Article

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Development of a 5-year Recurrence Risk Prediction Model After Conservative Surgery for Adenomyosis Based on Clinical and Imaging Features

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Background: Dysmenorrhea and menorrhagia are common consequences of adenomyosis. While conservative surgery can effectively preserve fertility in women with adenomyosis, they are still vulnerable to postoperative recurrence, for which a reliable long-term predictive tool is lacking. This study aimed to develop and validate a 5-year recurrence predictive model for adenomyosis patients after conservative surgery based on their clinical and imaging features.

Methods: In this retrospective study, 150 women aged 18–50 years who underwent uterus-preserving surgery for adenomyosis were analyzed. Clinical data, including imaging parameters, surgical characteristics, and postoperative management, were collected. Recurrence was defined as either a ≥3-point increase in Visual Analog Scale score for dysmenorrhea or a ≥50% increase in Pictorial Blood Assessment Chart score within five years. Multivariate Cox regression was used to construct a nomogram, with its predictive performance evaluated using concordance index (C-index), time-dependent receiver operating characteristic curves, calibration, and decision curve analysis (DCA).

Results: Four independent predictors were identified: older age, larger uterine volume, shorter duration of postoperative hormonal therapy, and concomitant endometriosis. The nomogram demonstrated good discriminative ability (C-index 0.766; AUCs 0.68, 0.73, 0.76 at 15, 24, and 48 months, respectively), along with reliable calibration and evident clinical net benefit. Kaplan–Meier analysis revealed that the nomogram effectively distinguished risk groups, with five-year recurrence-free survival rates of 78% in the low-risk group and 17% in the high-risk group.

Conclusion: By integrating clinical and imaging variables, the nomogram developed in this study demonstrates strong clinical applicability, accurately predicting recurrence risk in adenomyosis patients after conservative surgery and guiding personalized postoperative management.

Keywords: adenomyosis; conservative surgery; recurrence; nomogram; risk prediction

Introduction

Adenomyosis is a common gynecological disorder characterized by the presence of ectopic endometrial glands and stroma within the myometrium, leading to progressive uterine enlargement, chronic pelvic pain, dysmenorrhea, and menorrhagia [1,2]. The condition affects up to 20–30% of women of reproductive age, imposing a substantial clinical and social burden due to impaired quality of life, infertility, and the need for repeated interventions [3]. Although hysterectomy remains the definitive treatment, most patients of childbearing age who wish to preserve fertility and maintain uterine integrity opt for conservative surgical approaches [4].

Conservative surgery is an important uterus-sparing treatment option for adenomyosis, effectively relieving pain and menorrhagia while preserving fertility in patients of reproductive age [4]. However, symptomatic recurrence remains a major clinical challenge in patients receiving surgical intervention, with approximately one-third of the patients experiencing symptom relapse within five years, depending on surgical technique, disease extent, and postoperative management [5,6]. Identifying patients at higher risk of recurrence is therefore essential to optimize postoperative hormonal therapy and follow-up strategies.

Previous studies have explored the predictive value of various clinical and surgical factors for adenomyosis recurrence, such as age, parity, coexistence of endometriosis, extent of excision, and duration of postoperative hormonal suppressive therapy [7,8]. In recent years, a growing body of studies have increasingly established imaging-derived parameters, including junctional zone (JZ) thickness, uterine volume, and adenomyosis phenotype, as objective in-

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dicators of disease burden and myometrial involvement [9,10]. Nevertheless, most of these studies are limited by small sample sizes, heterogeneous inclusion criteria, relatively short follow-up durations, and inconsistent incorporation of imaging indicators, thereby diminishing the clinical applicability of the identified factors [11,12].

Currently, there is no long-term predictive model that incorporates imaging variables to assess postoperative recurrence in adenomyosis patients following conservative surgery. Therefore, the present study aimed to develop and internally validate a 5-year recurrence predictive model that combines clinical and imaging features, including JZ thickness, uterine volume, and adenomyosis phenotype, together with key clinical parameters such as age, coexistence of endometriosis, and postoperative hormonal suppressive therapy duration. This model is expected to provide a practical tool for personalized postoperative risk assessment and management.

Methods

Study Design and Setting

This study was designed as a retrospective cohort analysis conducted at The Fourth Affiliated Hospital of Soochow University (Suzhou Dushu Lake Hospital), a tertiary referral center specializing in gynecological surgery. A total of 150 patients diagnosed with adenomyosis who underwent conservative surgical treatment between February 2018 and February 2023 were screened for eligibility. The study period was defined to guarantee a minimum follow-up of 12 months for all patients by the database lock, with a subset of patients followed for up to five years. All relevant clinical, surgical, imaging, and follow-up data were extracted from the institutional electronic medical record system and imaging archives.

