CANADIAN JOURNAL OF UROLOGY

Tech Science Press

Doi:10.32604/cju.2026.068291
ARTICLE

Association between the severity of acute renal colic episodes and clinical, laboratory, and imaging parameters

Kai Dang,[1,2#] Teng Cui,[1,2#] Yongan Zhou,[1,2] Jiayuan Ji,[1,2] Yang Yang,[1,2] Xiangyu Wang,[1,2] Jing Xiao,[1,2*]

[1]Department of Urology, Beijing Friendship Hospital, Capital Medical University, Beijing, China
[2]Institute of Urology, Beijing Municipal Health Commission, Beijing, China

DANG K, CUI T, ZHOU Y, JI J, YANG Y, WANG X, XIAO J. Association between the severity of acute renal colic episodes and clinical, laboratory, and imaging parameters. *Can J Urol* 2026;33(2):403–415.

Objectives: *Although renal colic is a well-known acute manifestation of urolithiasis, the relationship between its pain severity and a range of clinical parameters has not been clearly established by comprehensive studies. This study aimed to construct and validate a simple and accurate clinical nomogram for predicting the occurrence of more intense acute renal colic (ARC) in patients with urolithiasis.*

Methods: *The development and validation of the prediction model followed the reporting standards outlined in the TRIPOD checklist. A retrospective analysis was conducted on 285 patients who visited the Department of Urology at Beijing Friendship Hospital, Capital Medical University, from March 2024 to November 2024. Propensity score matching (PSM) of the raw observational data was conducted. This study utilized univariate, multivariate logistic, and linear regression analysis to screen and evaluate the risk factors for ARC pain intensity and constructed a predictive model. An evaluation was performed using the receiver operating characteristic curve (ROC), calibration curve, and decision curve analysis (DCA).*

Results: *Univariate analysis after PSM and linear logistic regression analysis identified independent risk factors for higher Visual Analog Scale (VAS) scores: serum creatinine (β-Coefficient = 0.364, 95% CI: 0.117–0.610, p = 0.005), pyuria (β-Coefficient = 0.273, 95% CI: 0.006–0.548, p = 0.042), hydronephrosis (β-Coefficient = 0.128, 95% CI: 0.073–0.254, p = 0.007), CRP levels (β-Coefficient = 0.311, 95% CI: 0.113–0.582, p = 0.018), and urinary bacteriuria ≥5/HPF (β-Coefficient = 0.324, 95% CI: 0.074–0.641, p = 0.018). The nomogram model demonstrated good accuracy with an AUC value of 0.964, and in the validation cohort, the AUC value was 0.969. The calibration curve indicated a better consistency between the predictive model and the actual occurrence of more intense ARC in patients with urolithiasis. The decision curve analysis showed favorable clinical utility.*

Conclusion: *Serum creatinine, pyuria, hydronephrosis, CRP levels, and urinary bacteriuria ≥5/HPF are independent risk factors for higher VAS scores. The constructed predictive model based on these factors effectively assesses the risk of more intense ARC in patients with urolithiasis.*

Key Words: acute renal colic, urolithiasis, predictive model, hydronephrosis, urinary tract infections;

Introduction

Urolithiasis is the formation of calculi in any part of the urinary system.[1] According to a 2024 meta-analysis encompassing 46 studies across 22 provinces in China, the pooled prevalence of urolithiasis in China is 8.1%, with significantly higher rates in southern regions versus northern regions. Approximately

Received date 24 May 2025
Accepted for publication 05 February 2026
Published online 15 April 2026

[#]These authors contributed equally to this work

*Corresponding Author: Jing Xiao.
Email: drxiao12345@163.com

10% of individuals of the global population will experience urolithiasis in their lifetime, with a recurrence risk of 50–70%.[2] Sex disparities are evident, with a prevalence of 10.9% in males and 7.1% in females.[3,4] Urolithiasis typically progresses insidiously, peaking around the age of 30, often necessitating hospitalization and surgical intervention.[5]

Acute renal colic (ARC), an acute manifestation of urolithiasis, has an annual incidence of 0.9–3 cases per 1000 individuals.[6] ARC is a common urological emergency and a leading cause of severe acute pain.[7,8] Most ARC cases arise from ureteral obstruction by calculi, termed ureteral colic. Therefore, all the patients with renal colic in this study were only those with ARC caused by urinary tract stones. Cases of ureteral colic caused by any other reasons were excluded. The International Association for the Study of Pain (IASP) defines pain as "an unpleasant sensory and emotional experience associated with actual or potential tissue damage".[9] Although the pathogenesis of ARC remains incompletely understood, the prevailing hypothesis is that ureteral obstruction by calculi triggers spasmodic contractions, leading to impaired urinary drainage, hydronephrosis, and elevated intrarenal pressure. This process activates stretch-sensitive nociceptors along the ureter that radiate pain to the renal capsule, collectively contributing to ARC.[10] Prolonged obstruction exacerbates intraluminal pressure, compresses renal and ureteral microvasculature, and induces ischemia, hypoxia, and metabolic disturbances. Inflammatory mediators such as prostacyclin (PGI2) and thromboxane A2 (TXA2) further alter renal hemodynamics, amplify nociceptive signaling, and worsen clinical outcomes. Notably, PGI2 and TXA2 levels exhibit marked differences between ARC episodes and remission phases, with elevated release during acute attacks.[11] PGI2 dilates renal arteries, enhances renal blood flow, and increases the glomerular filtration rate, promoting diuresis. However, during obstruction, this mechanism paradoxically elevates intraluminal pressure, exacerbating colic.[12] TXA2 intensifies ureteral smooth muscle contractions, leading to spasms and aggravated pain during obstruction.[13]

C-reactive protein (CRP) and the neutrophil-to-lymphocyte ratio (NLR) are critical biomarkers for diagnosis, monitoring, and therapeutic decision-making. Serum CRP and NLR levels predict spontaneous stone passage in urolithiasis patients with ARC. During acute episodes, CRP levels rise significantly and correlate positively with pain severity, indicating their involvement in pathogenesis and prognostic evaluation.[14,15]

Hematuria and pyuria are frequently observed during ARC. Microscopic hematuria exhibits a sensitivity of approximately 90% in urolithiasis patients; however, 40% of cases presenting with acute flank pain and hematuria are unrelated to urinary stones,[15] underscoring the need to perform urinalysis for differential diagnosis. Furthermore, urine nitrite positivity is a key indicator of concurrent urinary tract infection in urolithiasis patients.[16] Nevertheless, few studies have been conducted on the associations among nitrite positivity, bacteriuria, and ARC, prompting its inclusion as a correlation variable in this study. Mark et al. observed 560 urolithiasis patients and noted a higher incidence of ARC during warmer months, whereas humidity and barometric pressure showed no significant association.[17] This study was conducted from March to November to align with temperate climatic conditions and minimize environmental confounding.

Given the aforementioned findings, we aimed to investigate the correlation between pain severity and clinical, laboratory, and imaging parameters in urolithiasis patients during ARC episodes and the consistency of such correlations, with the aim of identifying the most relevant parameter clusters. These findings may assist clinicians in developing personalized treatment plans to alleviate patients' suffering. These findings are expected to provide systematic evidence for optimizing clinical diagnostic and therapeutic strategies.

Materials and Methods

This prediction model was developed and validated following the reporting guidelines specified in the TRIPOD (Transparent Reporting of a Multivariable Prediction Model for Individual Prognosis or Diagnosis) checklist (Supplementary Material S1).[18]

General information

A retrospective analysis was conducted on 285 adults from March 2024 to November 2024, including urolithiasis patients with or without ARC treated at the Department of Urology, Beijing Friendship Hospital, Capital Medical University. All procedures involving human participants were conducted in accordance with the ethical standards of the Research Committee of Beijing Friendship Hospital and the principles of the Declaration of Helsinki. All participants provided written informed consent before taking part in the study. All experimental protocols were approved by the Research Committee of Beijing Friendship Hospital (2025-P2-086-02).

