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Research article

Construction of an alignment diagram model for predicting calculous obstructive pyonephrosis before PNL

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A R T I C L E I N F O

Keywords:
Pyonephrosis
Nephrostomy
Percutaneous nephrolithotomy
Alignment diagram
Prediction

A B S T R A C T

Background: To develop a model for the accurate prediction of calculous obstructive pyonephrosis prior to percutaneous nephrolithotomy (PNL), leading to early local anaesthesia microchannel nephrostomy for drainage of pyonephrosis.

Methods: By comparing the differences in baseline clinical indicators between the pyonephrosis group and nonpyonephrosis groups, independent risk factors were screened out, and a diagnostic alignment diagram model for predicting calculus obstructive pyonephrosis before PNL was established.

Results: Multivariate regression analysis showed that preoperative blood neutrophil count (Neu), serum creatinine level (Scr), serum albumin level (Alb), urine nitrite (UN), hydronephrosis density (HD) and fever history within one month (HFWOM) were independent risk factors for calculous obstructive pyonephrosis. The AUC value of the receiver operating characteristic (ROC) curve was 0.929. The calibration curves showed that the predictive model was well corrected and that the predictive model had strong consistency. Decision analysis curves showed good clinical efficacy of the model.

Conclusion: The alignment diagram model accurately predicts patients with preoperative calculous obstructive pyonephrosis in the PNL and provides an evidence-based basis for early renal microchannel nephrostomy.

1. Introduction

Urological stones are a common disease in urology, and urolithiasis is the most common urological condition among hospitalized patients. Epidemiological surveys in Western countries show that the incidence of urinary stones is approximately 1%–20% [1], and the incidence of urinary stones in China is approximately 1%–5%, of which approximately 1/4 of the patients need to be hospitalized for conservative treatment or surgical intervention [2,3]. Percutaneous nephrolithotomy (PNL), with the advantages of low trauma and a high stone removal rate, is the first-line treatment option for the management of large-loaded stones in the upper urinary tract

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and complex kidney stones [4].

Clinical practice has revealed that a small number of patients with calculous obstructive pyonephrosis do not have obvious acute phase manifestations of pyonephrosis before PNL, which we call asymptomatic pyonephrosis. The clinical manifestations of this group of patients are insidious and not accurately determined, and pyonephrosis is only found when surgery is performed after 2–3 days of preoperative preparation according to the routine protocols, and percutaneous renal access is established intraoperatively after general anaesthesia, when the renal stoma tube has to be retained and drained before elective surgery is performed [5]. Our statistics show that the length of hospital stay was significantly longer in the pyonephrosis group than in the non-pyonephrosis group, and the cost of medical care was significantly higher. If pyonephrosis is recognized when the patient is first admitted to the hospital and local anaesthesia microchannel renal puncture is performed to drain the pus prior to PNL, not only can the patient's hospital stay and cost be reduced, but healthcare resources can also be saved. In this study, we developed an alignment diagram model for the preoperative prediction of calculous obstructive pyonephrosis in the PNL.

Table 1
Comparison of clinical baseline levels of patients before PNL operation.

