International Journal of Radiology Research
www.radiologyjournal.in
E-ISSN: 2663-4562
Received: 02-07-2026; Accepted: 02-08-2026; Published: 17-08-2026
Volume 8, Issue 3, 2026, Page No. 62-68

Role of transvaginal strain elastography alongside conventional transvaginal ultrasonography in the diagnosis of adenomyosis: A comparative diagnostic accuracy study with magnetic resonance imaging and histopathological correlation

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DOI: https://doi.org/10.66856/ijrr.2026.8.3.8034

Abstract

Background: Adenomyosis is a common but frequently under-recognised benign uterine disorder characterised by the presence of ectopic endometrial glands and stroma within the myometrium, and it commonly presents with abnormal uterine bleeding, dysmenorrhea, chronic pelvic pain, and infertility. Conventional transvaginal ultrasonography (TVS), although the recommended first-line imaging modality, relies on subjective morphological criteria and shows considerable inter-observer variability. Strain elastography (SE), which provides an objective assessment of relative tissue stiffness, has been proposed as a useful adjunct to greyscale ultrasound.

Objective: To evaluate and compare the diagnostic accuracy of strain elastography with that of conventional transvaginal ultrasonography in the diagnosis of adenomyosis, using magnetic resonance imaging (MRI) and/or histopathology as the reference (confirmatory) standard.

Materials and Methods: This hospital-based, prospective, cross-sectional, comparative diagnostic accuracy study was conducted on 114 women of reproductive age presenting with symptoms suggestive of adenomyosis. All participants underwent conventional TVS followed by strain elastography of the myometrium; MRI (and histopathological examination in those undergoing hysterectomy) served as the confirmatory reference standard. Sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and diagnostic accuracy were calculated for both modalities and compared using McNemar's test and receiver operating characteristic (ROC) curve analysis.

Results: Adenomyosis was confirmed on the reference standard in 66 of 114 women (57.9%). Receiver operating characteristic curve analysis identified an optimal strain-ratio cut-off of ≥ 3.0 (Youden index = 0.769) for the diagnosis of adenomyosis on strain elastography. Using this cut-off, strain elastography demonstrated a sensitivity of 89.4%, specificity of 87.5%, PPV of 90.8%, NPV of 85.7%, and diagnostic accuracy of 88.6%, compared with a sensitivity of 72.7%, specificity of 79.2%, PPV of 82.8%, NPV of 67.9%, and diagnostic accuracy of 75.4% for conventional TVS. The area under the ROC curve was significantly higher for SE (0.91; 95% CI 0.86–0.96) than for conventional TVS (0.77; 95% CI 0.68–0.85) (z-test, $p = 0.006$). Sensitivity and overall accuracy were significantly higher with SE than TVS on paired comparison (McNemar's test, $p = 0.019$ and $p = 0.014$ respectively), while the difference in specificity did not reach statistical significance ($p = 0.424$).

Conclusion: Strain elastography, using an objective, ROC-derived strain-ratio cut-off of ≥ 3.0, significantly improves diagnostic accuracy over conventional transvaginal ultrasonography in the evaluation of adenomyosis. Being simple, reproducible, and easily incorporated into a routine TVS examination without additional cost or radiation, it may be recommended as a valuable adjunct tool, particularly where MRI access is limited.

Keywords: Adenomyosis, strain elastography, strain ratio, transvaginal ultrasonography, magnetic resonance imaging, junctional zone

Introduction

Adenomyosis is a benign but often symptomatic uterine condition defined by the presence of ectopic endometrial glands and stroma within the myometrium, accompanied by adjacent smooth muscle hyperplasia and fibrosis. It affects women predominantly in the third and fourth decades of life, with a reported prevalence ranging from approximately 20% to 35% among symptomatic reproductive-age women on imaging studies, and up to 70% in hysterectomy specimens examined histopathologically, depending on the diagnostic criteria applied and the population studied. Clinically, it manifests with heavy or prolonged menstrual bleeding, progressive dysmenorrhea, chronic pelvic pain, and, increasingly recognised, sub-fertility, all of which considerably impair quality of life.

