

Original Article

Analysis of risk factor for peritonitis in peritoneal dialysis patients

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Abstract: Objective: To investigate the risk factors for peritonitis in peritoneal dialysis patients and to develop and validate a predictive model. Methods: A total of 219 patients undergoing continuous ambulatory peritoneal dialysis (CAPD) who had their first peritoneal dialysis catheter placement and regular follow-up at Wuhan No. 1 Hospital between April 2020 and August 2023 were included in this study. Patients were categorized into two groups: a peritoneal dialysis-associated peritonitis (PDAP) group and a non-PDAP group, based on the occurrence of PDAP. Univariate and multivariate logistic regression analyses were conducted to identify risk factors for PDAP in peritoneal dialysis patients. A risk prediction model was constructed, and its predictive performance was assessed using the receiver operating characteristic (ROC) curve. Results: Among the study population, 59 patients developed PDAP, with an incidence rate of 26.94%. Univariate and multivariate Logistic regression analyses identified serum albumin, age, hemoglobin, diabetes mellitus, and dialysis duration as independent risk factors for PDAP (all $P < 0.05$). The ROC curve analysis of the predictive model yielded an area under the curve (AUC) of 0.914. A validation cohort consisting of 75 patients who underwent peritoneal dialysis between September 2023 and May 2024 included 22 PDAP. In this validation set, the predictive model achieved an AUC of 0.883 for PDAP. Conclusion: Serum albumin, age, hemoglobin, diabetes, and dialysis duration are independent risk factors for PDAP in peritoneal dialysis patients. The developed predictive model demonstrates strong performance in identifying patients at high risk for PDAP.

Keywords: Peritoneal dialysis, peritonitis, risk factors, predictive modeling, clinical validation

Introduction

Chronic kidney disease (CKD) is characterized by renal damage and a reduced glomerular filtration rate [$< 60 \text{ ml}/(\text{min} \cdot 1.73 \text{ m}^2)$] for more than 3 months, resulting from various causes. Renal damage may manifest as pathological abnormalities, abnormal blood or urine composition, or atypical imaging findings of the kidneys [1]. Globally, the incidence of CKD has been steadily increasing, making it a significant public health concern alongside cardiovascular diseases, cancer, and diabetes [2, 3]. Replacement therapies such as renal transplantation, hemodialysis, and peritoneal dialysis are primary treatments for end-stage renal disease (ESRD). Among these, kidney transplantation is often limited by high cost, scarcity of donor organs, and risks of post-transplant rejection.

In contrast, hemodialysis and peritoneal dialysis are more widely utilized in clinical practice due to their relative affordability and feasibility. Peritoneal dialysis, in particular, offers the advantages of being accessible and home-based. It provides effective removal of intermediate molecules, better preservation of residual renal function, and a reduced impact on the body's internal environment, hemodynamics, and cardiovascular stress [4, 5]. However, long-term peritoneal dialysis is associated with complications, the most common of which is peritoneal dialysis-related peritonitis (PDAP). PDAP significantly affects the treatment course, often leading to dialysis failure, kidney transplantation, or even mortality [6, 7]. Despite advancements in peritoneal dialysis technology and increased awareness, which have contributed to a declining incidence of PDAP, its multifactorial etiology means

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that there is still no consensus on its risk factors.

To improve understanding of PDAP risk factors in peritoneal dialysis patients, this study conducted a retrospective analysis of patients treated at our hospital and developed a predictive model to identify high-risk individuals, thereby aiding in the prevention of PDAP.

Information and methods

Clinical data

A total of 219 patients on continuous ambulatory peritoneal dialysis (CAPD) who received their first peritoneal dialysis catheter placement and had regular follow-up at Wuhan No. 1 Hospital between April 2020 and August 2023 were included in this study.

Inclusion criteria

(1) All patients underwent initial peritoneal dialysis catheter implantation via open surgical procedure in our nephrology department. (2) Patients and their caregivers received standardized training in peritoneal dialysis practices after catheter placement, using peritoneal dialysis fluid manufactured by Baxter. (3) Patients were 18 years of age or older. (4) Patients were regularly revisited at intervals of three months. (5) Complete clinical profile.