All participants met the clinical diagnostic and inclusion criteria, did not meet the exclusion criteria, and had complete clinical data. The follow-up window was restricted to three months post-renal colic onset. Peak pain intensity after specimen collection, assessed by Visual Analog Scale (VAS) scores within 72 h of symptom initiation, and subsequent colic recurrences after this assessment were also identified. The total population was divided into three groups by VAS score (Figure 1). According to prospective research, indicating more intense ARC pain scores of 7.5,[8] so we established VAS = 7.5 as the cutoff value.

(1) High Pain Score with Urolithiasis Group (HR group): Patients with urolithiasis and ARC (VAS score $\geq$ 7.5).
(2) Low Pain Score with Urolithiasis Group (LR group): Patients with urolithiasis and ARC (VAS score $<$ 7.5).
(3) Asymptomatic Urolithiasis Group (S group): Patients with urolithiasis but no ARC.

Pain scores were assessed via telephone follow-up, where patients rated their pain intensity using the VAS (0: no pain; 10: maximum pain). Scores were documented in standardized case report forms. Demographic data (age, sex, height, weight, and body mass index [BMI]), laboratory tests (complete blood count, blood biochemistry, and urinalysis), and imaging results (abdominopelvic computed tomography [CT] and CT urography) were collected by double-person verification. Hematuria was defined as $\geq$5 red blood cells per high-power field (RBC/HPF). Pyuria was defined as $\geq$10 white blood cells per high-power field (WBC/HPF). More intense ARC was defined as VAS $\geq$ 7.5. Board-certified radiologists interpreted the imaging findings (e.g., stone size and hydronephrosis grade). All analyses were conducted on a complete

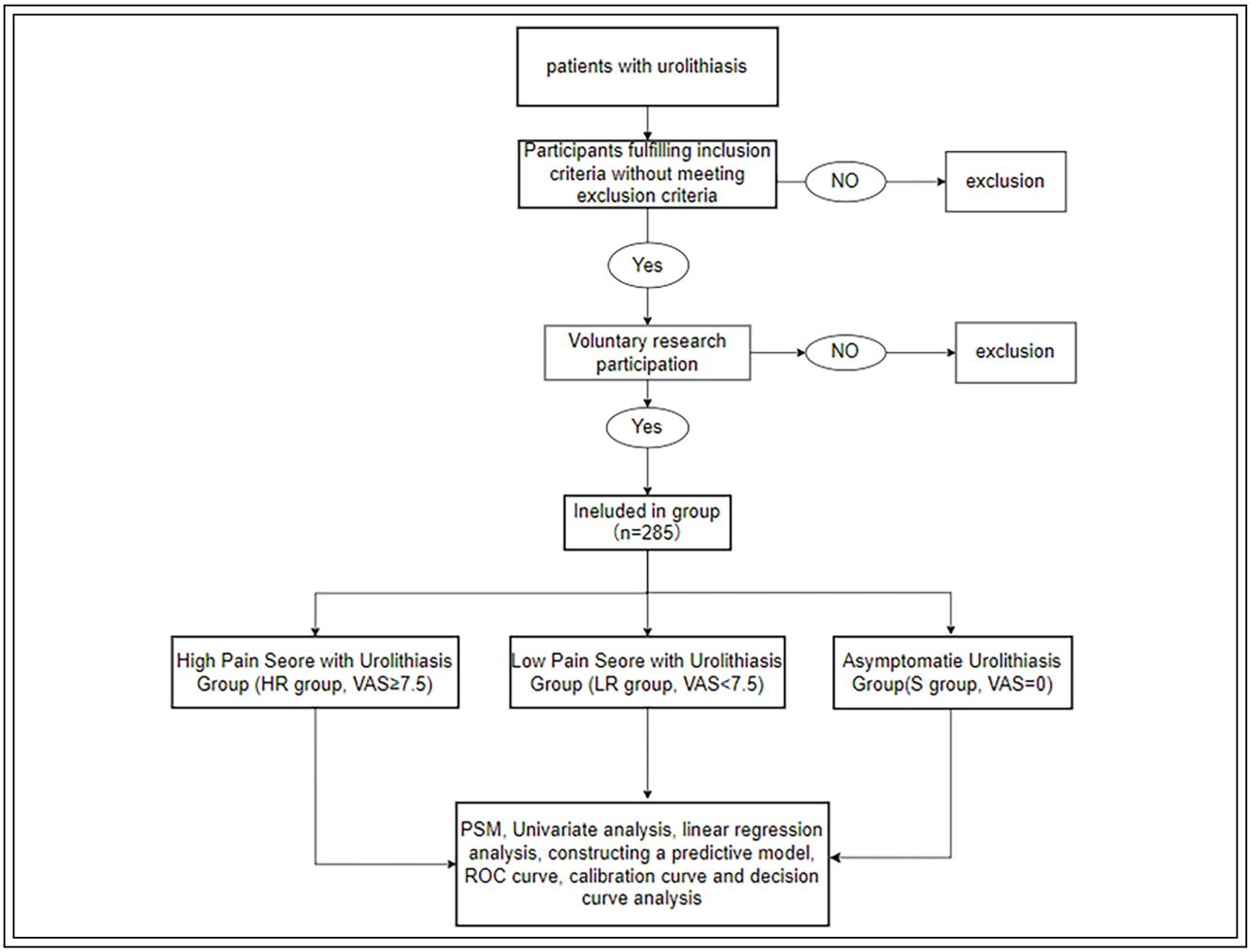

FIGURE 1. Patient flow chart. Note: VAS, Visual Analog Scale

case series, with no missing data across the study variables, ensuring data integrity.

Inclusion and exclusion criteria

Inclusion criteria

For HR Group: (i) Patients diagnosed with urolithiasis complicated by ARC through clinical manifestations and imaging studies; (ii) VAS score $\geq$ 7.5 after specimen collection; (iii) Adults aged 18–75 years who voluntarily participated in the study. (iv) Patients still exhibited persistent episodes of renal colic after specimen collection.

For LR Group: (i) Patients diagnosed with urolithiasis complicated by ARC through clinical manifestations and imaging studies; (ii) VAS score $<$ 7.5 after specimen collection; (iii) Adults aged 18–75 years who voluntarily participated in the study. (iv) Patients still exhibited persistent episodes of renal colic after specimen collection.

For S Group: (i) Patients diagnosed with urolithiasis without ARC through imaging studies; (ii) Adults aged 18–75 years who voluntarily participated in the study.

Exclusion criteria

Patients meeting any of the following criteria were excluded: (i) Ambiguous pain diagnosis (e.g., appendicitis, pyelonephritis, and gynecological diseases); (ii) Pregnancy; (iii) Bilateral or diffuse pain, or inability to assess pain scores; (iv) Age $<$ 18 years; (v) Acute abdominal symptoms requiring urgent intervention; (vi) Evidence of non-urinary tract infections; (vii) Hemodynamically unstable status; (viii) Incomplete clinical records; (ix) Unwillingness to participate or sign informed consent documentation; (x) Use of analgesics, muscle relaxants, or steroids within 12 h prior to enrollment or chronic use of these medications, leading to unreliable pain assessment.

