BMC Nephrology

RESEARCH

Open Access

A nomogram for predicting the risk of peritoneal dialysis-associated peritonitis in patients with end-stage renal disease undergoing peritoneal dialysis: model development and validation study

Yuehong Wang[1], Zhimin Wu[3], Liuqi Huang[4], Dan Suo[1], Min Zhang[5], Meifen Dai[3], Tianhui You[2*] and Jing Zheng[1*]

Abstract

Objective This study aimed to develop and validate a nomogram to predict the risk of peritoneal dialysis-associated peritonitis (PDAP) in patients undergoing peritopreneal dialysis.

Methods A retrospective analysis was conducted on clinical data from 376 patients at Nanhai District People's Hospital in Foshan City, Guangdong Province, between December 2017 and December 2024. The dataset was randomly divided into a training set ($n=244$) and a validation set ($n=132$). Risk factors for PDAP were identified using Least Absolute Shrinkage and Selection Operator (LASSO) regression and logistic regression, and a predictive nomogram was developed and validated using R4.1.3. The model's performance was evaluated through receiver operating characteristic (ROC) curves, the Hosmer-Lemeshow goodness-of-fit test, decision curve analysis (DCA), and clinical impact curves (CICs).

Results Eight potential predictors were selected by LASSO regression analysis. Multivariate logistic regression analysis confirmed that age, dialysis duration, albumin, hemoglobin, β_2-microglobulin, Potassium and lymphocyte count were independent risk factors for PDAP occurrence ($P=0.001$). The nomogram's area under the curve (AUC) was 0.929 (95% CI: 0.896–0.962) in the training set and 0.905 (95% CI: 0.855–0.955) in the validation set. The Hosmer-Lemeshow goodness-of-fit test indicated a good model fit (training set $\chi^2=13.181$, $P=0.106$; validation set $\chi^2=8.264$, $P=0.408$). Both DCA and CIC revealed that the nomogram model had good clinical utility in predicting PDAP.

Conclusion The proposed nomogram exhibited excellent predictive performance and clinical utility, providing a valuable tool for early identification and intervention in PDAP. Further external validation and prospective studies are recommended.

*Correspondence:
Tianhui You
youth888cn@aliyun.com
Jing Zheng
zhengj38@gdpu.edu.cn

Full list of author information is available at the end of the article

Keywords Dialysis-associated peritonitisc, Peritoneal dialysis, Nomogram, Clinical prediction model, End-stage renal disease

Introduction

Peritoneal dialysis is a widely used form of kidney replacement therapy for patients with end-stage renal disease (ESRD) [1], which is valued for its simplicity, stable hemodynamics, and better preservation of residual renal function compared to other dialysis modalities [2]. As a result, By the end of 2022, there were 140,544 peritoneal dialysis patients registered in China, accounting for 14.3% of all dialysis patients [3].

However, peritoneal dialysis-associated peritonitis (PDAP) remains a common and serious complication, leading to prolonged hospitalization, increased healthcare costs, and in severe cases, peritoneal dialysis failure or even death [4, 5]. Early and accurate diagnosis of PDAP is crucial for improving patient outcomes [6]. Despite its importance, few studies have developed reliable clinical prediction models for the early diagnosis of PDAP. Qiqi Yan et al. developed a prediction model based on C-reactive protein (CRP), serum albumin, diabetes mellitus, peritoneal dialysis duration, and pathogen type in patients undergoing peritoneal dialysis, primarily focusing on predicting refractory peritonitis [7]. Rong Dai et al. developed a prediction model for PDAP after peritoneal dialysis catheterization based on markers such as the neutrophil-to-lymphocyte ratio, serum albumin, uric acid, high-sensitivity CRP, and diabetes mellitus,This model was focused on inflammatory indicators at the time of catheterization [8].

Malnutrition is another common complication among patients undergoing peritoneal dialysis, which is significantly linked to poor prognosis. It has also been identified as an independent risk factor for the occurrence of PDAP [9, 10]. However, there is a lack of predictive models for early diagnosis of PDAP that incorporate nutrition-related indicators. Therefore, this study aims to analyze the relationship between nutrition-related laboratory indicators and PDAP in patients undergoing peritoneal dialysis, and to construct a nomogram for predicting the risk of PDAP based on these indicators.

Materials and methods

Study population

This retrospective case-control study included a total of 376 patients undergoing PD at the Nanhai District People's Hospital in Foshan City, Guangdong Province, China, from December 2017 to December 2024. 188 of them had PDAP, and 188 patients did not. The diagnostic criteria for PDAP were based on the 2022 International Society for Peritoneal Dialysis (ISPD) guidelines [11], which require the presence of at least two of the following three conditions, confirmed by two physicians independently: abdominal pain or cloudy peritoneal fluid with or without fever; peritoneal fluid leukocyte count $>100/\mu L$ or $>0.1\times10^9/L$ with $>50\%$ polymorphonuclear cells (duration of abdominal stay ≥ 2 hours); and positive microbiological culture of the peritoneal fluid.

The inclusion criteria were as follows: continuous ambulatory peritoneal dialysis (CAPD) as the dialysis modality; complete clinical data; aged 18 years or older; and regular follow-up while receiving standard treatment. The exclusion criteria were: patients with multi-organ failure; a history of acute cardiovascular or cerebrovascular events (e.g., acute heart failure, acute coronary syndrome, or stroke) within the past three months; patients who had undergone blood dialysis or kidney transplantation; patients with malignant tumors, hematological malignancies, or acute or chronic infections in the past 3 months; immunosuppressed patients who are taking immunosuppressants or have an autoimmune disease (e.g.,Acquired Immunodeficiency Syndrome). This study was approved by the Institutional Review Board of Nanhai District People's Hospital (Ethics Number: 2023361).