Study Population

Participants were women aged 18–50 years who had a confirmed diagnosis of adenomyosis. The diagnosis was established on the basis of either clinical manifestations combined with imaging findings according to the Morphological Uterus Sonographic Assessment (MUSA) criteria or magnetic resonance imaging (MRI), or histopathological evidence when available [13,14]. Both diffuse and focal types of adenomyosis were included. Eligible patients underwent conservative uterus-preserving surgery without hysterectomy, including focal adenomyotic lesion excision or uterine reconstructive repair. Furthermore, only those with standardized postoperative follow-up records from outpatient visits or structured telephone interviews, and with sufficient documentation of symptom changes for at least 12 months, were included in the analysis.

Patients were excluded if they had a prior hysterectomy or underwent hysterectomy during index admission. Additional exclusion criteria include: (1) diagnosis of malignancy or severe systemic disease during follow-up; (2) missing data exceeding 40% in any of the key variables, including age, body mass index (BMI), coexistence of endometriosis, JZ thickness, uterine volume, adenomyosis phenotype, and duration of postoperative hormonal suppressive therapy; and (3) the need for re-intervention within three months after conservative surgery for reasons other than perioperative complications, such as suspected residual adenomyotic lesions confirmed by imaging, uncontrolled symptoms unresponsive to early medical therapy, or newly developed severe uterine bleeding unrelated to surgical complications.

Data Collection and Variables

Data were extracted from the institutional electronic medical record system, operative notes, imaging archives, and follow-up records. Variables were selected for analysis based on their clinical significance, previously reported associations with adenomyosis recurrence, and availability within the dataset. Clinical variables (e.g., age, BMI, reproductive history [pregnancy and parity], concomitant endometriosis, and postoperative hormonal therapy duration) were chosen because they have been widely reported to influence disease recurrence or response to treatment. Imaging variables, including JZ thickness, uterine volume, and adenomyosis phenotype, were incorporated as objective indicators of disease burden and myometrial involvement according to published imaging studies [5,9]. All imaging assessments were independently performed by two experienced radiologists, and discrepancies were resolved by a third reviewer to ensure consistency.

Surgical variables included the extent of lesion excision (categorized as localized or extensive), the number of myometrial repair layers, and the method of hemostasis (categorized as suture, energy-based, or combined techniques). Data on postoperative management encompassed the type of hormonal suppressive therapy, such as gonadotropin-releasing hormone agonists, dienogest, levonorgestrel-releasing intrauterine system, or combined oral contraceptives, as well as the total duration of treatment in months.

Outcome Definition

The primary outcome of this study was symptom recurrence within five years after conservative surgery for adenomyosis. Recurrence was defined using standardized clinical criteria. Dysmenorrhea severity was assessed using the Visual Analogue Scale (VAS), a validated and widely used scoring system for pain intensity [15]. Menstrual blood loss was quantified using the Pictorial Blood Assessment Chart (PBAC), originally developed for objective estimation of menstrual blood volume [16]. Recurrence was defined as an increase of $\geq$3 points in VAS score or $\geq$50% increase in PBAC score from the patient's lowest postoperative score during follow-up. Time to recurrence was cal-