Statistical methods

Data were analyzed using SPSS 26.0 software (IBM Corp., Armonk, NY, USA) and R software version 4.2.2 (R Foundation for Statistical Computing, Vienna, Austria, packages: rms, dcurves, dplyr and ggplot2). Quantitative data conforming to normal distribution are expressed as the mean $\pm$ standard deviation (Mean $\pm$ SD), while nonnormally distributed quantitative data are presented as the median (quartile) [M (P_{25}, P_{75})]. Categorical variables are described as the frequency (percentage) or composition ratio (%). For continuous variables, one-way analysis of variance (ANOVA) was applied for normally distributed data, and the Kruskal-Wallis test was used for nonnormally distributed data. Categorical data were analyzed using the Chi-square or rank-sum tests, as appropriate. Propensity score matching (PSM) with a caliper of 0.05 was performed at a 1:1 ratio between the HR+LR and S groups to adjust for age, sex, height, weight, BMI, and stone size. Using computer-generated randomization, patients were allocated to a training cohort and an internal validation cohort at a ratio of 7:3. The total sample size of 285 was determined to satisfy the requirement of >10 events per predictor variable (EPV $>$ 10) for model development. A separate validation set comprising 50 subjects was allocated to provide an initial, unbiased evaluation of model performance. In the training cohort, potential risk factors for higher VAS scores were first screened using univariate analysis. Variables reaching statistical significance ($p < 0.05$) were subsequently included in the linear and multivariate logistic regression analysis model to identify independent predictors. Based on the multivariate logistic regression results, a nomogram was developed to estimate the probability of more intense ARC. The model's performance was evaluated through internal validation. Discriminatory ability was measured by the area under the receiver operating characteristic (AUC-ROC). Calibration was assessed by plotting observed outcomes against predicted probabilities using a calibration curve generated from 1000 bootstrap samples, with the Hosmer-Lemeshow test ($p > 0.05$ indicating good fit). Finally, the clinical net benefit of applying the model was quantified across various probability thresholds using decision curve analysis (DCA). $p < 0.05$ was considered statistically significant. Diagnostic accuracy was classified as follows: low for AUC values between 0.6 and 0.7, moderate for 0.7 to 0.8, good for values greater than 0.8, and excellent for values greater than 0.9.

Results

Univariate analysis of factors associated with ARC episode severity

A total of 285 patients were initially enrolled in this study, including 166 males (58.25%) and 119 females (41.75%). After PSM, 166 patients were included in the final analysis, comprising 26 with more intense ARC (15.66%), 57 with low-pain ARC (34.34%), and 83 with painless stones (50.00%). Using computer-generated randomization, patients were allocated to a training cohort (n = 116) and an internal validation cohort (n = 50) at a ratio of 7:3. Univariate

analysis after matching revealed significant differences between groups in the following parameters: serum potassium ($p = 0.048$), WBC count ($p = 0.036$), CRP levels ($p < 0.001$), PCT ($p = 0.047$), serum creatinine ($p < 0.001$), BUN ($p = 0.042$), hematuria ($p = 0.029$), pyuria ($p < 0.001$), positive urinary nitrite ($p = 0.016$), urinary bacteriuria ≥5/HPF ($p < 0.001$), and hydronephrosis ($p < 0.001$), as shown in Table 1. No significant differences were observed in baseline characteristics between the modeling and validation cohorts ($p > 0.05$, Table 2).

Linear and multivariate logistic regression analysis of factors associated with ARC episode severity

Given the preceding univariate analysis, taking the VAS score as a continuous variable, a linear regression analysis was constructed to further identify independent risk factors influencing the severity of ARC episodes in urolithiasis patients. All variables with $p < 0.05$ in the univariate analysis after PSM were included as covariates. The assessed parameters comprised: WBC count, CRP levels, PCT, serum creatinine, BUN, hematuria, pyuria, urinary nitrite, urinary bacteriuria ≥5/HPF, and hydronephrosis. As shown in Table 3, serum creatinine (β-Coefficient = 0.364, 95% CI: 0.117–0.610, $p = 0.005$), pyuria (β-Coefficient = 0.273, 95% CI: 0.006–0.548, $p = 0.042$), hydronephrosis (β-Coefficient = 0.128, 95% CI: 0.073–0.254, $p = 0.007$), CRP levels (β-Coefficient = 0.311, 95% CI: 0.113–0.582, $p = 0.018$), and urinary bacteriuria ≥ 5/HPF (β-Coefficient = 0.324, 95% CI: 0.074–0.641, $p = 0.018$) were identified as independent risk factors for higher pain scores during ARC episodes. In contrast, no significant associations were observed between pain severity and leukocyte count, PCT levels, BUN, serum potassium levels, hematuria, and positive urinary nitrite ($p > 0.05$). Besides, more intense ARC was defined as VAS ≥ 7.5. Variables showing $p < 0.05$ in univariate screening were entered into a multivariable logistic regression model. Results, including β-coefficients, OR, and corresponding 95% CI for each predictor, are presented in Table A1.

TABLE 1. **Baseline characteristics of participants (HR+LR Group and S Group) before and after propensity score matching (PSM)**

Characteristics	Before PSM			After PSM		
	HR+LR Group (N = 153)	S Group (N = 132)	*p*-value	HR+LR Group (N = 83)	S Group (N = 83)	*p*-value
Age (years)	54.82 ± 12.74	53.53 ± 11.43	0.382	54.21 ± 11.92	54.38 ± 10.87	0.921
Male gender (%)	87 (56.90)	79 (59.80)	0.617	46 (55.42)	50 (60.24)	0.529
Stone size (cm)	0.94 ± 0.53	1.03 ± 0.52	0.523	0.95 ± 0.52	0.97 ± 0.44	0.782
Sodium (mmol/L)	139.42 ± 2.64	139.70 ± 1.89	0.300	139.79 ± 2.39	139.68 ± 2.16	0.743
Chloride (mmol/L)	106.47 ± 3.29	106.47 ± 2.17	>0.99	106.49 ± 3.11	106.49 ± 2.19	>0.99
Calcium (mmol/L)	2.32 ± 0.89	2.31 ± 0.92	0.925	2.31 ± 0.89	2.31 ± 0.74	>0.99
Height (m)	1.67 ± 0.08	1.69 ± 0.09	0.041*	1.67 ± 0.06	1.68 ± 0.12	0.521
Weight (kg)	74.76 ± 14.09	73.48 ± 11.32	0.402	74.15 ± 12.76	73.96 ± 10.52	0.917
BMI (kg/m^2)	26.14 ± 3.87	25.76 ± 3.11	0.347	26.13 ± 3.58	26.05 ± 2.98	0.873
potassium (mmol/L)	3.98 ± 0.68	3.93 ± 0.36	0.429	3.98 ± 0.52	3.91 ± 0.32	0.048*
WBC count (109/L)	6.91 (5.31, 7.65)	6.24 (5.94, 8.32)	0.008**	6.95 (5.41, 7.44)	6.18 (5.98, 7.32)	0.036*
CRP levels (mg/L)	3.96 (2.48, 5.65)	1.42 (0.72, 5.31)	<0.001***	3.96 (2.51, 5.63)	1.46 (0.76, 5.13)	<0.001***
PCT (ng/mL)	0.18 (0.11, 0.28)	0.15 (0.08, 0.25)	0.061	0.17 (0.12, 0.23)	0.15 (0.11, 0.24)	0.047*
Serum Creatinine (μmol/L)	124.15 (102.36, 156.62)	73.41 (65.71, 87.18)	<0.001***	112.25 (103.83, 138.16)	73.86 (68.95, 84.53)	<0.001***
BUN (mmol/L)	7.33 (5.66, 9.13)	5.63 (3.73, 7.24)	<0.001***	7.12 (5.76, 7.95)	6.12 (4.98, 7.22)	0.042*
Hematuria (%)	99 (64.71)	62 (46.97)	0.003**	52 (62.65)	38 (45.78)	0.029*
Pyuria (%)	44 (28.76)	20 (15.15)	0.016*	33 (39.76)	8 (9.64)	<0.001***
Positive urinary nitrite (%)	23 (15.03)	11 (8.33)	0.082	13 (15.66)	4 (4.82)	0.016*
Urinary bacteria ≥5/HPF (%)	49 (32.03)	24 (18.18)	0.008**	34 (40.96)	9 (10.84)	<0.001***
Hydronephrosis (%)	118 (77.12)	24 (18.18)	<0.001***	69 (83.13)	15 (18.07)	<0.001***

Note. Statistical methods: Categorical data were analyzed using the Chi-square or rank-sum tests; Non-normally distributed data [expressed as median (quartile), M (P_{25}, P_{75})] were analyzed using the Kruskal-Wallis test; Normally distributed data (expressed as Mean ± SD) were analyzed using one-way ANOVA; Statistical significance was defined as *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$. Abbreviations: VAS = visual analog scale; PSM = propensity score matching; BMI = body mass index; WBC = white blood cell; CRP = C-reactive protein; PCT = procalcitonin; BUN = blood urea nitrogen.