Data collection

The clinical data collected for analysis included clinical data (gender, age), dialysis duration, primary disease and various laboratory parameters, such as hemoglobin (HGB): spectrophotometric method, albumin (ALB): immunoturbidimetric assay, serum prealbumin: immunoturbidimetric assay, serum creatinine (CR): sarcosine oxidase method, blood urea nitrogen (BUN): urease-glutamate dehydrogenase method, urinary albumin (UA): uric acid enzymatic method, β_2-microglobulin: latex enhanced immunoturbidimetric assay, serum sodium (Na): method of ISE, serum potassium (K): method of ISE, calcium (Ca): arsenazo III method, serum phosphorus (P): biuret method, urea clearance index(Kt/V), serum triglycerides (TG): GPO-PAP method, total cholesterol (TCH): CHOD-PAP method, lymphocyte count (LYM): semiconductor laser flow cytometry. Patients were divided into two groups based on the occurence of PDAP: the PDAP group and the non-PDAP group. For the patients in the PDAP group, data from the last follow-up prior to the occurrence of PDAP were collected. For patients in the non-PDAP group, laboratory results from the most recent test prior to data collection were used. For patients with recurrent PDAP, only data from the first episode were included in the analysis.

Statistical analysis

R 4.1.3 software were used for data analysis. Normally distributed measurement data (e.g., albumin, prealbumin, serum potassium, total cholesterol) were expressed as the mean ± standard deviation, and comparisons between groups were conducted using independent samples *t*-tests. For non-normally distributed data (e.g., age, dialysis duration, hemoglobin, creatinine, blood urea nitrogen, urinary albumin, β_2-microglobulin, serum sodium, serum calcium, serum phosphorus, Kt/V, triglycerides, and lymphocyte count), data were described by the median (interquartile range), and the Mann-Whitney U test was used for comparisons between groups. Categorical data (e.g., gender, primary disease) were expressed as frequencies and percentages, and comparisons between groups were made using the χ^2 test. The occurrence of PDAP was set as the dependent variable. Variables with $P<0.05$ in the univariate analysis were included in a multivariate logistic regression model. To prevent overfitting and multicollinearity, The "glmnet" and "palasso" software packages in R were used for LASSO regression analysis. The main role of the algorithm is to realize the automatic selection of variables through L1 regularization, effectively reduce the complexity of the model, and prevent overfitting, so as to improve the interpretation and prediction accuracy of the model.

Based on the selected variables, the clinical prediction model was constructed using multivariate logistic regression with a 0.65 : 0.35 training-validation split. The "rms" package in R was used to generate the nomogram model. Model discrimination was assessed using the receiver operating characteristic (ROC) curve analysis and calculation of area under the curve (AUC). The Hosmer-Lemeshow goodness-of-fit test and calibration curve were used to evaluate the goodness of fit of the model, and the bootstrap self-sampling test was performed for 1000 times. Decision curve analysis (DCA) and clinical impact curves (CICs) were drawn using the "rmda" package in R to evaluate the clinical validity of the model.

Results

General data of patients undergoing peritoneal dialysis

A total of 376 patients undergoing peritoneal dialysis were enrolled in this study, including 227 males and 149 females, with a median age of 56 years. The primary diseases of the patients included chronic nephritis ($n=112$), diabetes ($n=102$), hypertension ($n=112$) and other conditions ($n=50$). There were 188 patients in the PDAP group and 188 patients in the non-PDAP group. Univariate analysis revealed significant differences between the two groups in term of age, dialysis duration, hemoglobin, albumin,prealbumin, serum creatinine, blood urea nitrogen, urinary albumin, β_2-microglobulin, Serum potassium, Serum sodium, calcium, Kt/V, lymphocyte count ($P<0.05$), and there were no significant differences between the groups in terms of gender, primary disease, Serum phosphorus, serum triglycerides, total cholesterol (Table 1).

Risk factors of PDAP in patients undergoing peritoneal dialysis

The least absolute shrinkage and selection operator (LASSO) regression analysis was conducted for dimensionality reduction and cross validation. The optimal model was identified at regularization parameter (λ) = 0.038. Eight non-zero coefficient prognostic factors were selected as significant predictors for the risk of PDAP, including age, dialysis duration, hemoglobin, albumin, β_2-microglobulin, Serum phosphorus, Serum sodium, and lymphocyte count (Fig. 1).

Significant indicators identified from the univariate analyses were further screened according to the relevant literature [7–13]. The variables selected by LASSO regression (age, dialysis duration, hemoglobin, serum albumin, β_2-microglobulin, potassium, sodium and lymphocyte count were subsequently included in the multivariate logistic regression analysis. Multivariate regression analysis showed that the following factors were independent risk factors for PDAP: shortened dialysis duration, decreased hemoglobin, decreased albumin, lower serum potassium, lower lymphocyte count, increased age, and elevated β_2-microglobulin ($P<0.05$) (Table 2).

Development of a nomogram prediction model for PDAP risk in patients undergoing peritoneal dialysis

According to the results of LASSO regression and multivariate logistic regression analysis, the following facotors were selected to construct a nomogram for predicting the risk of PDAP: age, dialysis duration, hemoglobin, albumin, β_2-microglobulin, serum potassium and lymphocyte count. The nomogram developed using R software, assigns scores to each factor, with the total score representing the risks of PDAP (Fig. 2). A higher total score indicated the increased risk of PDAP.

Validation of the PDAP risk prediction model

The area under the receiver operating characteristic (ROC) curve (AUC) of the training set was 0.929 (95%CI: 0.896–0.962), and the best cut-off value was 0.166 (corresponding specificity and sensitivity were 0.825 and 0.918, respectively). The AUC of the validation set was 0.905 (95%CI: 0.855–0.955), and the best cut-off value was 0.417 (corresponding specificity and sensitivity were 0.819 and 0.849, respectively), Fig. 3a, b. To verify the model's calibration, calibration curves for both the training and verification sets were plotted. The fitted curves for both sets closely matched the ideal model curve,

Table 1 Comparison of patient characteristics between PDAP group and non-PDAP group