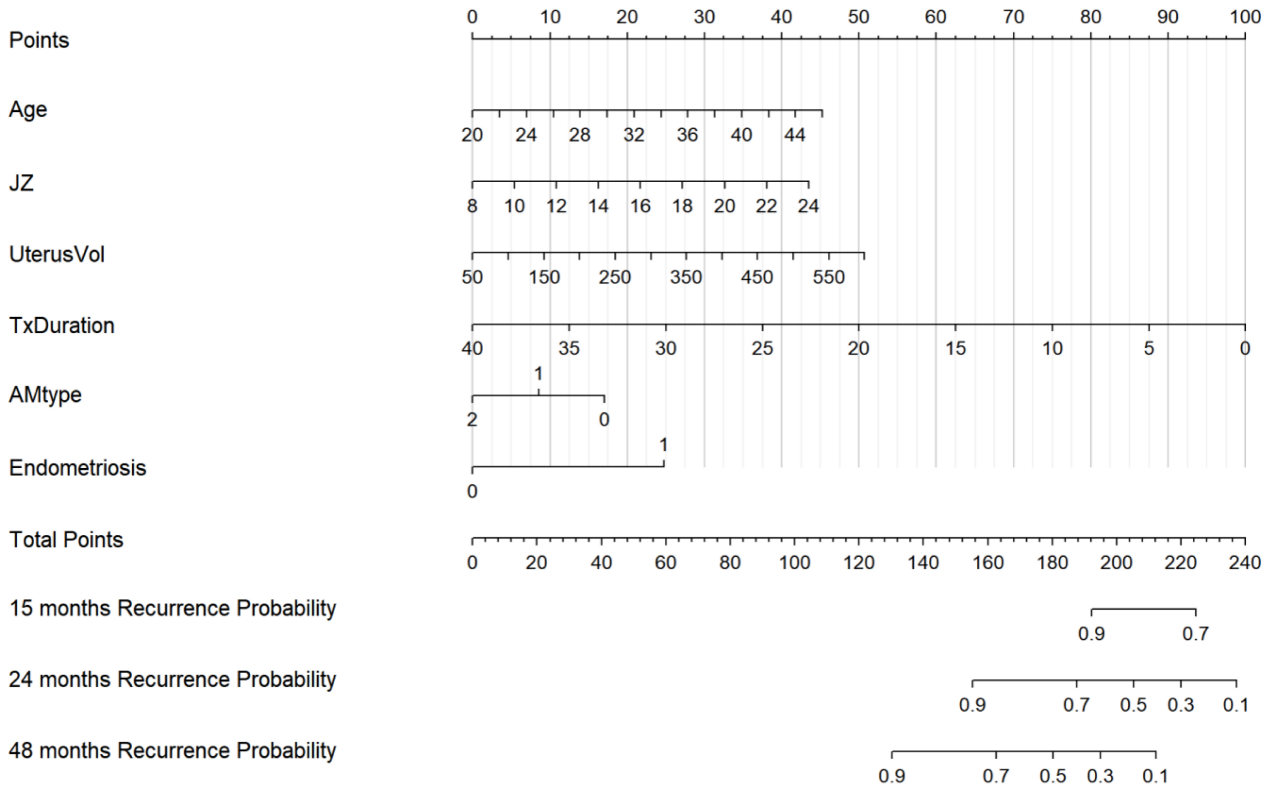

Fig. 1. Nomogram for predicting postoperative recurrence after conservative surgery for adenomyosis. The nomogram includes six variables: age, junctional zone (JZ) thickness, uterine volume (UterusVol), adenomyosis phenotype (AM type; 0 = focal, 1 = diffuse, 2 = mixed), duration of postoperative hormonal suppressive therapy (TxDuration), and concomitant endometriosis (0 = no, 1 = yes).

culated from the date of surgery to the first documented occurrence of symptom relapse, regardless of whether it was dysmenorrhea or menorrhagia. Patients without recurrence at the end of follow-up were censored at their last visit.

Statistical Analysis

All statistical analyses were performed using IBM SPSS Statistics 26.0 (IBM Corp., Armonk, NY, USA) and R software version 4.3.2 (R Foundation for Statistical Computing, Vienna, Austria). Baseline characteristics were summarized descriptively. Continuous variables were tested for normality using the Shapiro–Wilk test. The Mann–Whitney *U* test was employed to analyze intergroup data that do not follow a normal distribution, which are expressed as medians and interquartile ranges (IQRs), whereas the Chi-square test was used to compare categorical variables, which are presented as counts and percentages.

Univariate Cox proportional hazards regression analyses were conducted to evaluate the association between each variable and the risk of recurrence. Variables with clinical significance or $p < 0.05$ in the univariate analysis were subsequently entered into multivariable Cox regression to identify independent predictors. A nomogram that enables individualized prediction of recurrence risk at different postoperative time points was then developed based on the final multivariable Cox model. Variables of clinical significance, such as JZ thickness and adenomyosis phenotype, were retained in the final model regardless of their statistical significance, in accordance with Transparent Reporting of a Multivariable Prediction Model for Individual Prognosis or Diagnosis recommendations [17].

Model performance was assessed in terms of its discriminative ability, calibration, and clinical utility. Discriminative performance of the model was evaluated by calculating the concordance index (C-index) and plotting time-dependent receiver operating characteristic (ROC) curves to determine the corresponding area under the curve (AUC). Calibration was examined using bootstrap resampling with 1000 iterations, and plots were generated to compare predicted and observed probabilities of recurrence. Decision curve analysis (DCA) was applied to estimate the net clinical benefit of the predictive model across a range of threshold probabilities. Finally, patients were stratified into high- and low-risk groups according to their absolute predicted recurrence risk at 24 months, and Kaplan–Meier survival curves were used to compare recurrence-free survival between groups, with significance determined by the log-rank test.

Table 1. Baseline characteristics.