TABLE 2. **Study variables by data set grouping after propensity score matching (PSM)**

Variable		Total	Training Cohort	Validation Cohort	*p*-value
n		166	116	50	–
VAS, n (%)	≥ 7.5	26 (15.66)	18 (15.52)	8 (16.00)	0.874
	0–7.5	57 (34.34)	41 (35.34)	16 (32.00)	
	0	83 (50.00)	57 (49.14)	26 (52.00)	
Age (years), mean ± SD	continuous	54.30 ± 11.36	54.12 ± 11.58	54.76 ± 10.94	0.743
Gender, n (%)	male	96 (57.83)	68 (58.62)	28 (56.00)	0.856
	female	70 (42.17)	48 (41.38)	22 (44.00)	
Stone size (cm), mean ± SD	continuous	0.96 ± 0.48	0.95 ± 0.49	0.98 ± 0.46	0.692
Sodium (mmol/L), mean ± SD	continuous	139.74 ± 2.27	139.81 ± 2.32	139.58 ± 2.15	0.538
Chloride (mmol/L), mean ± SD	continuous	106.49 ± 2.68	106.42 ± 2.81	106.66 ± 2.36	0.592
Calcium (mmol/L), mean ± SD	continuous	2.31 ± 0.82	2.29 ± 0.85	2.36 ± 0.74	0.604
Height (m), mean ± SD	continuous	1.68 ± 0.09	1.67 ± 0.09	1.68 ± 0.10	0.512
Weight (kg), mean ± SD	continuous	74.06 ± 11.68	74.32 ± 12.01	73.44 ± 11.01	0.659
BMI (kg/m^2), mean ± SD	continuous	26.09 ± 3.29	26.17 ± 3.41	25.89 ± 3.01	0.605
potassium (mmol/L), mean ± SD	continuous	3.96 ± 0.43	3.95 ± 0.45	3.98 ± 0.38	0.691
WBC count (10^9/L), M (P_{25}, P_{75})	continuous	6.68 (5.88, 7.38)	6.72 (5.91, 7.41)	6.59 (5.82, 7.32)	0.834
CRP levels (mg/L), M (P_{25}, P_{75})	continuous	2.51 (0.99, 5.38)	2.63 (1.02, 5.45)	2.38 (0.95, 5.22)	0.723
PCT (ng/mL), M (P_{25}, P_{75})	continuous	0.15 (0.10, 0.21)	0.16 (0.10, 0.22)	0.14 (0.09, 0.20)	0.568
Serum Creatinine (μmol/L), M (P_{25}, P_{75})	continuous	89.7 (73.9, 112.3)	90.2 (74.3, 113.5)	88.6 (72.8, 109.4)	0.789
BUN (mmol/L), M (P_{25}, P_{75})	continuous	6.42 (5.37, 7.24)	6.38 (5.35, 7.21)	6.51 (5.42, 7.32)	0.655
Hematuria, n (%)	Yes	90 (54.22)	63 (54.31%)	27 (54.00%)	0.912
	No	76 (45.78)	53 (45.69%)	23 (46.00%)	
Pyuria, n (%)	Yes	41 (24.70)	28 (24.14%)	13 (26.00%)	0.783
	No	125 (75.30)	88 (75.86%)	37 (74.00%)	
Positive urinary nitrite, n (%)	Yes	17 (10.24)	11 (9.48%)	6 (12.00%)	0.641
	No	149 (89.76)	105 (90.52%)	44 (88.00%)	
Urinary bacteriuria ≥5/HPF, n (%)	Yes	43 (25.90)	30 (25.86)	13 (26.00)	0.985
	No	123 (74.10)	86 (74.14)	37 (74.00)	
Hydronephrosis, n (%)	Yes	84 (50.60)	58 (50.00%)	26 (52.00%)	0.856
	No	82 (49.40)	58 (50.00%)	24 (48.00%)	

Note. VAS, visual analog scale; PSM, propensity score matching; BMI, body mass index; WBC, white blood cell; CRP, C-reactive protein; PCT, procalcitonin; BUN, blood urea nitrogen. Statistical methods: Categorical data were analyzed using the Chi-square or rank-sum tests; Non-normally distributed data [expressed as median (quartile), M (P_{25}, P_{75})] were analyzed using the Kruskal-Wallis test; Normally distributed data (expressed as Mean ± SD) were analyzed using one-way ANOVA.

Development of the nomogram for predicting more intense ARC in patients with urolithiasis

Based on the training cohort, five independent predictors for more intense ARC in urolithiasis patients were identified through multivariate logistic regression analysis (Supplementary Table S1): serum creatinine, pyuria, hydronephrosis, CRP levels, and urinary bacteriuria ≥ 5/HPF. These variables were incorporated into a nomogram designed to estimate the probability of more intense ARC episodes. As illustrated in Figure 2, serum creatinine, hydronephrosis, and CRP levels provided the greatest contribution to the model's predictive capacity.

Validation of the nomogram model for predicting more intense ARC in patients with urolithiasis

The predictive model was subjected to three-dimensional validation in the internal validation cohort. First, discriminatory ability was evaluated using the AUC-ROC. As shown in Figure 3 and Table 4, the model exhibited strong differentiation, with AUC-ROC values of 0.964 (95% CI: 0.930–0.997) in the training cohort and 0.969 (95% CI: 0.930–1.000) in the validation cohort, outperforming any individual predictor in both cohorts. Second, calibration was assessed via calibration curves generated from 1000 bootstrap

TABLE 3. **Linear regression analysis of factors associated with pain severity during acute renal colic (ARC) episodes**

Variable	β-Coefficient	SE	*p*-value	95% CI
WBC count (continuous)	0.018	0.022	0.435	−0.032, 0.062
PCT (continuous)	0.124	0.132	0.524	−0.135, 0.383
CRP levels (continuous)	0.311	0.009	<0.001***	0.293, 0.329
Serum creatinine (continuous)	0.364	0.120	0.005**	0.117, 0.610
BUN (continuous)	−0.043	0.033	0.161	−0.113, 0.020
Serum potassium (continuous)	−0.032	0.122	0.805	−0.293, 0.241
Hydronephrosis (Reference: None)	0.128	0.086	0.007**	0.073, 0.254
Hematuria (Reference: Absence)	0.051	0.114	0.676	−0.186, 0.277
Pyuria (Reference: Absence)	0.273	0.133	0.042*	0.006, 0.548
Positive urinary nitrite (Reference: Negative)	−0.193	0.121	0.092	−0.431, 0.032
Urinary bacteriuria ≥5/HPF (Reference: <5/HPF)	0.324	0.137	0.018*	0.074, 0.641

Note. SE, standard error; CI, confidence interval; HPF, high-power field; WBC, white blood cell; PCT, procalcitonin; CRP, C-reactive protein; BUN, blood urea nitrogen. Reference groups: Absence of hydronephrosis, hematuria, pyuria, urinary nitrite positivity, or urinary bacteriuria <5/HPF. Statistical methods: Linear logistic regression adjusted for covariates with $p < 0.20$ in univariate analysis; Statistical significance was defined as $*p < 0.05$, $**p < 0.01$, $***p < 0.001$.

