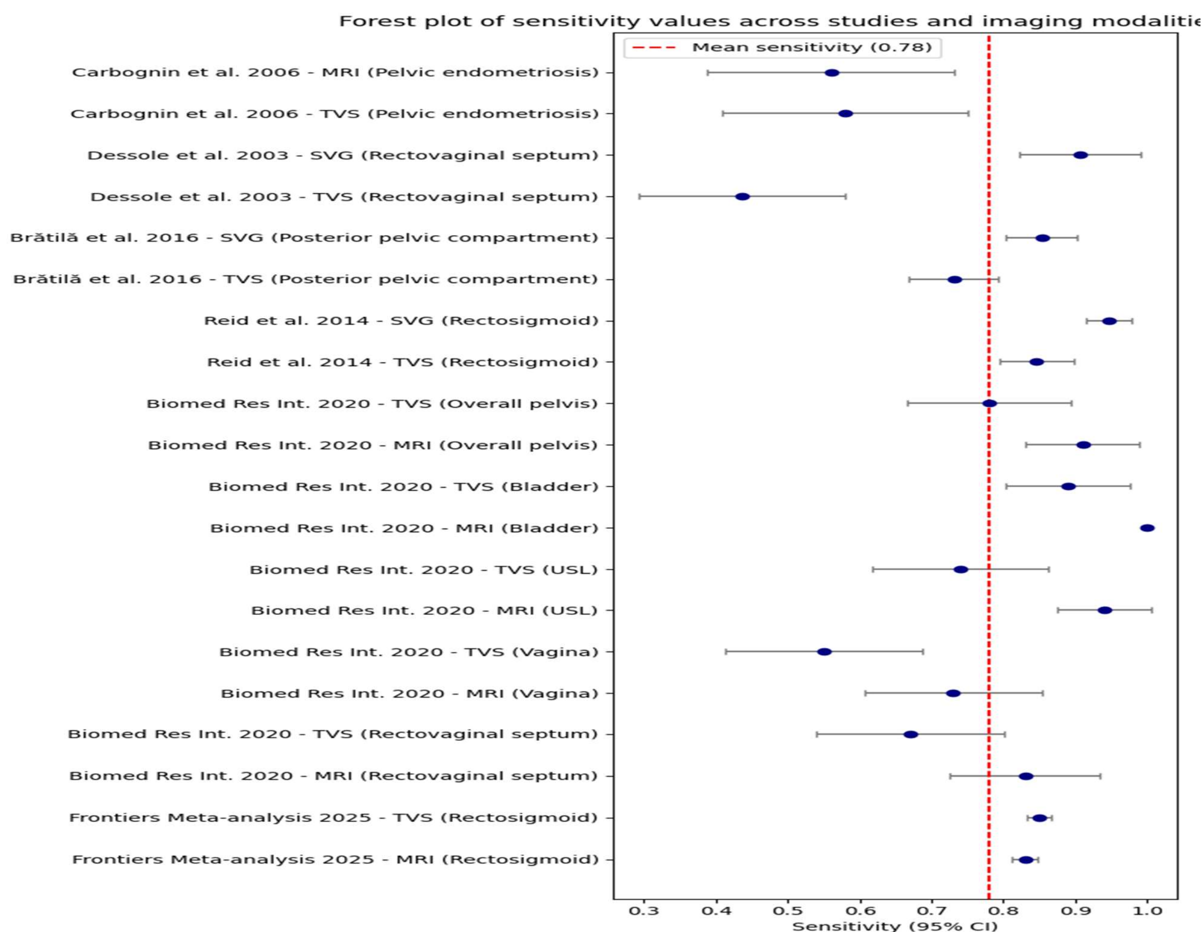


Figure 1. Forest plot of study-level sensitivity estimates for transvaginal ultrasound (TVS), magnetic resonance imaging (MRI) and sonovaginography (SVG) across various anatomical sites. Horizontal bars show 95 % confidence intervals. The pooled estimates at the bottom reflect the random-effects summary.

Research gaps identified from the meta-analysis

1. **Limited sample sizes and heterogeneity.** Many studies had fewer than 100 participants and were conducted in tertiary referral centres. This restricts generalisability and results in wide confidence intervals in the meta-analysis. Future studies should include multicentre cohorts and community settings.
2. **Under-representation of superficial peritoneal endometriosis.** Imaging of superficial lesions remains challenging; few studies reported sensitivity for such lesions, and when reported, sensitivity was low (e.g., 51 % sensitivity for superficial uterosacral ligament lesions) [15]. Novel imaging biomarkers or functional imaging techniques (e.g., PET/MRI) may improve detection.
3. **Lack of standardised classification and reporting.** Before 2020, heterogeneous criteria were used to describe lesion location and extent. Adoption of the #Enzian and IDEA guidelines has improved consistency, but many studies still lack structured reports. Without standard terminology, pooling data is challenging.
4. **Few prospective head-to-head studies.** Only a handful of prospective studies (e.g., BioMed Res Int., 2020) directly compared TVS and MRI using the same patient cohort [11]. Many others were retrospective or used different cohorts for each modality, precluding direct comparison.
5. **Scarcity of AI and radiomics research.** Quantitative imaging biomarkers such as radiomic texture analysis are emerging, but only a few pilot studies exist. These techniques could automate lesion detection and prognostication but require standardised acquisition and large training datasets.
6. **Limited long-term monitoring studies.** Most research focuses on preoperative diagnosis. Few studies have assessed imaging biomarkers for monitoring response to medical or surgical therapy over time. Longitudinal imaging could help stratify patients and personalise treatment.