Variables	Total($n=376$)	PDAP($n=188$)	Non-PDAP($n=188$)	P
sex,[c]				0.833
Male	227(60%)	115(61%)	112(60%)	
Age(year)[b]	56(43,67)	49(38,61)	61(52,72)	<0.001
Primary disease,[c]				0.097
Chronic nephritis	112(30%)	50(27%)	62(33%)	
Diabetes	102(27%)	47(25%)	55(29%)	
Hypertension	112(30%)	67(36%)	45(24%)	
Others	50(13%)	24(13%)	26(14%)	
Dialysis_duration(month)[b]	26(11,46.25)	35(19,53)	18(6,39.25)	<0.001
HGB(g/L)[b]	102(90,111)	106(101,117)	93(86,103)	<0.001
ALB(g/L)[a]	32.29 ± 5.66	35.37 ± 4.77	29.2 ± 4.74	<0.001
Prealbumin(mg/L)[a]	304.15 ± 100.96	315.62 ± 96.72	292.68 ± 104.03	0.027
CR(mg/dl)[b]	922(695,1132.25)	1008.5(761.75,1217.5)	834.5(639.75,1073.75)	<0.001
BUN(mmol/L)[b]	21.56(17.06,27.1)	23.31(18.54,28.6)	19.65(15.61,25.98)	<0.001
UA(mmol/L)[b]	399(342.5,474)	420(363,476.72)	383(331.75,470.75)	0.005
β_2-microglobulin(mg/dl)[b]	23.59(20.04,28.08)	21.7(18.27,25.86)	25.8(21.53,29.46)	<0.001
K(mmol/L)[a]	3.96 ± 0.76	4.19 ± 0.76	3.73 ± 0.68	<0.001
Na(mmol/L)[b]	137.55(135,139.5)	138.65(136.6,140.33)	136.25(133.85,138.7)	<0.001
Ca(mmol/L)[b]	2.13(1.96,2.27)	2.14(2,2.28)	2.09(1.91,2.24)	0.023
P(mmol/L)[b]	1.73(1.41,2.09)	1.76(1.47,2.17)	1.68(1.35,2.02)	0.113
Kt/V[b]	1.42(1.18,1.76)	1.48(1.21,1.83)	1.38(1.16,1.69)	0.036
TG,(mmol/L)[b]	1.36(0.88,1.95)	1.35(0.87,1.79)	1.4(0.89,2.11)	0.378
TCH,(mmol/L)[a]	4.33 ± 1.44	4.3 ± 1.16	4.36 ± 1.67	0.685
LYM,(10^9/L)[b]	1.05(0.65,1.43)	1.21(0.7,1.74)	0.92(0.58,1.26)	<0.001

Abbreviations:PDAP, peritoneal dialysis-associated peritonitis. HGB, hemoglobin. ALB, albumin. CR,Creatinine. BUN, blood urea nitrogen. UA,urinary albumin. K, serum phosphorus. Na, serum Sodium. Ca, serum calcium. P, serum phosphorus. Kt/V, urea clearance index. TG, triglycerides. TCH, total cholesterol. LYM, lymphocyte count.[a],Data shown as mean ± standard deviation; [b],data shown as median(Q1,Q3); [c],data shown as number of cases

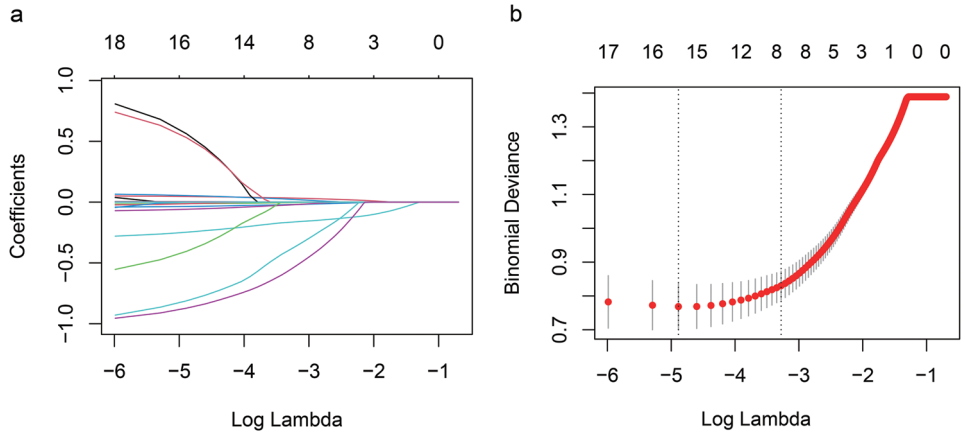

Fig. 1 Least absolute shrinkage and selection operator (LASSO) model feature selection. **a**: LASSO regression was used to analyze 19 general data and nutrition-related indicators of patients undergoing peritoneal dialysis. **b**: Bias of the LASSO cross validation

indicating good agreement between predicted and actual risk (Fig. 4a, b). Bootstrap resampling further confirmed the calibration, showing good aligment with the actual curve (training set Brier score = 0.389; validation set Brier score = 0.277). The Hosmer-Lemeshow test provided further validation, with $\chi^2 = 13.181$ ($P = 0.106$) for the training set and $\chi^2 = 8.264$ ($P = 0.408$) for the validation set, indicating that the prediction model had a good fitting, high predictive value and strong calibration.

Evaluation of risk prediction models for PDAP

The decision curve analysis (DCA) showed that, for threshold probabilities between 6–95% in the training set and 6–99% in the validation set, the prediction model showed a positive net benefit, highlighting its clinical

Table 2 Logistic regression analysis of PDAP

variables	*OR*	*95%CI*		*P*
Age	1.056	1.033	1.081	<0.001
dialysis duration	0.983	0.972	0.994	<0.001
HGB	0.959	0.938	0.980	<0.001
ALB	0.792	0.733	0.849	<0.001
β_2-microglobulin	1.073	1.027	1.124	<0.001
K	0.410	0.251	0.647	0.015
LYM	0.331	0.186	0.569	<0.001
Na	0.936	0.860	1.016	0.116

Abbreviations: PDAP, peritoneal dialysis-associated peritonitis.HGB, hemoglobin. ALB,albumin. K, serum potassium. Na, serum sodium. LYM, lymphocyte count.

value (Fig. 5a,b). Additionally, the clinical impact curves (CICs) demonstrated that when the prediction probability exceeded 0.6, the red and blue curves gradually overlapped, suggesting high clinical prediction efficiency (Fig. 6a,b).