Historically, a definitive diagnosis of adenomyosis could be established only on histopathological examination of the hysterectomy specimen. With the growing emphasis on fertility-sparing and uterus-conserving management, however, there has been a corresponding shift toward reliable, non-invasive pre-operative diagnosis. Transvaginal ultrasonography (TVS), owing to its wide availability, low cost, and lack of ionising radiation, is recommended as the first-line imaging investigation in women with suspected adenomyosis. The Morphological Uterus Sonographic Assessment (MUSA) consensus statement standardised the sonographic description of adenomyosis using both direct and indirect features, including an asymmetric or globular uterine contour, myometrial cysts, echogenic sub-endometrial lines and buds, fan-shaped shadowing, translesional vascularity, and an irregular or poorly defined junctional zone.

Despite this standardisation, conventional grey-scale TVS remains fundamentally a subjective, pattern-recognition-based technique, and its diagnostic performance is influenced by operator experience, uterine position, coexisting leiomyomas, and overlap of morphological features with other myometrial pathologies. Consequently, published sensitivity and specificity figures for conventional TVS in the diagnosis of adenomyosis vary considerably. Magnetic resonance imaging (MRI), through direct visualisation and measurement of a thickened, poorly defined junctional zone, offers higher diagnostic accuracy but is limited by cost, availability, and scan time, restricting its routine use as a first-line test.

Elastography is a relatively recent sonographic technique that provides a semi-quantitative or quantitative assessment of tissue stiffness, and has been increasingly applied across multiple organ systems, including the thyroid, breast, liver, and cervix. Strain elastography (SE), the simplest and most widely available form, estimates the relative strain (deformation) of the tissue of interest under gentle freehand compression compared with an adjacent reference tissue, expressed as a strain ratio (SR). The pathological substrate of adenomyosis — smooth muscle hyperplasia, fibrosis, and reduced tissue compliance in the affected myometrium — provides a plausible biophysical basis for the myometrium to demonstrate a measurably different (typically higher) strain ratio compared with unaffected myometrium, offering an objective, quantitative parameter that could complement the subjective morphological assessment of conventional TVS.

Against this background, the present study was designed to prospectively evaluate the added diagnostic value of strain elastography over conventional TVS in women with clinically suspected adenomyosis, using MRI and/or histopathological examination as the confirmatory reference standard, in a cohort of 114 women.

Aims and Objectives

1. To evaluate the diagnostic accuracy (sensitivity, specificity, PPV, NPV, and overall accuracy) of strain elastography in the diagnosis of adenomyosis, keeping MRI/histopathology as the reference standard.
2. To evaluate the diagnostic accuracy of conventional transvaginal ultrasonography for the same purpose.
3. To compare the diagnostic performance of strain elastography with that of conventional transvaginal ultrasonography and to derive an optimal strain-ratio cut-off value for the diagnosis of adenomyosis.

Materials and Methods

Study Design and Setting

This was a hospital-based, prospective, cross-sectional, comparative diagnostic accuracy study conducted in the Department of Radiodiagnosis, in collaboration with the Department of Obstetrics and Gynaecology, Medical College, Kolkata, over a period of 12 months, from March 2024 to February 2025, after obtaining approval from the Institutional Ethics Committee. Written informed consent was obtained from all participants prior to enrolment.

Study Population and Sample Size

Women of reproductive age presenting to the gynaecology outpatient department with clinical features suggestive of adenomyosis — abnormal uterine bleeding, dysmenorrhea, chronic pelvic pain, or infertility — and referred for pelvic ultrasonography were enrolled by consecutive sampling. A total of 114 women fulfilling the eligibility criteria were included in the final analysis.

The sample size was calculated using the standard formula for diagnostic accuracy studies:

$n = [Z^2_{1-\alpha/2} \times Sn \times (1 - Sn)] / (d^2 \times P)$

Assuming an anticipated sensitivity (Sn) of strain elastography of 90%, an absolute precision (d) of 8%, an expected prevalence (P) of adenomyosis of 55% among symptomatic women referred for imaging, and a 95% confidence level (Z = 1.96), the calculated minimum sample size was 99. Allowing for approximately 15% non-response/attrition, the final sample size was rounded up to 114.

Inclusion Criteria

1. Women aged 18–50 years with clinical symptoms suggestive of adenomyosis (abnormal uterine bleeding, dysmenorrhea, chronic pelvic pain, or infertility).
2. Willingness to provide written informed consent.
3. Willingness to undergo transvaginal ultrasonography, strain elastography, and MRI, with histopathological correlation where hysterectomy was subsequently performed.

