

Original Article

Neutrophil-to-lymphocyte ratio combined with serum albumin predicts catheter removal in patients with peritoneal dialysis-associated peritonitis: a retrospective cohort study of 156 cases

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Abstract: Objectives: Peritoneal dialysis-associated peritonitis (PDAP) can lead to catheter removal, but early risk stratification remains difficult. We evaluated whether neutrophil-to-lymphocyte ratio (NLR), combined with serum albumin, identifies patients at increased risk of catheter removal. Methods: This retrospective cohort included 156 patients with PDAP treated from August 2022 to July 2025. Baseline clinical, laboratory, microbiological, and outcome data were extracted from medical records. Blood samples were obtained within 24 hours after PDAP onset. Logistic regression, receiver operating characteristic analysis, restricted cubic spline analysis, bootstrap validation, and decision curve analysis were used to assess the NLR-albumin model. Results: Catheter removal occurred in 35 patients. These patients had higher NLR and lower serum albumin than those with catheter retention. In the multi-variable model using the enter method, NLR was positively associated with catheter removal, whereas serum albumin was inversely associated with this outcome. The combined NLR-albumin model performed better than either marker alone and retained acceptable discrimination and calibration after 1,000 bootstrap resamples. Restricted cubic spline analysis suggested a threshold pattern for NLR and an approximately linear inverse association for serum albumin. Conclusions: Baseline NLR and serum albumin may support early risk stratification in PDAP. The combined model was internally validated but requires external validation before clinical use.

Keywords: Peritoneal dialysis-associated peritonitis, neutrophil-to-lymphocyte ratio, serum albumin, catheter removal, risk prediction

Introduction

Peritoneal dialysis (PD) remains an important renal replacement therapy for patients with end-stage kidney disease (ESKD), partly because it helps preserve residual renal function, offers relatively stable hemodynamics, and supports home-based treatment [1]. Its use has increased over recent decades, particularly in Asian countries facing a growing burden of chronic kidney disease [1]. However, infectious complications continue to limit long-term PD technique survival. Peritoneal dialysis-associated peritonitis (PDAP) is the most frequent and clinically important of these complications, contributing to hospitalization, catheter loss, transfer to hemodialysis, and mortality [2, 3].

Previous epidemiological studies have reported PDAP rates of approximately 0.2-0.6 episodes per patient-year, and severe episodes can substantially increase the risks of technique failure and death [4]. Recurrent or refractory peritonitis may also cause irreversible peritoneal membrane injury, ultrafiltration dysfunction, and encapsulating peritoneal sclerosis, eventually leading to permanent technique failure [5, 6].

Although connection systems, patient education, and antimicrobial strategies have improved, outcomes after PDAP remain highly variable [2, 3]. Some patients respond promptly to antibiotic therapy and maintain catheter function, whereas others develop refractory infection requiring catheter removal despite

similar microbiological findings. Catheter removal is one of the most clinically relevant adverse outcomes in PDAP, as it often reflects severe intra-abdominal inflammation, uncontrolled infection, or advanced peritoneal injury [5]. It is also associated with longer hospitalization, higher medical costs, reduced quality of life, and poorer long-term prognosis [5]. Early identification of patients at increased risk of catheter removal may therefore help guide individualized treatment and improve technique survival.

Poor outcomes after PDAP are influenced by multiple factors, including pathogen virulence, host immune dysfunction, chronic microinflammation, nutritional impairment, and dialysis-related conditions [6]. Systemic inflammatory biomarkers have therefore attracted increasing attention because they may reflect host responses more broadly than conventional laboratory indicators alone. Among these markers, the neutrophil-to-lymphocyte ratio (NLR) is a simple and inexpensive index derived from routine blood tests [7]. It incorporates information from both neutrophil-mediated inflammation and lymphocyte-related immune status, with higher neutrophil counts reflecting inflammatory activation and lower lymphocyte counts indicating immune dysregulation or physiological stress [7, 8]. Elevated NLR has been associated with adverse outcomes in cardiovascular disease, malignancy, sepsis, and chronic kidney disease [8]. In patients undergoing PD, higher NLR has also been linked to all-cause mortality, cardiovascular mortality, and infection-related complications [9]. A recent systematic review and meta-analysis further confirmed the prognostic significance of NLR in patients undergoing PD [10]. Recent prediction model studies have further suggested that NLR may help identify adverse outcomes in PDAP [4]. However, most previous work has focused on mortality or peritonitis occurrence rather than catheter removal.

Serum albumin is another routinely available marker that reflects both nutritional and inflammatory status in patients undergoing PD [11]. Hypoalbuminemia is common in this population because chronic inflammation, protein-energy wasting, peritoneal protein loss, and recurrent infection can all reduce serum albumin levels [11, 12]. Low serum albumin has

been associated with higher risks of peritonitis, hospitalization, cardiovascular events, and mortality in PD cohorts [11, 12]. Changes in albumin levels during treatment may also reflect disease severity and recovery capacity [12]. In PDAP, hypoalbuminemia may indicate poor nutritional reserve, ongoing inflammation, protein loss, or more severe illness, all of which are related to adverse clinical outcomes and catheter loss. Previous studies of inflammatory-nutritional indicators in PDAP also suggest that combining nutritional and inflammatory markers may improve prognostic assessment [13].

Combining inflammatory and nutritional indicators may offer a more complete view of host vulnerability during PDAP. NLR mainly reflects systemic inflammatory activation, whereas serum albumin reflects nutritional reserve and chronic inflammatory burden. Evaluating these two markers together may therefore better characterize the inflammatory-nutritional imbalance associated with PDAP progression and technique failure. However, evidence on the combined predictive value of NLR and serum albumin for catheter removal in PDAP remains limited. In particular, it remains unclear whether this combined marker profile improves early risk stratification in real-world PDAP cohorts.

Therefore, this retrospective study evaluated the predictive value of NLR combined with serum albumin for catheter removal in patients with PDAP. We also examined the independent and joint associations of these biomarkers with adverse clinical outcomes using multivariable regression and restricted cubic spline analyses.

Methods

Study design and patient population

This retrospective observational study was conducted at the Department of Nephrology of Ganzhou Hospital-Nanfang Hospital. Consecutive patients diagnosed with PDAP from August 2022 to July 2025 were screened through the electronic medical record system. After applying predefined inclusion and exclusion criteria, 156 eligible PDAP cases were ultimately included in the final analysis.

PDAP was diagnosed according to the recommendations of the International Society for Peritoneal Dialysis, requiring at least two of the following criteria: clinical manifestations consistent with peritonitis (including abdominal pain and/or cloudy dialysate effluent), dialysate white blood cell count $>100 \times 10^6/L$ with polymorphonuclear neutrophils accounting for $>50\%$ after a dwell time of at least 2 hours, or positive dialysate culture results [2].

Patients were included if they were aged ≥ 18 years, had received maintenance peritoneal dialysis for at least 3 months, fulfilled the diagnostic criteria for PDAP, and had complete baseline laboratory data required for the primary analysis available within 24 hours after PDAP onset. Patients were excluded if they had secondary peritonitis caused by gastrointestinal perforation or abdominal surgery, active autoimmune disease, hematologic disease, malignant tumors, severe systemic infection unrelated to PDAP, recent immunosuppressive therapy, or incomplete records for the primary outcome, NLR, serum albumin, or other variables required for the primary analyses. For patients experiencing multiple PDAP episodes during the study period, only the first eligible episode was included to minimize repeated-measurement bias.

