Research Square

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Development and Internal Validation of a Clinical Prediction Model for Rapid Renal Function Decline After Urinary Stone Surgery: A Retrospective Cohort Study

wei jin
renji hospital affiliated to shanghai jiaotong university school of medicine
xiaoqian yang
renji hospital affiliated to shanghai jiaotong university school of medicine
Shan Mou
renji hospital affiliated to shanghai jiaotong university school of medicine
lei xia
renji hospital affiliated to shanghai jiaotong university school of medcine
yang cao
renji hospital affiliated to shanghai jiaotong university school of medcine
zhebing du
renji hospital affiliated to shanghai jiaotong university school of medcine
fangzhou li
renji hospital affiliated to shanghai jiaotong university school of medcine
huan liu
renji hospital affiliated to shanghai jiaotong university school of medcine
qin wang
qinwang_1975@126.com

renji hospital affiliated to shanghai jiaotong university school of medicine
qi chen
renji hospital affiliated to shanghai jiaotong university school of medcine

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Research Article

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Abstract

Background

Urinary stone disease and its surgical management may adversely affect renal function, yet validated tools for predicting postoperative rapid renal function decline remain lacking. We aimed to develop and internally validate a clinical prediction model for 1-year postoperative rapid renal function decline in patients undergoing urinary stone surgery.

Methods

This retrospective cohort study included 3,726 adult patients who underwent urinary stone surgery between January 1 and December 31, 2024, at Renji Hospital, Shanghai Jiao Tong University School of Medicine, with follow-up through December 31, 2025. The primary outcome was rapid renal function decline at approximately 1 year, defined as > = 30% reduction in eGFR from baseline. Candidate predictors were identified a priori based on clinical relevance and prior literature; LASSO logistic regression was used for data reduction, and variables with stable contributions together with clinically established predictors were incorporated into the final multivariable logistic model. Internal validation used 1,000 bootstrap resamples. Model performance was assessed by discrimination (AUC), calibration (intercept and slope), Brier score, and decision curve analysis.

Results

At 1 year, 306 patients (8.2%) experienced rapid renal function decline. The final model included seven predictors: age, baseline eGFR, diabetes, gout, hyperuricemia, hydronephrosis, and proteinuria. Proteinuria was the strongest predictor (OR = 2.762, 95% CI 2.028–3.761). The apparent AUC was 0.912, with an optimism-corrected AUC of 0.911 (95% CI 0.910–0.912). Bootstrap-corrected calibration intercept was − 0.017 and slope was 0.987 (95% CI 0.900–1.084); Brier score was 0.048. Sensitivity analysis showed the full model provided a modest but statistically significant improvement over baseline eGFR alone (ΔAUC = 0.014). A five-variable parsimonious model (excluding diabetes and gout) achieved comparable discrimination (AUC = 0.912).

Conclusion

We developed and internally validated a clinical prediction model and nomogram that accurately predicts 1-year postoperative rapid renal function decline after urinary stone surgery. The model may facilitate preoperative risk stratification and guide postoperative surveillance. External validation is warranted before clinical implementation.

Trial registration

Not applicable.

1. Introduction

Urolithiasis is a common urological disorder worldwide, with substantial geographic variation in prevalence and an increasing disease burden in many populations [1, 2]. Endourological procedures, including ureteroscopy, retrograde intrarenal surgery, and percutaneous nephrolithotomy, are widely used for the surgical management of urinary stones according to stone location, size, and complexity [3, 4].

Despite these advances, the renal consequences of urinary stone disease and its surgical treatment remain a significant clinical concern. Epidemiological studies have shown that individuals with kidney stones are at increased risk of chronic kidney disease and subsequent loss of kidney function compared with individuals without stones [5, 6]. Although renal function is preserved or improved in many patients after stone removal, a subset may experience postoperative kidney function deterioration, particularly in the presence of impaired baseline renal function, a solitary kidney, diabetes, or perioperative kidney injury [7–11].

While previous studies have identified factors associated with renal outcomes after stone surgery, few dedicated prediction models have been developed and internally validated for this population. Existing kidney-failure prediction tools, such as the Kidney Failure Risk Equation (KFRE), were developed in populations with CKD and were designed to predict progression to kidney failure over longer horizons [24]. Their direct application to surgical stone patients may therefore be limited by differences in population characteristics, outcome definitions, and prediction horizons.

A validated prediction model for postoperative rapid renal function decline would enable preoperative risk stratification, guide individualized surveillance protocols, and inform shared decision-making. Accordingly, we developed and internally validated a multivariable logistic regression model and nomogram for predicting 1-year postoperative rapid renal function decline (≥ 30% eGFR reduction) in patients undergoing urinary stone surgery. We additionally evaluated the incremental predictive value of clinical and laboratory variables beyond baseline eGFR alone, given the potential mathematical coupling between baseline eGFR and percentage-based decline outcomes.

2. Methods

This study was reported in accordance with the Transparent Reporting of a multivariable prediction model for Individual Prognosis Or Diagnosis (TRIPOD) statement. The study protocol was approved by the Ethics Committee of Renji Hospital, Shanghai Jiao Tong University School of Medicine (approval number: LY2026-257-B). The requirement for informed consent was waived by the ethics committee due to the retrospective, non-interventional design. All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research

committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. All data were de-identified prior to analysis.

2.1 Study Design and Population

This was a single-center, retrospective, observational cohort study conducted at Renji Hospital, Shanghai Jiao Tong University School of Medicine. All adult patients (> = 18 years) who underwent surgical treatment for urinary calculi between January 1, 2024, and December 31, 2024, were screened for eligibility. The follow-up period extended through December 31, 2025, providing approximately 1 year of postoperative follow-up for all patients.

Inclusion criteria were: (1) age ≥ 18 years; (2) documented surgery for urinary calculi; (3) available baseline serum creatinine and at least one follow-up serum creatinine measurement at approximately 1 year postoperatively (range 10–14 months). Patients with missing surgery type (n = 131) were excluded. No missing data were present for the variables included in the final prediction model among the analysis cohort. Patients with acute kidney injury within 30 days preoperatively or active urinary tract infection at the time of surgery were also excluded.