Characteristic	Overall N = 755	Control group N = 708	Experimental group N = 47	p-value
Age (years)	53 (44,62)	52 (44,61)	61 (52,66)	0.001
Gender				0.2
Female	315 (42%)	291 (41%)	24 (51%)	
Male	440 (58%)	417 (59%)	23 (49%)	
BMI(kg/m^2)	23.5 (21.4,26.0)	23.6 (21.4,26.0)	22.9 (21.3,25.3)	0.2
Diabetes	101 (13%)	90 (13%)	11 (23%)	0.062
Hypertension	182 (24%)	173 (24%)	9 (19%)	0.519
HFWOM	31 (4.1%)	16 (2.3%)	15 (32%)	<0.001
Previous surgery of calculi	103 (13.6%)	93 (13.1%)	10 (21.3%)	0.175
Location of calculi				0.502
Renal pelvis or calyces	363 (48%)	344 (49%)	19 (40%)	
Ureter	126 (17%)	118 (17%)	8 (17%)	
Both	266 (35%)	246 (35%)	20 (43%)	
Laterality of calculi				0.701
Left	299 (40%)	279 (39%)	20 (43%)	
Right	273 (36%)	255 (36%)	18 (38%)	
Both	183 (24%)	174 (25%)	9 (19%)	
Multiple ureteral stones	531 (70%)	496 (70%)	35 (74%)	0.5
Staghorn stone (%)	106 (14%)	101 (14%)	5 (11%)	0.634
Maximum diameter of calculi (mm)	18 (12,24)	18 (12,24)	18 (12,27)	0.4
Stone density (Hu)	1219 (1,058,1,362)	1222 (1,060,1,364)	1163 (1,017,1,238)	0.1
Degree of hydronephrosis				0.001
Mild	308 (41%)	297 (42%)	11 (23%)	
Moderate	181 (24%)	173 (24%)	8 (17%)	
Severe	266 (35%)	238 (34%)	28 (60%)	
Hydronephrosis density	5.00 (3.00,7.00)	5.00 (3.00,6.00)	7.00 (5.00,8.00)	<0.001
Perinephric stranding				0.2
Grade 0 + 1+2	395 (52%)	375 (53%)	20 (43%)	
Grade 3 + 4+5	360 (48%)	333 (47%)	27 (57%)	
Urine WBC count				<0.001
Weakly positive	278 (36.8%)	271 (38.3%)	7 (14.9%)	
Moderately	135 (17.9%)	125 (17.7%)	10 (21.3%)	
Strongly positive	184 (24.4%)	159 (22.5%)	25 (53.2%)	
Urine nitrite				<0.001
Negative	688 (91%)	653 (92%)	35 (74%)	
Positive	67 (8.9%)	55 (7.8%)	12 (26%)	
Urine culture				0.4
Negative	631 (84%)	594 (84%)	37 (79%)	
Positive	124 (16%)	114 (16%)	10 (21%)	
Blood WBC count (10ˆ12/L)	7.11 (6.00,8.94)	7.01 (5.93,8.71)	9.68 (7.38,11.56)	<0.001
Neutrophil (10ˆ12/L)	4.20 (3.30,5.60)	4.11 (3.26,5.40)	6.59 (5.00,9.39)	<0.001
Hemoglobin (g/L)	138 (126,151)	139 (128,152)	121 (106,137)	<0.001
Platelet (10ˆ9/L)	253 (211,299)	252 (212,297)	266 (194,349)	0.4
Serum creatinine (umol/L)	78 (65,102)	78 (64,98)	110 (76,205)	<0.001
Albumin (g/L)	43.2 (39.6,46.6)	43.7 (40.0,46.7)	36.4 (29.4,40.2)	<0.001
Hospital stays (days)	11.0 (8.0,15.0)	11.0 (8.0,14.0)	15.0 (12.5,19.0)	<0.001
Hospitalization costs	29,909 (24,540,36,062)	29,323 (24,469,35,410)	38,782 (33,105,51,098)	<0.001

Median (IQR) for continuous; n (%) for categorical; BMI:body mass index; HFWOM:History of fever within one month.

2. Methods

2.1. Patients

A total of 755 patients were diagnosed with calculous obstructive hydronephrosis and treated with PNL between January 2018 and December 2022. There were 440 males and 315 females with a mean age of 53 (44, 62) years. There were 363 patients with simple renal stones, 126 patients with simple upper ureteral stones, and 266 patients with both renal and ureteral stones. There were 572 unilateral stones and 183 bilateral stones. There were 101 patients with combined diabetes mellitus and 182 patients with combined hypertension. The enrolled patients were divided into 47 patients in the pyonephrosis group and 708 patients in the nonpyonephrosis group.

2.2. Inclusion and exclusion criteria

The inclusion criteria were as follows: 1. patients above 18 years old, 2. patients diagnosed with upper urinary tract stones combined with renal effusion by urological ultrasound and CT examination with complete clinical data, and 3. patients who finally underwent PNL surgery.

The exclusion criteria were as follows: (1) patients with tumours, haematological diseases, urinary tuberculosis, or an immunocompromised status; (2) patients with severe cardiopulmonary insufficiency; (3) patients who received nephrostomy or retrograde ureteral intubation before admission; and (4) patients with sepsis manifestation at the time of admission.