The study protocol was approved by the Institutional Review Board of Ganzhou Hospital-Nanfeng Hospital. Because of the retrospective design, the requirement for written informed consent was waived. The study was not prospectively registered because it was a retrospective record-based observational analysis using existing clinical data and did not involve prospective enrollment or an interventional protocol.

Clinical outcome definition

The primary endpoint was catheter removal during PDAP treatment. Catheter removal was defined according to the clinical records documenting permanent removal of the peritoneal dialysis catheter because of refractory peritonitis, relapsing infection, fungal infection, uncontrolled abdominal infection, severe tunnel infection, or persistent inflammatory deterioration despite appropriate antimicrobial therapy [2]. Patients were subsequently classified into the catheter removal group and cath-

eter retention group. Secondary outcomes included immediate transfer to hemodialysis after catheter removal, recurrent or relapsing peritonitis, in-hospital mortality, and length of hospitalization. Long-term dialysis-modality outcomes, including PD catheter reinsertion and maintenance hemodialysis status, were not systematically available.

Clinical data collection

Clinical information was independently extracted by two trained investigators from the hospital electronic medical record system and peritoneal dialysis database using standardized forms. Demographic and baseline clinical variables included age, sex, body mass index (BMI), smoking history, alcohol consumption history, primary renal disease, dialysis vintage, history of diabetes mellitus, hypertension, cardiovascular disease, cerebrovascular disease, previous peritonitis episodes, residual urine volume, and blood pressure at admission.

Routine peripheral venous blood samples were obtained within 24 hours after PDAP onset, before initiation of empirical antimicrobial therapy whenever feasible, and analyzed by the hospital central laboratory. The exact interval from symptom onset to blood sampling was not consistently recorded in the retrospective database and was therefore not available for quantitative analysis. Hematological parameters, including white blood cell count (WBC), neutrophil count, lymphocyte count, monocyte count, hemoglobin, platelet count, and red blood cell count, were measured using an automated hematology analyzer (Sysmex XN series, Sysmex Corporation, Kobe, Japan) based on fluorescence flow cytometry and impedance methods. The neutrophil-to-lymphocyte ratio (NLR) was calculated as the absolute neutrophil count divided by the absolute lymphocyte count.

Serum biochemical parameters were measured using a fully automated biochemical analyzer (Hitachi 7600, Hitachi High-Tech-nologies Corporation, Tokyo, Japan). Serum albumin and total protein levels were determined using the bromocresol green colorimetric method. Serum creatinine, blood urea nitrogen, uric acid, triglycerides, total cholesterol, high-density lipoprotein cholesterol, and low-density lipoprotein cholesterol were measured

by enzymatic assays. Serum electrolytes, including potassium, sodium, calcium, and phosphorus, were detected using ion-selective electrode or colorimetric methods according to standard laboratory protocols. Liver function indicators, including alanine aminotransferase and aspartate aminotransferase, were analyzed using kinetic enzyme assays.

Inflammatory biomarkers were simultaneously assessed. Serum C-reactive protein (CRP) levels were measured using immunoturbidimetric assays, whereas procalcitonin (PCT) levels were detected using electrochemiluminescence immunoassays. Erythrocyte sedimentation rate (ESR), when available, was measured using the Westergren method.

Peritoneal dialysis effluent samples were collected under sterile conditions before initiation of empirical antibiotic treatment. Baseline blood and dialysate measurements used in the present analysis were obtained during the initial clinical evaluation of PDAP. The study database was designed for collection of baseline clinical and laboratory data; serial NLR and serum albumin measurements on treatment days 3 and 5 were not consistently available or recorded at standardized time points and were therefore not included in the present analysis. Dialysate white blood cell count and polymorphonuclear neutrophil percentage were analyzed using automated cell counting systems and microscopic examination. Dialysate culture samples were inoculated into aerobic and anaerobic blood culture bottles and processed using standard microbiological culture techniques. Pathogens were subsequently classified as Gram-positive bacteria, Gram-negative bacteria, fungal infection, polymicrobial infection, or culture-negative peritonitis according to microbiological results.

Treatment protocol

All patients received empirical antimicrobial therapy immediately after collection of blood and dialysate specimens according to institutional PDAP management protocols based on ISPD recommendations [2]. Initial antibiotic regimens generally provided coverage for both Gram-positive and Gram-negative organisms and were administered intraperitoneally and/or intravenously according to disease severity. Antibiotic regimens were subsequently adjust-

ed according to microbiological culture findings and antimicrobial susceptibility testing. Routine supportive treatment included correction of electrolyte imbalance, blood pressure management, dialysis prescription adjustment, glycemic control in diabetic patients, fluid balance optimization, and nutritional supplementation when clinically indicated.

Statistical analysis

Statistical analyses were performed using SPSS version 27.0 (IBM Corp., Armonk, NY, USA) and R software version 4.3.1 (R Foundation for Statistical Computing, Vienna, Austria). Continuous variables were initially assessed for normality using the Shapiro-Wilk test. Normally distributed variables were expressed as mean $\pm$ standard deviation and compared using the independent-samples t test. Non-normally distributed variables were expressed as median with interquartile range and compared using the Mann-Whitney U test. Categorical variables were presented as frequencies and percentages and analyzed using the chi-square test or Fisher's exact test when appropriate. Variables with $P < 0.10$ in univariate analysis or those considered clinically relevant according to previous studies were initially considered as candidate predictors. For clinical interpretability, dialysate white blood cell count was analyzed as a continuous variable per $1,000 \times 10^6/L$ increase (i.e., per 1,000 cells/ μL) rather than per $1 \times 10^6/L$ increase. A categorical sensitivity analysis using a threshold of $>1,000 \times 10^6/L$ was also conducted; Fisher's exact test was used when sparse cells or complete separation prevented stable logistic-regression estimation. Because of the limited number of catheter-removal events, the number of predictors in the primary prediction model was restricted to reduce the risk of overfitting. Neutrophil-to-lymphocyte ratio (NLR) and serum albumin were prespecified as the primary predictors because they represent complementary inflammatory and nutritional domains and were the principal variables of interest in this study. Multivariable logistic regression was performed using the Enter method, with all prespecified predictors entered simultaneously. No forward, backward, or stepwise variable-selection procedure was used. History of previous PDAP episodes was not excluded on the basis of collinearity.