2.2 Data Collection and Variable Definitions

Data were extracted from the hospital electronic medical record system, laboratory information system, and surgical anesthesia records. Collected variables included demographic characteristics (age, sex), comorbidities (diabetes mellitus, hypertension, hyperlipidemia, gout, hyperuricemia, smoking status, drinking status), stone characteristics (stone size, laterality, ureteral involvement, hydronephrosis, proteinuria), and preoperative laboratory measurements (serum creatinine, eGFR, blood urea nitrogen, hemoglobin, serum uric acid, serum calcium, serum phosphorus).

eGFR was calculated using the 2021 CKD-EPI creatinine equation (without race coefficient) [13]. Baseline eGFR was defined as the most recent preoperative measurement within 30 days before surgery. Follow-up eGFR was defined as the measurement at approximately 1 year postoperatively (range: 10–14 months).

Proteinuria was primarily defined by urine dipstick result of ≥ 1+ (trace or negative classified as absent), consistent with standard clinical practice in our center. For a subset of patients with available albumin-to-creatinine ratio (ACR) measurements, ACR ≥ 30 mg/g was considered equivalent to dipstick ≥ 1+; sensitivity analyses using dipstick-only definition yielded consistent results. Hydronephrosis was graded on preoperative computed tomography (CT) according to the Society for Fetal Urology (SFU) classification; for the primary analysis, hydronephrosis was dichotomized as absent (SFU grade 0) versus present (SFU grades 1–4).

2.3 Outcome Definition

The primary outcome was rapid renal function decline at approximately 1 year postoperatively, defined as a ≥ 30% reduction in eGFR from baseline to the 1-year follow-up measurement: (eGFR_baseline − eGFR_1year) / eGFR_baseline × 100% ≥ 30%. This binary outcome was selected because all patients had a single primary follow-up assessment at approximately 1 year, precluding time-to-event analysis. A ≥ 30% decline in eGFR has been associated with a substantially higher subsequent risk of kidney failure and mortality and has been proposed as an alternative endpoint for CKD progression [14, 15].

Secondary outcomes for sensitivity analysis included: (1) annual eGFR decline rate (continuous variable, calculated as [baseline eGFR − follow-up eGFR] / follow-up duration); and (2) significant renal function decline defined as ≥ 25% eGFR reduction (binary variable).

2.4 Candidate Predictors and Variable Selection

Candidate predictors were identified a priori based on clinical relevance and prior literature, including 18 variables: age, sex, baseline eGFR, diabetes, hypertension, hyperlipidemia, gout, hyperuricemia, smoking status, drinking status, stone size, bilateral stones, ureteral stones, hydronephrosis, proteinuria, serum uric acid, hemoglobin, and blood urea nitrogen. All candidate predictors were assessed for multicollinearity using variance inflation factors (VIF); all VIFs were below 2.0, indicating no significant multicollinearity.

Variable selection followed a structured approach: LASSO (Least Absolute Shrinkage and Selection Operator) logistic regression with 10-fold cross-validation was used as a data-reduction technique to identify variables with stable contributions across regularization paths. Variables showing prominent and stable contributions in LASSO, together with clinically established predictors considered important a priori (diabetes and gout, which are recognized risk factors for CKD progression and were retained despite not reaching statistical significance in LASSO), were incorporated into the final multivariable model. This approach balances data-driven variable reduction with clinical judgment.

2.5 Model Development and Nomogram

A multivariable logistic regression model was fitted using the seven selected predictors on the full cohort. The model included all seven variables simultaneously without further stepwise elimination. Model fit was assessed using McFadden's pseudo-R^2 and Akaike Information Criterion (AIC). A nomogram was constructed based on the final model coefficients to facilitate clinical application. The nomogram assigns points to each predictor based on its regression coefficient; the total points correspond to the predicted probability of 1-year postoperative rapid renal function decline.

2.6 Internal Validation

Internal validation was performed using bootstrap resampling with 1,000 iterations on the full cohort rather than a random holdout split, thereby making efficient use of the available data and allowing estimation of optimism in model performance [25, 26]. For each bootstrap iteration, the model was refitted on the bootstrap sample and evaluated on the original cohort. Optimism in model performance was estimated as the difference between apparent performance in the bootstrap sample and test

performance in the original sample. Optimism-corrected performance was calculated as apparent performance minus mean optimism.

Model performance was assessed using three metrics: (1) Discrimination—area under the receiver operating characteristic curve (AUC) with 95% bootstrap confidence interval; (2) Calibration—calibration intercept (ideal value = 0), calibration slope (ideal value = 1), calibration plot, and Brier score (range 0–1, lower values indicate better calibration); and (3) Clinical utility—decision curve analysis (DCA) to quantify net benefit across a range of threshold probabilities, comparing the model with the "treat-all" and "treat-none" strategies.

2.7 Sensitivity Analyses

Four sensitivity analyses were performed: (1) Model comparison—three nested models were developed and compared: baseline eGFR alone, clinical predictors excluding baseline eGFR, and the full seven-variable model; discrimination (AUC), calibration (slope and intercept), Brier score, and AIC were compared; (2) Five-variable parsimonious model—excluding diabetes and gout (the two non-significant predictors) to assess whether a more parsimonious model achieves comparable performance; (3) Alternative outcome definition—using ≥ 25% eGFR decline as the outcome; (4) Linear regression—using annual eGFR decline rate as a continuous outcome to verify the direction and magnitude of predictor effects.

2.8 Risk Stratification and Subgroup Analysis

Patients were stratified into three risk groups based on prespecified pragmatic predicted probability thresholds selected to illustrate clinically interpretable risk strata: low risk (< 5%), intermediate risk (5–15%), and high risk (> 15%). These thresholds were chosen to facilitate clinical communication and are not intended as validated treatment cutoffs. Subgroup analyses were performed to assess whether the association between predicted risk and outcome varied across clinically relevant subgroups (age, sex, diabetes, hypertension, baseline CKD, surgery type, stone laterality); results are presented in the Supplementary Material.

2.9 Statistical Software

All statistical analyses were performed using Python (version 3.12) and R (version 4.3.0). Key packages included statsmodels, scikit-learn, lifelines, and rms. A two-sided p-value < 0.05 was considered statistically significant. All analysis code is available upon request.

3. Results

3.1 Study Population and Baseline Characteristics

Among 3,857 patients who underwent urinary stone surgery during the study period, 131 were excluded due to missing surgery type, leaving 3,726 patients in the final analysis cohort (Fig. 1). The median age was 58 years (IQR 46–68), and 31.3% were male. The median baseline eGFR was 90 mL/min/1.73m²

(IQR 71–103), with 14.1% of patients having baseline CKD (eGFR < 60). The most prevalent comorbidities were hypertension (35.0%), hyperlipidemia (22.0%), hyperuricemia (18.1%), and diabetes (15.1%). Hydronephrosis was present in 70.2% and proteinuria in 44.8% of patients. RIRS was the most common surgical procedure (44.8%), followed by URS (27.0%), PCNL (15.8%), bladder stone surgery (5.9%), and other procedures (6.6%).

