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ORIGINAL RESEARCH

Analysis of Pathogenic Bacteria, Drug Resistance and Treatment of Emphysematous Pyelonephritis: A Case Series

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Purpose: Emphysematous pyelonephritis (EPN) is a rare, acute, gas-producing necrotizing infection of the kidney. This study aims to improve the understanding of EPN, optimize diagnostic and therapeutic strategies, reduce the incidence of severe infections, and improve patient prognosis.

Patients and Methods: Patients with a definitive diagnosis of EPN confirmed by computed tomography (CT) were retrospectively reviewed between December 2012 and May 2025. Patient demographics, clinical characteristics, treatment approaches, and outcomes were evaluated. Representative imaging findings were presented, along with an analysis of pathogenic bacteria and antimicrobial resistance in EPN patients.

Results: This series includes 15 patients with EPN, representing the largest single-center cohort reported from mainland China in the past 30 years. Body fluid cultures identified 12 pathogenic bacterial strains, with *Escherichia coli* being the most prevalent (66.7%, 8/12), followed by *Klebsiella pneumoniae* (25.0%, 3/12) and *Pseudomonas aeruginosa* (8.3%, 1/12). Multi-drug resistance was observed in 75.0% (9/12) of strains. Drug susceptibility testing showed 100% susceptibility to amikacin (n=12), cefotetan (n=5), and cefoperazone-sulbactam (n=8). Imipenem (n=11), meropenem (n=11), and piperacillin-tazobactam (n=11) demonstrated a susceptibility rate of 91.7%. Overall, 86.7% (13/15) of patients were cured, while 13.3% (2/15) died.

Conclusion: We recommend the use of sensitive antibiotics as early as possible, combined with fluid resuscitation, blood glucose control, supportive care, and early minimally invasive therapy.

Keywords: Emphysematous pyelonephritis, body fluid cultures, pathogenic bacteria, drug susceptibility analysis, minimally invasive therapy

Introduction

Emphysematous pyelonephritis (EPN) is a rare, severe urological infection characterized by gas formation and necrotizing involvement of the renal parenchyma and surrounding tissues. Due to its sporadic and rare nature, epidemiological data are limited, and global incidence remains unclear. EPN is typically diagnosed by computed tomography (CT).[1] Treatment involves antibiotics and comprehensive supportive care; without prompt intervention, it can lead to serious outcomes, including septic shock, multiple organ dysfunction syndrome (MODS), and death. This is partly due to limited awareness of EPN and the lack of standardized diagnostic and anti-infective protocols. Reported mortality rates range from 12.5% to 25%.[2–5]

Although antibiotics are central to EPN management, there is a paucity of studies—particularly in Asian populations—focusing on associated pathogenic bacteria. Current anti-infective therapy is largely empirical, and drug-resistant strains have been reported, though data are limited. A study by Subramaniyan et al found that 77.8% of strains causing

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urological diseases were multidrug-resistant.[6] It remains unclear whether these patterns apply to Asian populations. There is a global research gap, especially in Asian cohorts, regarding pathogenic bacteria and resistance profiles, limiting evidence-based clinical guidance. This study aimed to analyze common causative pathogens and antimicrobial susceptibility to guide targeted anti-infective strategies, reduce severe infections, lower mortality, and help control the spread of resistant strains.

Materials and Methods

Patients

This was a retrospective study of all patients diagnosed with EPN at Peking University First Hospital between December 2012 and May 2025. Of 20 initially identified patients, five were excluded due to incomplete key data. The remaining 15 patients formed the basis of this report.

Data Collection

Data were extracted from electronic medical records, including demographics, medical history, laboratory results, imaging findings, treatment, and prognosis.

EPN Grading Standard

EPN was classified according to the system proposed by Huang and Tseng (2000):[1] Class 1: gas in the collecting system; Class 2: gas in the renal parenchyma without extrarenal extension; Class 3A: gas or abscess in the perirenal space; Class 3B: gas or abscess in the pararenal space; Class 4: bilateral involvement or solitary kidney with EPN.

Laboratory Documentation

Bacterial culture and drug susceptibility testing were performed in accordance with standard Chinese clinical laboratory protocols. Venous blood, urine, and drainage fluid specimens were inoculated onto blood agar plates. Isolated strains were identified, and susceptibility testing was conducted using the Vitek 2 Compact automated system (bioMérieux). Quality control strains included *Escherichia coli* ATCC 25922, *Klebsiella pneumoniae* subsp. pneumoniae ATCC 700603, and *Pseudomonas aeruginosa* ATCC 27853.