3. Diagnosis of pyonephrosis

The diagnosis of pyonephrosis was based on the following: 1. imaging studies that confirmed calculous obstructive pyonephrosis and ruled out other causes of obstruction, and 2. the presence of varying degrees of pus effusion visible to the naked eye during the creation of percutaneous renal access during PNL.

3.1. Statistical analysis

Measurement data are expressed as medians (quartiles), and count data are expressed as frequencies (percentages). Risk factor analyses were performed using univariate and multivariate logistic regression analyses. Receiver operating characteristic (ROC) curve analysis was used to determine the diagnostic value of the predictive model for calculous obstructive pyonephrosis. Statistical analyses were performed using R language 4.31 software, and statistical significance was defined as $P < 0.05$.

3.2. Study design chart

Univariate and multivariate analyses were performed on the baseline indicators of the pyonephrosis group and nonpyonephrosis group, the related independent risk factors were screened out, and an alignment diagram prediction model was established. Discrimination (ROC curve), compliance (calibration curve) and effectiveness (decision analysis curve) were used to verify the effectiveness of the prediction model.

4. Results

Upper urinary tract stones secondary to renal pyonephrosis were associated with patient age, history of fever within one month

Table 2
Univariate and multivariate analysis of Independent risk factors before PNL.

Characteristic	Univariate analysis			Multivariate analysis		
	OR	95%CI	p-value	OR	95%CI	p-value
Age	1.04	1.01–1.07	<0.001			
Hypertension	0.73	0.35–1.55	0.41			
HFWOM	20.27	9.21–44.6	<0.001	6.56	1.87, 22.0	0.003
Degree of hydronephrosis	2.91	1.59–5.32	<0.001			
Hydronephrosis density	1.41	1.23–1.61	<0.001	1.48	1.25, 1.78	<0.001
Urine WBC count	4.35	2.22–8.53	<0.001			
Urine nitrite	4.07	2–8.29	<0.001	6.37	2.41–16.52	<0.001
Blood WBC count	1.31	1.19–1.43	<0.001			
Neutrophil	1.5	1.35–1.68	<0.001	1.22	1.04, 1.42	0.013
Hemoglobin	0.95	0.94–0.97	<0.001			
Serum creatinine	1.02	1.01–1.02	<0.001	1.01	1.01, 1.02	<0.001
Albumin	0.78	0.74–0.83	<0.001	0.87	0.81, 0.94	<0.001

HFWOM:History of fever within one month.

(HFWOM), stone density, degree of hydronephrosis, hydronephrosis density (HD), perirenal stranding, urinary leukocyte count, urinary nitrites (UN), blood leukocyte count, blood neutrophil count (Neu), blood haemoglobin concentration, blood creatinine level (Scr), and blood albumin level (Alb) ($P < 0.05$) (Table 1). Univariate and multivariate logistic regression analyses showed that Neu, Scr, Alb, UN, HD, and HFWOM were independent risk factors for preoperative upper urinary tract stones combined with pyonephrosis in PNL (Table 2).

Incorporating six independent risk factors into the prediction model, we developed an alignment diagram prediction model for whether patients needed local anaesthesia for nephrostomy drainage before PNL (Fig. 1). The ROC curve showed that the AUC for the prediction of upper urinary tract stones combined with pyonephrosis by the alignment diagram model was 0.929 (95% CI: 0.892–0.965) (Fig. 2). Based on the optimal critical value of the ROC curve, the corresponding score of the alignment diagram model was calculated to be 26.7, and we classified patients with scores lower than 26.7 into the low-risk group (not recommended microchannel nephrostomy) and patients with scores equal to or greater than 26.7 into the high-risk group (recommended primary microchannel nephrostomy plus secondary PNL), with a sensitivity of 0.851 and a specificity of 0.867. Calibration curve validation showed that the predicted values were generally in agreement with the actual measured values. The decision analysis curve suggested good clinical utility of the column-line diagram model (Fig. 3).