The baseline characteristics of the entire cohort and stratified by outcome status are summarized in Table 1. The median age was 58 years (IQR 46–68), and median baseline eGFR was 90 mL/min/1.73m² (IQR 71–103). Patients who experienced rapid renal function decline were older (median 68 vs 57 years), had lower baseline eGFR (median 49 vs 92 mL/min/1.73m²), higher rates of diabetes (21.2% vs 14.6%), gout (12.1% vs 6.6%), hyperuricemia (27.8% vs 17.2%), hydronephrosis (78.4% vs 69.4%), and proteinuria (71.2% vs 42.4%) compared with those without decline (all $p < 0.01$).

Table 1
Baseline characteristics of the study cohort stratified by 1-year postoperative rapid renal function decline

Variable	Overall (n = 3726)	Event (n = 306)	No Event (n = 3420)	P value
Age, years	58.0 (46.0–68.0)	68.0 (60.0–73.0)	57.0 (45.0–67.0)	< 0.001
Baseline eGFR, mL/min/1.73m²	90.0 (71.0–103.0)	49.0 (32.0–63.8)	92.0 (76.0–104.0)	< 0.001
Serum creatinine, μmol/L	78.0 (65.0–94.6)	124.5 (97.2–174.3)	76.0 (63.1–90.0)	< 0.001
Stone size, mm	12.0 (8.0–15.0)	12.0 (8.0–16.0)	12.0 (8.0–15.0)	0.1735
Serum uric acid, μmol/L	342.0 (287.0–406.0)	379.5 (317.0–464.8)	339.0 (286.0–402.0)	< 0.001
Hemoglobin, g/L	142.0 (130.0–152.0)	134.5 (119.0–145.8)	142.0 (131.0–153.0)	< 0.001
Blood urea nitrogen, mmol/L	6.0 (4.9–7.2)	8.4 (6.8–10.9)	5.8 (4.8–7.0)	< 0.001
Male sex	1167 (31.3%)	98 (32.0%)	1069 (31.3%)	0.8309
Diabetes mellitus	563 (15.1%)	65 (21.2%)	498 (14.6%)	0.0023
Hypertension	1303 (35.0%)	145 (47.4%)	1158 (33.9%)	< 0.001
Hyperlipidemia	820 (22.0%)	74 (24.2%)	746 (21.8%)	0.3752
Gout	264 (7.1%)	37 (12.1%)	227 (6.6%)	< 0.001
Hyperuricemia	673 (18.1%)	85 (27.8%)	588 (17.2%)	< 0.001
Current smoking	896 (24.0%)	89 (29.1%)	807 (23.6%)	0.0373
Current drinking	676 (18.1%)	78 (25.5%)	598 (17.5%)	< 0.001
Bilateral stones	667 (17.9%)	81 (26.5%)	586 (17.1%)	< 0.001
Ureteral stones	2573 (69.1%)	236 (77.1%)	2337 (68.3%)	0.0018
Hydronephrosis	2614 (70.2%)	240 (78.4%)	2374 (69.4%)	0.0012
Proteinuria (dipstick ≥ 1+)	1669 (44.8%)	218 (71.2%)	1451 (42.4%)	< 0.001
Baseline CKD (eGFR < 60)	525 (14.1%)	220 (71.9%)	305 (8.9%)	< 0.001
PCNL	587 (15.8%)	58 (19.0%)	529 (15.5%)	0.0619

Note: Categorical variables are presented as n (%). Continuous variables are presented as median (IQR). eGFR, estimated glomerular filtration rate; CKD, chronic kidney disease; PCNL, percutaneous nephrolithotomy; RIRS, retrograde intrarenal surgery; URS, ureteroscopy.

Variable	Overall (n = 3726)	Event (n = 306)	No Event (n = 3420)	P value
RIRS	1668 (44.8%)	149 (48.7%)	1519 (44.4%)	0.0619
URS	1006 (27.0%)	73 (23.9%)	933 (27.3%)	0.0619
Bladder	220 (5.9%)	11 (3.6%)	209 (6.1%)	0.0619
Other	245 (6.6%)	15 (4.9%)	230 (6.7%)	0.0619

Note: Categorical variables are presented as n (%). Continuous variables are presented as median (IQR). eGFR, estimated glomerular filtration rate; CKD, chronic kidney disease; PCNL, percutaneous nephrolithotomy; RIRS, retrograde intrarenal surgery; URS, ureteroscopy.

3.2 Primary Outcome

At approximately 1 year postoperatively (median follow-up: 1.0 year, IQR: 1.0–1.0), 306 patients (8.2%) met the primary outcome of ≥ 30% eGFR decline. The median annual eGFR decline rate was 3.38 mL/min/1.73m²/year (IQR: 2.20–5.34), and the median percentage eGFR decline was 7.73% (IQR: 3.87–14.14). Patients in the event group had a markedly higher median annual decline rate (9.09 vs. 3.18 mL/min/1.73m²/year, $p < 0.001$) and percentage decline (45.09% vs. 7.02%, $p < 0.001$) compared with non-event patients.

3.3 Variable Selection and Final Prediction Model

LASSO logistic regression with 10-fold cross-validation identified five variables with prominent and stable contributions across the regularization path: baseline eGFR, proteinuria, age, hydronephrosis, and hyperuricemia (Fig. 2). Diabetes and gout were additionally retained in the final model because of their prespecified clinical relevance as established risk factors for CKD progression, yielding a seven-variable final model.

The multivariable logistic regression model achieved a McFadden pseudo-R^2 of 0.400 and AIC of 1285.0. Five of the seven predictors were statistically significant ($p < 0.05$): proteinuria (OR = 2.762, 95% CI 2.028–3.761), hyperuricemia (OR = 1.562, 95% CI 1.114–2.188), hydronephrosis (OR = 1.564, 95% CI 1.105–2.213), baseline eGFR (OR = 0.930 per mL/min/1.73m², 95% CI 0.923–0.937), and age (OR = 1.018 per year, 95% CI 1.005–1.031). Diabetes (OR = 1.335, 95% CI 0.928–1.921, $p = 0.120$) and gout (OR = 1.324, 95% CI 0.797–2.200, $p = 0.279$) were not statistically significant but were retained for clinical relevance. In sensitivity analysis, a five-variable parsimonious model excluding diabetes and gout achieved comparable discrimination (AUC = 0.912 for both models) and slightly better AIC (1284.3 vs 1285.0), suggesting that diabetes and gout contribute modest incremental value primarily through clinical interpretability. All VIFs were below 2.0.