Data Statistics

Age is presented as median and quartiles (non-normal distribution); other data are expressed as counts and percentages.

Results

Demographics and Clinical Characteristics

The median age at diagnosis was 66 years (range 49–89), with 60% (9/15) female patients. Characteristics are summarized in Table 1. Underlying factors included urinary stones in 33.3% (5/15), nephropyosis in 33.3% (5/15), urinary retention in 6.7% (1/15), and undetermined etiology in 26.7% (4/15). In these patients, urinary stones and nephropyosis were independent findings.

At presentation, 26.7% (4/15) had altered consciousness (2 lethargic, 2 shallow coma), 73.3% (11/15) had fever, 33.3% (5/15) presented with shock, and 66.7% (10/15) met criteria for systemic inflammatory response syndrome (SIRS). Diabetes mellitus was present in 73.3% (11/15), and hypertension in 66.7% (10/15).

Pathogenic Bacteria and Drug Resistance

All 15 patients completed body fluid cultures, including 40.0% (6/15) blood culture, 40.0% (6/15) urine culture, and 46.7% (7/15) drainage fluid culture. Pathogenic bacteria were detected in body fluid cultures from 12 of 15 patients, resulting in a positivity rate of 80.0%. *Escherichia coli* was the predominant bacteria, accounting for 66.7% (8/12), four strains were identified as extended- spectrum beta-lactamase (ESBL) positive (patients 5, 6, 10, and 11). Followed by *Klebsiella pneumoniae* accounted for 25.0% (3/12) of the isolates, and one strain was classified as a carbapenem-resistant

Table 1 Demographics, Clinical Characteristics, CT Features, Body Fluid Culture, and Outcomes of Patients

		No. of Patients (n=15)	%
Demographics			
Age, y (range)		66 (49–89)	
Sex	Male	6	40.0
	Female	9	60.0
Clinical characteristics			
The cause of EPN	Urinary stone	5	33.3
	Nephropyosis	5	33.3
	Urinary retention	1	6.7
	Unknown	4	26.7
Conscious state	Clear	11	73.3
	Lethargy	2	13.3
	Shallow coma	2	13.3
Fever	Low-grade fever	1	6.7
	Mid-grade fever	8	53.3
	High fever	2	13.3
Shock		5	33.3
SIRS		10	66.7
Medical history	Diabetes mellitus	11	73.3
	Hypertension	10	66.7
CT features			
Huang-Tseng classification	1	4	26.7
	2	3	20.0
	3A	3	20.0
	3B	3	20.0
	4	2	13.3
Side	Right	5	33.3
	Left	8	53.3
	Bilateral	2	13.3
Body fluid culture			
	Escherichia coli	8	53.3
	Klebsiella pneumoniae	3	20.0
	Pseudomonas aeruginosa	1	6.7
	Sterile	3	20.0
Outcome			
	Recover	10	66.7
	Adverse	3	20.0
	Death	2	13.3

enterobacteriales (CRE) (patient 3). *Pseudomonas aeruginosa* was the least frequently detected bacteria, representing 8.3% (1/12) of the isolated strains (patient 4). Notably, 75% (9/12) of the strains exhibited resistance to three or more antibiotics, indicating the presence of multidrug-resistant bacteria. Detailed drug susceptibility results for the strains are presented in Figure 1A.

Amikacin (n=12), cefotetan (n=5), and cefoperazone-sulbactam (n=8) demonstrated 100% susceptibility against 12 strains of the three bacteria obtained from cultures (Figure 1B). 91.7% of the strains (11/12) exhibited susceptibility rates exceeding 90% to imipenem, meropenem, and piperacillin-tazobactam. Ceftazidime (n=11) and cefepime (n=9) showed susceptibility rates of 72.7% and 77.8%, respectively, but were resistant to some strains of *Escherichia coli* and *Klebsiella pneumoniae*. The susceptibility rates for gentamicin, tobramycin, and aztreonam, as well as compound