Rather, because of its clinical relevance and significant univariate association, it was evaluated in a prespecified sensitivity analysis by entering it simultaneously with NLR and serum albumin in an Enter-method logistic regression model. Thus, the primary model included NLR and serum albumin entered simultaneously, whereas the sensitivity model included NLR, serum albumin, and history of previous PDAP episodes entered simultaneously. Odds ratios (ORs) and 95% confidence intervals (CIs) were calculated. Receiver operating characteristic (ROC) curve analysis was performed to evaluate the predictive performance of NLR, serum albumin, and the combined NLR-albumin model for catheter removal. The optimal cutoff values for NLR and serum albumin were determined according to the maximum Youden index. These ROC-derived thresholds were used uniformly to define the dichotomous inflammatory-nutritional high-risk pattern for subgroup and catheter-survival analyses. Differences between areas under the curve (AUCs) were compared using the DeLong test. Internal validation of the final model was performed using 1,000 bootstrap resamples. For each bootstrap sample, the model was refitted and evaluated in the original dataset to estimate optimism. Model discrimination was assessed using the apparent and optimism-corrected C-index. Calibration was evaluated using the bootstrap-corrected calibration curve, calibration intercept, calibration slope, and Brier score. Decision curve analysis (DCA) was used to assess the potential net clinical benefit of the final model across a range of threshold probabilities. Restricted cubic spline analysis with three knots was performed to explore potential nonlinear associations between NLR, serum albumin, and catheter-removal risk. Exploratory subgroup analyses were conducted to assess whether the association between the ROC-defined NLR-albumin high-risk pattern and catheter removal differed by age, sex, diabetes status, culture positivity, bacterial culture type, and fungal infection status. The high-risk pattern was defined as $\text{NLR} \geq 6.03$ combined with serum albumin ≤ 33.9 g/L. Interaction was assessed by adding a product term between the high-risk pattern and the subgroup variable to logistic regression models. Subgroup analyses stratified by NLR or serum albumin were not conducted because both variables were used

to define the high-risk pattern. Catheter survival was evaluated using the Kaplan-Meier method and compared using the log-rank test. All tests were two-sided, and $P < 0.05$ was considered statistically significant.

Results

Patient cohort and baseline characteristics

A total of 486 PDAP cases were initially screened from August 2022 to July 2025, of which 156 cases met the inclusion criteria after excluding secondary peritonitis, malignancy, autoimmune disease, or incomplete clinical/laboratory data (**Figure 1**). No missing values were present for the primary outcome, NLR, serum albumin, or other variables included in the primary analytic models among the final 156 patients (**Figure 1**). Of the included cases, 121 (77.6%) were in the catheter retention group and 35 (22.4%) in the catheter removal group.

The mean age of the cohort was 52.6 ± 13.8 years, and 59.0% were male. Diabetes mellitus and cardiovascular disease were present in 39.1% and 24.4% of patients, respectively, with a median dialysis vintage of 34.5 months (IQR 16.8-62.4). Baseline clinical characteristics are summarized in **Table 1**. Patients in the catheter removal group were older (60.2 ± 12.5 vs 50.4 ± 13.1 years, $P < 0.001$) and had a higher prevalence of diabetes (60.0% vs 33.1%, $P = 0.005$) and cardiovascular disease (40.0% vs 19.8%, $P = 0.013$). There were no significant differences in sex or BMI between the groups. Residual renal function was significantly lower in the catheter-removal group than in the catheter-retention group ($P = 0.002$).

Laboratory parameters revealed that the catheter removal group had significantly higher inflammatory markers including WBC ($12.2 \pm 4.0 \times 10^9/\text{L}$ vs $9.1 \pm 3.2 \times 10^9/\text{L}$, $P < 0.001$), neutrophils ($10.0 \pm 3.5 \times 10^9/\text{L}$ vs $6.8 \pm 2.7 \times 10^9/\text{L}$, $P < 0.001$), NLR (13.1 vs 5.5, $P < 0.001$), CRP, procalcitonin, dialysate WBC, and dialysate PMN percentage (all $P < 0.01$). Lymphocyte count ($0.89 \pm 0.38 \times 10^9/\text{L}$ vs $1.41 \pm 0.49 \times 10^9/\text{L}$, $P < 0.001$) and serum albumin (28.9 ± 4.9 g/L vs 35.2 ± 4.8 g/L, $P < 0.001$) were significantly lower in the catheter removal group. Culture-positive infections were more frequent in this group (85.7% vs 65.3%, $P = 0.021$), par-

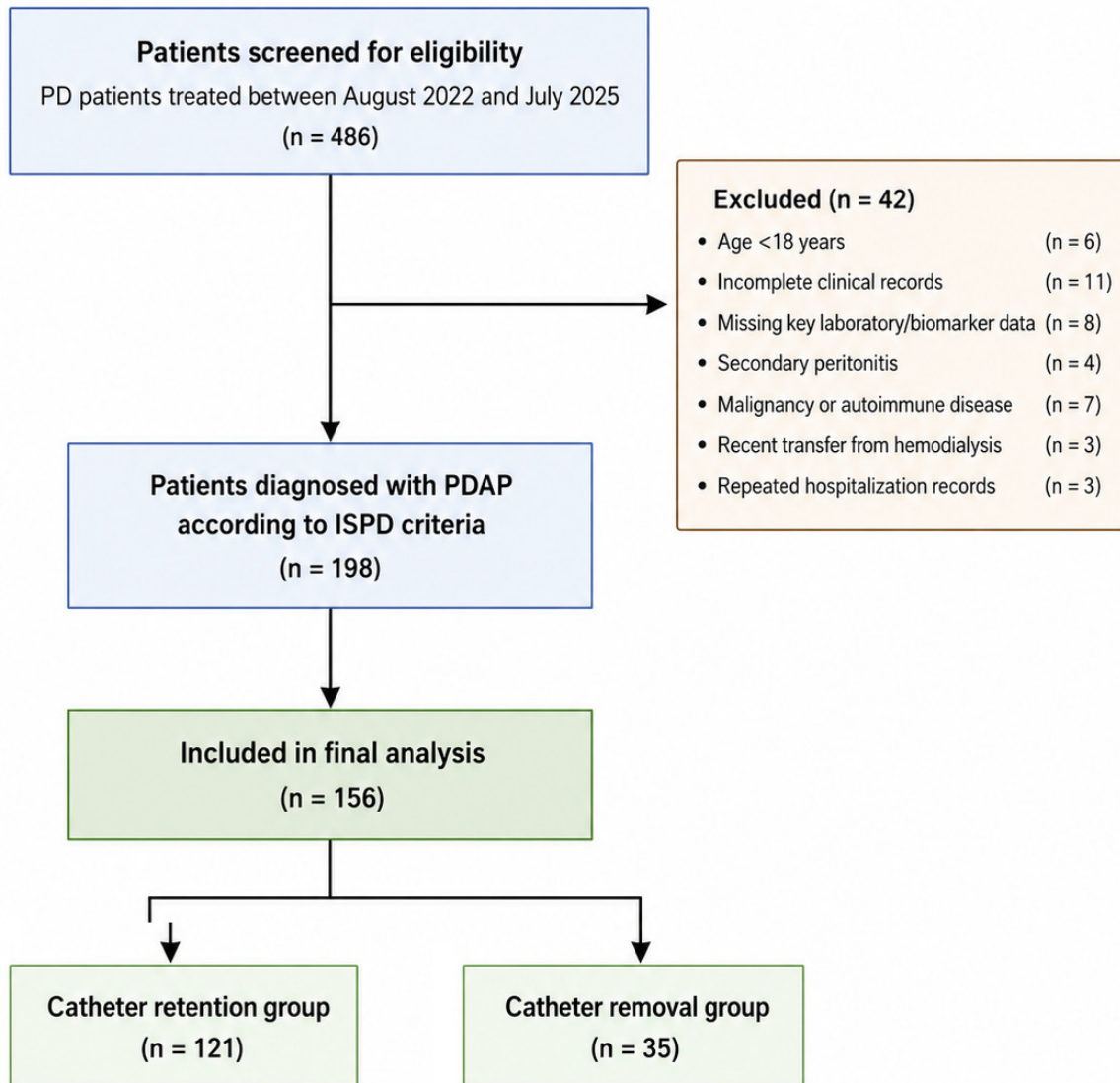


Figure 1. Patient screening and inclusion flowchart. Flow diagram illustrating the selection of PDAP patients for the retrospective cohort study. Out of 486 screened cases from August 2022 to July 2025, 156 eligible cases were included after excluding patients with secondary peritonitis, autoimmune disease, malignancy, or incomplete data. The final cohort was classified into the catheter retention group (n=121) and catheter removal group (n=35) based on clinical outcomes.

ticularly fungal infections (25.7% vs 2.5%, $P<0.001$) (**Table 1**).