Exclusion criteria

(1) Patients who received hemodialysis treatment in addition to peritoneal dialysis. (2) Patients with concurrent malignancy, heart failure, or stroke. (3) Patients with tuberculous ascites. (4) Patients with dysfunctions of other organs such as heart, liver, lungs. (5) Patients with immune system disorders. (6) Patients on dialysis for less than 3 months.

PDAP diagnostic criteria and grouping

Following the guidelines of the International Society for Peritoneal Dialysis (ISPD) [8], patients were diagnosed with PDAP if they met at least two of the following criteria: (1) Presence of clinical signs and symptoms of peritonitis, such as abdominal pain and/or cloudy peritoneal fluid. (2) A transudate leukocyte count $>100 \times 10^6$ with neutrophil percentage of $>50\%$. (3) A positive culture for pathogens in the transudative fluid.

Patients were categorized based on PDAP occurrence: those with one episode of PDAP or more were assigned to the PDAP group, and those without PDAP episodes were assigned to the non-PDAP group.

Research method

Collection of clinical data: Clinical data of the patients were collected and recorded, including gender, age, body mass index (BMI), education level, smoking history, alcohol consumption, place of residence, marital status, primary disease, diabetes mellitus, hypertension, dialysis course, blood creatinine, blood urea, serum albumin, hemoglobin, uric acid, blood potassium, blood phosphorus, and C-reactive protein (CRP).

Culture of pathogenic bacteria: Peritoneal dialysis effluent was collected as the sample for bacterial culture. The waste fluid bag was disinfected with iodophor twice. After drying, 10-15 ml of the effluent was drawn with a 20 ml sterile syringe. The sample was injected into a standard blood culture bottle (aerobic and anaerobic) for bacterial culture.

Statistical analysis

SPSS 27.0 was used for statistical analysis. The measurement data were expressed as mean \pm standard deviation and compared by *t*-test; count data were expressed as numbers and percentage and compared by Chi-square test; rank data were expressed as percentile and compared using rank-sum test. Univariate and multivariate logistic regression analyses were performed to identify risk factors for the occurrence of PDAP. A risk prediction model was constructed. The predictive value of the model for PDAP occurrence was evaluated using a receiver operating characteristic (ROC) curve. The difference was statistically significant when $P < 0.05$.

Results

Clinical data

The study included 219 patients on peritoneal dialysis, including 124 males and 95 females, with an average age of (59.11 ± 10.95) years and an average BMI of (23.24 ± 2.91) kg/m². 132 cases had an educational level of junior high school or below, while 87 cases had a level

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Table 1. Distribution of pathogenic bacteria detected in PDAP patients

Pathogenic bacteria	The number of pathogenic bacteria	Composition ratio (%)
Gram-negative bacteria	11	28.95
Escherichia coli (E. coli)	5	13.16
Klebsiella pneumonia	3	7.89
Pseudomonas aeruginosa	1	2.63
Acinetobacter baumannii	1	2.63
Aeromonas hydrophilia	1	2.63
Gram-positive bacteria	24	63.16
Staphylococcus aureus	13	34.21
Streptococcus hemolyticus	7	18.42
Staphylococcus epidermidis	3	7.89
Enterococcus faecium	1	2.63
Fungi	3	7.89
Candida albicans	2	5.26
Candida tropicalis	1	2.63
Total	38	100.00

Note: PDAP: Peritoneal dialysis-associated peritonitis.

of high school or above. Among them, 63 patients were smokers, 50 consumed alcohol, 128 resided in urban areas, and 91 in rural areas. Marital status indicated that 176 were married, while 43 were unmarried, divorced, or widowed. The underlying diseases included chronic glomerulonephritis in 95 cases, diabetic nephropathy in 61 cases, hypertension nephropathy in 27 cases, and other causes in 36 cases. Additionally, 69 patients had diabetes, and 71 had hypertension.