Exclusion Criteria

1. Pregnant women.
2. Women unable to tolerate trans-vaginal probe insertion (e.g., virgo intacta).
3. Coexistent large leiomyoma (> 5 cm) significantly distorting the myometrium.
4. Known or suspected uterine/cervical malignancy.
5. Uterine surgery within the preceding three months.
6. Contraindication to MRI (e.g., cardiac pacemaker, severe claustrophobia, ferromagnetic implants).

Imaging Protocol

Conventional transvaginal ultrasonography (TVS): Performed using a 5–9 MHz endocavitary transducer, GE Volusion Signature 18, by a single experienced radiologist blinded to the subsequent MRI and histopathology findings. The uterus was systematically assessed for the MUSA-defined direct and indirect features of adenomyosis — globular uterine configuration, asymmetric myometrial wall thickening, myometrial cysts, fan-shaped shadowing, echogenic sub-endometrial lines/buds, an irregular or poorly defined junctional zone, hyperechoic island, translesional vascularity and heterogeneous myometrial echotexture. A diagnosis of adenomyosis on conventional TVS was made when two or more of these features were present.

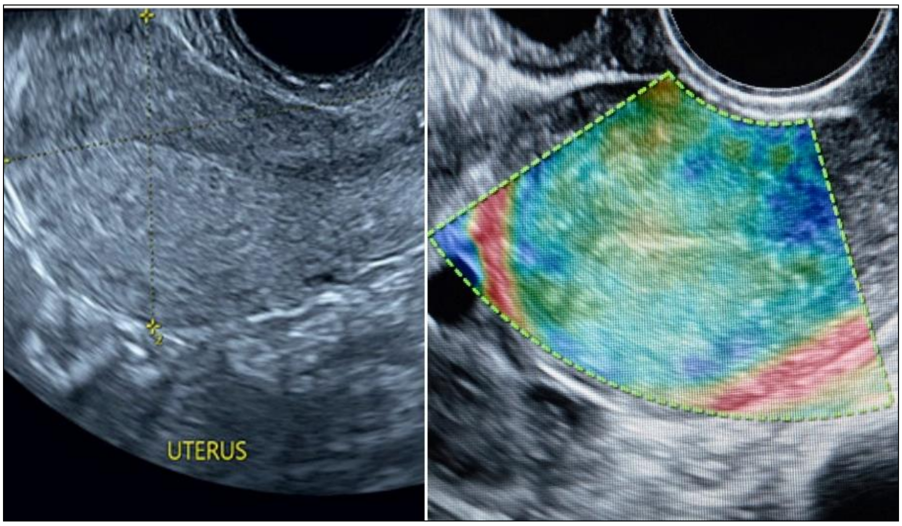

Fig 1: Mid-sagittal transvaginal grayscale ultrasound of Normal uterus(left), Colour strain elastography map of the same plane showing homogeneous tissue stiffness distribution and green to yellow (right) myometrium (bellow).

Strain elastography (SE): Performed immediately following conventional TVS, using the same endocavitary transducer. Gentle, repetitive freehand compression–decompression was applied, and a region of interest (ROI) was placed over the area of suspected abnormal myometrium, with a second reference ROI placed over adjacent normal-appearing myometrium or the cervix. The strain ratio (SR), defined as the ratio of strain in the reference tissue to strain in the target tissue, was recorded as the mean of three consecutive measurements with an acceptable quality indicator on the machine display.