Univariate and multivariate predictors of catheter removal

Univariate logistic regression showed that history of previous PDAP episodes, fungal infection, diabetes mellitus, inflammatory biomarkers, and dialysate WBC were associated with catheter removal (**Table 2**). When dialysate WBC was expressed per $1,000 \times 10^6/L$ increase, the OR was 1.358 (95% CI: 1.096-1.681,

$P=0.005$). Because the number of catheter-removal events was limited, we constructed a parsimonious primary multivariable model using the two prespecified predictors, NLR and serum albumin. Both variables were entered simultaneously using the Enter method, and no stepwise selection procedure was applied. In this model, higher NLR was associated with increased risk of catheter removal (adjusted OR=1.504, 95% CI: 1.225-1.846, $P<0.001$), whereas higher serum albumin was associated with lower risk (adjusted OR=0.555, 95% CI: 0.429-0.719, $P<0.001$) (**Table**

Table 1. Baseline clinical characteristics of PDAP patients according to catheter outcome

Variable	Overall (n=156)	Catheter Retention (n=121)	Catheter Removal (n=35)	Test Statistic	P value
Age (years)	52.6 ± 13.8	50.4 ± 13.1	60.2 ± 12.5	t=3.98	<0.001
Male sex, n (%)	92 (59.0)	68 (56.2)	24 (68.6)	$\chi^2=1.72$	0.189
BMI (kg/m ²)	23.4 ± 3.7	23.7 ± 3.6	22.3 ± 3.8	t=1.95	0.053
Dialysis vintage (months)	34.5 (16.8-62.4)	29.7 (15.1-56.8)	51.6 (26.4-81.2)	Z=3.21	0.001
Diabetes mellitus, n (%)	61 (39.1)	40 (33.1)	21 (60.0)	$\chi^2=7.94$	0.005
Hypertension, n (%)	128 (82.1)	97 (80.2)	31 (88.6)	$\chi^2=1.23$	0.267
Cardiovascular disease, n (%)	38 (24.4)	24 (19.8)	14 (40.0)	$\chi^2=6.11$	0.013
History of previous PDAP episodes, n (%)	69 (44.2)	45 (37.2)	24 (68.6)	$\chi^2=10.68$	0.001
Residual renal function (mL/min)	3.2 (1.1-5.9)	3.8 (1.6-6.3)	1.7 (0.5-3.4)	Z=3.04	0.002
Culture-positive infection, n (%)	109 (69.9)	79 (65.3)	30 (85.7)	$\chi^2=5.31$	0.021
Gram-positive infection, n (%)	66 (42.3)	53 (43.8)	13 (37.1)	$\chi^2=0.49$	0.482
Gram-negative infection, n (%)	31 (19.9)	20 (16.5)	11 (31.4)	$\chi^2=4.05$	0.044
Fungal infection, n (%)	12 (7.7)	3 (2.5)	9 (25.7)	$\chi^2=21.63$	<0.001
WBC ($\times 10^9$ /L)	9.8 ± 3.6	9.1 ± 3.2	12.2 ± 4.0	t=4.62	<0.001
Neutrophils ($\times 10^9$ /L)	7.5 ± 3.1	6.8 ± 2.7	10.0 ± 3.5	t=5.61	<0.001
Lymphocytes ($\times 10^9$ /L)	1.29 ± 0.52	1.41 ± 0.49	0.89 ± 0.38	t=5.92	<0.001
NLR	6.8 (4.2-10.9)	5.5 (3.8-8.2)	13.1 (8.5-18.9)	Z=6.34	<0.001
CRP (mg/L)	52.7 (24.1-96.3)	41.5 (18.6-75.2)	112.8 (67.3-165.1)	Z=5.89	<0.001
Procalcitonin (ng/mL)	1.21 (0.44-3.62)	0.84 (0.31-2.28)	4.16 (1.75-8.93)	Z=5.12	<0.001
Serum albumin (g/L)	33.8 ± 5.4	35.2 ± 4.8	28.9 ± 4.9	t=6.73	<0.001
Hemoglobin (g/L)	98.3 ± 18.2	101.5 ± 17.4	87.1 ± 16.2	t=4.38	<0.001
Platelet count ($\times 10^9$ /L)	226 ± 74	219 ± 69	252 ± 82	t=2.31	0.022
Serum phosphorus (mmol/L)	1.71 ± 0.46	1.69 ± 0.43	1.79 ± 0.55	t=1.07	0.287
Serum creatinine (μ mol/L)	845 ± 228	829 ± 219	901 ± 251	t=1.62	0.107
Dialysate WBC ($\times 10^6$ /L)	1180 (640-2480)	920 (510-1870)	2960 (1580-4850)	Z=5.74	<0.001
Dialysate PMN (%)	78.5 ± 11.2	74.8 ± 10.6	91.1 ± 7.8	t=8.54	<0.001

PDAP, peritoneal dialysis-associated peritonitis; BMI, body mass index; WBC, white blood cell; NLR, neutrophil-to-lymphocyte ratio; CRP, C-reactive protein; PMN, polymorphonuclear neutrophil.

3). The combined NLR-albumin model showed stronger discrimination than either marker alone. Bootstrap validation showed limited optimism, with an optimism-corrected C-index of 0.956, calibration slope of 0.906, calibration intercept of -0.094, and optimism-corrected Brier score of 0.071.

History of previous PDAP episodes was significantly associated with catheter removal in univariate analysis. Given its clinical relevance, a sensitivity analysis was performed using an Enter-method logistic regression model in which history of previous PDAP episodes was entered simultaneously with NLR and serum albumin. After adjustment, history of previous PDAP episodes was not independently associated with catheter removal (adjusted OR= 1.552, 95% CI: 0.417-5.779, P=0.512). The associations of NLR and serum albumin remained stable in the sensitivity model, with adjusted ORs of 1.518 (95% CI: 1.230-1.872,

P<0.001) and 0.553 (95% CI: 0.425-0.719, P<0.001), respectively. The apparent AUC of the sensitivity model was 0.960, which was nearly identical to that of the primary NLR-albumin model (AUC=0.959). Thus, inclusion of previous PDAP history did not materially improve model discrimination.