Incidence and pathogen distribution of PDAP in peritoneal dialysis patients

PDA occurred in 59 out of 219 peritoneal dialysis patients, with an incidence of 26.94%. Of the 59 patients with PDAP, 38 patients had positive culture results for pathogenic bacteria, yielding a positive detection rate of 64.41%. Each patient was infected with a single strain, with a total of 38 strains identified: 11 gram-negative bacteria (28.95%), 24 gram-positive bacteria (63.16%), and 3 fungi (7.89%) (Table 1).

Univariate analysis of factors associated with PDAP

Significant differences were found in age, diabetes, dialysis course, serum albumin, hemoglobin, uric acid, and CRP between the PDAP

group and the non-PDAP group (all $P < 0.05$) (Table 2).

Determination of cutoff values for significant variables

ROC analyses were used to determine the cutoff values for significant variables derived from univariate analysis, as shown in Table 3.

Risk factors for PDAP identified by multivariate logistic regression analysis

Values were assigned to variables, as shown in Table 4. Each factor found to be statistically significant

in the univariate analysis was further analyzed using multivariate logistic regression. The results showed that serum albumin, age, hemoglobin, diabetes mellitus, and dialysis course were independent risk factors for PDAP (all $P < 0.05$), as shown in Table 5.

Construction of a PDAP prediction model

Based on the results of the multivariate Logistic regression analysis, a stepped-wedge plot model, in the form of line chart, was constructed using R 3.6.3 software and rms package, as shown in Figure 1.

ROC curve was further used to assess the predictive value of the constructed model for PDAP, and the analysis yielded an area under the curve (AUC) of 0.914, indicating high predictive value, as shown in Figure 2.

Model validation

A validation group of 75 patients who underwent peritoneal dialysis from September 2023 to May 2024, meeting the same inclusion and exclusion criteria, was selected. Among these patients, 22 had PDAP. The predictive model demonstrated a predictive value of 0.883 for PDAP in the validation set, as shown in Figure 3.

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Table 2. Comparison of baseline data between PDAP and non-PDAP groups

Parameters	PDAP group (n=59)	Non-PDAP group (n=160)	t/ χ^2	P
Gender [n (%)]				
Male	33 (55.93)	91 (56.88)	0.016	0.901
Female	26 (44.07)	69 (43.13)		
Age (years, $\bar{x} \pm s$)	63.14 \pm 12.04	57.63 \pm 10.28	3.356	0.001
BMI (kg/m ² , $\bar{x} \pm s$)	23.43 \pm 2.67	23.17 \pm 2.81	0.616	0.539
Education level [n (%)]				
Junior high and below	35 (59.32)	97 (60.63)	0.031	0.861
High school or above	24 (40.68)	63 (39.38)		
Smoking [n (%)]				
Yes	18 (30.51)	45 (28.13)	0.120	0.730
No	41 (69.49)	115 (71.88)		
Alcohol consumption [n (%)]				
Yes	13 (22.03)	37 (23.13)	0.029	0.865
No	46 (77.97)	123 (76.88)		
Place of residence [n (%)]				
Urban	32 (54.24)	96 (60.00)	0.589	0.443
Rural	27 (45.76)	64 (40.00)		
Marital status [n (%)]				
Married	47 (79.66)	129 (80.63)	0.025	0.873
Unmarried, divorced or widowed	12 (20.34)	31 (19.38)		
Uderlying disease [n (%)]				
Chronic glomerulonephritis	24 (40.68)	71 (44.38)	0.725	0.867
Diabetic nephropathy	16 (27.12)	45 (28.13)		
Hypertensive nephropathy	9 (15.25)	18 (11.25)		
Others	10 (16.95)	26 (16.25)		
Diabetes mellitus [n (%)]				
Yes	35 (59.32)	34 (21.25)	28.953	<0.001
No	24 (40.68)	126 (78.75)		
Hypertension [n (%)]				
Yes	20 (33.90)	51 (31.88)	0.188	0.664
No	49 (83.05)	109 (68.13)		
Dialysis course (months, $\bar{x} \pm s$)	34.49 \pm 12.05	28.66 \pm 9.60	3.712	<0.001
Blood creatinine (μ mol/L, $\bar{x} \pm s$)	895.64 \pm 124.76	887.26 \pm 159.41	0.365	0.716
Blood urea (mmol/L, $\bar{x} \pm s$)	15.02 \pm 2.97	14.85 \pm 3.12	0.362	0.718
Serum albumin (g/L, $\bar{x} \pm s$)	28.94 \pm 2.65	32.47 \pm 2.95	8.067	<0.001
Hemoglobin (g/L, $\bar{x} \pm s$)	81.05 \pm 7.62	89.92 \pm 8.33	7.149	<0.001
Uric acid (μ mol/L, $\bar{x} \pm s$)	431.04 \pm 58.67	407.34 \pm 42.16	3.301	0.001
Potassium (mmol/L, $\bar{x} \pm s$)	4.25 \pm 1.36	4.42 \pm 1.47	0.774	0.440
Blood phosphorus (mmol/L, $\bar{x} \pm s$)	1.39 \pm 0.42	1.44 \pm 0.36	0.871	0.385
CRP (mg/L)	10.65 \pm 1.74	8.31 \pm 1.67	9.096	<0.001