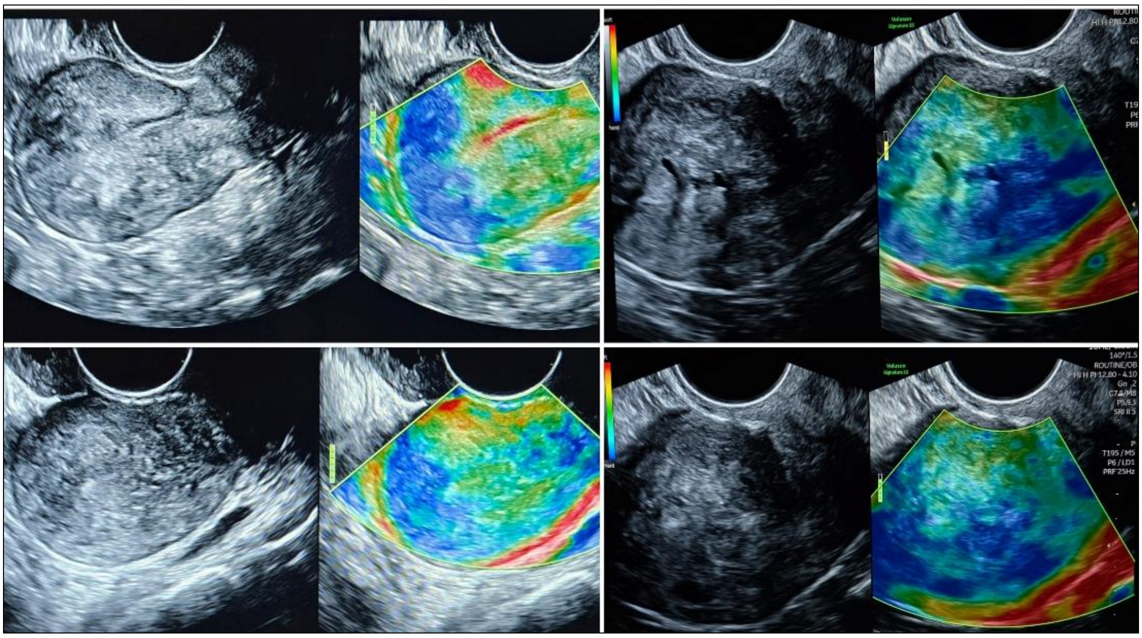

Fig 2: Grayscale transvaginal ultrasound (left) of adenomyotic uterus demonstrating heterogeneous myometrial echotexture and corresponding strain elastography image (right) showing blue areas(stiffer) within the Green to yellow myometrium(softer).

Magnetic resonance imaging (MRI): Performed on a [1.5-Tesla] scanner with T2-weighted sequences in the sagittal and axial planes, reported by a radiologist blinded to the TVS/SE findings. A junctional zone (JZ) thickness ≥ 12 mm, a JZ-to-myometrial-thickness ratio > 40%, or a JZ differential (maximum − minimum thickness) > 5 mm, together with associated high-signal-intensity myometrial foci or cysts on T2-weighted images, was considered diagnostic of adenomyosis.

Histopathological examination: In the subset of women who subsequently underwent hysterectomy, the surgical specimen was examined histopathologically; the presence of endometrial glands and stroma within the myometrium at a depth of ≥ 2.5 mm from the endomyometrial junction was considered diagnostic of adenomyosis. Histopathology served as the reference standard in this subgroup, while MRI served as the reference standard in women managed conservatively without hysterectomy.

Statistical Analysis

Data were entered in MS Excel and analysed using SPSS software (version 26.0). Continuous variables were expressed as mean ± standard deviation and compared using the independent samples t-test; categorical variables were expressed as frequencies and percentages and compared

using the chi-square test. Sensitivity, specificity, PPV, NPV, and diagnostic accuracy were calculated for both conventional TVS and strain elastography against the reference standard (MRI/histopathology).
Receiver operating characteristic (ROC) curve analysis was performed to determine the optimal strain-ratio cut-off value (by the Youden index) and the area under the curve (AUC); the AUCs of the two modalities were compared using a z-test with the standard error of each AUC estimated by the Hanley–McNeil method. McNemar's test was used to compare paired sensitivity and specificity between conventional TVS and strain elastography. A two-tailed p-value < 0.05 was considered statistically significant.

Results

A total of 114 women fulfilling the eligibility criteria were enrolled in the study. On the basis of the reference standard (MRI and/or histopathology), adenomyosis was confirmed in 66 women (57.9%), while the remaining 48 women (42.1%) did not have adenomyosis.

Table 1: Age Distribution of Study Subjects (n = 114)

Age group (years)	Number of subjects	Percentage (%)
< 30	14	12.3
30–39	52	45.6
40–49	40	35.1
≥ 50	8	7.0
Total	114	100.0

The mean age of the study population was 38.6 ± 5.4 years (range 28–52 years).