Table 2
Final multivariable logistic regression model for predicting 1-year postoperative rapid renal function decline

Variable	OR	95% CI	P value
age	1.018	(1.005–1.031)	0.0050
baseline_egfr	0.930	(0.923–0.937)	< 0.001
diabetes	1.335	(0.928–1.921)	0.1199
gout	1.324	(0.797–2.200)	0.2785
hyperuricemia	1.562	(1.114–2.188)	0.0096
hydronephrosis	1.564	(1.105–2.213)	0.0116
proteinuria	2.762	(2.028–3.761)	< 0.001

Note: OR, odds ratio; CI, confidence interval. Model fit: McFadden pseudo-R^2 = 0.400, AIC = 1285.0. All variance inflation factors < 2.0.

3.4 Nomogram

A nomogram was constructed based on the seven-variable logistic regression model (Fig. 3). Proteinuria contributed the highest point weight (up to 100 points), followed by hydronephrosis, hyperuricemia, baseline eGFR (inverse relationship), age, diabetes, and gout. The total points across all variables were mapped to the predicted 1-year probability of rapid renal function decline, ranging from < 1% to > 60%.

3.5 Internal Validation

Bootstrap internal validation (1,000 iterations) demonstrated good model performance. The apparent AUC was 0.912, with an optimism of 0.002 and an optimism-corrected AUC of 0.911 (95% bootstrap CI 0.910–0.912). The apparent calibration intercept was 0.000 and slope was 1.000; after bootstrap optimism correction, the calibration intercept was − 0.017 (95% CI -0.199–0.171) and slope was 0.987 (95% CI 0.900–1.084). The Brier score was 0.048. Decision curve analysis showed that the model provided greater net benefit than the treat-all or treat-none strategies across a wide range of threshold probabilities (Fig. 4).

3.6 Sensitivity Analysis: Model Comparison

The full seven-variable model (AUC = 0.912) outperformed both baseline eGFR alone (AUC = 0.898) and clinical predictors excluding baseline eGFR (AUC = 0.771) (Fig. 5). The full model provided a statistically significant, although modest, improvement in discrimination compared with baseline eGFR alone (ΔAUC = 0.014). The five-variable parsimonious model (excluding diabetes and gout) achieved an AUC of 0.912, comparable to the full model.

In sensitivity analyses using alternative outcome definitions, the direction and magnitude of predictor effects remained consistent. In the linear regression model with annual eGFR decline rate as the outcome, six of the seven predictors showed effects in the same direction as the logistic model (gout was not significant, p = 0.875). In the logistic model using ≥ 25% eGFR decline as the outcome, six of seven predictors remained significant (gout not significant, p = 0.435), confirming the robustness of the identified predictors.

3.7 Risk Stratification

Using prespecified pragmatic predicted probability thresholds, 2,639 patients (70.8%) were classified as low risk (< 5%), 522 (14.0%) as intermediate risk (5–15%), and 565 (15.2%) as high risk (> 15%). The observed event rates were 1.3% in the low-risk group, 9.0% in the intermediate-risk group, and 39.6% in the high-risk group, demonstrating clear separation across risk strata (Fig. 6).

3.8 Subgroup Analysis

Subgroup analyses demonstrated that the association between high predicted risk and rapid renal decline was generally consistent across clinically relevant subgroups, including age, sex, diabetes, hypertension, baseline CKD status, surgery type, and stone laterality, with no significant effect modification (all p for interaction > 0.05; Supplementary Figure).

4. Discussion

In this large retrospective cohort study of 3,726 patients undergoing urinary stone surgery, we developed and internally validated a seven-variable clinical prediction model and nomogram for 1-year postoperative rapid renal function decline (≥ 30% eGFR reduction). To our knowledge, few dedicated prediction models have specifically addressed postoperative renal outcomes in this population. The model demonstrated good discrimination (optimism-corrected AUC = 0.911), adequate calibration (corrected slope = 0.987), and positive net benefit across clinically relevant threshold ranges.

4.1 Key Predictors and Mechanistic Considerations

Proteinuria emerged as the strongest independent predictor (OR = 2.762), consistent with its established role as a marker of kidney damage and an important prognostic indicator of CKD progression and adverse renal outcomes [16, 17]. In the context of urinary stone disease, proteinuria may reflect pre-existing renal parenchymal injury or concomitant kidney disease, identifying patients who may be particularly vulnerable to subsequent functional deterioration.

Hydronephrosis (OR = 1.564) was independently associated with rapid renal function decline, underscoring the importance of urinary tract obstruction. Prolonged obstruction can alter intrarenal hemodynamics and promote tubular injury, inflammation, interstitial fibrosis, and progressive loss of

renal function [18, 19]. These findings suggest that the severity and duration of obstruction warrant further investigation as potentially modifiable determinants of postoperative renal outcomes.

Hyperuricemia (OR = 1.562) was independently associated with rapid renal decline. Experimental and clinical evidence has implicated uric acid in renal and vascular injury through mechanisms involving endothelial dysfunction, activation of the renin–angiotensin system, oxidative stress, and inflammation [20, 21]. Hyperuricemia and gout may therefore identify patients at higher renal risk; however, whether urate-lowering therapy modifies postoperative renal outcomes requires prospective evaluation.

Lower baseline eGFR (OR = 0.930 per mL/min/1.73m² increment) was, as expected, a strong predictor, reflecting reduced renal functional reserve. Older age (OR = 1.018 per year) may reflect age-related nephron loss and reduced renal reserve. Diabetes and gout were retained a priori for clinical interpretability despite not reaching statistical significance. Their incremental contribution to overall predictive performance appeared limited, as the five-variable parsimonious model achieved similar discrimination [22].

4.2 Incremental Value Beyond Baseline eGFR

The full seven-variable model provided a statistically significant, although modest, improvement in discrimination compared with baseline eGFR alone (ΔAUC = 0.014, 95% CI 0.008–0.021). This finding is particularly important given the potential mathematical coupling between baseline eGFR and a percentage-based decline outcome. Although the incremental AUC was modest, the full model also offered clinically interpretable risk stratification and positive decision-curve net benefit. The clinical-only model excluding eGFR achieved an AUC of 0.771, confirming that baseline renal function was the dominant predictor while other clinical and laboratory variables contributed additional prognostic information.