Predictive performance of NLR and albumin

ROC analysis showed that NLR, serum albumin, and CRP each had discriminatory value for catheter removal. CRP showed an AUC of 0.839 but was not included in the final model because the primary model was prespecified as a parsimonious NLR-albumin model. The combined NLR-albumin model demonstrated improved discrimination compared with either marker alone, with an apparent AUC of 0.959 (95% CI: 0.927-0.983), sensitivity of 91.2%, and specificity of 86.1% (**Figure 2** and **Table 4**). Bootstrap internal validation yielded an opti-

Table 2. Univariate logistic regression analysis for catheter removal

Variable	OR	95% CI	P value
Age	1.048	1.019-1.078	0.001
Dialysis vintage	1.017	1.007-1.027	0.001
Diabetes mellitus	3.034	1.392-6.611	0.005
Cardiovascular disease	2.698	1.192-6.106	0.017
History of previous PDAP episodes	3.681	1.662-8.151	0.001
Residual renal function	0.731	0.592-0.902	0.004
Culture-positive infection	3.181	1.085-9.327	0.035
Gram-negative infection	2.321	1.009-5.337	0.048
Fungal infection	13.667	3.424-54.551	<0.001
WBC	1.238	1.108-1.383	<0.001
Neutrophils	1.389	1.194-1.617	<0.001
Lymphocytes	0.108	0.037-0.314	<0.001
NLR	1.262	1.152-1.383	<0.001
CRP	1.018	1.010-1.026	<0.001
Procalcitonin	1.291	1.121-1.486	<0.001
Serum albumin	0.752	0.673-0.840	<0.001
Hemoglobin	0.951	0.926-0.977	<0.001
Platelet count	1.006	1.001-1.011	0.024
Dialysate WBC, per 1000×10 ⁶ /L increase	1.358	1.096-1.681	0.005
Dialysate PMN	1.179	1.105-1.258	<0.001

WBC, white blood cell; NLR, neutrophil-to-lymphocyte ratio; CRP, C-reactive protein; PMN, polymorphonuclear neutrophil.

Table 3. Enter-method multivariable logistic regression model for catheter removal based on NLR and serum albumin

Variable	β	SE	Adjusted OR	95% CI	P value
NLR	0.408	0.105	1.504	1.225-1.846	<0.001
Serum albumin (g/L)	-0.588	0.132	0.555	0.429-0.719	<0.001
Constant	15.345	4.044	-	-	<0.001

Model performance: apparent AUC = 0.959; optimism-corrected C-index = 0.956 after 1,000 bootstrap resamples; apparent Brier score = 0.065; optimism-corrected Brier score = 0.071; optimism-corrected calibration slope = 0.906; optimism-corrected calibration intercept = -0.094. NLR, neutrophil-to-lymphocyte ratio.

mism-corrected C-index of 0.956, supporting the internal stability of the combined model while not replacing the need for independent external validation. The ROC-derived thresholds of NLR ≥ 6.03 and serum albumin ≤ 33.9 g/L were subsequently used to define the dichotomous inflammatory-nutritional high-risk pattern for subgroup and catheter-survival analyses.

Dialysate WBC was further evaluated using the clinically interpretable threshold of $>1,000 \times 10^6$ /L. However, 145 patients had dialysate

WBC values $>1,000 \times 10^6$ /L, whereas only 11 patients had values $\leq 1,000 \times 10^6$ /L. No catheter-removal event occurred in the $\leq 1,000 \times 10^6$ /L group; therefore, logistic regression produced complete separation and could not generate stable odds ratio estimates. Fisher's exact test showed no statistically significant difference between the two categories ($P=0.123$). Given this marked imbalance and the limited number of outcome

events, dialysate WBC was not retained in the final parsimonious NLR-albumin prediction model.

Clinical outcomes according to catheter status

Clinical outcomes of PDAP patients according to catheter outcome are summarized in **Table 5**. Compared with the catheter retention group, patients undergoing catheter removal had significantly longer hospital stay duration (22.1 ± 7.9 vs 12.4 ± 4.8 days, $P<0.001$) and higher rates of intensive care unit admission (34.3%

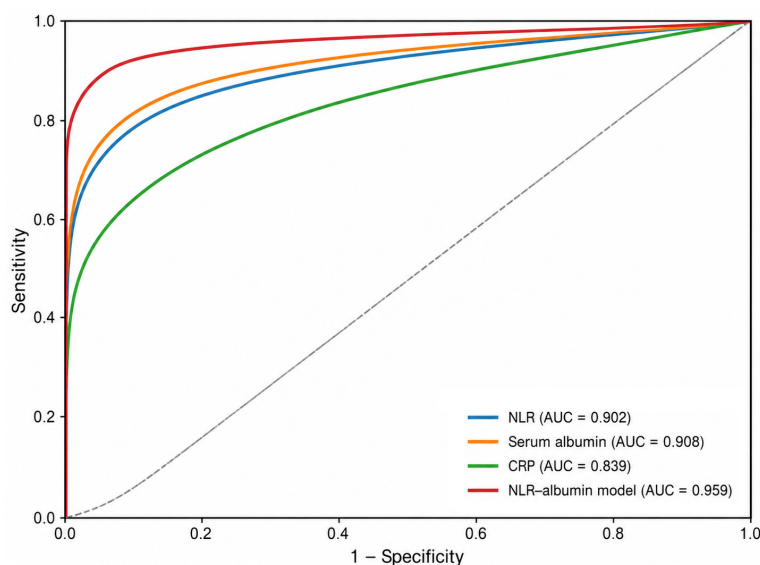


Figure 2. ROC curve analysis of inflammatory and nutritional markers for catheter removal. Receiver operating characteristic curves showing the discriminatory performance of NLR, serum albumin, CRP, and the combined NLR-albumin model for catheter removal in patients with PDAP. The combined NLR-albumin model showed higher discrimination than either NLR or serum albumin alone. CRP showed univariable discriminatory value but was not incorporated into the final model because the primary model was pre-specified as a parsimonious inflammatory-nutritional model. Optimal cutoff values for NLR and serum albumin were determined using the maximum Youden index.

vs 4.1%, $P < 0.001$). In addition, the catheter removal group exhibited significantly increased frequencies of recurrent or relapsing PDAP episodes (42.9% vs 13.2%, $P < 0.001$), persistent infection lasting longer than 5 days (68.6% vs 11.6%, $P < 0.001$), fungal secondary infection (20.0% vs 2.5%, $P < 0.001$), in-hospital mortality (17.1% vs 1.7%, $P < 0.001$), and 90-day mortality (25.7% vs 3.3%, $P < 0.001$). All patients in the catheter-removal group received hemodialysis immediately after catheter removal (Table 5). However, subsequent PD catheter reinsertion, resumption of peritoneal dialysis, and long-term maintenance hemodialysis status were not systematically captured in the retrospective database.

Subgroup analyses

Exploratory subgroup analyses were performed using the ROC-defined inflammatory-nutritional high-risk pattern, defined as $\text{NLR} \geq 6.03$ combined with serum albumin ≤ 33.9 g/L. The high-risk pattern remained significantly associated with catheter removal in the overall cohort and showed a directionally consistent associa-

tion across age, sex, diabetes status, culture positivity, and bacterial culture-type subgroups (Table 6). The use of the ROC-derived thresholds did not materially alter the overall subgroup interpretation compared with the preliminary exploratory threshold definition. A nominal interaction was observed for fungal infection status; however, because the fungal infection subgroup was small and the corresponding confidence interval was wide, this result should be interpreted cautiously and considered as exploratory. Subgroup analyses stratified by NLR or serum albumin were not performed because these variables were used to define the high-risk pattern.

Correlation of NLR and serum albumin with clinical parameters

Spearman correlation analysis (Table 7) showed that NLR was positively associated with CRP ($r = 0.681$, $P < 0.001$), procalcitonin ($r = 0.544$, $P < 0.001$), and dialysate WBC ($r = 0.603$, $P < 0.001$), and negatively correlated with lymphocyte count ($r = -0.738$, $P < 0.001$) and residual renal function ($r = -0.326$, $P < 0.001$). Serum albumin showed inverse correlations with CRP ($r = -0.592$, $P < 0.001$), dialysate WBC ($r = -0.488$, $P < 0.001$), and procalcitonin ($r = -0.421$, $P < 0.001$), supporting the mechanistic relevance of the inflammatory-nutritional axis.