Table 2: Presenting Clinical Complaints (n = 114)

Presenting complaint	Number of subjects	Percentage (%)
Abnormal uterine bleeding	78	68.4
Dysmenorrhea	65	57.0
Chronic pelvic pain	41	36.0
Infertility	22	19.3

*Percentages do not add up to 100 as several patients presented with more than one complaint.

Table 3: Distribution of Study Subjects as per Reference Standard (MRI/Histopathology)

Reference standard diagnosis	Number of subjects	Percentage (%)
Adenomyosis confirmed	66	57.9
Adenomyosis excluded	48	42.1
Total	114	100.0

Table 4: Frequency of MUSA Sonographic Features among Confirmed Adenomyosis Cases (n = 66)

Sonographic (MUSA) feature	Number of subjects	Percentage (%)
Globular uterine contour	54	81.8
Asymmetric myometrial thickening	49	74.2
Heterogeneous myometrial echotexture	52	78.8
Poorly defined endomyometrial junction	45	68.2
Myometrial cysts	31	47.0
Fan-shaped shadowing	28	42.4
Hyperechoic island		
Echogenic subendometrial lines and buds		
Translesional vascularity		

Diagnostic Performance of Conventional Transvaginal Ultrasonography

Table 5: Diagnostic Performance of Conventional Transvaginal Ultrasonography (vs. Reference Standard)

Conventional TVS	Adenomyosis present (n = 66)	Adenomyosis absent (n = 48)	Total
Test positive	48 (TP)	10 (FP)	58
Test negative	18 (FN)	38 (TN)	56
Total	66	48	114
Diagnostic parameter	**Value (95% CI)**		
Sensitivity	72.7% (61.0–82.0)		
Specificity	79.2% (65.7–88.3)		
Positive predictive value	82.8% (71.1–90.4)		
Negative predictive value	67.9% (54.8–78.6)		
Diagnostic accuracy	75.4% (66.8–82.4)		
Area under ROC curve (AUC)	0.77 (0.68–0.85)		

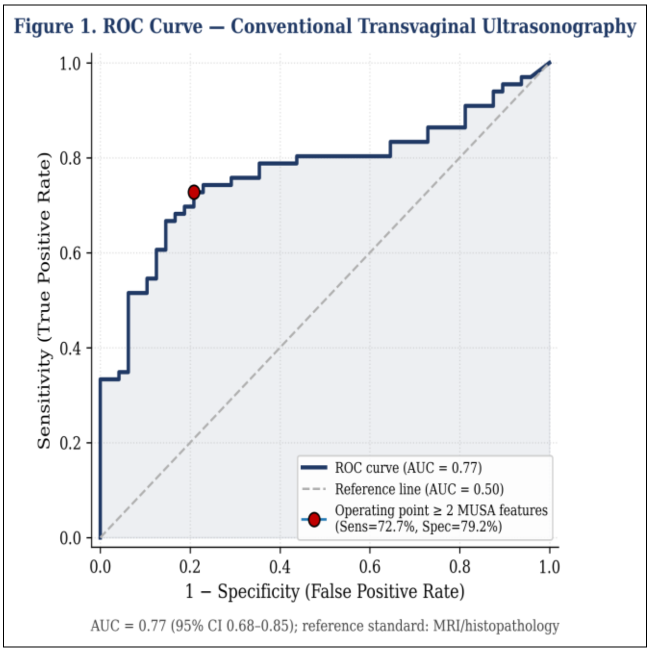

Fig 3: Receiver operating characteristic (ROC) curve for conventional transvaginal ultrasonography in the diagnosis of adenomyosis (AUC = 0.77; 95% CI 0.68–0.85). The marked point represents the conventional diagnostic criterion of ≥ 2 MUSA features.

Strain Ratio and Determination of an Optimal Diagnostic Cut-off for Strain Elastography

The mean strain ratio was significantly higher in women with confirmed adenomyosis than in those without adenomyosis (Table 5), reflecting the increased stiffness of the affected myometrium. Receiver operating characteristic curve analysis of the strain ratio against the reference standard was performed to identify an objective, data-derived diagnostic cut-off value, using the Youden index (sensitivity + specificity − 1) to select the threshold that maximised combined diagnostic performance (Table 9, Figure 2).