4.3 Comparison with Previous Studies

Our findings are broadly consistent with previous studies of renal outcomes after stone surgery while extending the literature through formal prediction-model development. Studies of PCNL and ureteroscopic stone treatment generally indicate that renal function is preserved or improves in many patients after stone removal, although adverse renal outcomes may occur in higher-risk subgroups [7–11, 23].

The discriminative performance of our model (optimism-corrected AUC = 0.911) is not directly comparable with established kidney-failure prediction tools such as the KFRE because of fundamental differences in study population, outcome definition, and prediction horizon [24]. Our model is specifically tailored to the perioperative stone-surgery context. External validation in independent populations is required to evaluate transportability before clinical implementation [27].

Notably, surgery type was not included in the final prediction model, as it did not provide incremental predictive value beyond baseline patient characteristics. This is consistent with a recent systematic

review concluding that endoscopic stone surgery does not overall impair renal function, and that observed differences in renal outcomes are largely explained by baseline patient characteristics and stone burden rather than the specific surgical technique [23].

4.4 Clinical Implications

The proposed nomogram has several potential clinical applications. First, it enables rapid preoperative risk assessment using variables that are routinely collected in clinical practice, without requiring additional testing. Patients identified as high risk (predicted probability > 15%, observed event rate 39.6%) may benefit from intensified perioperative management, including optimization of glycemic control, urate management, prompt treatment of urinary tract infections, and careful selection of surgical approach to minimize renal trauma.

Second, the nomogram can guide individualized postoperative surveillance protocols. Low-risk patients (predicted probability < 5%, observed event rate 1.3%) may be managed with standard follow-up, while high-risk patients warrant more frequent renal function monitoring, earlier nephrology referral, and proactive management of modifiable risk factors. This risk-stratified approach has the potential to optimize resource allocation while ensuring that patients at greatest risk receive appropriate attention.

Third, the identification of risk factors—particularly proteinuria, hyperuricemia, and potentially reversible obstruction—highlights targets for preoperative optimization and postoperative management. Whether modification of these factors (e.g., urate-lowering therapy for hyperuricemia, or earlier intervention for obstructing stones) improves postoperative renal outcomes requires prospective evaluation; our retrospective design cannot establish causal relationships.

4.5 Strengths and Limitations

This study has several notable strengths. First, the large sample size (3,726 patients) with 306 outcome events provides a substantial dataset for multivariable modeling; contemporary guidance emphasizes considering the number of participants and outcome events relative to candidate predictor parameters when developing prediction models [30]. Second, the study followed TRIPOD reporting principles [12, 25] and used bootstrap internal validation with optimism correction for discrimination and calibration [26]. Third, we explicitly addressed potential mathematical coupling between baseline eGFR and percentage-based decline through nested model comparison. Fourth, no missing data were present for variables in the final model. Fifth, the nomogram provides a clinically interpretable tool for risk quantification.

Several limitations should be acknowledged. First, the retrospective design introduces potential for unmeasured confounding and selection bias. Second, this was a single-center study; external validation in independent cohorts is required before widespread clinical application [27]. Third, the follow-up period was limited to approximately 1 year; longer-term renal outcomes remain unknown. Fourth, proteinuria was primarily assessed by urine dipstick, which is less precise than quantitative albumin-to-creatinine ratio measurement; proteinuria nevertheless carries independent prognostic information across eGFR strata [17]. Fifth, hydronephrosis was dichotomized rather than graded by severity, which may have

attenuated its predictive value. Sixth, diabetes and gout were not statistically significant in the final model and a five-variable parsimonious model achieved comparable discrimination. Finally, the pragmatic risk thresholds (< 5%, 5–15%, > 15%) were selected for illustrative purposes and require validation as clinically actionable cutoffs.

5. Conclusion

We developed and internally validated a seven-variable clinical prediction model and nomogram for 1-year postoperative rapid renal function decline in patients undergoing urinary stone surgery. The model incorporates age, baseline eGFR, diabetes, gout, hyperuricemia, hydronephrosis, and proteinuria—all routinely available preoperative variables—and demonstrated excellent discrimination (optimism-corrected AUC = 0.911), good calibration, and significant clinical net benefit. Critically, the full model provided statistically significant incremental predictive value beyond baseline eGFR alone. Pending external validation, this tool may facilitate preoperative risk stratification, guide individualized postoperative renal surveillance, and inform targeted renal protection strategies for patients with urinary calculi.

Abbreviations

ACR
albumin-to-creatinine ratio
AIC
Akaike information criterion
AUC
area under the receiver operating characteristic curve
CI
confidence interval
CKD
chronic kidney disease
CKD-EPI
Chronic Kidney Disease Epidemiology Collaboration
CT
computed tomography
DCA
decision curve analysis
eGFR
estimated glomerular filtration rate
IQR
interquartile range
KFRE
Kidney Failure Risk Equation

LASSO
Least Absolute Shrinkage and Selection Operator
OR
odds ratio
PCNL
percutaneous nephrolithotomy
RCT
randomized controlled trial
ROC
receiver operating characteristic
SFU
Society for Fetal Urology
TRIPOD
Transparent Reporting of a multivariable prediction model for Individual Prognosis Or Diagnosis
VIF
variance inflation factor.

Declarations

Ethics approval and consent to participate

This study was approved by the Ethics Committee of Renji Hospital, Shanghai Jiao Tong University School of Medicine (approval number: LY2026-257-B). The requirement for informed consent was waived by the Ethics Committee due to the retrospective, non-interventional design. All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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Author Contribution

WJ contributed to the study conception and design, data acquisition, statistical analysis, interpretation of results, and drafting of the manuscript. XY and SM contributed to data acquisition and patient follow-up. LX, YC, ZD, FL, and HL contributed to data acquisition, surgical data collection, and critical revision of the manuscript. QW and QC supervised the study, contributed to the study design and interpretation of results, and critically revised the manuscript for important intellectual content. All authors read and approved the final manuscript.

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Availability of data and materials

The datasets generated and analysed during the current study are not publicly available due to ethical/restricted reasons but are available from the corresponding author on reasonable request.