	Overall (n = 150)	Non-recurrence group (n = 97)	Recurrence group (n = 53)	Z/χ^2	p
Age (years)	34.00 [30.00, 37.00]	33.00 [29.00, 37.00]	34.00 [31.00, 39.00]	–1.712	0.087
BMI (kg/m^2)	22.10 [19.52, 24.40]	22.60 [20.00, 24.80]	21.10 [19.30, 23.20]	–1.980	0.048
Duration of follow-up (months)	27.00 [18.00, 38.00]	30.00 [18.00, 42.00]	24.00 [18.00, 38.00]	–0.538	0.591
JZ thickness (mm)	14.85 [12.93, 16.80]	13.90 [12.00, 15.50]	16.30 [14.90, 18.00]	–5.295	<0.001
Uterine volume (mL)	178.00 [141.00, 238.00]	161.00 [128.00, 201.00]	238.00 [193.00, 304.00]	–5.772	<0.001
TxDuration (months)	7.00 [2.00, 11.00]	10.00 [6.00, 12.00]	2.00 [0.00, 6.00]	–5.958	<0.001
Pregnancy (%)				0.029	0.864
No	15 (10.0)	10 (10.3)	5 (9.4)		
Yes	135 (90.0)	87 (89.7)	48 (90.6)		
Cesarean section (%)				0.035	0.852
No	41 (27.3)	27 (27.8)	14 (26.4)		
Yes	109 (72.7)	70 (72.2)	39 (73.6)		
Endometriosis (%)				45.730	<0.001
No	89 (59.3)	77 (79.4)	12 (22.6)		
Yes	61 (40.7)	20 (20.6)	41 (77.4)		
Adenomyosis phenotype (%)				26.795	<0.001
Diffuse	76 (50.7)	34 (35.1)	42 (79.2)		
Focal	42 (28.0)	36 (37.1)	6 (11.3)		
Mixed	32 (21.3)	27 (27.8)	5 (9.4)		
Extent of lesion excision (%)				1.933	0.164
Localized	65 (43.3)	38 (39.2)	27 (50.9)		
Extensive	85 (56.7)	59 (60.8)	26 (49.1)		
Repair layers (%)				4.297	0.117
1	13 (8.7)	5 (5.2)	8 (15.1)		
2	78 (52.0)	52 (53.6)	26 (49.1)		
≥3	59 (39.3)	40 (41.2)	19 (35.8)		
Hemostasis method (%)				0.381	0.827
Suture	52 (34.7)	32 (33.0)	20 (37.7)		
Energy-based	31 (20.7)	21 (21.6)	10 (18.9)		
Combined	67 (44.7)	44 (45.4)	23 (43.4)		
PostopTx (%)				12.298	0.015
GnRH agonist	26 (17.3)	18 (18.6)	8 (15.1)		
Dienogest	33 (22.0)	24 (24.7)	9 (17.0)		
LNG-IUS	33 (22.0)	25 (25.8)	8 (15.1)		
COCs	25 (16.7)	17 (17.5)	8 (15.1)		
None	33 (22.0)	13 (13.4)	20 (37.7)		

Notes: Values that do not conform to the normal distribution are presented as median [IQR].

Abbreviations: BMI, body mass index; COCs, combined oral contraceptives; GnRH, gonadotropin-releasing hormone; JZ, junctional zone; LNG-IUS, levonorgestrel-releasing intrauterine system; TxDuration, duration of postoperative hormonal therapy; PostopTx, postoperative treatment.

Results

Baseline Characteristics

A total of 150 patients were included, comprising 97 (64.7%) in the non-recurrence group and 53 (35.3%) in the recurrence group (Table 1). Compared with the non-recurrence group, patients who experienced recurrence had a significantly lower BMI (21.1 vs. 22.6 kg/m^2, $p = 0.048$), greater JZ thickness (16.3 vs. 13.9 mm, $p < 0.001$), and larger uterine volume (238 vs. 161 mL, $p < 0.001$). The diffuse type of adenomyosis was significantly more common in the recurrence group (79.2% vs. 35.1%), whereas focal and mixed types predominated in the non-recurrence cases ($p < 0.001$). In addition, patients with recurrence showed a markedly higher prevalence of concomitant endometriosis (77.4% vs. 20.6%, $p < 0.001$) and a shorter duration of postoperative hormonal suppressive therapy (median 2 vs. 10 months, $p < 0.001$). The proportion of patients without postoperative treatment was also higher in the recurrence group (37.7% vs. 13.4%, $p = 0.015$). Other baseline char-