Notes: PDAP: Peritoneal dialysis-associated peritonitis; BMI: Body mass index; CRP: C-reactive protein.

Discussion

Peritoneal dialysis-related peritonitis (PDAP) is a specific intraperitoneal infection that arises as a complications of peritoneal dialysis. It is characterized by symptoms such as abdominal

pain, fever, and cloudy dialysate, all indicative of peritonitis [9, 10]. PDAP is a major complication in peritoneal dialysis patients, serving as a leading cause of treatment failure and mortality in this population. Recurrent episodes of PDAP often result in peritoneal ultrafiltration

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Table 3. Cutoff values for significant variables determined by ROC analysis

Index	AUC	Cut-off value	Sensitivity	Specificity	P	95% CI
Age	0.643	61.02 years	64.40%	65.00%	0.001	0.557-0.729
Dialysis course	0.654	32.47 months	44.10%	88.70%	0.000	0.566-0.742
Serum albumin	0.817	30.97 g/L	71.20%	81.20%	0.000	0.751-0.882
Hemoglobin	0.781	87.13 g/L	79.70%	62.50%	0.000	0.713-0.849
Uric acid	0.624	420.10 $\mu\text{mol/L}$	47.50%	82.50%	0.005	0.532-0.716
CRP	0.719	9.57 mg/L	71.20%	65.60%	0.000	0.644-0.793

Notes: ROC: Receiver operating characteristic; AUC: Area under the curve; CRP: C-reactive protein.

Table 4. Variable assignment

Variables	Assignment
Age	<61.02 years old = 0, \geq 61.02 years old = 1
Diabetes	Yes = 0, No = 1
Dialysis course	<32.47 months = 0, \geq 32.47 months = 1
Serum albumin	<30.97 g/L = 0, \geq 30.97 g/L = 1
Hemoglobin	<87.13 g/L = 0, \geq 87.13 g/L = 1
Uric acid	<420.10 $\mu\text{mol/L}$ = 0, \geq 420.10 $\mu\text{mol/L}$ = 1
CRP	<9.57 mg/L = 0, \geq 9.57 mg/L = 1

Note: CRP: C-reactive protein.

failure, ultimately leading to peritoneal dialysis technique failure. Additionally, PDAP-related deaths account for approximately 10% to 20% of all peritoneal dialysis-associated fatalities [11-14]. Despite advancements in dialysis technology and improved disinfection protocols, PDAP remains a significant cause of treatment failure in peritoneal dialysis patients, although its incidence has gradually declined in recent years [15-18].