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Figures

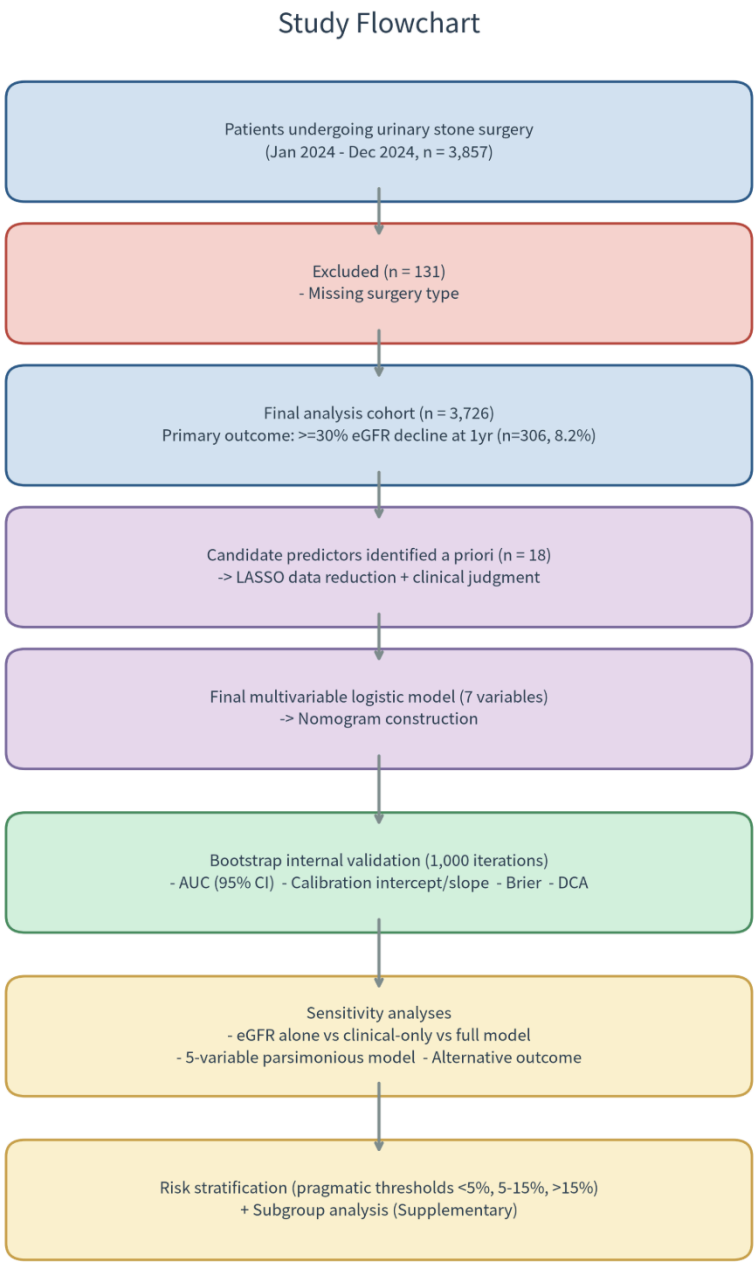


Figure 1

Study flowchart. Schematic representation of patient screening, inclusion, exclusion, variable selection, model development, internal validation, and sensitivity analyses.

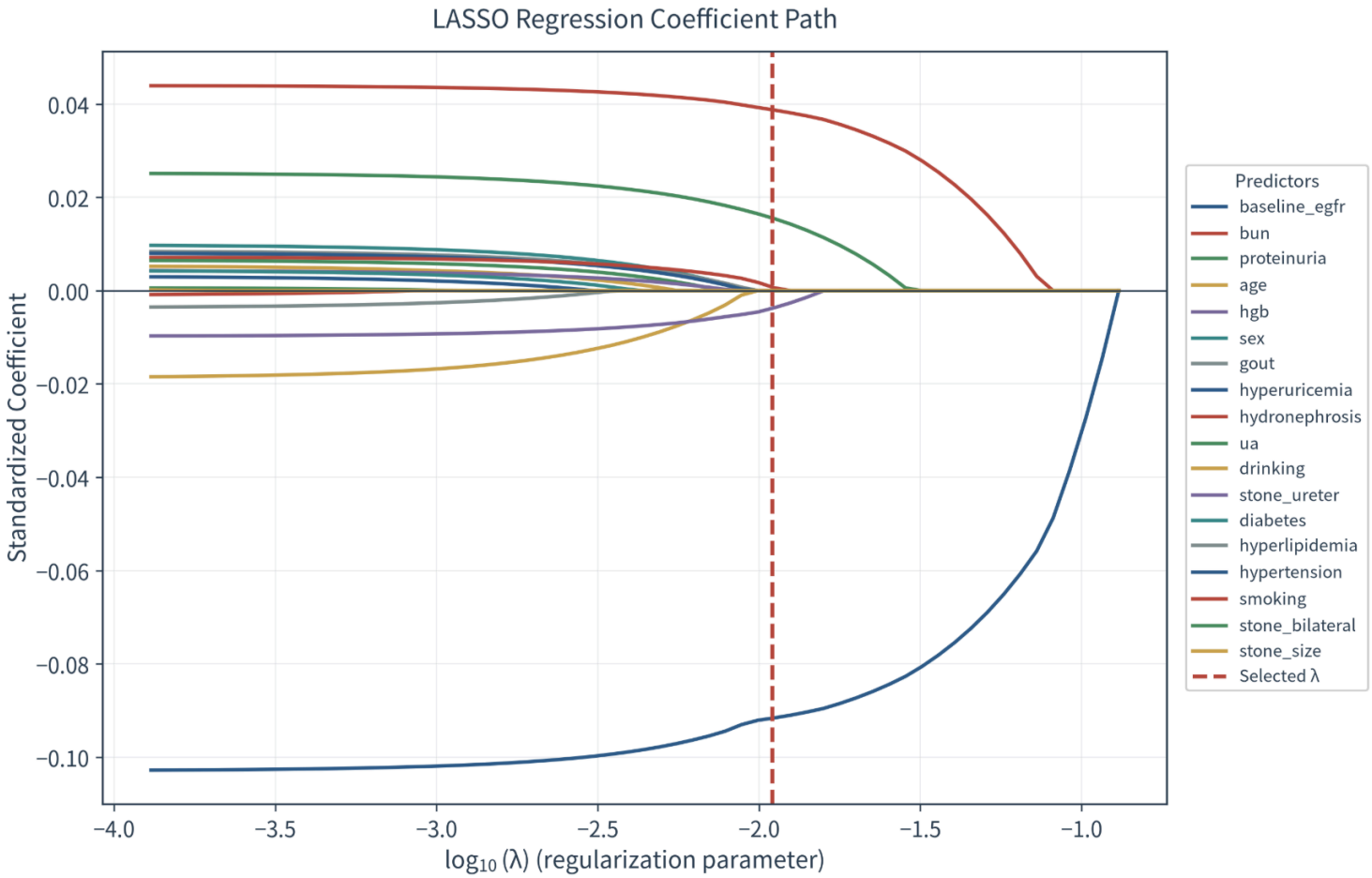


Figure 2

LASSO regression coefficient path. Standardized coefficient paths for 18 candidate predictors as a function of the regularization parameter log10(lambda). The dashed vertical line indicates the selected lambda. Variables with stable non-zero coefficients at the selected lambda were considered for inclusion in the final model.