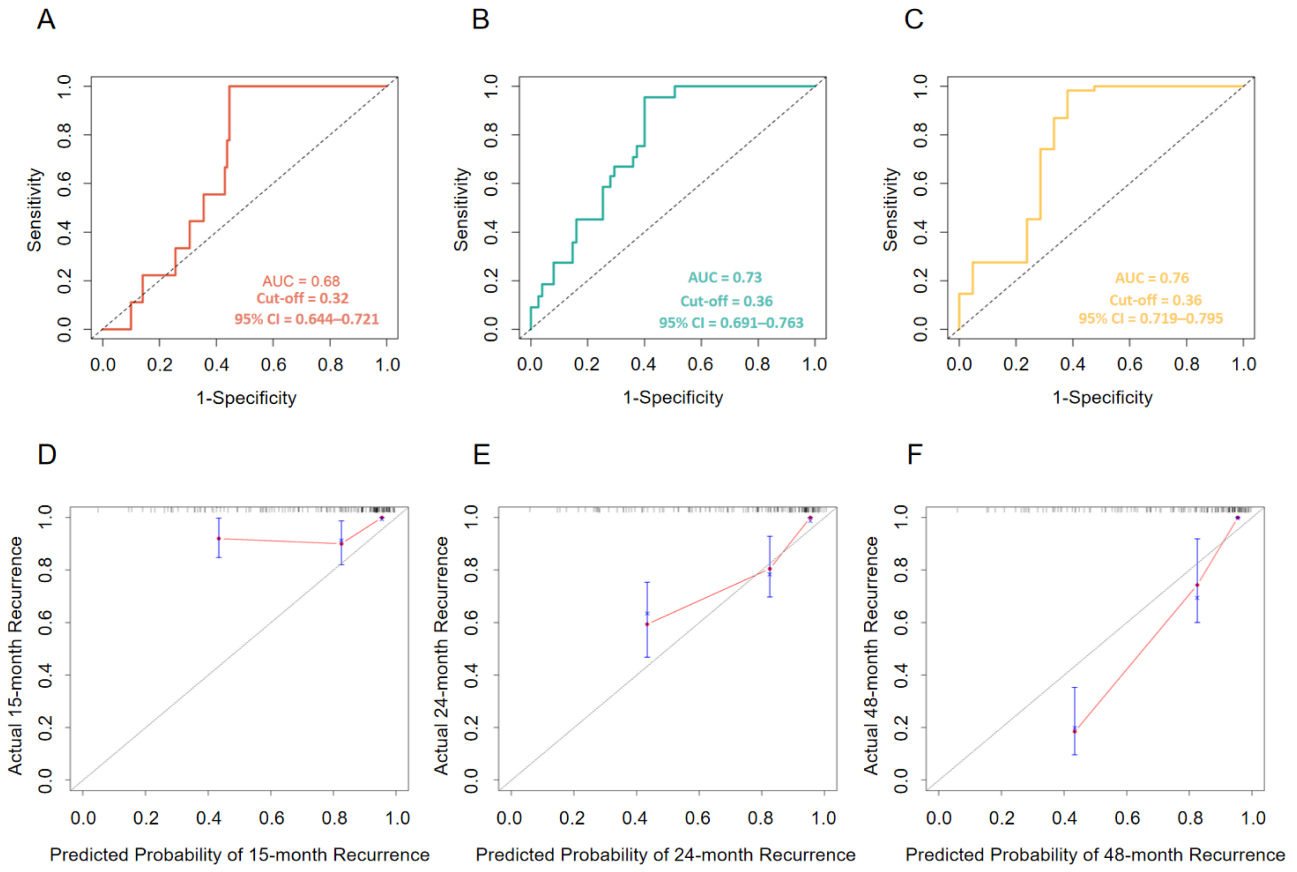

Fig. 2. Model performance evaluation. (A–C) Time-dependent receiver operating characteristic (ROC) curves at 15, 24, and 48 months with area under the curve (AUC) values of 0.68, 0.73, and 0.76, respectively. (D–F) Calibration plots for 15-, 24-, and 48-month recurrence probabilities showing agreement between predicted and observed outcomes.

acteristics, including age, parity, history of cesarean section, extent of lesion excision, number of repair layers, and hemostasis method, showed no significant differences between the two groups (all $p > 0.05$).

Univariate and Multivariate Cox Regression Analysis

Univariate Cox regression showed that age (Hazard Ratio [HR] = 1.072, 95% CI = 1.015–1.132, $p = 0.013$), JZ thickness (HR = 1.160, 95% CI = 1.063–1.266, $p < 0.001$), uterine volume (HR = 1.005, 95% CI = 1.003–1.008, $p < 0.001$), adenomyosis phenotype (HR = 0.421, 95% CI = 0.267–0.665, $p < 0.001$), concomitant endometriosis (HR = 4.850, 95% CI = 2.548–9.233, $p < 0.001$), postoperative treatment (HR = 1.265, 95% CI = 1.035–1.547, $p = 0.022$), and treatment duration (HR = 0.857, 95% CI = 0.804–0.913, $p < 0.001$) were significantly associated with recurrence.