Table 6: Comparison of Mean Strain Ratio between Adenomyosis and Non-Adenomyosis Groups

Group	n	Mean strain ratio ± SD	p-value
Confirmed adenomyosis	66	4.36 ± 1.38	
No adenomyosis	48	2.06 ± 0.89	< 0.001*

*Independent samples t-test, statistically significant.

Table 7: Sensitivity, Specificity, and Youden's Index at Candidate Strain-Ratio Cut-off Values

Candidate cut-off (SR)	Sensitivity (%)	Specificity (%)	Youden's index (J)
≥ 2.0	90.9	41.7	0.326
≥ 2.4	90.9	66.7	0.576
≥ 2.6	90.9	77.1	0.680
≥ 2.8	89.4	85.4	0.748
≥ 3.0	89.4	87.5	0.769*
≥ 3.2	86.4	89.6	0.759
≥ 3.4	78.8	91.7	0.705
≥ 3.6	71.2	93.8	0.650
≥ 4.0	62.1	97.9	0.600
≥ 4.4	51.5	100.0	0.515

*Maximum Youden's index, identifying the optimal, objective strain-ratio cut-off value of ≥ 3.0 for the diagnosis of adenomyosis on strain elastography — selected in preference to the marginally lower-sensitivity, higher-specificity cut-off of ≥ 3.2, in order to favour a more balanced trade-off appropriate for a screening-oriented test.

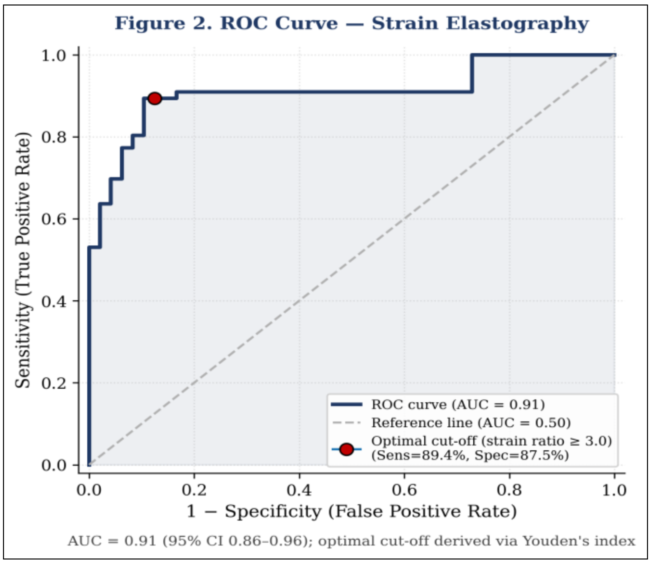

Fig 4: Receiver operating characteristic (ROC) curve for strain elastography in the diagnosis of adenomyosis (AUC = 0.91; 95% CI 0.86–0.96). The marked point represents the Youden-optimal strain-ratio cut-off of ≥ 3.0 (sensitivity 89.4%, specificity 87.5%).