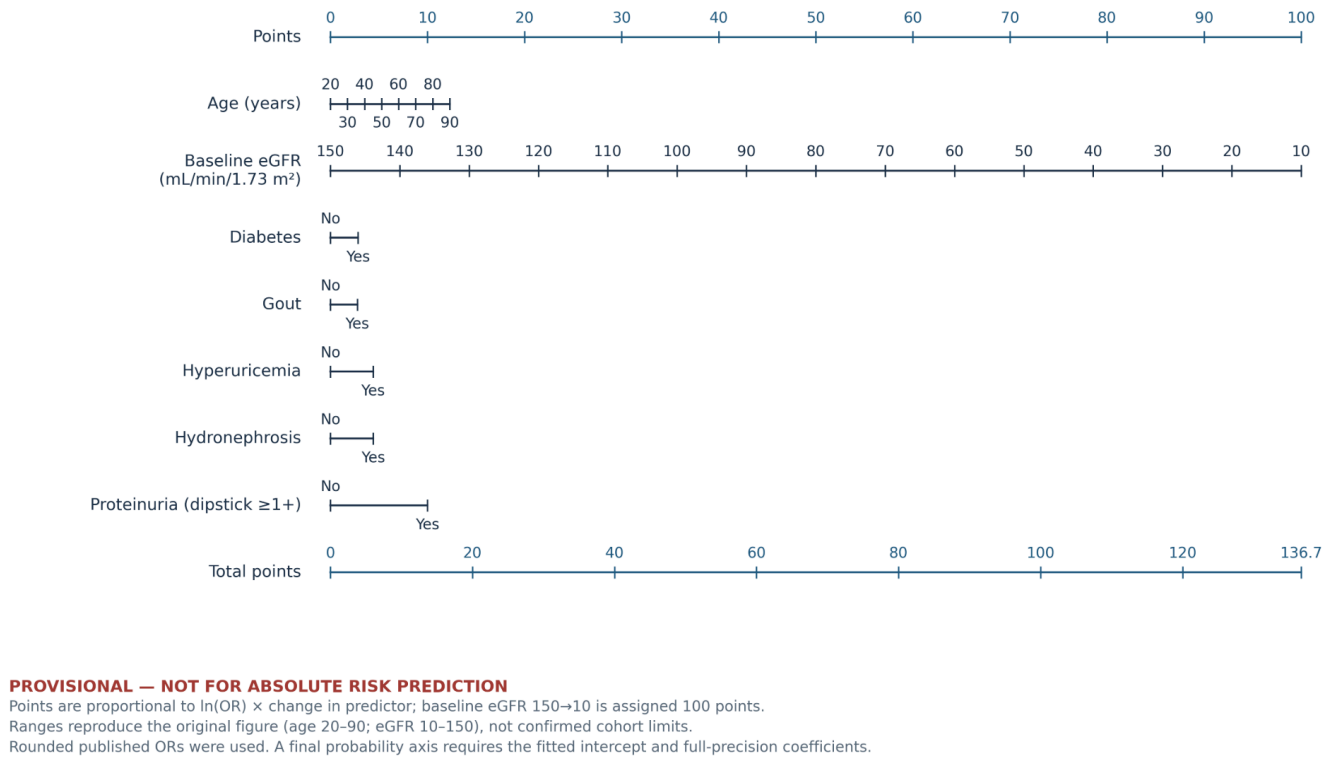


Figure 3

Nomogram for predicting 1-year postoperative rapid renal function decline. The nomogram integrates seven independent predictors. To use: locate each patient value on the corresponding variable axis, read the points assigned, sum the points across all variables, and locate the total on the Total Points axis to read the corresponding predicted probability of 1-year >=30% eGFR decline.

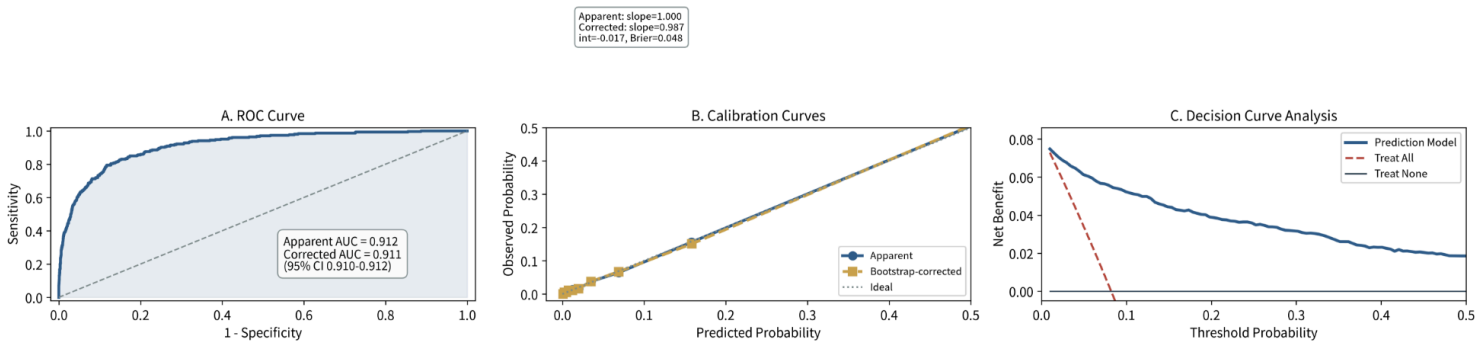


Figure 4

Model performance assessment. (A) Receiver operating characteristic (ROC) curve showing discrimination performance (apparent AUC=0.912; optimism-corrected AUC=0.911, 95% CI 0.910-0.912). (B) Calibration curves comparing apparent (blue circles) and bootstrap-corrected (gold squares) calibration against the

ideal diagonal; corrected calibration intercept=-0.017, slope=0.987 (95% CI 0.900-1.084), Brier score=0.048. (C) Decision curve analysis showing net benefit across threshold probabilities; the model (blue) outperforms treat-all (red dashed) and treat-none (black) strategies.