Based on the multivariate Cox regression results, older age (HR = 1.069, 95% CI = 1.004–1.138, $p = 0.037$), larger uterine volume (HR = 1.003, 95% CI = 1.001–1.006, $p = 0.018$), a significantly shorter duration of postoperative therapy (HR = 0.905, 95% CI = 0.843–0.971, $p = 0.006$), and concomitant endometriosis (HR = 2.564, 95% CI = 1.27–5.178, $p = 0.009$) remained significantly associated with recurrence, making them the four independent predictors of recurrence. During the analysis, JZ thickness, adenomyosis phenotype, and postoperative treatment lost statistical significance following adjustment (Table 2).

Nomogram Development and Model Performance

Variables with statistical significance (age, uterine volume, duration of postoperative hormonal suppressive therapy, and concomitant endometriosis) in the multivariate Cox regression analysis were included in the nomogram (Fig. 1). In addition, JZ thickness and adenomyosis phenotype were incorporated because of their well-recognized clinical relevance as imaging indicators of disease burden and morphological subtype, despite not reaching statistical significance in multivariate analysis. The nomogram provided an individualized prediction of recurrence risk at 15, 24, and 48 months after surgery, with higher total scores corresponding to higher recurrence probabilities.

The discriminative ability of the model was acceptable, with a C-index of 0.766 in the overall cohort. Bootstrap validation with 1000 resamples confirmed robust internal validity, yielding a corrected C-index of 0.767. Time-dependent ROC analyses demonstrated AUC values of 0.68

Table 2. Univariate and multivariate Cox regression analysis of risk factors for recurrence after conservative surgery for adenomyosis.

Variable	Univariate analysis		Multivariate analysis	
	HR (95% CI)	*p*	HR (95% CI)	*p*
Age	1.072 (1.015–1.132)	0.013	1.069 (1.004–1.138)	0.037
BMI	0.916 (0.833–1.008)	0.072		
Pregnancy	1.063 (0.423–2.673)	0.896		
Cesarean section	1.195 (0.648–2.203)	0.568		
Endometriosis	4.850 (2.548–9.233)	<0.001	2.564 (1.27–5.178)	0.009
Duration of follow-up	0.000 (0–Inf)	0.984		
JZ thickness	1.160 (1.063–1.266)	<0.001	1.107 (0.98–1.251)	0.102
Uterine volume	1.005 (1.003–1.008)	<0.001	1.003 (1.001–1.006)	0.018
Adenomyosis phenotype	0.421 (0.267–0.665)	<0.001	0.73 (0.427–1.249)	0.250
Extent of lesion excision	0.737 (0.429–1.265)	0.268		
Repair layers	0.731 (0.48–1.113)	0.144		
Hemostasis method	0.952 (0.702–1.29)	0.749		
PostopTx	1.265 (1.035–1.547)	0.022	0.957 (0.785–1.167)	0.665
TxDuration	0.857 (0.804–0.913)	<0.001	0.905 (0.843–0.971)	0.006

Abbreviations: HR, hazard ratio; CI, confidence interval; Inf, infinity.