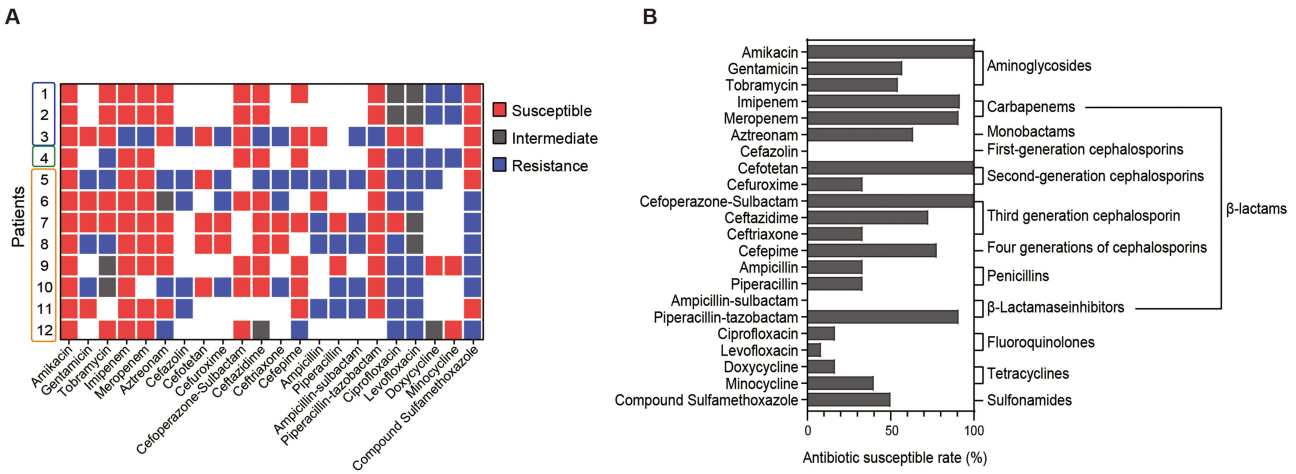

Figure 1 (**A**) Drug susceptibility results for blood, urine, or drainage fluid cultures from all patients. The body fluid cultures revealed *Klebsiella pneumoniae* in patients 1–3 (blue square line), *Pseudomonas aeruginosa* in patient 4 (green square line), and *Escherichia coli* in patients 5–12 (orange square line). Blank spots indicate that the drug was not tested. (**B**) Antibiotic susceptibility rates (number of susceptible patients divided by the number of tested patients) and antibiotic classification.

sulfamethoxazole, ranged from 50% to 63.6%, and the remaining antibiotics had susceptibility rates of less than 50%. Cefazolin (n=5) and ampicillin-sulbactam (n=6) showed complete resistance to all strains. In fluoroquinolones, ciprofloxacin and levofloxacin, were tested against all 12 strains, revealing susceptibility rates of 16.7% and 8.3%, only 1–2 strains were sensitive, while most strains exhibited resistance or intermediate susceptibility.

CT Features and Representation

Class 1 was most common (26.7%, 4/15), followed by Classes 2, 3A and 3B (20%, 3/15 each), with Class 4 least common (13.3%, 2/15). The left kidney was affected in 53.3% (8/15), right in 33.3% (5/15), and both kidneys in 13.3% (2/15). Emphysematous cystitis was concurrent in 13.3% (2/15). Representative images (Classes 1–4) are shown in Figure 2A.