Discussion

Analysis of the risk factors for the development of PDAP in patients undergoing peritoneal dialysis

In this study, a prediction model of PDAP was constructed based on clinical data and nutritional indicators of patients undergoing peritoneal dialysis. Key indicators included age, dialysis duration, hemoglobin, albumin,

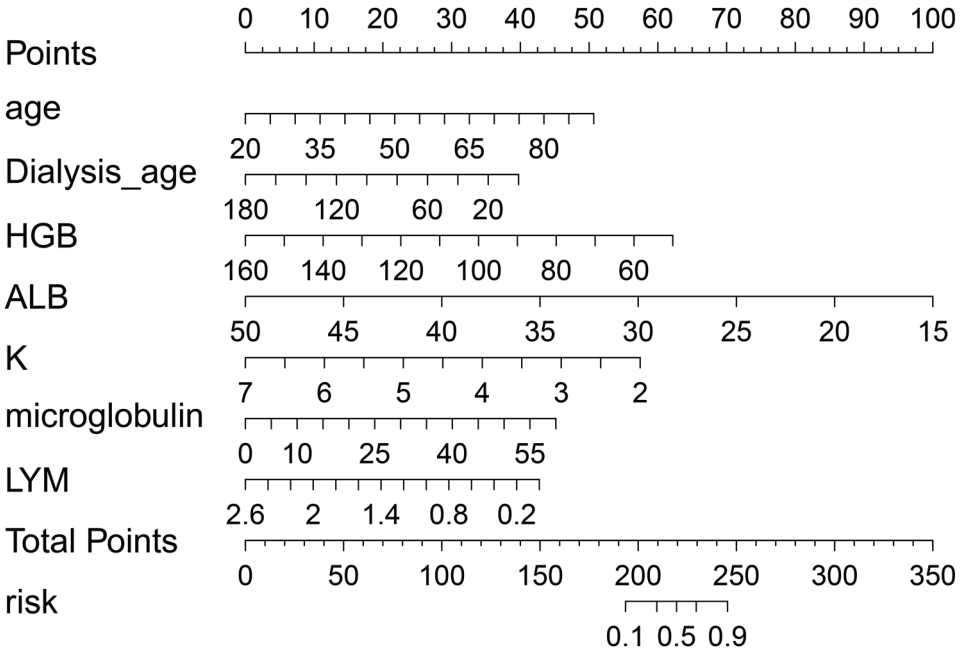

Fig. 2 Nomogram risk prediction model for PDAP in peritoneal dialysis patients. Abbreviations: PDAP:Peritoneal dialysis-associated peritonitis,HGB: Hemoglobin, ALB: Albumin. K: Serum potassium Na: Serum sodium, LYM: Lymphocyte count

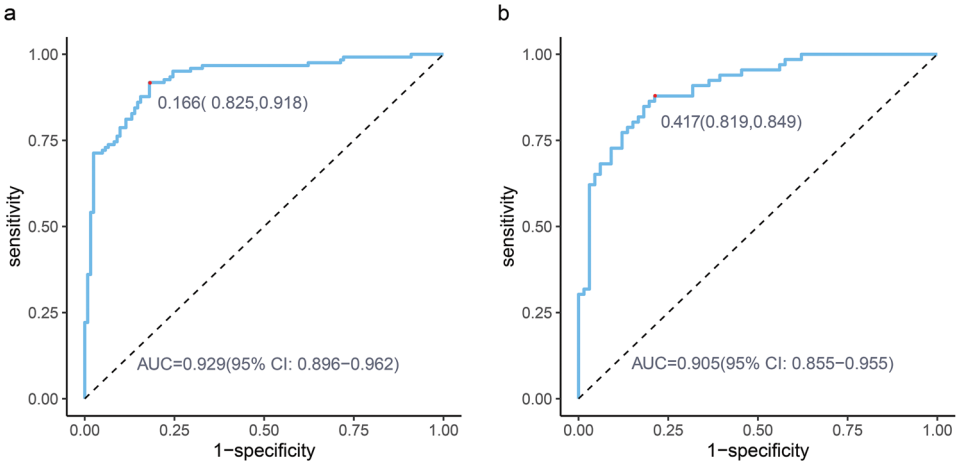

Fig. 3 ROC curve was used to analyze the predictive value of the prediction model for the occurrence of PDAP. **a**: Training set. **b**: Validation set

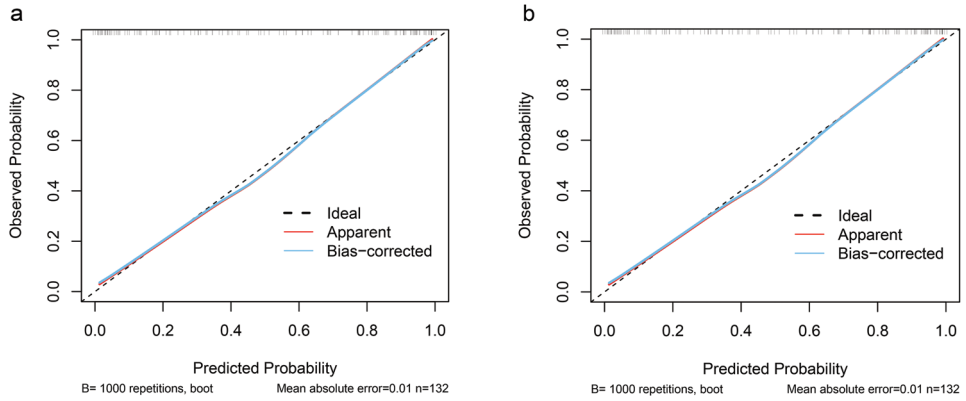

Fig. 4 Calibration curve of PDAP prediction model. **a**: Training set. **b:** Validation set., X-axis represents the predicted risk of PDAP occurrence, while the Y-axis represents the actual occurrence. The diagonal dotted line represents perfect prediction

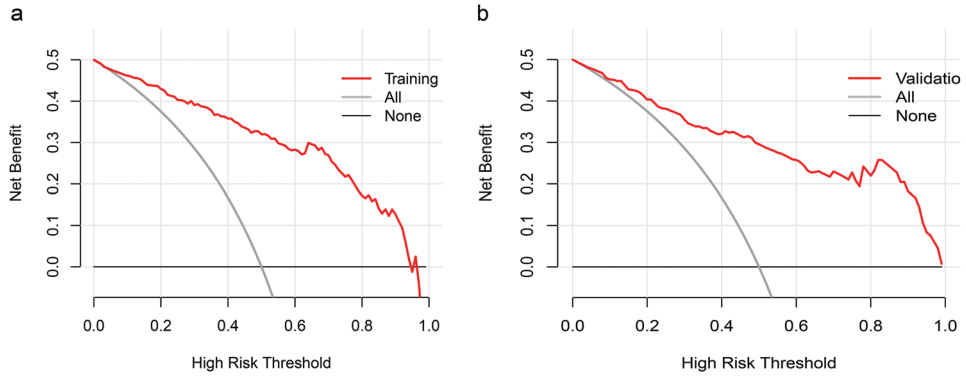

Fig. 5 Clinical decision curve analysis(DCA) of PDAP prediction model. **a**: Training set. **b**: Validation set. The X-axis represents the threshold probability and the Y-axis represents the net benefit expressed as a ratio. The red line indicates the net benefit of the therapeutic intervention in patients with PDAP; The gray line is the net benefit of treatment interventions for all, based on the statistical model; The black line is the net benefit of no treatment intervention for all