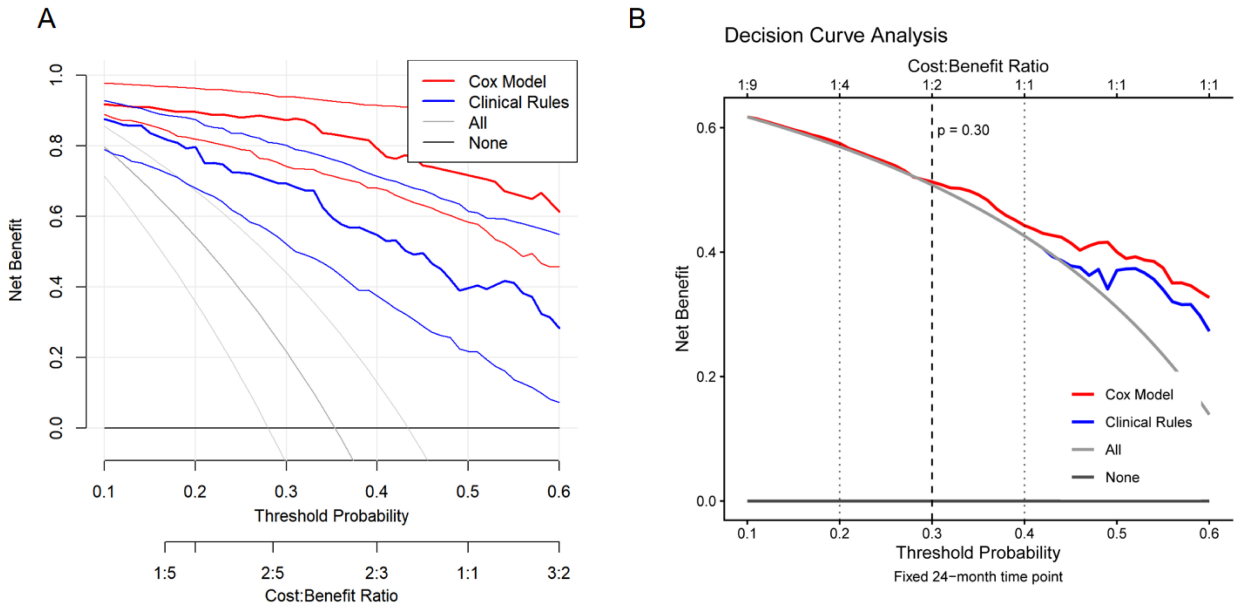

Fig. 3. Decision curve analysis (DCA) of the recurrence-prediction model. (A) DCA curves showing the net benefit of the Cox model, clinical rules, "all", and "none" strategies across a range of threshold probabilities. (B) DCA at the fixed 24-month time point, illustrating the net benefit of the Cox model compared with clinical rules, "all", and "none" strategies.

(95% CI: 0.644–0.721), 0.73 (95% CI: 0.691–0.763), and 0.76 (95% CI: 0.719–0.795) at 15, 24, and 48 months, respectively (Fig. 2A–C), indicating stable predictive performance over time. Calibration plots for 15-, 24-, and 48-month predictions (Fig. 2D–F) showed close agreement between predicted and observed probabilities, suggesting no significant overfitting. The numbers of patients remaining at risk at these time points were approximately 140, 125, and 100, respectively, indicating adequate sample sizes to ensure reliable calibration, particularly at the later time point. Decision curve analysis further indicated that the nomogram consistently provided a greater net clinical benefit than the traditional clinical rules when the threshold probability ranged between 0.15 and 0.45 (Fig. 3).

Risk Stratification

A 24-month predicted recurrence risk threshold of ≥30% was applied, which was selected because it falls

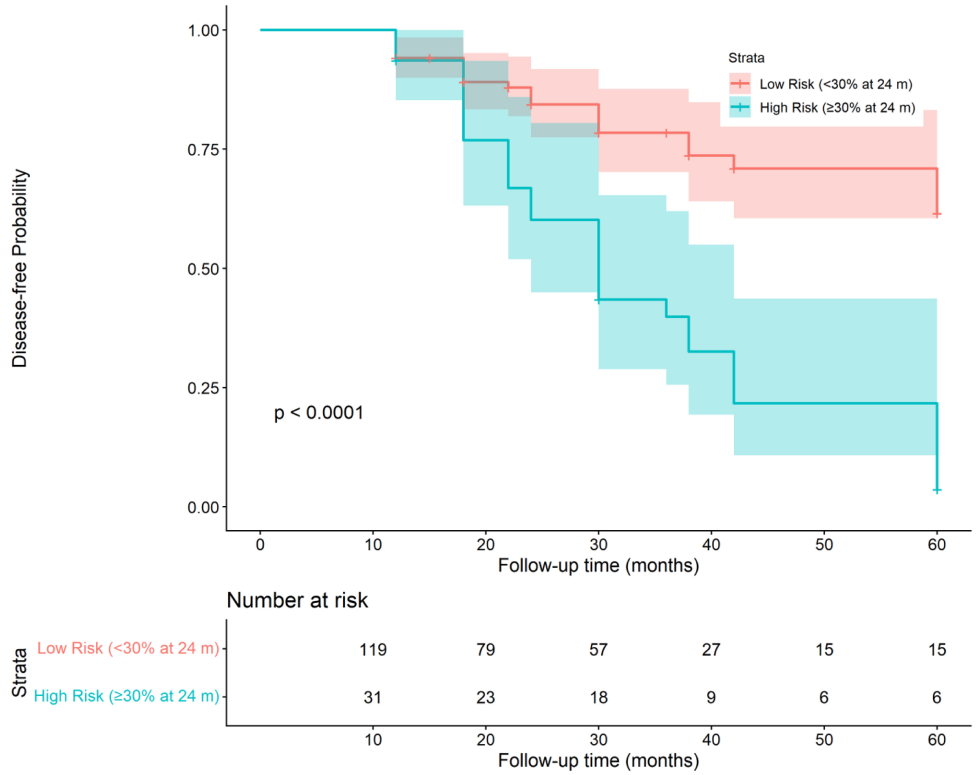

Fig. 4. Kaplan–Meier curves of recurrence-free survival stratified by 24-month predicted recurrence risk. Patients with a predicted risk of ≥30% at 24 months (high-risk group, $n = 31$) had significantly higher recurrence rates than those with <30% risk (low-risk group, $n = 119$).

within the DCA-identified optimal threshold probability range, where the model provides the greatest net clinical benefit (Fig. 3B). Using this threshold, 31 patients (20.7%) were classified as high-risk and 119 (79.3%) as low-risk. The five-year recurrence-free survival was 78% in the low-risk group and 17% in the high-risk group (Fig. 4), with a statistically significant difference between the two groups (log-rank $p < 0.0001$).