Nonlinear association of NLR and albumin with catheter removal risk

Restricted cubic spline analysis (Figure 3) indicated a threshold effect for NLR, with risk rising sharply above ~ 8.0 , while lower serum albumin was linearly associated with increased catheter removal risk. Both associations remained significant after adjustment for confounders, and 95% confidence intervals indicated stable estimates.

NLR and albumin in predicting catheter removal in PD

Table 4. Predictive performance of NLR, serum albumin, and the combined NLR-albumin model for catheter removal

Model	AUC	95% CI	Sensitivity (%)	Specificity (%)	Youden index	Cutoff
NLR alone	0.902	0.848-0.947	97.1	73.0	0.700	6.03
Serum albumin alone	0.908	0.855-0.950	88.2	79.5	0.677	≤33.9 g/L
NLR-albumin model	0.959	0.927-0.983	91.2	86.1	0.772	0.190

NLR, neutrophil-to-lymphocyte ratio.

Table 5. Clinical outcomes of PDAP patients

Outcome	Catheter Retention (n=121)	Catheter Removal (n=35)	Test Statistic	P value
Hospital stay (days)	12.4 ± 4.8	22.1 ± 7.9	t=9.07	<0.001
ICU admission, n (%)	5 (4.1)	12 (34.3)	χ ² =25.67	<0.001
Relapse/recurrent PDAP, n (%)	16 (13.2)	15 (42.9)	χ ² =15.28	<0.001
Immediate transfer to HD after catheter removal, n (%)	0 (0.0)	35 (100.0)	-	-
In-hospital mortality, n (%)	2 (1.7)	6 (17.1)	χ ² =12.49	<0.001
90-day mortality, n (%)	4 (3.3)	9 (25.7)	χ ² =17.26	<0.001
Persistent infection >5 days, n (%)	14 (11.6)	24 (68.6)	χ ² =44.02	<0.001
Fungal secondary infection, n (%)	3 (2.5)	7 (20.0)	χ ² =13.11	<0.001

Transfer to HD reflects immediate renal replacement therapy after PD catheter removal. Information on subsequent PD catheter reinsertion, resumption of peritoneal dialysis, and long-term maintenance HD status was not systematically available in the retrospective database. PDAP, peritoneal dialysis-associated peritonitis.

Table 6. Exploratory subgroup analysis of the association between the ROC-defined NLR-albumin high-risk pattern and catheter removal

Subgroup	n	OR	95% CI	P value	Interaction P
Overall cohort	156	5.821	2.741-12.364	<0.001	-
Age <60 years	97	4.963	2.011-12.244	<0.001	0.418
Age ≥60 years	59	6.734	2.289-19.811	<0.001	
Male	92	5.117	2.011-13.019	0.001	0.682
Female	64	6.481	2.182-19.255	0.001	
Diabetes mellitus	61	7.292	2.418-21.990	<0.001	0.271
Non-diabetes	95	4.932	1.978-12.298	0.001	
Culture-positive infection	109	6.874	2.931-16.117	<0.001	0.194
Culture-negative infection	47	3.964	1.129-13.914	0.032	
Gram-positive infection	66	4.581	1.602-13.100	0.004	0.377
Gram-negative infection	31	8.937	2.241-35.636	0.002	
Fungal infection absent	144	4.982	2.244-11.064	<0.001	0.046
Fungal infection present	12	14.286	1.492-136.845	0.021	

High-risk inflammatory-nutritional pattern was defined using the ROC-derived thresholds of NLR ≥6.03 combined with serum albumin ≤33.9 g/L. Interaction P values were calculated using product terms between the high-risk pattern and each subgroup variable in logistic regression models. The overall direction and interpretation of the subgroup findings were materially unchanged after applying these ROC-derived thresholds. Interaction analyses stratified by NLR or serum albumin were not performed because these variables are components of the high-risk pattern itself. The fungal infection subgroup was small; therefore, the corresponding interaction result should be interpreted as exploratory. ROC, receiver operating characteristic; NLR, neutrophil-to-lymphocyte ratio.

Catheter survival analysis

Kaplan-Meier analysis compared catheter survival between patients with the ROC-defined

high-risk inflammatory-nutritional pattern, defined as NLR ≥6.03 combined with serum albumin ≤33.9 g/L, and all remaining patients. Patients with the high-risk pattern continued

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Table 7. Correlation analysis between NLR, serum albumin, and clinical parameters in PDAP patients

Variable	NLR (r)	P value	Serum Albumin (r)	P value
CRP	0.681	<0.001	-0.592	<0.001
Procalcitonin	0.544	<0.001	-0.421	<0.001
Dialysate WBC count	0.603	<0.001	-0.488	<0.001
Dialysate PMN (%)	0.572	<0.001	-0.437	<0.001
Hospital stay	0.517	<0.001	-0.396	<0.001
Hemoglobin	-0.412	<0.001	0.481	<0.001
Lymphocyte count	-0.738	<0.001	0.366	<0.001
Residual renal function	-0.326	<0.001	0.287	0.001
Serum phosphorus	0.148	0.065	-0.192	0.017
Platelet count	0.214	0.007	-0.136	0.091
Dialysis vintage	0.298	<0.001	-0.344	<0.001
90-day mortality risk score	0.627	<0.001	-0.558	<0.001

Correlation analysis was performed using Spearman rank correlation tests. PDAP, peritoneal dialysis-associated peritonitis; BMI, body mass index; WBC, white blood cell; NLR, neutrophil-to-lymphocyte ratio; CRP, C-reactive protein; PMN, polymorphonuclear neutrophil.

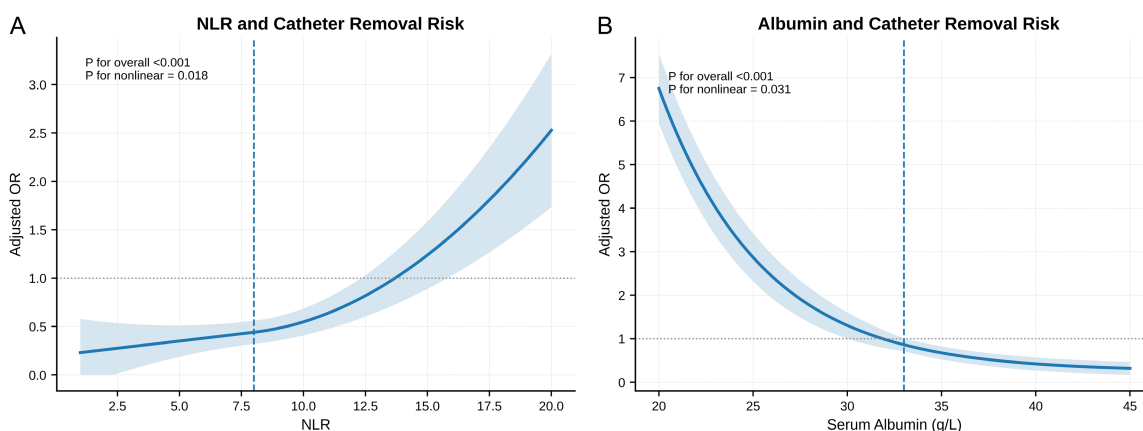


Figure 3. Restricted cubic spline (RCS) analysis of NLR and serum albumin on catheter removal risk. Two-panel RCS plots depicting the nonlinear associations of (A) NLR and (B) serum albumin with the odds ratio for catheter removal. The spline analyses were exploratory and were adjusted for prespecified clinical covariates, including age, sex, diabetes mellitus, dialysis vintage, and baseline laboratory variables selected to minimize overfitting. Solid lines represent adjusted odds ratios, and shaded areas indicate 95% confidence intervals. NLR showed a threshold effect around the 75th percentile, whereas lower albumin was linearly associated with increased catheter removal risk.

to experience earlier and more frequent catheter removal than those without this pattern. The log-rank test remained statistically significant, indicating poorer catheter survival in the high-risk group (Figure 4). Thus, use of the ROC-derived cutoffs did not change the overall conclusion of the catheter-survival analysis.