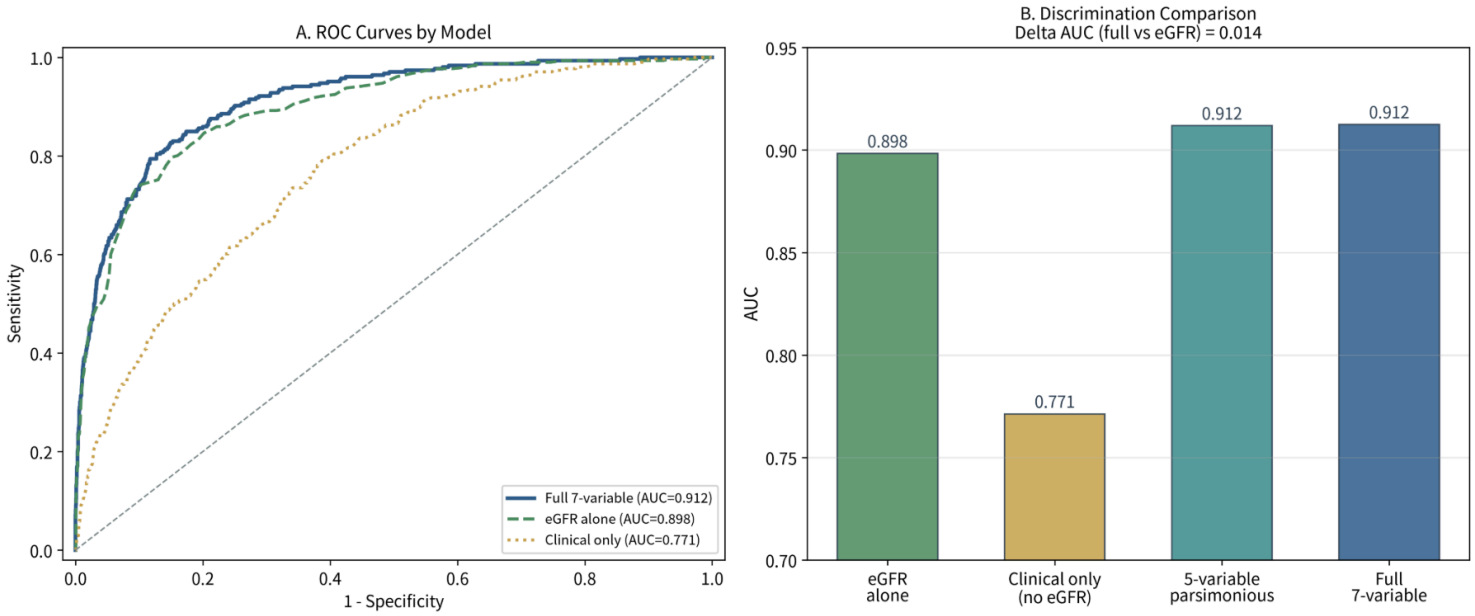


Figure 5

Sensitivity analysis: model comparison. (A) ROC curves comparing four models: full seven-variable (AUC=0.912), five-variable parsimonious (AUC=0.912), baseline eGFR alone (AUC=0.898), and clinical-only excluding eGFR (AUC=0.771). (B) Bar chart comparing AUC across models; Delta AUC (full vs eGFR alone)=0.014.

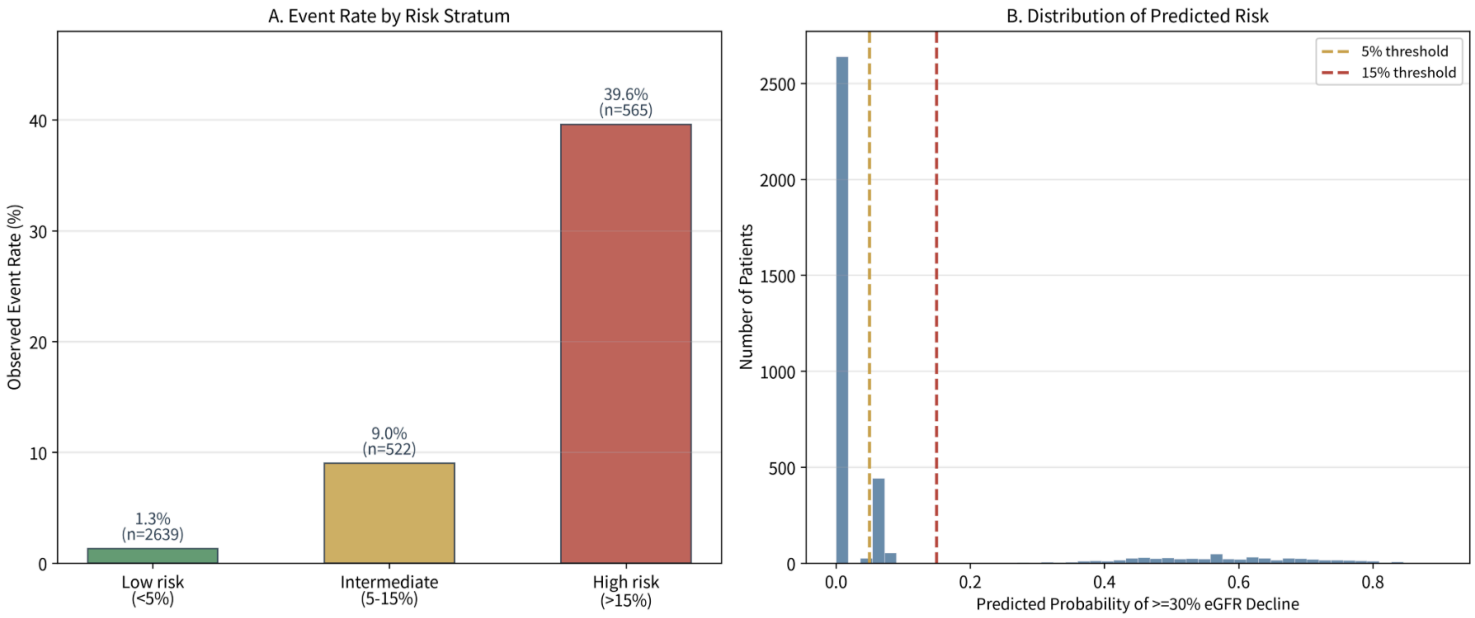


Figure 6

Risk stratification. (A) Observed event rates by risk stratum based on prespecified pragmatic predicted probability thresholds: low risk (<5%, event rate 1.3%), intermediate risk (5-15%, event rate 9.0%), and high risk (>15%, event rate 39.6%). (B) Distribution of predicted probabilities across the cohort, with vertical dashed lines indicating the 5% and 15% thresholds.