Discussion

In this study, a nomogram integrating clinical and imaging parameters was developed and internally validated to predict 5-year postoperative recurrence after conservative surgery for adenomyosis. The model showed good discriminative ability (C-index 0.766) and calibration, with time-dependent AUCs increasing from 0.68 to 0.76 across 15–48 months, reflecting stable and reliable performance. These findings suggest that the selected variables—age, uterine volume, JZ thickness, adenomyosis phenotype, duration of postoperative hormonal suppressive therapy, and coexistence of endometriosis—may serve as valuable predictors for long-term recurrence risk.

The recurrence rate of 35.3% observed in this study aligns with previous research [5], which showed recurrence rates ranging from 30% to 40% following conservative surgery. Several studies have identified age, uterine size, and incomplete lesion resection as major risk factors influencing postoperative outcomes [5,18]. Our findings confirm that larger uterine volume and shorter duration of postoperative hormonal suppressive therapy are independently associated with higher recurrence risk, consistent with earlier literature emphasizing disease burden and insufficient hormonal suppression as key contributors.

Imaging indicators such as JZ thickness and adenomyosis phenotype have been recognized as objective markers of disease severity and morphological subtype [9]. Although these parameters were not statistically significant in multivariate analysis, they were retained in the final model due to their strong biological plausibility and extensive prior validation as imaging indicators of myometrial invasion and treatment response [19]. Moreover, the model's slight improvement in discriminative performance at later follow-up time points (24–48 months) may reflect the delayed manifestation of true recurrences, as transient postoperative inflammatory or hormonal changes could obscure early symptom differentiation [5,20].

The current nomogram offers a clinically practical approach for individualized postoperative management. Patients classified as high-risk may benefit from prolonged postoperative hormonal suppressive therapy, early imaging surveillance, or fertility counseling. By integrating both

clinical and imaging markers, the model connects traditional risk factor analysis with individualized recurrence prediction, thereby facilitating evidence-based follow-up planning.

The main strengths of this study include its relatively large, well-characterized surgical cohort, the use of standardized imaging protocols, and long-term (5-year) follow-up data, which enhance the robustness of the findings. However, several limitations should be noted. As a single-center retrospective study, potential selection bias and incomplete control of confounding factors cannot be fully excluded. The model was only internally validated, and external validation in larger, multicenter prospective cohorts is needed to confirm its generalizability. In addition, heterogeneity in surgical techniques and postoperative treatment strategies may have influenced the research outcomes, and imaging parameters could be affected by interobserver variability. Furthermore, molecular biomarkers and advanced imaging features such as radiomics, which have additional predictive value, were not included in our analysis. Future research should therefore focus on multicenter prospective validation, incorporation of molecular and radiomic signatures, and development of dynamic predictive tools that update risk over time. Such efforts may refine individualized risk assessment and ultimately improve long-term outcomes for women undergoing conservative surgery for adenomyosis.

Conclusion

This study highlights the value of integrating clinical and imaging characteristics into a nomogram for predicting recurrence risk after conservative surgery for adenomyosis. The proposed model serves as a practical tool for individualized postoperative management, supporting more accurate risk stratification and clinical decision-making.

Availability of Data and Materials

The data used to support the findings of this study are available from the corresponding author upon request.

Author Contributions

Study concept and design: ANS and LLH; Analysis and interpretation of data: XQC; Drafting of the manuscript: ANS; Critical revision of the manuscript for important intellectual content: ANS, XQC and LLH; Statistical analysis: XQC; Study supervision: all authors. All authors have read and approved the final manuscript and agreed to be accountable for all aspects of the work, ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Ethics Approval and Consent to Participate

This study was approved by The Fourth Affiliated Hospital of Soochow University (Suzhou Dushu Lake Hospital) (2024-241023). Given the retrospective nature of the analysis, the requirement to obtain patients' informed consent was waived by the ethics committee. All data were anonymized to protect patient confidentiality in accordance with the principles of the Declaration of Helsinki.

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Conflict of Interest

The authors declare no conflict of interest.

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