Nomogram and clinical utility

A two-variable nomogram incorporating NLR and serum albumin was constructed to estimate the individual probability of catheter re-

moval (Figure 5). Higher NLR and lower serum albumin values corresponded to higher total points and a higher predicted risk of catheter removal. Bootstrap-corrected calibration analysis showed acceptable agreement between predicted and observed catheter-removal probabilities, with an optimism-corrected calibration slope of 0.906 and a calibration intercept of -0.094 (Figure 6A). Decision curve analysis showed that the NLR-albumin model provided a greater net benefit than treat-all and treat-none strategies across clinically relevant threshold probabilities (Figure 6B).

NLR and albumin in predicting catheter removal in PD

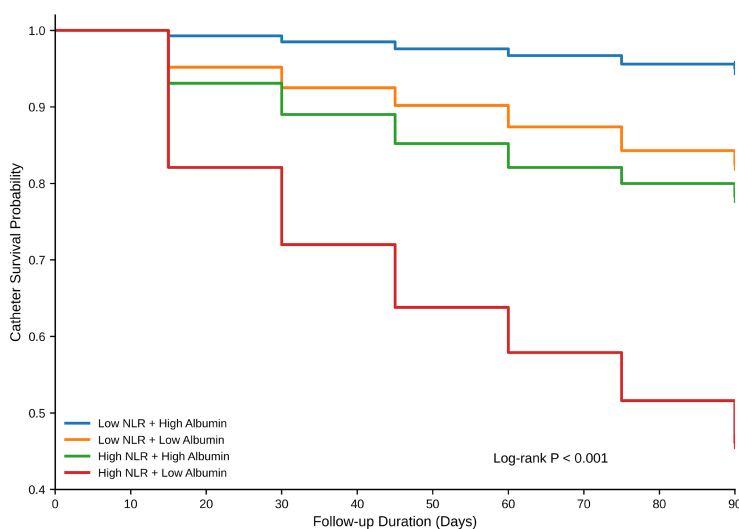


Figure 4. Kaplan-Meier catheter-survival curves according to the ROC-defined inflammatory-nutritional risk pattern. Kaplan-Meier curves comparing catheter survival between patients with NLR ≥ 6.03 combined with serum albumin ≤ 33.9 g/L and all remaining patients. Patients with the ROC-defined high-risk pattern had poorer catheter survival. Use of these ROC-derived thresholds did not materially change the overall survival-analysis conclusion compared with the preliminary exploratory risk definition.

Discussion

This retrospective cohort study showed that higher NLR and lower serum albumin were independently associated with catheter removal in patients with peritoneal dialysis-associated peritonitis. The model was developed and internally evaluated in a single-center cohort, so its discrimination should be interpreted as preliminary rather than definitive. Even so, the findings support the potential value of combining inflammatory and nutritional markers for early risk stratification in PDAP [1, 2, 4].

Systemic inflammation is closely related to PDAP outcomes. NLR, which is calculated from the complete routine blood count, reflects the balance between neutrophil-mediated inflammatory activation and lymphocyte-related immune status. This feature may allow NLR to capture a broader inflammatory-immune profile than a single acute-phase reactant. Elevated NLR has been associated with adverse outcomes in dialysis populations, including all-cause mortality, cardiovascular mortality, and infection-related complications [14, 15]. In the present cohort, CRP also showed univariable discriminatory value for catheter removal. However, CRP was not included in the final model because the primary model was pre-

specified as a parsimonious inflammatory-nutritional model based on NLR and serum albumin. This choice was not made because CRP lacked prognostic value. Rather, it reflected the limited number of catheter-removal events, the correlation between CRP and NLR, and the need to avoid adding multiple related inflammatory markers to a small prediction model. In clinical practice, NLR can be calculated directly from the complete blood count, while serum albumin provides complementary information on nutritional-inflammatory status. The NLR-albumin combination may therefore offer a practical approach to initial risk stratification, although external cohorts should compare it directly with CRP-based models.

In the current study, ROC analysis identified NLR ≥ 6.03 and serum albumin ≤ 33.9 g/L as the optimal individual biomarker thresholds for discrimination of catheter removal. These ROC-derived thresholds were subsequently applied uniformly to define the dichotomous inflammatory-nutritional high-risk pattern in subgroup and catheter-survival analyses. Importantly, the association between the combined high-risk pattern and catheter removal remained directionally and statistically consistent after cutoff harmonization, indicating that the central conclusion of the study was not dependent on the preliminary exploratory thresholds [16, 17]. Clinically, these internally derived thresholds may help identify patients who could warrant closer monitoring and earlier clinical reassessment; however, they should not be interpreted as evidence that modification of NLR or albumin levels will directly prevent catheter removal. Moreover, serum albumin, an established marker of nutritional and inflammatory status, was inversely associated with catheter removal risk. Hypoalbuminemia was independently associated with a higher risk of catheter removal in this cohort and may reflect poor nutritional reserve, systemic inflammatory burden, protein loss, or greater illness severity during PDAP [18, 19]. Unlike NLR, serum albumin showed an approximately linear

NLR and albumin in predicting catheter removal in PD

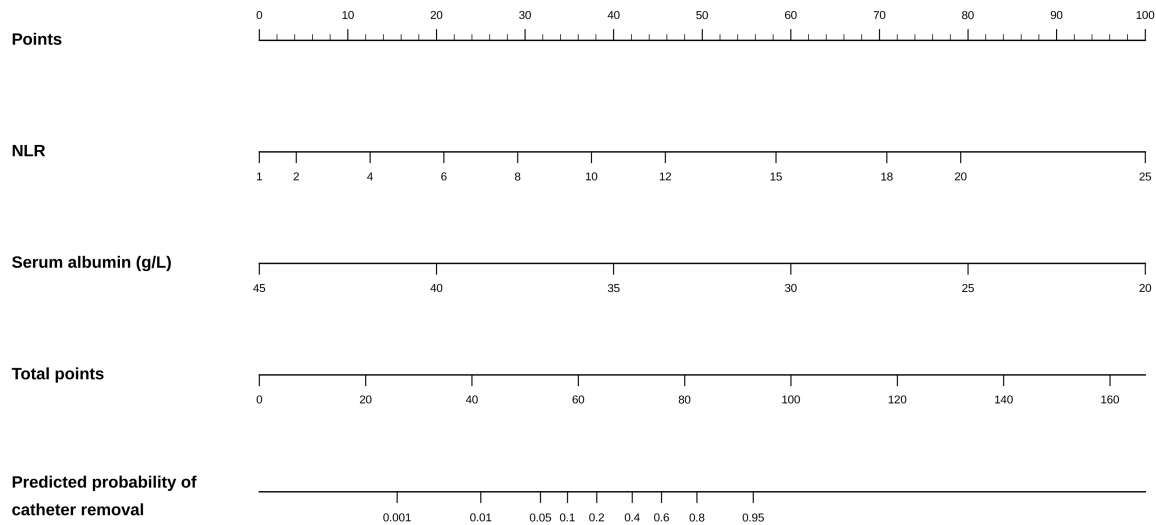


Figure 5. Nomogram for predicting catheter removal in patients with peritoneal dialysis-associated peritonitis. The nomogram incorporates neutrophil-to-lymphocyte ratio and serum albumin. For each predictor, a corresponding number of points is assigned using the top points scale. The total points correspond to the estimated probability of catheter removal.