In this study, we analyzed 219 patients from our hospital, using univariate and multivariate logistic regression analyses to identify factors influencing the development of PDAP in peritoneal dialysis patients. Our findings identified serum albumin, age, hemoglobin, diabetes mellitus, and dialysis duration as independent risk factors for the PDAP, consistent with reports from other studies [19-21]. Peritoneal dialysis patients with low serum albumin and hemoglobin levels were found to have a higher risk of developing PDAP. Albumin plays a vital role in maintaining plasma colloid osmotic pressure and in the transport of insoluble small-molecule organic substances. Low albumin levels can lead to malnutrition, protein loss, and systemic inflammatory responses, all of which contribute to the onset of peritonitis [22, 23]. Hypoproteinemia is particularly common

among peritoneal dialysis patients due to protein leakage during dialysis and poor nutritional intake caused by anorexia [24, 25]. Therefore, providing dietary guidance to improve nutritional status is of critical significance in reducing the risk of PDAP.

Aging is associated with a decline in physiological functions and immunity, and elderly patients often have multiple chronic conditions such as hypertension, heart failure, and diabetes,

significantly increasing the risk of PDAP [26-28]. Patients with diabetes are particularly susceptible to PDAP, as chronic hyperglycemia impairs immune function, reduces the adhesion capacity of white blood cells, but enhances chemotaxis, all of which contribute to the development of peritonitis. In addition, diabetic patients frequently require insulin administration via dialysis fluid, further elevating the risk of infection [29-31]. Longer durations of peritoneal dialysis predispose patients to peritoneal fibrosis, which impairs peritoneal function and reduces the peritoneal cavity's defense capacity [32, 33]. Furthermore, prolonged exposure to glucose-based dialysate can increase intra-abdominal pressure and intestinal wall tension, leading to intestinal mucosa hypoxia and ischemia. This weakens the mucosal barrier, increases permeability, and facilitates bacterial translocation into peritoneal cavity, thereby heightening the risk of PDAP [34, 35].

We identified the risk factors for PDAP through a comprehensive analysis of variables including serum albumin, age, hemoglobin, diabetes mellitus, and dialysis duration. These findings provided valuable insights for clinicians, aiding in the prevention and management of peritonitis and improving the quality of life for peritoneal dialysis patients. In addition to identifying

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Table 5. Multivariate logistic regression analysis of independent risk factors for PDAP

Factor	b	S.E	χ^2	P	OR	95% CI
Serum albumin	-1.856	0.475	15.268	0.000	0.156	0.062-0.397
Age	1.664	0.512	10.563	0.001	5.280	1.936-14.404
Hemoglobin	-1.658	0.567	8.551	0.003	0.191	0.063-0.579
Diabetes	1.401	0.492	8.109	0.004	4.059	1.548-10.647
Dialysis course	1.388	0.576	5.807	0.016	4.007	1.296-12.391

Note: PDAP: Peritoneal dialysis-associated peritonitis.