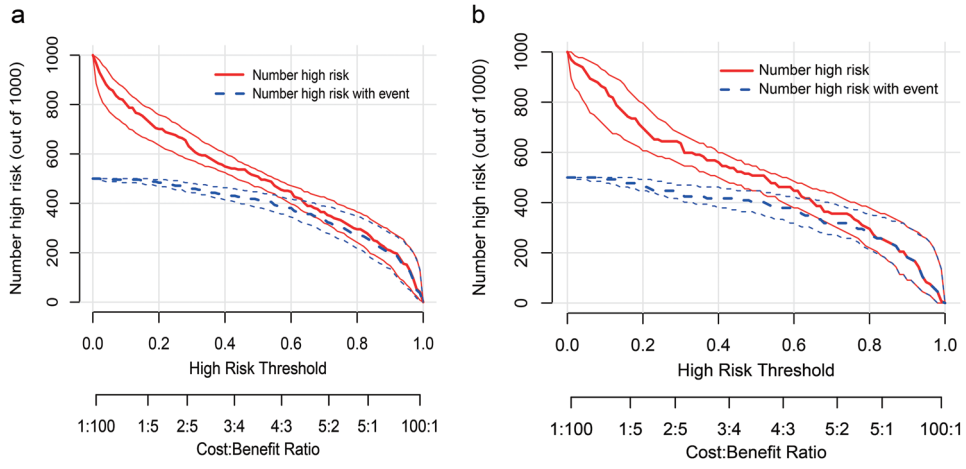

Fig. 6 Clinical impact curve (CIC) of PDAP prediction model. **a**: Training set. **b**: Validation set.The red curve in the CIC represents the number of people classified as positive (high risk) by the model under each threshold probability; the blue curve represents the number of true positives at each threshold probability

β_2-microglobulin, serum potassium and lymphocyte count. Rigorous testing in the validation set confirmed the model's reliability, demonstrating robust differentiation, accuracy and clinical utility. Compared to previous studies [7, 8], this study expanded the scope of clinical indicators by incorporating nutritional parameters, highlighting the predictive role of nutrition-related indicators in the occurrence of PDAP.

Age was identified as an independent risk factor for PDAP, with older patients showing an increased risk of developing PDAP. This is consistent with the findings of HTAY [12], who noted that elderly patients undergoing peritoneal dialysis are at a higher risk of PDAP, which could lead to early PD withdrawal. The increased vulnerability of elderly patients is likely due to a combination of factors, including diminished cognitive function, reduced awareness of aseptic procedures, the presence of comorbidities, and compromised immune defence. These factors can exacerbate the risk of abdominal infections, particularly when localized infections are not managed promptly and adequately. To ensure the safety of elderly individuals during home PD procedures, it is advisable for young family members to assist and monitor the patient to mitigate potential complications.

Additionally, shorter dialysis duration was found to be a significant risk factor for PDAP, with patients who had a shorter dialysis duration being more likely to develop peritonitis compared to those with longer dialysis experiences. This finding indicates that patients who start PD early in their disease course may be at higher risk for PDAP. Previous studies and meta-analysis had shown that early onset of peritonitis significantly increase the risk of all-cause mortality in patients undergoing peritoneal dialysis [13, 14]. However, other studies have suggested that long dialysis duration could also be a risk factor for PDAP [7, 15], which underscores the complexity of this relationship. Haijiao Li's [16] study showed that short dialysis duration might be associated with increased risk of PDAP, potentially due to factors such as older age, low education level, insufficient understanding of the disease in the early stage, and poor aseptic procedures. In addition, in the early stage of dialysis, patients may not have fully developed good PD operation habits, and their training on proper PD techniques may be inadequate.To reduce the risk of PDAP, it is crucial to provide comprehensive training to both patients and their caregivers soon after the initiation of PD. This training should emphasize the importance of aseptic techniques, potential complications such as PDAP, and proper handling of the PD catheter. By enhancing education and support from the outset, patients and their families will be better equipped to manage PD effectively and reduce the likelihood of complications.

Hemoglobin levels play a critical role in the overall health of patients undergoing peritoneal dialysis. Impaired erythropoiesis due to both renal dysfunction and inflammation contributes to lower hemoglobin levels, which are often exacerbated in 17]. Malnutrition is an independent risk factor for the development of infectious peritonitis. Additionally, anemia has been linked to a vicious cycle with peritonitis: inflammation from peritonitis can suppress erythropoiesis, leading to further anemia, which in turn weakens the immune system and worsens infection outcomes [18]. This study corroborates these findings by demonstrating that lower hemoglobin levels were independently associated with an increased risk of PDAP (OR = 0.969, 95%CI: 0.954–0.9831, $P < 0.001$). This finding was consistent with other studies that had shown improving anaemia in patients undergoing peritoneal dialysis could reduce the incidence of PDAP [19]. Furthermore, another study indicated that hemoglobin levels < 100 g/L predict significantly higher mortality risk (OR = 1.83, 95%CI: 1.19–2.81, $P = 0.006$) in patients undergoing peritoneal dialysis [20].