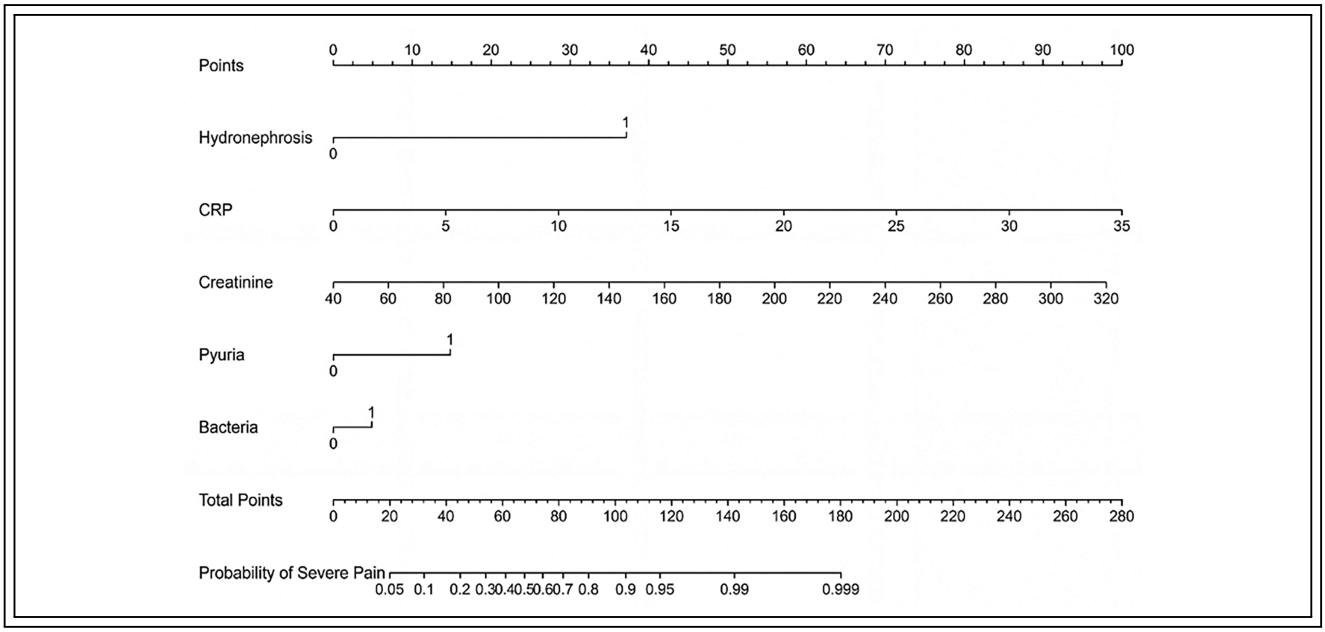

FIGURE 2. Prediction model of more intense ARC in patients with urolithiasis. Note. CRP, C-reactive protein.

samples and the Hosmer-Lemeshow goodness-of-fit test (Figure 4A,B). The curves indicated close agreement between predicted probabilities and observed outcomes, and the Hosmer-Lemeshow test demonstrated good fit without significant deviation ($p = 0.782$ in the training cohort and $p = 0.831$ in the validation cohort). Third, DCA performed on both cohorts (Figure 5A,B) revealed that the integrated model provided higher net clinical benefit than both "treat-all" and "treat-none" strategies across wide threshold probability ranges (0.04–0.95 in the training cohort, 0.05–0.99 in the validation cohort), supporting its favorable clinical utility.

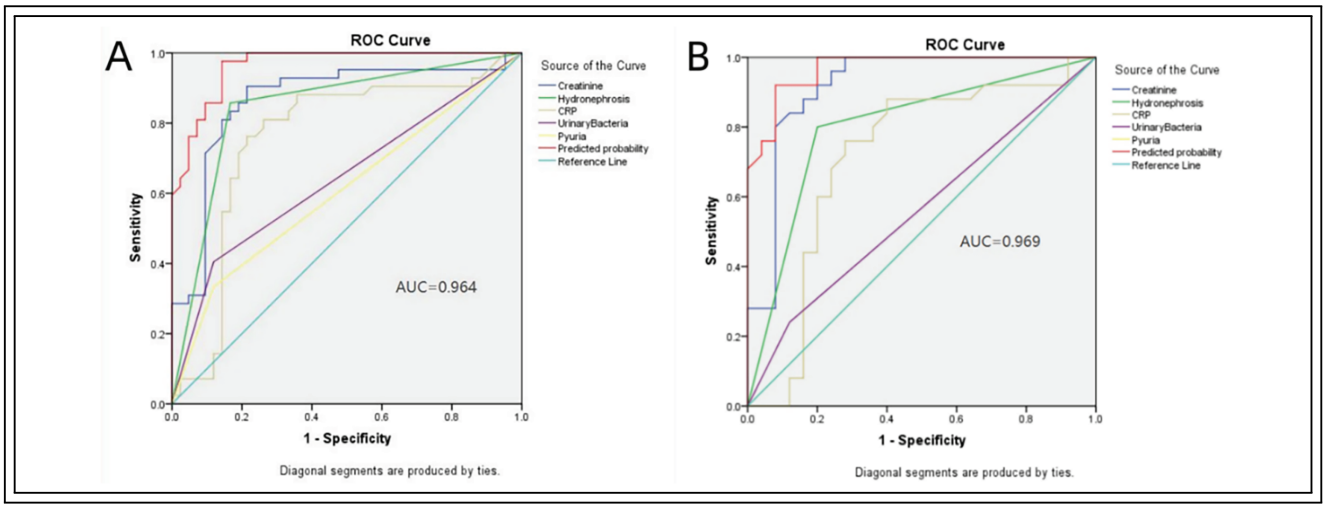

FIGURE 3. Receiver operating characteristic (ROC) curves of predictive factors for more intense acute renal colic (ARC) in patients with urolithiasis. (**A**) Training cohort, (**B**) Internal validation cohort. Note: AUC, area under the curve; CI, confidence interval; CRP, C-reactive protein

TABLE 4. **Predictive performance of indicators for acute renal colic (ARC)**

Cohort	Variables	Cut-off value	AUC	95% CI	Sensitivity	Specificity	*p*-value
Training cohort	Predicted probability	–	0.964	0.930, 0.997	–	–	<0.001***
	CRP (mg/L)	2.960	0.757	0.644, 0.870	0.762	0.738	<0.001***
	Serum creatinine (μmol/L)	105.680	0.865	0.780, 0.950	0.833	0.810	<0.001***
	Hydronephrosis	Presence	0.845	0.755, 0.935	0.857	0.833	<0.001***
	Pyuria	Presence	0.607	0.486, 0.728	0.333	0.881	0.091
	Urinary bacteria ≥5/HPF	Presence	0.643	0.524, 0.762	0.405	0.881	0.082
Validation cohort	Predicted probability	–	0.969	0.930, 1.000	–	–	<0.001***
	CRP (mg/L)	2.958	0.714	0.571, 0.857	0.840	0.880	0.009**
	Serum creatinine (μmol/L)	107.340	0.919	0.838, 1.000	0.760	0.720	<0.001***
	Hydronephrosis	Presence	0.800	0.676, 0.924	0.800	0.800	<0.001***
	Pyuria	Presence	0.500	–	0.200	0.800	>0.99
	Urinary bacteria ≥5/HPF	Presence	0.560	0.400, 0.720	0.240	0.880	0.467

Note. Statistical methods: ROC curve analysis; Statistical significance was defined as $^{**}p < 0.01$, $^{***}p < 0.001$. Abbreviations: AUC = area under the ROC curve; CI = confidence interval; CRP = C-reactive protein.