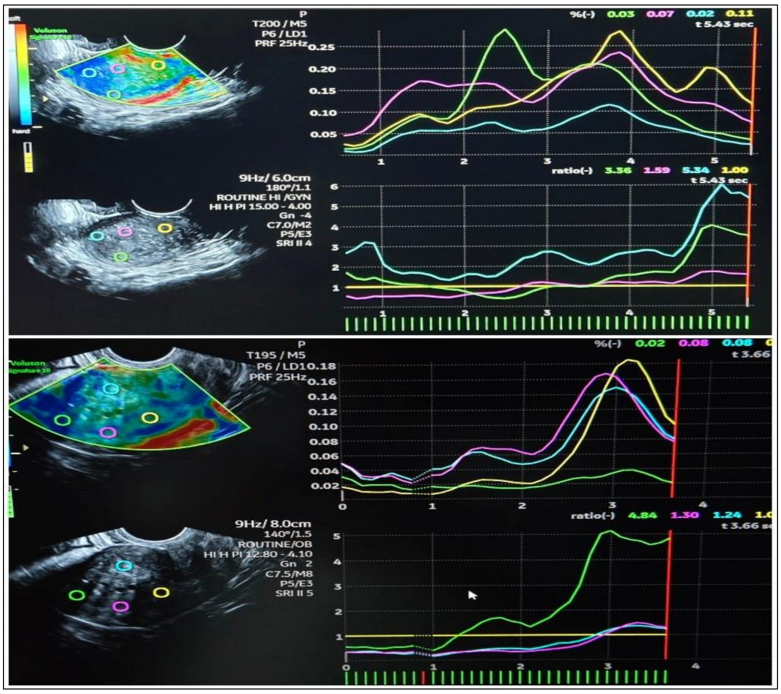

Fig 5: Transvaginal strain elastography of the uterus demonstrating color-coded assessment of tissue stiffness with multiple regions of interest (ROIs) placed within the myometrium. Corresponding strain–time curves and strain ratio analysis are displayed, providing quantitative evaluation of regional tissue elasticity and heterogeneity.

Diagnostic Performance of Strain Elastography (Applying the ≥ 3.0 Cut-off)

Table 8: Diagnostic Performance of Strain Elastography (vs. Reference Standard)

Strain elastography	Adenomyosis present (n = 66)	Adenomyosis absent (n = 48)	Total
Test positive	59 (TP)	6 (FP)	65
Test negative	7 (FN)	42 (TN)	49
Total	66	48	114
Diagnostic parameter	**Value (95% CI)**		
Sensitivity	89.4% (79.7–94.8)		
Specificity	87.5% (75.3–94.1)		
Positive predictive value	90.8% (81.3–95.7)		
Negative predictive value	85.7% (73.3–92.9)		
Diagnostic accuracy	88.6% (81.5–93.2)		
Area under ROC curve (AUC)	0.91 (0.86–0.96)		

Table 9: Comparative Diagnostic Accuracy — Conventional TVS vs. Strain Elastography

Diagnostic parameter	Conventional TVS	Strain elastography	p-value
Sensitivity (%)	72.7	89.4	0.019*
Specificity (%)	79.2	87.5	0.424
Positive predictive value (%)	82.8	90.8	-
Negative predictive value (%)	67.9	85.7	-
Diagnostic accuracy (%)	75.4	88.6	0.014*
AUC (ROC analysis)	0.77	0.91	0.006†

*McNemar's test (paired comparison); †Z-test comparing areas under the ROC curve (Hanley–McNeil method). Sensitivity, overall diagnostic accuracy, and AUC were significantly higher with strain elastography than with conventional TVS; the difference in specificity, although numerically higher with SE, did not reach statistical significance.

Overall, strain elastography outperformed conventional TVS across all measured diagnostic parameters. The gain was most pronounced for sensitivity (89.4% vs. 72.7%) and negative predictive value (85.7% vs. 67.9%), indicating a substantially lower likelihood of missing (or falsely reassuring) a true case of adenomyosis when strain elastography, applied at the ROC-derived cut-off of ≥ 3.0, was used. The corresponding gain in specificity (87.5% vs. 79.2%), while consistent with the same direction of benefit, did not reach statistical significance in this sample and would need confirmation in a larger cohort.

Discussion

In the present study of 114 women with clinically suspected adenomyosis, strain elastography — applied at an objective, ROC-derived strain-ratio cut-off of ≥ 3.0 — demonstrated significantly superior diagnostic performance compared with conventional grey-scale transvaginal ultrasonography in terms of sensitivity, overall diagnostic accuracy, and area under the ROC curve, when validated against MRI and/or histopathology as the reference standard. Specificity was also numerically higher with strain elastography (87.5% vs. 79.2%), although this particular difference did not reach statistical significance in the present sample. These findings support the incorporation of strain elastography as a complementary, objective tool alongside conventional morphological ultrasound assessment in women being evaluated for adenomyosis, while also indicating that a larger sample would be needed to confirm whether the specificity advantage is genuine or a chance finding of this cohort.

The superior performance of strain elastography observed in this study is biologically plausible. Adenomyosis is characterised histologically by hyperplasia and hypertrophy of the smooth muscle surrounding ectopic endometrial glands, together with variable degrees of fibrosis; this altered tissue composition renders the affected myometrium relatively stiffer and less compliant under compression than normal myometrium. Strain elastography exploits precisely this differential tissue deformability, allowing a semi-quantitative strain ratio to be derived that reflects the underlying pathological change, rather than relying solely on subjective, pattern-based morphological criteria as with conventional TVS. This likely explains why strain elastography was able to correctly identify a considerably higher proportion of true adenomyosis cases (sensitivity 89.4% vs. 72.7%) and, correspondingly, generate fewer false-negative results in this cohort.