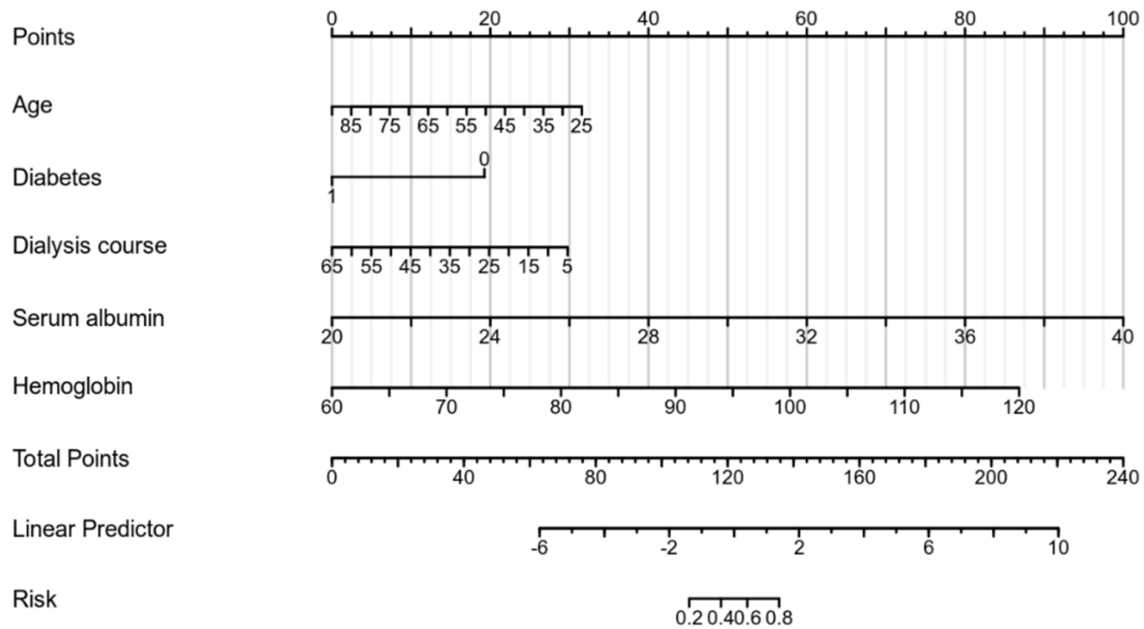


Figure 1. Line chart model.

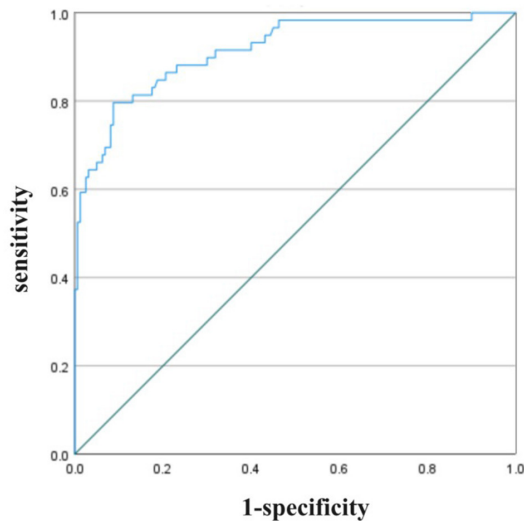


Figure 2. Predictive value of the model for PDAP analyzed by ROC curve analysis. Notes: PDAP: Peritoneal dialysis-associated peritonitis; ROC: Receiver operating characteristic.

these key risk factors, we developed a risk prediction model for PDAP, which demonstrated strong predictive value with an AUC of 0.914. To validate the model, it was applied to a separate validation set of 75 patients, yielding an AUC of 0.883. These results further support the model's effectiveness in predicting PDAP risk.

In summary, serum albumin, hemoglobin, age, diabetes mellitus, and dialysis duration are independent risk factors for PDAP in peritoneal dialysis patients. The risk prediction model based on these factors shows strong potential for identifying patients at high clinical risk of PDAP, facilitating proactive and targeted clinical management.

Disclosure of conflict of interest

None.

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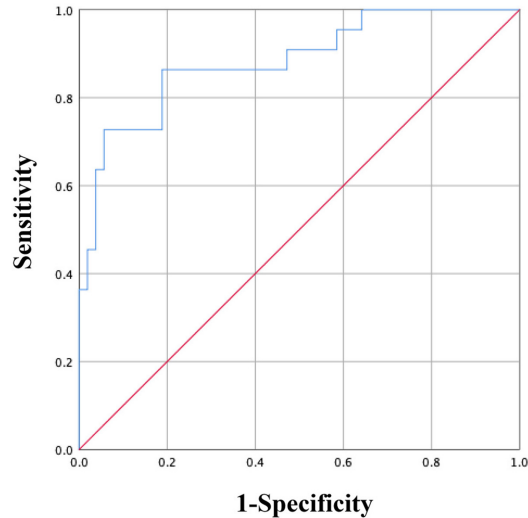


Figure 3. Application of the predictive model in the validation set.

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