5. Discussion

Depending on the size, location, presence or absence of symptoms or obstruction of upper urinary tract stones, treatment modalities mainly include conservative treatment with drugs, extracorporeal shock wave lithotripsy (ESWL), soft ureteroscopic lithotripsy (RIRS), and PNL. PNL is a minimally invasive procedure for intracavitary lithotripsy and stone extraction through percutaneous renal channels of different sizes, which has largely replaced open surgery [4], but the complications of severe postoperative infections should not be ignored.

Urogenic sepsis is caused by urinary tract infection. The probability of urogenic sepsis after PNL is approximately 8.9%–43.0%, and there is a rising trend of sepsis and infectious shock complicating PNL in recent years [5,6], which not only leads to the use of more antibiotics but also significantly increases the length of hospitalization and the medical cost of the patients, and some patients even need to be admitted to the intensive care unit for treatment [7]. Upper urinary tract stones are prone to cause different degrees of hydronephrosis, which often leads to pyonephrosis when the fluid persists and is infected with pathogenic bacteria and the body is immunocompromised. Upper urinary tract stones combined with obstructive pyonephrosis account for approximately 3.2% of upper urinary tract stones (the data of this study are 6.2%, 47/755); in the acute stage, they often manifest as fever, chills, lumbago, oliguria and even infectious shock; and they are easy to diagnose in combination with imaging examinations [8]. At this time, renal puncture fistula or retrograde ureteral stenting should be performed in a timely manner to relieve the obstruction and with the use of antibiotic therapy, pending systemic infection control and elective stone removal. Usually, patients with asymptomatic pyonephrosis do not present with fever, low back pain, or blood leucocytosis [9] until they are identified during the creation of a skin-to-renal channel during a PNL, at which point sepsis or even infectious shock may result if the PNL is continued [8]. Although it has been suggested that one-stage PNL is safe and effective in the treatment of calculous obstructive pyonephrosis after careful evaluation and screening [10], early prediction and diagnosis of pyonephrosis is the key to successful treatment, and drainage of pus through one-stage nephron puncture can improve the safety of two-stage PNL [11,12].

Nonenhanced CT scans have high resolution and are the imaging test of choice in patients with renal colic due to stones [13]. Yuruk et al. [14] calculated that the HU of the renal collecting system in patients with pyonephrosis was significantly higher than that of patients with hydronephrosis; the sensitivity for diagnosing pyonephrosis with a HU of $\geq$9.21 was 65.96%; and the specificity was 87.93%. A study by Erdogan et al. reached similar conclusions [15,16]. Many studies have focused on finding risk factors for complications of SIRS and sepsis after PNL [17–24], including female sex, diabetes mellitus, volume of renal stones, degree of

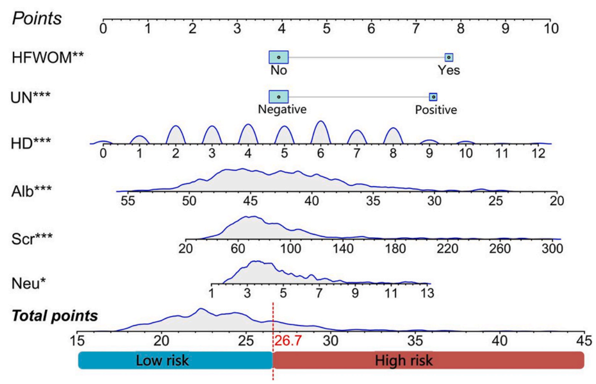

Fig. 1. Alignment diagram for the preoperative prediction of upper urinary calculi complicated with pyonephrosis in PNL. The scores corresponding to each independent risk factor were added, and the corresponding risk stratification group was found (low-risk group and high-risk group), with the total score obtained.