Predictive performance of indicators for more intense ARC in patients with urolithiasis

As illustrated in Figure 3A,B and Table 4, in the training cohort, the ROC analysis indicated that serum creatinine and hydronephrosis demonstrated good predictive ability for the intensity of ARC, while serum CRP showed moderate predictive performance. The AUC for serum creatinine was 0.865 ($p < 0.001$), with an optimal cut-off value of 105.68 μmol/L, corresponding to a sensitivity of 83.3% and a specificity of 81.0% in predicting ARC. Hydronephrosis yielded an AUC of 0.845 ($p < 0.001$), with a

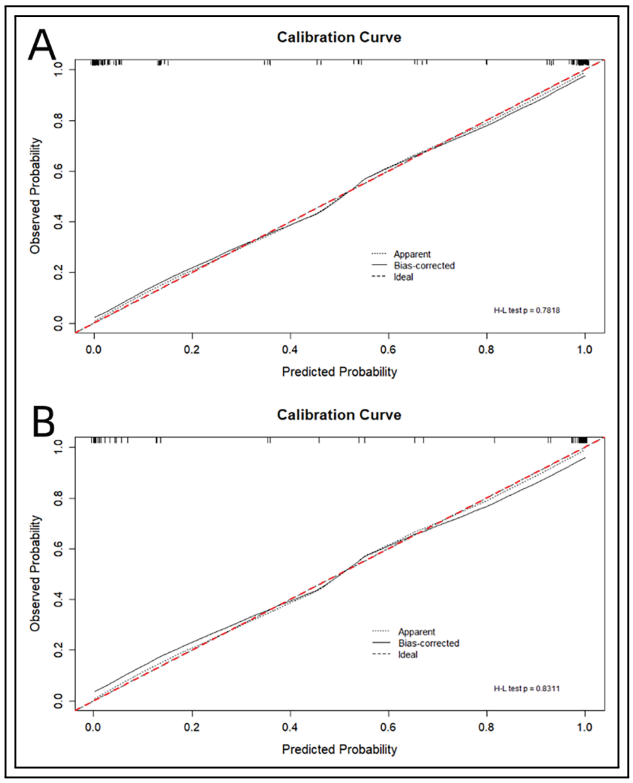

FIGURE 4. Calibration curves of the nomogram for predicting more intense ARC. (**A**) Training cohort; (**B**) Internal validation cohort. Note. The solid line is the calibration curve, the dotted line is the ideal reference line, and the dotted line is the actual curve

sensitivity of 85.7% and a specificity of 83.3%. For serum CRP, the AUC was 0.757 ($p < 0.001$); the optimal cut-off value was 2.960 mg/L, which provided a sensitivity of 76.2% and a specificity of 73.8% for ARC prediction. The internal validation cohort yielded results largely consistent with those from the training cohort. The AUC-ROC values for the training and validation cohorts were 0.964 and 0.969.

Discussion

This study investigated the association between the severity of urolithiasis-related ARC and clinical, laboratory, and imaging parameters. No significant associations were observed between pain severity and demographic parameters such as age, gender, height, or weight ($p > 0.05$). Notably, pyuria showed a strong correlation with pain intensity in univariate and multivariate analysis ($p < 0.001$), consistent with the findings ($p = 0.015$) of a prospective study by Shrirang and Nidhi.[19] Accordingly, we hypothesize that higher pain scores in patients with pyuria may result from concurrent UTIs, which are often exacerbated by urinary stasis caused by calculi. Previous studies have identified bacteriuria as a critical predictor of infection-related ARC.[16] For instance, in a cohort of 100 ARC patients, 36% exhibited bacteriuria, further supporting its statistical relevance.[20] Hematuria also showed a correlation with pain intensity in univariate analysis ($p = 0.029$), aligning with findings by Lallas et al.[21] and Sasmaz and Kirpat,[8] who reported higher mean VAS scores in patients with hematuria ($p \leq 0.001$). Mechanistically, mucosal injury during difficult ureteral stone passage may amplify nociceptive signaling, which is accompanied by hematuria and local inflammatory reaction resulting from mucosal injury. In inflammatory conditions such as infection or trauma, the levels of acute-phase reactants such as leukocytes and CRP increase rapidly.[8,22] CRP, a well-established inflammation biomarker, demonstrated a significant correlation with ARC severity ($p < 0.001$). Furthermore, serum Na^+, Cl^-, and other ion concentrations showed no correlation with ARC, consistent with the findings of Hermieu and Prévot, suggesting that urolithiasis-related pain is not directly linked to systemic electrolyte imbalances.[23] Although serum potassium demonstrated a significant association in univariate analysis ($p = 0.048$), likely due to its role as an algogenic ion, it was not retained in the multivariate model. This indicates that while it may contribute to pain locally, its effect is not a specific independent predictor in the broader clinical context of severe ARC.

Renal colic is caused by increased intraluminal pressure within the collecting system and heightened ureteral wall tension resulting from acute obstruction. The presence of a lodged stone accompanied by hydronephrosis initiates this cascade, leading to sustained isometric ureteral contractions. These contractions activate inflammatory pathways and cause muscular ischemia. Such pathophysiological alterations stimulate both Aδ- and C-fibers, resulting in the characteristic pain of renal colic. Within the first 90 min of hydronephrosis, prostacyclin and prostaglandin E2 (PGE2) promote the dilation of the afferent arterioles, thereby increasing intraluminal pressure and renal blood flow.[24] Between 90 min and 5 h after the onset of obstruction, TXA2 and angiotensin II (Ang II) induce efferent arteriole vasoconstriction. During this phase, ureteral pressure reaches its peak, corresponding to the maximum pain intensity.[25] Moreover, mammalian models of ureteral obstruction demonstrate that acute unilateral proximal ureteral

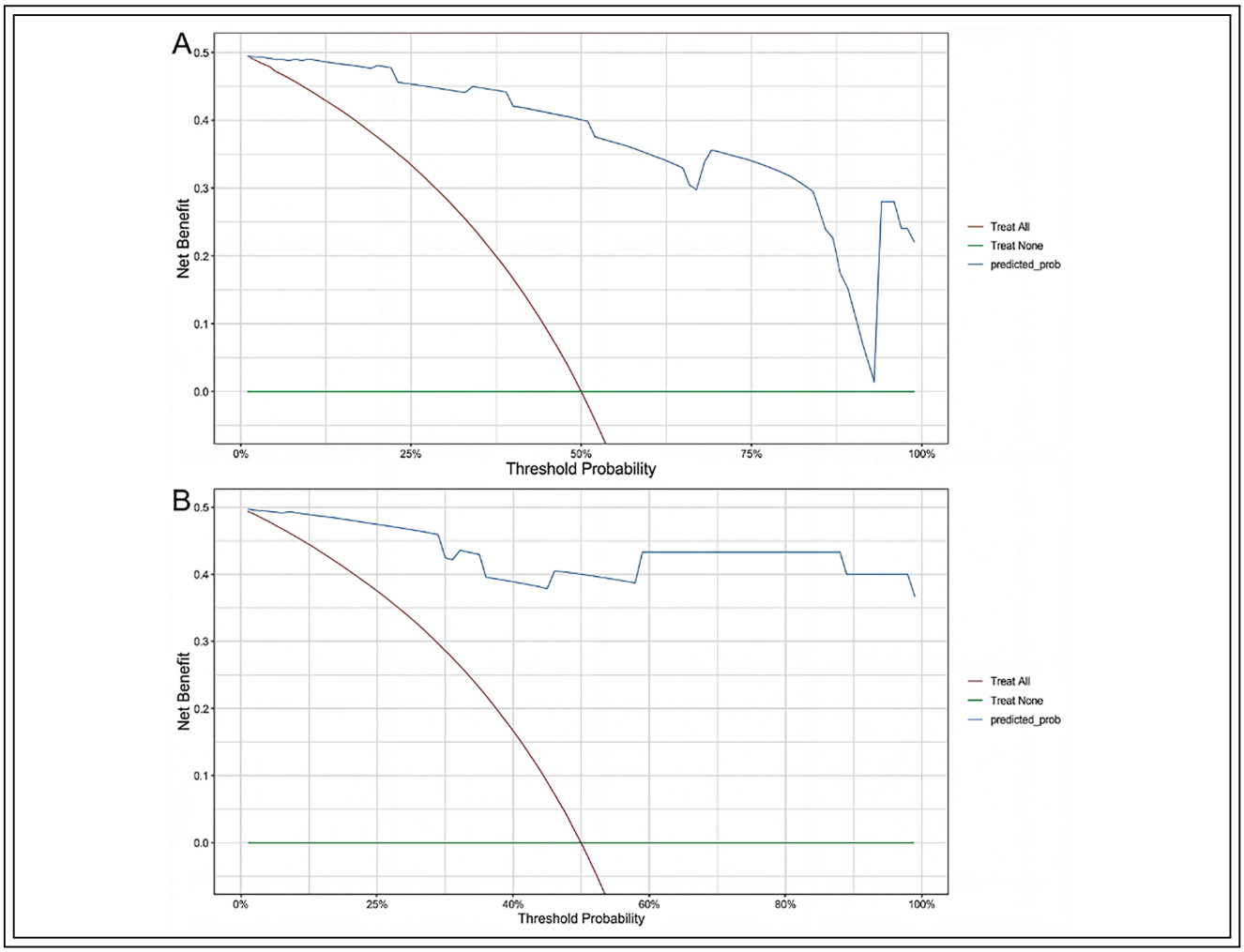

FIGURE 5. Decision curve analysis of nomogram prediction model for predicting more intense acute renal colic (ARC). (**A**) Training cohort; (**B**) Validation cohort