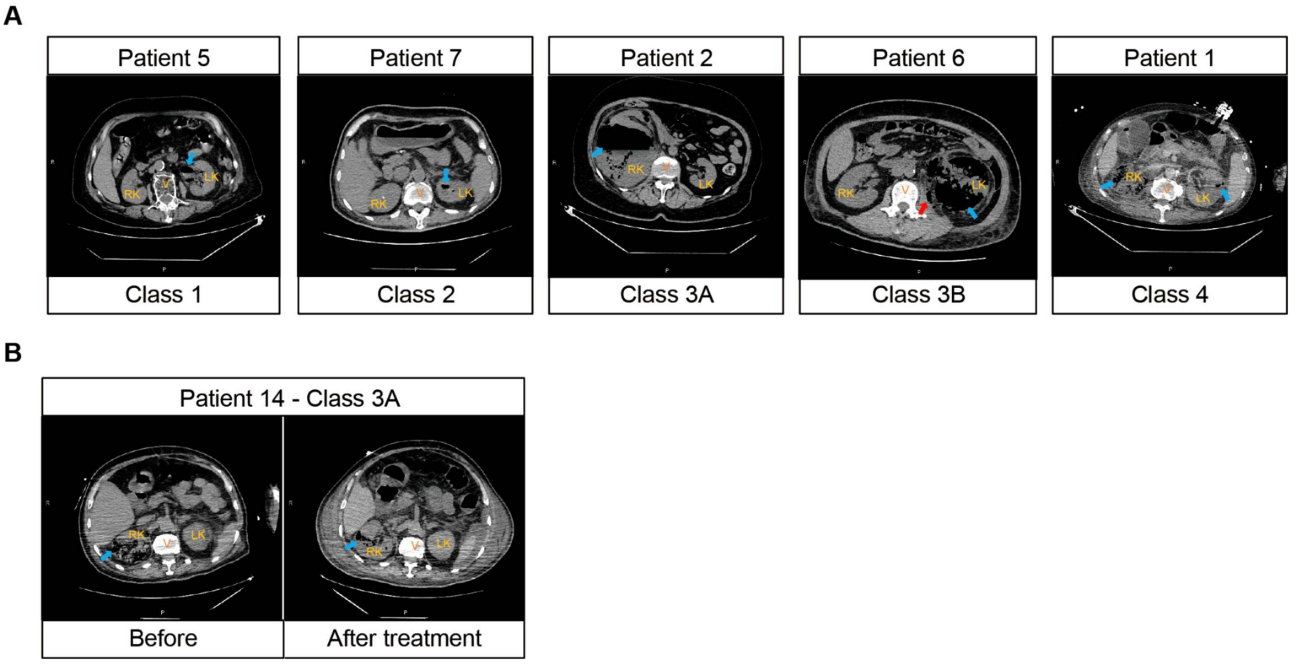

Figure 2 (**A**) Representative CT images from Classes 1–4. Blue arrows indicate gas in renal/perirenal spaces; red arrow indicates gas in left pararenal space. (**B**) Pre- and post-treatment CT images of patient 14 (Class 3A).

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Therapy and Outcome

Among the 15 patients who received empirical anti-infective medications, carbapenems were the most frequently prescribed antibiotics, being utilized in 80% patients (12/15). Patients with renal function impairment will have their antibiotic dosages adjusted based on renal function and pharmacokinetic factors. A total of 12 patients underwent 13 minimally invasive therapies (MIT) (Table 2), which included 46.7% (7/15) percutaneous nephrostomy (PCN), 20.0% (3/15) placement of double-J (DJ) tubes to relieve obstruction, and 20.0% (3/15) procedures such as percutaneous nephrolithotomy (PCNL) or ureteroscopy (URS) to manage the underlying infection. Figure 2B represents a significant reduction in gas and pus before and after puncture drainage.

Overall, 66.7% (10/15) of the patients were cured following initial treatment, while 20% (3/15) experienced adverse outcomes. Among them, one patient was transferred to the endocrinology department due to poor glycemic control. Another patient's Ultrasound did not show sufficient liquefaction of the abscess or dilation of the renal pelvis and ureter, then received conservative medical management and was transferred back to the local hospital with high fever at the request of the family members, and was lost to follow-up thereafter. The other patient, a Class 4 patient, recovered slowly after receiving antibiotics and nephrostomy and was transferred to another hospital for treatment. Notably, three of the patients eventually recovered.

Unfortunately, 13.3% (2/15) patients died, both were Class 2 EPN patients who presented with infectious shock, altered consciousness, multiple organ failure, and significantly impaired renal function (eGFR G4/G5) at the time of