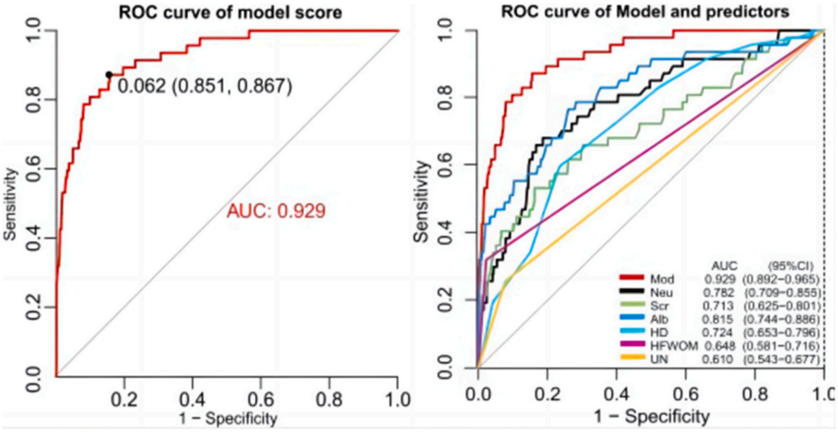

Fig. 2. Diagnostic efficiency of ROC curve analysis. The AUC value of the ROC curve was 0.928, which was greater than the AUC for each independent risk factor.

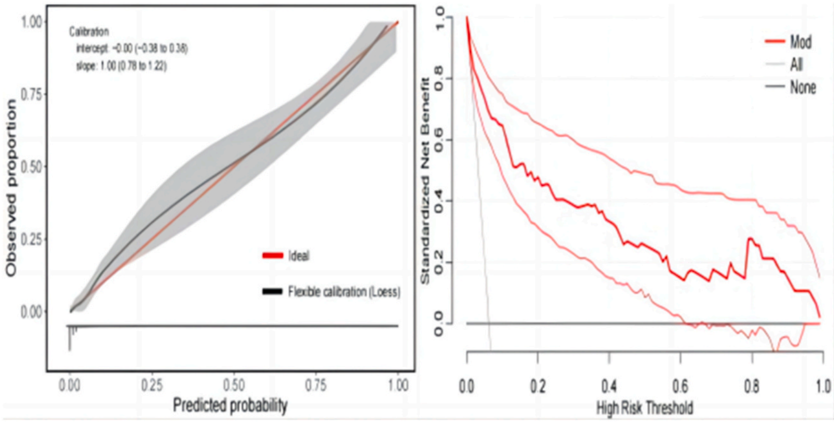

Fig. 3. Alignment diagram predictive model calibration test. The calibration curve of the regression model essentially aligns with the reference line, indicating a good match between the predicted and observed values, thereby reflecting a well-calibrated model. The decision curve analysis, situated above both the pale grey line (all treatments) and dark grey line (no treatment), demonstrates a net benefit greater than zero, signifying high clinical utility of the curve.

hydronephrosis, density of hydronephrosis, urinary leukocytes, positive urine cultures and elevated blood neutrophils. There is still no precise stratified scoring system or comprehensive model to predict preoperative calculous obstructive pyonephrosis before PNL.

In this study, we retrospectively analyzed the pre-PNL clinical baseline indices of patients with calculous obstructive pyonephrosis, and the results showed that age, stone density, degree of renal effusion, HD, degree of perirenal stranding, urinary leukocyte count, blood leukocyte count, Neu, and Scr were significantly higher in the pyonephrosis group than in the nonpyonephrosis group and that the ratios of HFWOM and UN were higher than those in the nonpyonephrosis group. However, the haemoglobin and Alb concentrations were lower than those in the nonpyonephrosis group, and these results were generally consistent with the actual clinical observations. Notably, HFWOM and perirenal stranding are less commonly mentioned in the previous literature. We observed a higher percentage of HFWOM in patients in the pyonephrosis group, which is often overlooked by clinicians. Perinephric stranding, also known as perinephric whiskering, is a nonspecific CT manifestation usually due to the presence of fluid within the septa present in the perinephric space. The most common cause of this pathological change is obstruction due to ureteral stones [25]. The present study with reference to the method of grading perirenal stranding reported by Abushamma et al. [26] showed that the grade of perirenal stranding was significantly higher in the pyonephrosis group than in the nonpyonephrosis group. Previous scholars have less frequently used haemoglobin and Alb as risk factors for predicting infection, and because of our clinical observation that patients with upper urinary tract stones combined with severe infections tend to exhibit anaemia and hypoproteinaemia, the present study included baseline haemoglobin and Alb concentrations in the analysis, which showed that the pyonephrosis group had a lower haemoglobin and Alb concentration, probably due to chronic infectious depletion. Leukocytes and Neu are increased in varying degrees for patients suffering from bacterial infections. However, Neu are the major cytosolic component of the immune system of the host and the main mediator of innate immune defense against invading microorganisms [27]. Patients with septic kidneys are often caused by pyogenic bacterial infections, in which case the susceptibility to elevated Neu is higher. Patients with upper urinary tract stone obstruction combined with hydronephrosis on one side often have compensatory on the contralateral side, but patients with obstructive septic kidneys often have impaired renal function bilaterally due to bacterial infection leading to an elevated Scr [28]. The major reasons for the decrease in Alb are liver damage and malnutrition, as well as wasting diseases such as persistent chronic infections [29]. The presence of urinary UN is the result of infection by gram-negative bacilli (*Escherichia coli*, Aspergillus chimera, etc.), which promote the conversion of the urinary protein product nitrate to nitrite. Leibo Wang et al. demonstrated that a positive urinary UN proved to be a good diagnostic for renal pyonephrosis [22].