obstruction leads to a rapid increase in renal pelvic pressure, rising from approximately 10 mmHg to 55.6 ± 15.5 mmHg within 1 min. This abrupt elevation in pressure is accompanied by behavioral signs of distress, suggesting the existence of a potential pain threshold in mammals.[26] In clinical contexts, patients with post-renal injury also exhibit significantly elevated levels of kidney injury molecule-1 (KIM-1) in the serum and urine, decreased glomerular filtration rates, and increased creatinine concentrations.[27] Mechanistically, the intracellular domain of KIM-1 contributes to pain signal transduction and promotes the upregulation of neutrophil gelatinase-associated lipocalin (NGAL) expression,[28] whereas its extracellular domain functions as a proinflammatory mediator that enhances cytokine-induced pain responses.[29]

Regarding imaging parameters, chi-square analysis confirmed a significant association between hydronephrosis and ARC severity ($p < 0.001$). Shrirang and Kaeley similarly reported that hydronephrosis severity correlates with pain intensity, likely due to increased renal pelvic pressure and ureteral distension. Pathophysiologically, elevated upstream pressure during acute obstruction triggers renal capsular stretching and nociceptor activation.[19] Kruskal-Wallis tests revealed a significant association between serum creatinine levels and pain severity ($p < 0.001$). Unlike serum creatinine, BUN was excluded from the multivariate analysis, suggesting that its elevation may reflect transient glomerular filtration rate reduction or stress-induced catabolism rather than a primary risk factor. This finding provides a new perspective on the

clinical differentiation between acute compensation and the chronic progression of renal function injury.[30] Notably, existing evidence indicates that sharply angulated, highly mobile calcium oxalate stones (particularly the predominant monohydrate and dihydrate subtypes) correlate strongly with severe renal colic.[31,32] However, postprocedural failure to obtain specimens precluded stone composition analysis in this cohort, potentially confounding our findings. Future studies should incorporate stone morphology and compositional profiling. Additionally, as a single-center study conducted in Beijing, our results may reflect certain geographical specificities in urolithiasis epidemiology and clinical practices. Future multi-center studies are needed to validate our findings.

According to the latest EAU 2025 guidelines, clear intervention criteria for managing renal colic remain inadequately defined.[33] In this study, a nomogram was developed based on independent risk factors derived from multivariate logistic regression to estimate the probability of more intense ARC in patients with urolithiasis. The model demonstrated strong performance in discrimination, calibration, and clinical utility. These results suggest that our predictive tool holds meaningful clinical relevance, offering urologists informative guidance for identifying high-risk patients who may benefit from earlier or more intensive intervention to prevent severe colic episodes. This study analysis indicated that serum creatinine and the hydronephrosis exhibited high predictive value for the occurrence of more intense ARC, and the predictive value of CRP was moderate. This discrepancy may be attributed to the ureteral wall's higher sensitivity to mechanical tension compared to mild inflammatory stimuli. Therefore, clinicians should promptly evaluate imaging and renal function parameters in patients with urolithiasis. We recommend that these two parameters be incorporated as evidence-based triage criteria for emergency physicians to prioritize hospitalization and treatment management in patients with suspected renal colic.

The present study had some limitations. Stone composition analysis (e.g., calcium phosphate stones, which may cause greater mucosal injury due to surface roughness) was not included. Long-term follow-up data were unavailable; thus, we could not assess the correlations between pain intensity and renal functional outcomes. In addition, one limitation of this study is that data collection was conducted after the onset of renal colic symptoms. Although we employed multiple analytical approaches and validated the predictive performance of the model, and confirmed that patients experienced recurrent colic episodes after parameter measurement, it remains possible that the measured parameters may reflect concurrent physiological alterations rather than purely predictive biomarkers, which could introduce some degree of confounding to the predictions. Besides, the validation strategy relied on a single random data split from a mono-centric cohort, an approach that inherently yields a validation set of limited size. Consequently, the performance metrics, including the notably high AUC, should be viewed as preliminary estimates that may be optimistic. The potential for overfitting cannot be fully dismissed despite the internal calibration results. Thus, the primary limitation lies in the need for rigorous external validation across diverse settings to substantiate the model's robustness and true clinical utility.

Conclusions

Serum creatinine, pyuria, hydronephrosis, CRP levels, and urinary bacteriuria ≥5/HPF are independent risk factors for higher VAS scores. The constructed nomogram based on these factors effectively assesses the risk of more intense ARC in patients with urolithiasis.

Acknowledgement

The authors gratefully acknowledge all patients participating in this study and the healthy volunteers who served as controls. We sincerely thank them for contributing their clinical, laboratory, imaging results, and demographic information. We thank LetPub (www.letpub.com.cn) for its linguistic assistance during the preparation of this manuscript.

Funding Statement

This work was partially supported by Beijing Key Clinical Specialty Project (20240930; Jing Xiao; https://wjw.beijing.gov.cn/xwzx_20031/jcdt/202410/t20241014_3920507.html); Capital Health Research and Development Program (Key Research Projects: No. 2024-1-4072; Jing Xiao; https://wjw.beijing.gov.cn/zwgk_20040/tzgg/202312/t20231207_3493300.html); Beijing Physician Scientist Training Project (BJPSTP-2024-30; Yang Yang); National Natural Science Foundation of China (82000717; Yang Yang; https://kd.nsfc.cn/finalDetails?id= 5a6dbf37aa3d6

d7f34cd08dcae268a5b); Beijing Hospitals Authority Youth Programme (code: QML20190106; Yang Yang); National Key Clinical Specialty Project (20250829; Jing Xiao; https://www.bfh.com.cn/Html/News/Articles/8295.html).

Author Contributions

Conception and design: Kai Dang, Jing Xiao, and Teng Cui; Data collection: Kai Dang, Teng Cui, Yongan Zhou, Jiayuan Ji, and Jing Xiao; Analysis and interpretation of results: Kai Dang, Yang Yang, Xiangyu Wang, and Jing Xiao; Draft preparation: Kai Dang, Teng Cui, Xiangyu Wang, and Jing Xiao. All the authors reviewed and approved the final version of the manuscript.

Availability of Data and Materials

All raw data from this study are included in this published article and its supplementary information files. The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Ethics Approval

All procedures involving human participants were conducted in accordance with the ethical standards of the Research Committee of Beijing Friendship Hospital and the principles of the Declaration of Helsinki. All participants provided written informed consent before taking part in the study. All experimental protocols were approved by the Research Committee of Beijing Friendship Hospital (2025-P2-086-02).

Conflicts of Interest

The authors declare no conflicts of interest.

Supplementary Materials

The supplementary material is available online at https://www.techscience.com/doi/10.32604/cju.2026.068291/s1.