Table 2 Profile of the Patients Admitted with EPN

Patient	Gender	Age	Class of EPN	Side	With EC	Culture	Pathogenic	MIT	Days of Treatment	Outcome
1	M	69	4	B	N	Drainage fluid	*K. pneumoniae*	PCN	22	Adverse
2	F	66	3A	R	N	Drainage fluid	*K. pneumoniae*	PCN	8	Recover
3	M	52	1	R	N	Urine	*K. pneumoniae*	DJ + URS	15	Recover
4	M	65	1	L	N	Urine	*P. aeruginosa*	PCNL	11	Recover
5	F	75	1	L	N	Blood	*E. coli*	DJ	19	Recover
6	F	57	3B	L	N	Drainage fluid	*E. coli*	PCN	26	Recover
7	F	66	2	L	Y	Blood, urine	*E. coli*	–	2	Death
8	F	65	2	R	N	Blood	*E. coli*	PCN	21	Adverse
9	F	53	4	B	N	Drainage fluid	*E. coli*	PCN	35	Recover
10	F	56	3B	L	N	Drainage fluid, urine	*E. coli*	PCN	26	Recover
11	M	49	1	L	N	Drainage fluid, urine	*E. coli*	PCNL	20	Recover
12	F	71	3A	L	N	Blood	*E. coli*	DJ	51	Recover
13	F	89	2	L	N	Urine	Sterile	–	5	Death
14	M	74	3A	R	Y	Drainage fluid, blood	Sterile	PCN	19	Recover
15	M	67	3B	R	N	Blood	Sterile	–	17	Adverse

Abbreviations: EC, emphysematous cystitis; *K. pneumoniae*, *Klebsiella pneumoniae*; *P. aeruginosa*, *Pseudomonas aeruginosa*; *E. coli*, *Escherichia coli*; M, male; F, female; B, bilateral; R, right; L, left; N, no; Y, yes; MIT, minimally invasive therapy; PCN, percutaneous nephrostomy; DJ, double-J tube drainage; URS, ureteroscopy; PCNL, percutaneous nephrolithotomy.

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presentation. These patients did not undergo minimally invasive therapy or surgical intervention, their condition rapidly deteriorated, and the mean time to death was 3.5 days. The mean duration of hospitalization for all patients was 19.8 days. The therapy and prognosis of all 15 patients are presented in Table 2.

Discussion

EPN is a severe necrotizing infectious disease characterized by the production of gas, which can occur in the renal parenchyma, perirenal interstitium, or pararenal interstitium. Three conditional mechanisms that may lead to gas production include elevated glucose levels in tissues, the presence of gas-producing bacteria, and ischemic necrosis of tissues due to impaired perfusion.[1] In patients with EPN, the absence of normal circulation in the affected kidney is confirmed by immediate arteriography after kidney removal, and the renal parenchyma shows obvious abnormalities upon incision. The primary pathological features include vasculopathy, extensive micro-abscesses, interstitial inflammation, glomerulosclerosis, and detachment of the renal papillae.[7]

Research indicates that 75–96% of EPN patients have diabetes mellitus.[1,2,8–10] In our study, there were 11 cases of diabetes, accounting for 73.3%. Among them, 7 cases were using sodium glucose co-transporter-2 inhibitors (SGLT2), accounting for 63.6%. Increased blood glucose levels may predispose the urinary tract environment to infection, highlighting the importance of glycemic management in EPN patients. Although diabetes mellitus is prevalent among EPN patients, some studies suggest that it is not a risk factor for mortality.[2,4,9] A meta-analyses of randomized controlled trials showed no significant difference in urinary tract infections between SGLT2 inhibitors versus control (2,526/29,086 vs. 1,278/14,940, RR=1.05, 95% CI=0.98-1.12).[11]

The largest patient cohort study analyzing EPN risk factors was a meta-analysis by Ngo et al in 2022. This study identified risk factors, including sepsis (OR=15.99), shock (OR=15.57), disturbance of consciousness (OR=12.11), acute renal failure (OR=5.41), thrombocytopenia (OR=7.85), and Huang-Tseng classification III–IV (OR=2.4).[5] Other studies have reported risk factors as disturbance of consciousness,[1,2,4,9] shock,[1,2,10,12,13] thrombocytopenia,[1,2,4,9,10] acute renal impairment,[1] hyponatremia,[2,9] and sepsis.[2] In our study, two cases that initially presented with altered states of consciousness, shock, and renal impairment ultimately died. We found that the grading of EPN is not representative of the grading of condition and prognosis, but patient presence of multiple risk factors indicates a high risk of mortality, which requires us to be cautious.