Serum albumin is another crucial marker of nutritional status and immune function. Low albumin levels are associated with impaired antioxidant defenses, increased inflammation, and a compromised ability to repair tissues, all of which exacerbate, the risk of peritonitis [21]. According to the KDOQI guidelines, maintaining serum albumin at 40 g/L or higher is recommended for dialysis patients to reduce complications [22]. In another study, a decrease in albumin level of 20% or more (HR = 2.3, 95% CI 1.40–3.90) was independently associated with reduced survival in patients [23]. Furthermore, decreased serum albumin has been established as an independent risk factor for early-onset peritonitis. Protein loss leads to a negative nitrogen balance and malnutrition, resulting in decreased immune function and increased susceptibility to peritonitis. Additionally, the occurrence of early-onset peritonitis signifies a poorer clinical prognosis [17]. In this study, the serum albumin levels in the non-PDAP group were significantly higher than that in the PDAP group (OR = 0.919, 95%CI: 0.859–0.983, $P < 0.05$), consistent with previous research findings [8, 24]. Malnutrition, as reflected by low albumin, leads to immune dysfunction and increases susceptibility to infections, including peritonitis. This underscores the importance of monitoring albumin levels and addressing malnutrition in patients undergoing peritoneal dialysis to reduce PDAP risk.

Lymphocyte count serves as another important indicator of immune function. A decreased lymphocyte count is frequently observed in malnourished patients and is associated with increased susceptibility to infections, including PDAP. He et al. [25] confirmed that decreased lymphocyte counts were linked to a higher risk of treatment failure in PDAP, emphasizing the critical

role of lymphocytes in immune defense.In the context of PDAP, reduced lymphocyte levels not only directly impair immune function, but also indirectly affect peritoneal defense mechanisms through malnutrition, thereby increasing the risk of peritoneal dialysis-related peritonitis.

Serum potassium levels are often low in malnourished, a condition that frequently coexists with hypoproteinemia and anemia. Hypokalemia is associated with weakened intestinal peristalsis and the imbalance of intestinal flora, which can facilitate the translocation of bacteria into the abdominal cavity,thereby increasing the risk of PDAP. Liu D et al. [26] reported a significant association between low serum potassium levels and PDAP occurrence. A meta-analysis [27] also showed that hypokalemia increased the risk of PDAP, with a hazard ratio of 1.53 (95% CI: 1.23–1.88). These findings highlight the importance of maintaining appropriate serum potassium levels in patients undergoing peritoneal dialysis to prevention infections.

β_2-microglobulin is a small globular protein produced by lymphocytes and other polymorphonuclear leukocytes. It serves as a significant indicator of systemic inflammation [28]. Previous studies have consistently shown a strong association between elevated levels of β_2-microglobulin and mortality in patients with non-dialysis chronic kidney disease, supporting its use as a predictive marker for mortality risk [29, 30]. Notably, previous research has highlighted the role of β_2-microglobulin in patients undergoing peritoneal dialysis, linking elevated levels of β_2-microglobulin with declining residual kidney function and increased overall mortality in patients undergoing peritoneal dialysis [31, 32]. Further, β_2-microglobulin may even serve as a potential predictor of the occurrence of culture-negative peritonitis in patients undergoing peritoneal dialysis [14]. However, its direct relationship with peritonitis risk had not been fully established in earlier studies. In this study, a significant association was observed between an elevated β_2-microglobulin level and the risk of developing PDAP, highlighting its potential as a predictive biomarker for peritonitis. More importantly, when combined with other malnutrition-related markers such as decreased hemoglobin, albumin and blood urea nitrogen, β_2-microglobulin exhibited strong predictive performance in identifying PDAP risk. The findings underscore the importance of β_2-microglobulin not only as an indicator of systemic inflammation but also as a valuable tool in assessing infection risk in patients undergoing peritoneal dialysis. By integrating β_2-microglobulin with nutritional indicators, clinicians can more accurately identify at-risk patients, enabling early intervention and more targeted treatment strategies to prevent PDAP.

In summary, hemoglobin, albumin, β_2-microglobulin, serum potassium and lymphocyte count are closely associated with nutritional status in patients undergoing peritoneal dialysis. Clinicians should be particularly vigilant for abnormalities such as low hemoglobin, albumin, serum potassium, lymphocyte count and elevated β_2-microglobulin. Upon detecting these abnormalities, it is imperative to promptly assess the patient's nutritional status and use the nomogram to calculate the specific risk of developing PDAP. To minimaze the risk of PDAP, attention should be focused on these patients, and dietary guidance should be tailored according to their risk, expecially for those with a predicted risk greater than 0.6, as indicated by the CIC. A high-quality protein diet is strongly recommended to enhance the patient's nutritional levels, which can help reduce the risk of PDAP. These preventive measures aim to protect the health of patients undergoing peritoneal dialysis and prevent serious complications like PDAP.

Prediction model and evaluation of its effectiveness

While a limited number of studies have developed clinical prediction models for PDAP using cross-sectional designs, most of these models have predominantly focused on inflammatory markers such as neutrophil-to lymphocyte ratio (NLR), high-sensitivity C-reactive protein (hs-CRP), and white cell count in peritoneal dialysate [7, 8]. However, the elevation of these inflammatory markers indicates an existing infection, limiting the utility of prediction models based mainly on these indicators for early intervention in patients at risk for PDAP. In contrast, Al-Othman and colleagues' study demonstrated that malnutrition is an independent risk factor for PDAP [9]. In this study, combining clinical data (such as age and dialysis age) and nutritional indicators (such as hemoglobin and albumin) as the main indicators to construct a model for predicting the risk of PDAP. Notably, the inclusion of urinary creatinine and β_2-microglobulin further enhances the model's diagnostic accuracy. This model allows for generation of graphical representations that are simple to interpret, offering clinicians a tool to intuitively estimate the risk of PDAP without reliance on electronic devices, based on straightforward numerical addition [33]. By utilizing logistic regression results, a nomogram was constructed to visually display the probability of PDAP occurrence. The nomogram incorporates six predictive variables: age, dialysis duration, hemoglobin, albumin, urine creatinine and β_2-microglobulin. The model exhibited good calibration and discrimination, indicating its robust performance. Clinicians can apply this nomogram alongside a patient's laboratory test results to make individualized predictions, identify high-risk patients early, and implement targeted interventions for individuals with a predicted risk greater than 0.6. This

approach would significantly reduce the incidence of adverse outcomes associated with PDAP.