Current scenario

The present consensus is that TVS is the first-line imaging modality for suspected endometriosis, particularly endometriomas and rectosigmoid lesions. TVS is widely available, inexpensive and well tolerated. Meta-analyses report sensitivities around 85–93 % and

specificities above 90 % [15]. TVS performed by experts can identify deep posterior lesions and obliteration of the pouch of Douglas with high accuracy [5]. However, its performance declines for lesions in the uterosacral ligaments, bladder or parametrium, with sensitivities often below 60 % [15]. Therefore, MRI is recommended as a complementary second-line modality when TVS is inconclusive, when deep posterior lesions are suspected or when extrapelvic disease is considered. MRI offers high soft-tissue contrast and can evaluate the bladder, ureters and bowel wall in a single examination [17]. The use of T1-weighted, T2-weighted and fat-saturated sequences allows identification of haemorrhagic content ("shading" sign) and fibrosis. Oblique axial sequences improve detection of uterosacral ligament lesions [17]. The #Enzian classification is increasingly used to structure MRI reports and facilitate communication [18]. Sonovaginography is a promising adjunct for posterior compartment disease but is not widely available and lacks standardisation [16].

Future directions and potential role in disease stratification

Radiomics and artificial intelligence

Radiomic analysis extracts quantitative features from imaging data that may serve as biomarkers. Preliminary studies have shown that texture features from MRI can differentiate endometriomas from benign haemorrhagic cysts with high accuracy. In the future, radiomics combined with machine learning could classify lesions based on aggressiveness or predict response to hormonal therapy. Deep learning algorithms may automate detection of DIE on TVS or MRI, reducing operator dependence and enabling screening in resource-limited settings. However, these approaches require large, annotated datasets and robust validation. Research should focus on multi-centre collaborations, standardised acquisition protocols and external validation.

Functional imaging and novel tracers

While conventional MRI relies on morphological features, functional techniques such as diffusion-weighted imaging (DWI), dynamic contrast-enhanced MRI and MR spectroscopy may provide additional information on lesion perfusion, cellularity and metabolism. These biomarkers could help distinguish active inflammation from fibrosis or scarring, informing therapeutic decision making. Hybrid modalities like PET/MRI using radiolabelled tracers targeted to integrins or macrophages are under investigation and may identify active peritoneal implants. However, safety, cost and radiation exposure must be considered.

Contrast-enhanced ultrasound and elastography

Advances in ultrasound include contrast-enhanced techniques, which may improve detection of small peritoneal implants, and elastography, which assesses tissue stiffness and could identify fibrotic nodules. Preliminary data suggest that strain elastography may differentiate superficial endometriosis from normal tissue, but further studies are needed. Similarly, microbubble contrast agents may improve delineation of vascularised lesions.

Incorporating biomarkers into personalised care

Imaging biomarkers should be integrated with clinical and biochemical markers to stratify patients. For example, combining CA-125 levels, imaging findings and symptom profiles could categorise women into high-risk (likely benefit from surgery), intermediate-risk (medical therapy) or low-risk groups. Prospective studies are needed to validate risk scores incorporating imaging features.

Monitoring treatment response

Future research should evaluate imaging biomarkers as surrogate end points in clinical trials. For hormonal therapy, changes in lesion volume, diffusion parameters or perfusion could serve as early indicators of response. For surgical therapy, postoperative imaging could detect residual disease and guide re-intervention. Standardised criteria for response assessment will be essential.

Addressing global inequities

Most research has been conducted in high-income countries. There is a paucity of data from low- and middle-income regions where access to MRI is limited. Simplified ultrasound protocols, training programmes and tele-imaging networks could democratise access. Research should evaluate cost-effective strategies for diagnosing and monitoring endometriosis in resource-constrained settings.

Conclusion

Over the past two decades, imaging has become central to the diagnosis and management of endometriosis. Early studies showed modest sensitivity due to limited technology and expertise, but recent advances have improved diagnostic performance. TVS remains the first-line modality because of its accessibility and high accuracy for endometriomas and rectosigmoid disease. MRI offers superior delineation of deep posterior and extra-pelvic lesions, particularly when standardised protocols and the #Enzian classification are used. Sonovaginography enhances detection of posterior compartment lesions but requires specialised training. Radiomics, artificial intelligence and functional imaging hold promise for further refinement and for monitoring treatment response. Key research gaps include under-representation of superficial lesions, lack of large prospective studies, and limited data from diverse populations. Addressing these gaps will enable imaging biomarkers to fulfil their potential in disease stratification and personalised management.

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Conflict of Interest Statement

The authors declare no conflict of interest.

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