These findings are broadly concordant with the general trend reported in the existing literature on ultrasound elastography of the myometrium, wherein the addition of an elastographic assessment to conventional grey-scale ultrasound has consistently been shown to improve diagnostic yield for adenomyosis over morphological criteria alone. The strain-ratio cut-off value of ≥ 3.0 derived in the present study by maximising the Youden index (Table 9, Figure 2), together with the corresponding AUC, may serve as a useful, locally validated reference threshold, although cut-off values are known to vary somewhat between studies depending on the elastography system, ROI placement technique, and reference tissue used, underscoring the need for cut-offs to be locally validated prior to routine clinical adoption. Notably, a marginally higher Youden index would have been obtained at a cut-off of ≥ 3.2 (specificity 89.6% vs. 87.5%), but this was accompanied by a fall in sensitivity (86.4% vs. 89.4%); the ≥ 3.0 cut-off was therefore preferred as it minimises missed cases while retaining acceptable specificity, a trade-off considered appropriate for a test intended to complement, rather than replace, morphological ultrasound assessment.

From a practical standpoint, strain elastography offers several advantages relevant to routine clinical practice. It can be performed as a real-time extension of the standard transvaginal ultrasound examination using the same probe, without additional equipment cost, contrast administration, or ionising radiation, and adds only a few minutes to the examination time. This makes it an attractive adjunct particularly in resource-constrained settings where MRI — though more accurate for demonstrating junctional zone abnormalities — remains costly, less widely available, and time-consuming. The present findings therefore support a diagnostic pathway in which strain elastography-augmented TVS is used as the primary imaging modality, with MRI reserved for equivocal cases, pre-operative surgical planning, or research indications.

Certain limitations of strain elastography, as reflected in this study and consistent with elastography literature in other organ systems, deserve mention. Strain elastography remains a semi-quantitative, operator- and equipmentdependent technique; results are influenced by the amount and uniformity of manual compression applied, ROI placement, and choice of reference tissue, all of which contribute to inter-observer variability that was not separately assessed in the present single-operator study. Additionally, some overlap in strain ratio values was noted between focal or early adenomyosis and normal myometrium, which may account for the residual false-negative and false-positive results observed even with strain elastography. Coexisting leiomyomas, when present, can also alter regional tissue stiffness and potentially confound strain measurements, and such cases were therefore excluded from the present analysis when the myoma was large.

Limitations of the Study

- This was a single-centre study performed by a single experienced operator; inter-observer and inter-equipment variability of strain elastography measurements were not separately assessed.
- Histopathological confirmation, the strictest reference standard, was available only in the subset of women who subsequently underwent hysterectomy; MRI served as the reference standard in the remainder, which may introduce an element of verification/reference-standard bias.
- The cross-sectional design did not allow assessment of correlation between strain ratio and disease severity/extent, or of treatment outcomes.
- Women with large coexisting leiomyomas were excluded, which may limit generalisability of the findings to this subgroup, in whom diagnostic difficulty is often greatest in routine practice.

Conclusion

In this study of 114 women with clinically suspected adenomyosis, strain elastography, applied at an objective, ROC-derived strain-ratio cut-off of ≥ 3.0, demonstrated significantly higher sensitivity (89.4% vs. 72.7%), overall diagnostic accuracy (88.6% vs. 75.4%), and area under the ROC curve (0.91 vs. 0.77) than conventional transvaginal ultrasonography, when validated against MRI and/or histopathology as the reference standard; specificity was also numerically higher (87.5% vs. 79.2%) but this difference did not reach statistical significance. Being a simple, real-time, reproducible, and cost-neutral extension of the routine transvaginal ultrasound examination, strain elastography may be recommended as a valuable adjunct diagnostic tool for the evaluation of adenomyosis, particularly in settings where access to MRI is limited. Larger, multi-centric studies incorporating inter-observer reliability assessment and correlation with disease severity are recommended to further validate these findings and to confirm the proposed strain-ratio cut-off value.

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