Previous studies have indicated that the predominant bacteria flora in body fluid cultures of EPN patients is *Escherichia coli*, followed by *Klebsiella pneumoniae*.[1,10] Our findings align with these studies, in addition four strains were identified as ESBL *Escherichia coli*, and one *Klebsiella pneumoniae* was CRE. An analysis by Eswarappa et al revealed that hospitals commonly used the carbapenems meropenem, imipenem, or penicillins such as piperacillin in the treatment of patients with EPN, and most patients did not require alterations to their antimicrobial therapy following the acquisition of drug susceptibility results[14] Clinical urological infections are predominantly treated empirically, the use of antibiotics lacking adequate antimicrobial coverage can lead to aggravation of the condition, increased economic burden, and the proliferation of drug-resistant pathogens. In our research, Amikacin, cefotetan, and cefoperazone-sulbactam were 100% sensitive to strains cultured from body fluid; Imipenem, meropenem, and piperacillin-tazobactam had a susceptibility rate exceeding 90% in 91.7% patients, the drugs mentioned above can be considered the drugs of choice.

In 2008, a study by Somani et al demonstrated that the overall mortality rate for patients with EPN was 21% Specifically, the mortality rates for medical management (MM) alone was 50%, for MM with emergency nephrectomy (EN) was 25%, for MM with percutaneous drainage was 13.5%, and for elective nephrectomy following MM with percutaneous drainage was 6.6%.[3] In 2022, Desai et al indicated that 143 out of 1146 patients died, the overall mortality rate was 12.5%, the mortality rates for MM alone and MM with MIT were 9.7% and 10%. The mortality rate for EN was reported as 26%, and the mortality rate for EN after the failure to undergo MM with MIT was 27%.[2] The decrease in mortality observed in EPN may be attributed to the advanced anti-infective drugs and the increasing number of patients treated with MIT at an early stage. Another meta-analysis indicated that MM alone (OR=2.04) and EN (OR=3.73) were identified as risk factors, whereas minimally invasive therapy (such as PCN or placing DJ tube) were associated with a protective effect (OR=0.47).[5] The mortality rate for MIT was found to be 8%, with a 92% functional salvage rate for the kidney.[9] Fukunaga et al reported that patients classified as Huang and Tseng classification 3B with non-extensive

emphysematous abscess recovered following treatment with MM and PCN, preserving renal function[15] In our study, one case fail to MIT, the remaining five patients classified as 3A and 3B recovered after receiving MM with MIT (including PCN and placing DJ tube). Patient 14 (Figure 2B) experienced timely puncture and drainage, leading to rapid infection recovery, restoration of the kidney to its normal morphological structure, and preservation of renal function.

Management of patients with EPN using MM combine with MIT results in a significantly lower mortality rate compared to EN. However, EN should be considered when the patient's condition does not improve with other treatments or when the remaining kidney is nonfunctional.[16,17] Kapoor et al indicated that extensive renal parenchymal destruction exceeding 50%, as indicated by CT imaging, can significantly predict the necessity for nephrectomy ($P < 0.001$).[9] Consequently, we recommend that patients initially receive MM in combination with MIT. Nephrectomy should be considered only if these treatments are ineffective and there is extensive renal parenchymal destruction (> 50%) or non-functioning kidneys. In such cases, the removal of the kidney on the side of the infection should be regarded as a last resort to control the infection.

To Improving the diagnosis and treatment processes, we have developed a flowchart for EPN (Figure 3). When a patient is diagnosed with EPN by CT, it's important to notice the risk factors. Fluid resuscitation should be given