Nevertheless, this study has several limitations that warrant acknowledgment. Firstly, it was a single-center case-control study without external validation,which may limit its generalizability. Although internal validation methods such as cross-validation were employed, these measures may not fully mitigate potential biases or model overfitting. Future studies should aim to conduct multi-center validations to enhance the generalizability and robustness of the model. Additionally, this study did not perform subgroup analyses based on different population characteristics due to the small sample size, which could limit the model's applicability to specific clinical contexts. Future studies should group populations by characteristics (e.g., age groups, dialysis duration) and perform subgroup analyses to determine whether the effects differ in specific populations. Finally, in view of the above problems and the application of the model, further prospective studies on the model are needed. The development of prospective studies also needs to take full account of the collection of general demographic characteristics, such as dietary habits, smoking history, drinking history, and medication related to chronic diseases.

Conclusion

Advanced age, shorter dialysis duration, decreased hemoglobin and albumin levels, low potassium, reduced lymphocyte count, and elevated β_2-microglobulin were identified as independent risk factors for PDAP. A nomogram prediction model was established based on these factors, and this model exhibited good discrimination, calibration and clinical utility. The model proved accurate and reliable in predicting the occurrence of PDAP, offering a valuable tool for risk assessment in patients undergoing peritoneal dialysis. This study highlights the importance of nutrition-related indicators in patients undergoing peritoneal dialysis, providing a new perspective for early prediction of PDAP. The nomogram can guide clinical decision-making and help inform targeted disease management strategies. Future research building on these findings may further advance personalized medical care approaches, ultimately improving the management and outcomes of patients undergoing peritoneal dialysis.

Supplementary information

The online version contains supplementary material available at https://doi.org/10.1186/s12882-025-04165-5.

Supplementary Material 1

Supplementary Material 2

Supplementary Material 3

Supplementary Material 4

Author contributions

JZ was responsible for the conception and design of the study; YHW proposed the main research objectives, carried out the research implementation, and wrote the paper; YHW, ZMW and LQH are responsible for data collection, chart drawing and presentation; MZ was responsible for statistical guidance and practical operation; DS and FMD are responsible for the revision of the paper, JZ and THY are responsible for the quality control and review of the paper, and have overall responsibility for the supervision and management of the paper. All authors contributed to the planning, design and implementation and approved the final draft of the study.

Funding

This study was funded by the Department of Science and Technology of Guangdong. Province of China, Grant/Award Number: 2017ZC0028.

Data availability

The datasets used and analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethical approval

The proposed study protocol has been approved and granted the necessary ethical approvals by the Ethics Committee of the of Nanhai District People's Hospital, Foshan City (No. 2023361). Our study investigations and methods was conducted in compliance with the Helsinki Declaration.

Consent for publication

Not Applicable.

Competing interests

The authors declare no competing interests.

Author details

[1]School of Nursing, Guangdong Pharmaceutical University, Guangzhou, Guangdong Province, China
[2]School of Continuing Education, Guangdong Pharmaceutical University, Guangzhou, Guangdong Province, China
[3]Department of Nursing, The Sixth Affiliated Hospital, School of Medicine, South China University of Technology, Foshan City, Guangdong Province, China
[4]Department of Nephrology, The Sixth Affiliated Hospital, School of Medicine, South China University of Technology, Foshan City, Guangdong Province, China
[5]School of Public Health, Guangdong Pharmaceutical University, Guangzhou, China

Received: 25 November 2024 / Accepted: 8 May 2025
Published online: 19 May 2025

References

1. Franco MR, Bastos MG, Qureshi AR, Schreider A, de Andrade Bastos K, Divino-Filho JC.Incident elderly patients on peritoneal dialysis: epidemiological characteristics and modality impact on survival time. Saudi J Kidney Dis Transpl. 2017;28(4):782–91.
2. Cho Y, Bello AK, Levin A, Lunney M, Osman MA, Ye F. Peritoneal dialysis use and practice patterns: an international survey study. Am J Kidney Dis. 2021;77(3):315–25. https://doi.org/10.1053/j.ajkd.2020.05.032
3. Wang L, Xu X, Zhang M. 2023. Prevalence of chronic kidney disease in China: results from the sixth China chronic disease and risk factor surveillance. JAMA Intern Med. 183(4):298–310. https://doi.org/10.1001/jamainternmed.2022.6817
4. Perl J, Fuller DS, Bieber BA, Boudville N, Kanjanabuch T, Ito Y. 2020. Peritoneal dialysis–related infection rates and outcomes: results from the Peritoneal Dialysis Outcomes and Practice Patterns Study (PDOPPS). Am J Kidney Dis. 76(1):42–53. https://doi.org/10.1053/j.ajkd.2019.09.016
5. Chung M-C, Yu T-M, Wu M-J, Chuang Y-W, Muo C-H, Chen C-H. 2022. Impact of peritoneal dialysis-related peritonitis on PD discontinuation and mortality:

a population-based national cohort study. Peritoneal Dialysis Int. 42(2):194–203. https://doi.org/10.1177/08968608211018949
6. Al Sahlawi M, Bargman JM, Perl J. 2020. Peritoneal dialysis–associated peritonitis: suggestions for management and mistakes to avoid. Kidney Medicine. 2(4):467–75. https://doi.org/10.1016/j.xkme.2020.04.010
7. Yan Q, Liu G, Wang R. 2024. Development and validation of a nomogram for predicting refractory peritoneal dialysis related peritonitis. Renal Failure. 46(2):2368083. https://doi.org/10.1080/0886022X.2024.2368083
8. Dai R, Peng C, Sang T, Cheng M, Wang Y, Zhang L. Construction and validation of a predictive model for the risk of peritoneal dialysis-associated peritonitis after peritoneal dialysis catheterization. Front Med. 2023;10:1193754. https://doi.org/10.3389/fmed.2023.1193754.
9. Al-Othman AM, Al-Naseeb AJM, Almajwal AM. Association of malnutrition in peritoneal dialysis patients of Saudi Arabia. Arabian J. Chem. 2016;9:S1059–S1062. https://doi.org/10.1016/j.arabjc.2011.11.015.
10. Tennankore KK, Bargman JM. 2013. Nutrition and the kidney: recommendations for peritoneal dialysis. Adv Chronic Kidney Disease. 20(2):190–201. https://doi.org/10.1053/j.ackd.2012.10.010
11. Pk-t L, Chow KM, Cho Y, Fan S, Figueiredo AE, Harris T. 2022. ISPD peritonitis guideline recommendations: 2022 update on prevention and treatment. Perit Dial Int. 42(2):110–53. https://doi.org/10.1177/08968608221080586
12. Wu H, Ye H, Huang R, Yi C, Wu J, Yu X. 2020. Incidence and risk factors of peritoneal dialysis-related peritonitis in elderly patients: a retrospective clinical study. Peritoneal Dialysis Int. 40(1):26–33. https://doi.org/10.1177/0896860819879868
13. Zhang J, Lu X, Li H, Wang S. 2021. Risk factors for mortality in PD patients: a systematic review and meta-analysis. Renal Failure. 43(1):743–53. https://doi.org/10.1080/0886022X.2021.1918558
14. Shima H, Okamoto T, Tashiro M, Inoue T, Wariishi S, Bando H, et al. Predictors of culture-negative peritoneal dialysis-associated peritonitis: a single center, retrospective study. Renal Replacement Therapy 2023;9(1):55. https://doi.org/10.1186/s41100-023-00498-9
15. Yu J, Zhu L, Ni J, Tong M, Wang H.Technique Failure in Peritoneal Dialysis-related Peritonitis: risk Factors and Patient Survival. Renal Failure 2023;45(1):2205536. https://doi.org/10.1080/0886022x.2023.2205536
16. Li HJ, Zheng HG. Analysis of risk factors for frequent peritonitis associated with peritoneal dialysis. J Chronic Disease Chronic Pathematology J. 2020. https://doi.org/10.16440/j.cnki.1674-8166.2020.08.007.
17. Ma X, Shi Y, Tao M, Jiang X, Wang Y, Zang X. 2020. Analysis of risk factors and outcome in peritoneal dialysis patients with early-onset peritonitis: a multicentre, retrospective cohort study. BMJ Open. 10(2):e029949. https://doi.org/10.1136/bmjopen-2019-029949
18. Zhao L, Hong L. Inflammatory status of patients with chronic kidney disease and its effect on the treatment of renal anemia. China Blood Purification 2020;19(03):149-52. https://doi.org/10.3969/j.issn.1671-4091.2020.03.002
19. Zhang W, Wang X, Liu Y, Han Y, Li J, Sun N.The Synergistic Value of Time-averaged Serum Albumin and Globulin in Predicting the First Peritonitis in Incident Peritoneal Dialysis Patients. Blood Purification 2020;49(3):272-80. https://doi.org/10.1159/000504036
20. Xu X, Yang Z, Li S, Pei H, Zhao J, Zhang Y. Cut-off values of hemoglobin and clinical outcomes in incident peritoneal dialysis: the PDTAP study. Nephrol Dial Transplant. 2023;gfad166. https://doi.org/10.1093/ndt/gfad166.
21. Banno T, Shima H, Kawahara K, Okada K, Minakuchi J. 2021. Risk factors for peritoneal dialysis withdrawal due to peritoneal dialysis-related peritonitis. Néphrologie ThérApeutique. 17(2):108–13. https://doi.org/10.1016/j.nephro.2020.10.007
22. Ikizler TA, Burrowes JD, Byham-Gray LD, Campbell KL, Carrero -J-J, Chan W. 2020. KDOQI clinical practice guideline for nutrition in CKD: 2020 update. Am J Kidney Dis. 76(3):S1–S107. https://doi.org/10.28996/2618-9801-2022-2-143-278
23. Finne P, Vartiainen H, Bitar W.# 1439 Risk factors and significance of a reduction of serum albumin after start of PD. Nephrol Dial Transplant. 2024;39(Supplement_1):gfae069–1658–1439.
24. Yin S, Tang M, Rao Z, Chen X, Zhang M, Liu L. Risk Factors and Pathogen Spectrum in Continuous Ambulatory Peritoneal Dialysis-Associated Peritonitis: a Single Center Retrospective Study. Med Sci Monit. 2022;28:e937112. https://doi.org/10.12659/msm.937112.
25. HE YJ, HUANG XY, ZHANG JW. Decreased peripheral blood lymphocyte count predicts poor treat▪ment response in peritoneal dialysis▪associated peritoni▪tis. J Inflamm Res. 2023;16:5327–38. https://doi.org/10.2147/JIR.S438674.
26. Liu D, Lin Y, Gong N. 2021. Degree and duration of hypokalemia associated with peritonitis in PD patients.Int. J Clin Pract. 75(8):e14188. https://doi.org/10.1111/ijcp.14188
27. Yang C, Hu X, Ling X. Prevalence and adverse outcomes of hypokalemia and the role of potassium supplementation in patients receiving peritoneal dialysis. Nephrol Dial Transplant. 2024;39:I149–I150. https://doi.org/10.1016/j.xkme.2024.100923.
28. Zeng X, Hossain D, Bostwick DG, Herrera GA, Zhang PL. Urinary β2-Microglobulin Is a Good Indicator of Proximal Tubule Injury: a Correlative Study with Renal Biopsies. J Biomark. 2014;2014:492838. https://doi.org/10.1155/2014/492838.
29. Foster MC, Inker LA, Levey AS, Selvin E, Eckfeldt J, Juraschek SP.Novel Filtration Markers as Predictors of All-cause and Cardiovascular Mortality in US Adults. Am J Kidney Dis 2013;62(1):42-51. https://doi.org/10.1053/j.ajkd.2013.01.016
30. Inker LA, Tighiouart H, Coresh J, Foster MC, Anderson AH, Beck GJ.GFR Estimation Using β-trace Protein and β_2-microglobulin in CKD. Am J Kidney Dis 2016;67(1):40-8. https://doi.org/10.1053/j.ajkd.2015.07.025
31. Jaques DA, Davenport A. Serum β_2-microglobulin as a predictor of residual kidney function in peritoneal dialysis patients. J Nephrol 2021;34:473-81 https://doi.org/10.1007/s40620-020-00906-x.
32. Maruyama Y, Nakayama M, Abe M, Yokoo T, Minakuchi J, Nitta K.Association between Serum β_2-microglobulin and Mortality in Japanese Peritoneal Dialysis Patients: a Cohort Study. Plos One 2022;17(4):e0266882. https://doi.org/10.1371/journal.pone.0266882
33. Iasonos A, Schrag D, Raj GV, Panageas KS. How to build and interpret a nomogram for cancer prognosis. J Clin Oncol 2008;26(8):1364-70. https://doi.org/10.1200/jco.2007.12.9791

Publisher's Note