Appendix A

TABLE A1. **Multivariate logistic regression analysis of factors associated with pain severity during ARC episodes**

Variables	β-Coefficient	OR	95% CI	*p*-value
WBC (For every increase of 1×10^9/L)	0.018	1.018	0.977, 1.061	0.387
PCT (For every increase of 1 ng/mL)	0.048	1.049	0.892, 1.234	0.563
CRP (For every increase of 10 mg/L)	1.805	6.080	1.239, 29.832	0.026*
Serum creatinine (For every increase of 10 μmol/L)	0.226	1.253	1.030, 1.526	0.024*
BUN (For every increase of 1 mmol/L)	0.008	1.008	0.964, 1.055	0.727
Serum potassium (For every increase of 1 mmol/L)	0.088	1.092	0.766, 1.557	0.627
Hydronephrosis (Reference: None)	2.369	10.684	2.530, 45.128	<0.001***
Hematuria (Reference: Absence)	0.168	1.183	0.464, 3.017	0.725
Pyuria (Reference: Absence)	0.885	2.422	1.050, 5.586	0.038*
Positive urinary nitrite (Reference: Negative)	0.379	1.461	0.608, 3.508	0.397
Urinary bacteria ≥5/HPF (Reference: <5/HPF)	0.316	1.372	1.012, 1.860	0.041

Note. Reference groups: Absence of hydronephrosis, hematuria, pyuria, urinary nitrite positivity, or urinary bacteria <5/HPF; Statistical methods: Multivariate logistic regression adjusted for covariates with $p < 0.05$ in univariate analysis; Significance: *$p < 0.05$ and ***$p < 0.001$ indicate statistical significance. Abbreviations: OR = odds ratio; CI = confidence interval; HPF = high-power field; WBC = white blood cell count; PCT = procalcitonin; CRP = C-reactive protein; BUN = blood urea nitrogen.

References

1. Huang H, Li M, Fan H, et al. Temporal trend of urolithiasis incidence in China: an age-period-cohort analysis. *Int J Gen Med* 2021;14:2533–2539.
2. Kachkoul R, Touimi GB, El Mouhri G, et al. Urolithiasis: history, epidemiology, aetiologic factors and management. *Malays J Pathol* 2023;45(3):333–352.
3. Tan S, Yuan D, Su H, et al. Prevalence of urolithiasis in China: a systematic review and meta-analysis. *BJU Int* 2024;133(1):34–43.
4. Ferraro PM, Taylor EN, Gambaro G, et al. Dietary and lifestyle risk factors associated with incident kidney stones in men and women. *J Urol* 2017;198(4):858–863.
5. Liu Y, Chen Y, Liao B, et al. Epidemiology of urolithiasis in Asia. *Asian J Urol* 2018;5(4):205–214.
6. Fontenelle LF, Sarti TD. Kidney stones: treatment and prevention. *Am Fam Physician* 2019;99(8):490–496.
7. Holdgate A, Pollock T. Systematic review of the relative efficacy of non-steroidal anti-inflammatory drugs and opioids in the treatment of acute renal colic. *BMJ* 2004;328(7453):1401.
8. Sasmaz M, Kirpat V. The relationship between the severity of pain and stone size, hydronephrosis and laboratory parameters in renal colic attack. *Am J Emerg Med* 2019;37(11): 2107–2110.
9. Raja SN, Carr DB, Cohen M, et al. The revised international association for the study of pain definition of pain: concepts, challenges, and compromises. *Pain* 2020;161(9):1976–1982.
10. Golzari SE, Soleimanpour H, Rahmani F, et al. Therapeutic approaches for renal colic in the emergency department: a review article. *Anesthesiol Pain Med* 2014;4(1):e16222.
11. Hoffman A, Braun MM, Khayat M. Kidney disease: kidney stones. *FP Essentials* 2021;509:33–38.
12. Wang MR, Ji JX, Lai JH, et al. Choice of medical treatment for renal colic: A survey of Chinese urologists. *Beijing Da Xue Xue Bao Yi Xue Ban = J Peking Univ Health Sci* 2023;55(5): 871–875.
13. Zwergel U, Zwergel T, Leis HJ, et al. Eicosanoid synthesis in the isolated human renal pelvis, ureter and bladder. *Br J Urol* 1991;67(3):246–250.
14. Ahmad A, Mahmood K, Kumar N, et al. Predictive value of C-reactive protein in the spontaneous passage of lower ureteric stones: a prospective single-centre study. *Cureus* 2024;16(6):e62669.
15. Wren JA, Lally A. Renal colic: streamlining investigations to improve patient outcomes in emergency medicine. *Emerg Med Aust* 2025;37(1):e14551.
16. Rosenhammer B, Spachmann PJ, Burger M, et al. Prospective evaluation of predictive parameters for urinary tract infection in patients with acute renal colic. *J Emer Med* 2018;55(3):319–326.
17. Mark S, Shemesh A, Raz O, et al. Effect of climate on emergency department admissions for renal colic: a comparative analysis of sedentary and non-sedentary lifestyles. *World J Urol* 2024;42(1):417.
18. Collins GS, Reitsma JB, Altman DG, et al. Transparent reporting of a multivariable prediction model for individual prognosis or diagnosis (TRIPOD): the TRIPOD statement. *BMJ* 2015;350:g7594.
19. Joshi SS, Kaeley N, Nagasubramanyam V, et al. Correlation of severity of renal colic with clinical, laboratory, and radiological parameters: an emergency department-based prospective observational study. *Cureus* 2022;14(11):e31277.
20. Tavichakorntrakool R, Prasongwattana V, Sungkeeree S, et al. Extensive characterizations of bacteria isolated from catheterized urine and stone matrices in patients with nephrolithiasis. *NepNephrol Dial Transplant* 2012;27(11):4125–4130.
21. Lallas CD, Liu XS, Chiura AN, et al. Urolithiasis location and size and the association with microhematuria and stone-related symptoms. *J Endourol* 2011;25(12):1909–1913.
22. Mester P, Birner C, Schmid S, et al. Elevated plasma soluble lectin-like oxidised low-density lipoprotein receptor 1 as an independent prognostic biomarker in sepsis. *Lipids Health Dis* 2025;24(1):47.
23. Hermieu JF, Prévot MH, Ravery V, et al. [Nephritic colic due to indinavir]. *Presse Med* 1998;27(10):465–467.
24. Lanzone JA, Gulmi FA, Chou SY, et al. Renal hemodynamics in acute unilateral ureteral obstruction: contribution of endothelium-derived relaxing factor. *J Urol* 1995;153(6):2055–2059.
25. Travaglini F, Bartoletti R, Gacci M, et al. Pathophysiology of reno-ureteral colic. *Urol Int* 2004;72(Suppl 1):20–23.
26. Moriel E, Krausz M, Farkas A. Effect of indomethacin on unilateral obstructed renal pelvis and on ureteral peristalsis. Experimental study in awake sheep. *Euro Urol* 1990;18(3):222–226.
27. Urbschat A, Gauer S, Paulus P, et al. Serum and urinary NGAL but not KIM-1 raises in human postrenal AKI. *Euro J Clin Invest* 2014;44(7):652–659.
28. Majumder S, Pushpakumar S, Juin SK, et al. Toll-like receptor 4 mutation protects the kidney from Ang-II-induced hypertensive injury. *Pharmacol Res* 2022;175:106030.
29. van Timmeren MM, van den Heuvel MC, Bailly V, et al. Tubular kidney injury molecule-1 (KIM-1) in human renal disease. *J Pathol* 2007;212(2):209–217.
30. Wang M, Yang N, Wu X, et al. Insight into nephrotoxicity and processing mechanism of *Arisaema erubescens* (Wall.) Schott by metabolomics and network analysis. *Drug Des Devel Ther* 2023;17:1831–1846.
31. Pérez JA, Palmes Mde L, Ferrer JF, et al. Renal colic at emergency departments. Epidemiologic, diagnostic and etiopathogenic study. *Arch Esp Urol* 2010;63(3):173–187.
32. Glazer K, Brea IJ, Leslie SW, et al. Ureterolithiasis. Treasure Island, FL, USA: StatPearls Publishing. 2025 [cited 2026 Jan 1]. Available from: https://pubmed.ncbi.nlm.nih.gov/32809509/.
33. Safaie A, Tavoli M, Babaniamansour S, et al. Intravenous morphine plus ibuprofen or ketorolac versus intravenous morphine alone in reducing renal colic pain intensity in emergency department: a randomized, double-blind clinical trial. *Turk J Emerg Med* 2022;22(1):8–14.