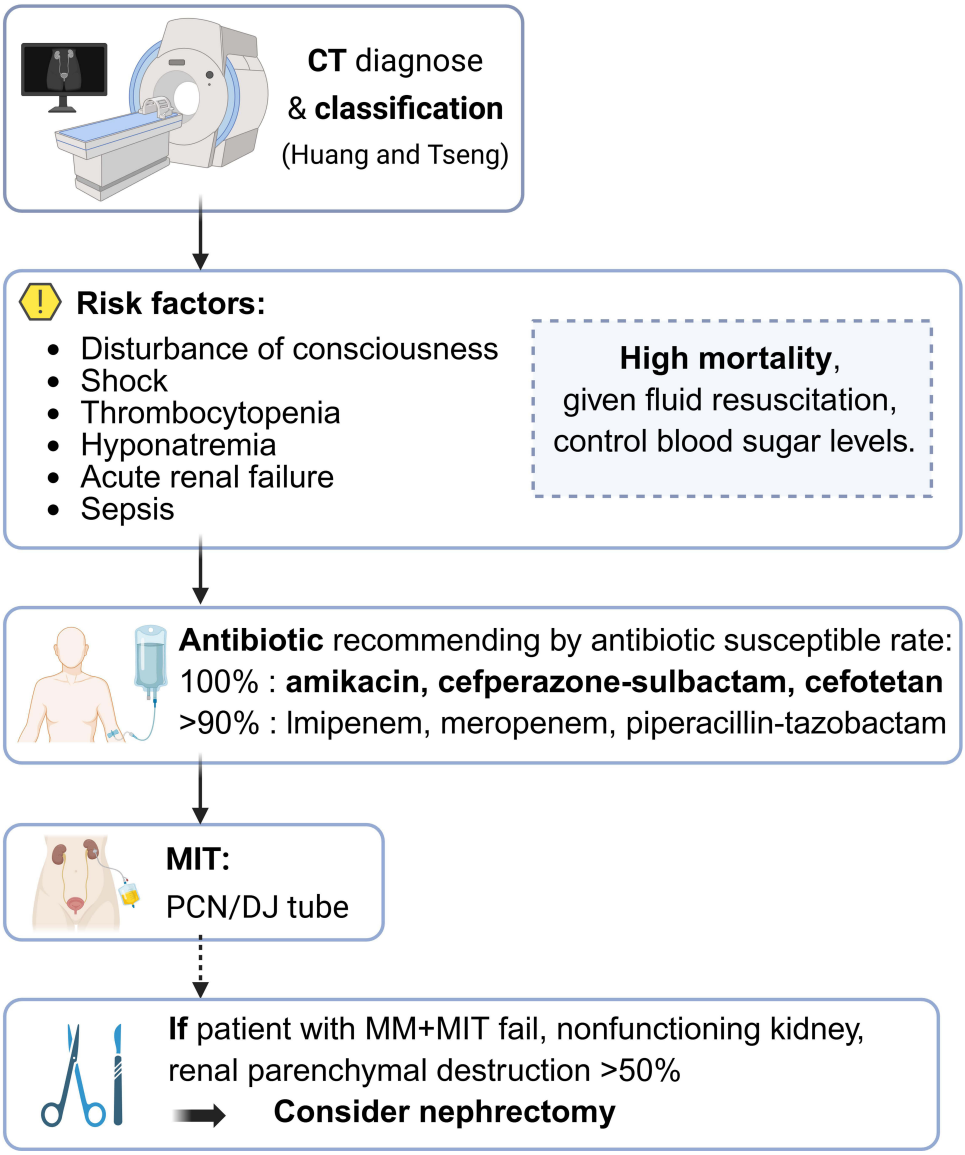

Figure 3 Diagnosis and treatment flowchart.

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immediately, and blood glucose levels should be controlled. Using sensitive antibiotics and MIT early can facilitate successful treatment and preserve renal function.[18] We recommended antibiotic including Amikacin, cefotetan, cefoperazone-sulbactam, imipenem, meropenem, and piperacillin-tazobactam. MIT including DJ tube placement and PCN, PCN is invasive but can be performed under bedside with local anesthesia to effectively drain intrarenal or perirenal abscesses.[19] In our experience, PCN can be performed on patients with a significant renal abscess, while DJ/PCNL/URS can be selected for patients with urinary stone according to medical conditions, but more clinical data are needed to summarize.

This study was conducted based on single-center results, and not all patients underwent drug susceptibility testing for each antibiotic. In our study, we found that the current CT classification grading cannot reflect the severity of patients. We hope to summarize a better classification and conduct a more comprehensive drug susceptibility for EPN in further research.

Conclusion

EPN is a severe gas-producing urinary tract infection lacking international guidelines. Our findings inform optimal management, emphasizing the use of targeted antibiotics and early minimally invasive intervention.

Ethics Committee Approval and Patient Consent

This study was approved by the Medical Research Ethics Committee of Peking University First Hospital (Approval No. 2024 Research 249-001). As this was a retrospective study involving the review of existing medical records, the requirement for individual patient informed consent was waived by the committee. All patient-identifiable information was removed or anonymized prior to analysis. The researchers maintained strict confidentiality of all data, ensuring that no individual patient could be identified in this report, in accordance with the Declaration of Helsinki.

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Disclosure

The authors report no conflicts of interest in this work.

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