We did not include urine culture results in the univariate and multivariate analyses not only because PNL was often performed when urine culture results were not published but also because intraoperative pelvic urine and stone cultures are more credible than preoperative urine culture results, and the former can be taken as evidence for direct antimicrobial therapy [30].

In recent years, alignment diagrams, also known as nomograms, have gained increasing attention and application in medical research and clinical practice as tools for the risk and prognosis assessment of disease occurrence [31]. In this study, patients with calculous obstructive pyonephrosis were taken as the study population, and the development of pyonephrosis infection into renal pus was taken as the outcome variable. The alignment diagram prediction model was constructed by screening the modelled variables that might cause pyonephrosis, identifying the independent risk factors, and then the model was validated and evaluated. Multifactorial regression analysis showed that Neu, Scr, Alb, UN, HD, and HFWOM were independent risk factors for calculous obstructive pyonephrosis. Incorporation of the six independent risk factors into the prediction model showed that the individualized alignment diagram model for preoperative prediction of pyonephrosis in PNL had an AUC value of 0.928, a sensitivity for diagnosis of 0.845, and a specificity of 0.872. Comparison of efficacy with each of the individual independent risk factors showed a more significant discriminatory efficacy for the alignment diagram model. The calibration test of the alignment diagram predictive model suggested reliable agreement between predicted and observed values, and the decision analysis curve suggested the clinical utility of the alignment diagram model. Therefore, patients with positive HFWOM and UN accompanied by higher values of Neu, Scr, and HD and lower values of Alb have a higher probability of upper urinary tract stone obstruction combined with pyonephrosis, and when the composite score reaches the optimal cut-off value, it is recommended to carry out primary microchannel nephrostomy plus secondary PNL treatment.

However, as a retrospective study, our research may have information bias in the data collection stage. And then, since patients with asymptomatic obstructive renal pyonephrosis had no obvious fever manifestations on admission, most of them were not tested for blood indicators reflecting bacterial infections, such as C-reactive protein and procalcitonin, which resulted in their absence and could not be included in the analysis of independent risk factors.

6. Conclusions

In conclusion, Neu, Scr, Alb, UN, HD, and HFWOM are independent risk factors for calculous obstructive pyonephrosis. The visual alignment diagram model we constructed can effectively identify patients with renal pyonephrosis before PNL. The next step is to externally validate our predictive model with a view to entering clinical promotion.

Ethics statement

This study was reviewed and approved by the Ethics Committee of the Second Hospital of Fujian Medical University, with the approval number: (2023) Ethical Examination No. 303 of the Second Hospital of Fujian Medical University. All patients provided informed consent to participate in the study.

Availability of data and materials

The datasets generated or analyzed during this study areavailable from the corresponding author on reasonable request.

CRediT authorship contribution statement

Weihui Liu: Writing – original draft, Validation, Investigation, Formal analysis, Data curation. **Changjin Liu:** Methodology, Investigation, Data curation, Conceptualization. **Wei zhuang:** Data curation, Conceptualization. **Junyi Chen:** Supervision, Conceptualization. **Qingliu He:** Validation, Investigation, Data curation. **Xueyi Xue:** Writing – review & editing, Supervision. **Tingfang Huang:** Supervision, Project administration.

Declaration of competing interest

The authors have no conflicts of interest to disclose.

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