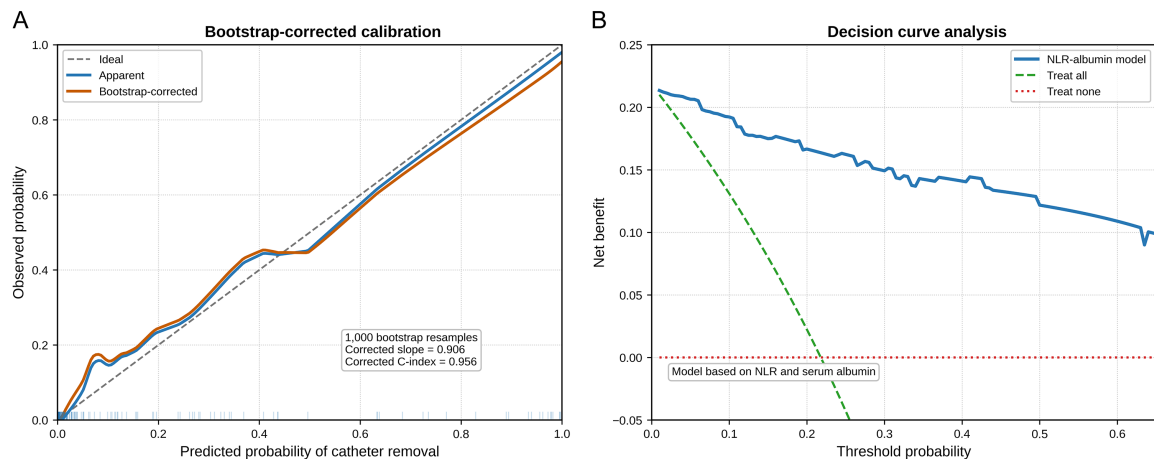


Figure 6. Calibration and decision curve analysis of the nomogram. Internal validation and clinical utility of the NLR-albumin prediction model for catheter removal. A. Bootstrap-corrected calibration curve based on 1,000 resamples. The dashed diagonal line represents ideal calibration. B. Decision curve analysis showing the net benefit of the NLR-albumin model compared with treat-all and treat-none strategies across a range of threshold probabilities.

inverse association with catheter removal, suggesting that progressively lower albumin levels may serve as a marker of increasing nutritional-inflammatory vulnerability during PDAP. Previous studies also show that albumin correlates with peritonitis risk, hospitalization, and mortality in PD populations [20, 21]. The combined NLR-albumin risk pattern identified patients at increased risk of catheter removal across most demographic and clinical subgroups. No statistically significant interaction was observ-

ed by age, sex, diabetes status, culture positivity, or bacterial culture type, suggesting that the direction of association was generally consistent across these strata. A nominal interaction was observed for fungal infection status; however, this finding was based on only 12 fungal-infection cases and had wide confidence intervals. Therefore, it should be regarded as exploratory and should not be used to define a separate fungal-specific risk threshold without confirmation in larger PDAP cohorts [22].

Clinically, the NLR-albumin pattern may help identify patients who could benefit from intensified monitoring and early reassessment, while fungal infection should continue to be managed according to established organism-specific treatment and catheter-removal recommendations.

In univariate analysis, history of previous PDAP episodes, fungal infection, diabetes mellitus, and dialysate WBC were associated with catheter removal. These variables may represent different aspects of PDAP severity and host vulnerability, including prior peritoneal injury, microbial burden, metabolic comorbidity, and local inflammatory activity. Dialysate WBC, for example, may serve as an indicator of intra-peritoneal inflammatory response during PDAP and was associated with catheter removal in univariable analysis [23]. Similarly, fungal infection and diabetes mellitus may identify patients with more complex clinical courses or a greater burden of comorbidity rather than being interpreted as direct causal determinants of catheter removal [23]. However, these variables were not retained in the primary prediction model because the model was deliberately restricted to the two prespecified inflammatory-nutritional biomarkers to preserve an adequate events-per-variable ratio and reduce overfitting. When history of previous PDAP episodes was added to the NLR-albumin model in sensitivity analysis, it did not materially alter the NLR or serum albumin estimates or improve model discrimination.

We developed a parsimonious nomogram based on NLR and serum albumin, two readily available biomarkers representing inflammatory and nutritional status. The model showed good apparent discrimination and retained an optimism-corrected C-index of 0.956 after bootstrap internal validation. The bootstrap-corrected calibration slope of 0.906 and calibration intercept of -0.094 indicated acceptable calibration after accounting for optimism.

Nevertheless, several limitations of this work should be considered. First, the limited number of catheter-removal events may have increased the risk of model overfitting. To address this issue, the final model was restricted to two prespecified predictors, resulting in approximately 17 events per predictor,

and internal validation was performed using 1,000 bootstrap resamples. Although a history of previous PDAP episodes was clinically relevant and showed a significant univariable association with catheter removal, it was assessed separately in a sensitivity analysis rather than included in the primary model. In addition, the fungal-infection interaction was based on a small subgroup and should be considered hypothesis-generating rather than evidence of a definitive differential effect. Its inclusion did not materially alter the NLR or serum albumin estimates or improve model discrimination. However, internal bootstrap validation cannot replace independent external validation. Because the model was developed in a single-center retrospective cohort, its discrimination, calibration, and clinical utility may differ in external populations with different demographic characteristics, microbial profiles, dialysis practices, antimicrobial strategies, and thresholds for catheter removal. Third, the present model was based only on NLR and serum albumin values obtained during the initial clinical assessment. These biomarkers may change substantially during PDAP treatment, and serial trajectories may provide additional information regarding treatment response, persistent inflammation, nutritional deterioration, and subsequent catheter-removal risk. Moreover, the exact interval from PDAP symptom onset to baseline blood sampling was not consistently documented. We therefore could not assess whether variation in baseline sampling time within the 24-hour enrollment window influenced NLR or serum albumin values. Because NLR and serum albumin measurements on treatment days 3 and 5 were not consistently recorded at standardized time points, we were unable to evaluate whether changes in these markers during treatment were associated with catheter removal. Fourth, although all patients undergoing catheter removal received hemodialysis immediately after the procedure, the database did not systematically capture subsequent PD catheter reinsertion, recovery of peritoneal dialysis technique, or long-term maintenance hemodialysis. Therefore, the present study could not fully characterize the long-term dialysis-modality consequences of catheter removal. Future prospective multicenter studies should externally validate the model, collect NLR and serum albumin at standardized baseline and follow-

up time points, including treatment days 3 and 5, and record long-term dialysis-modality outcomes, including PD catheter reinsertion, PD resumption, and sustained hemodialysis dependence.

In conclusion, higher NLR and lower serum albumin were independently associated with catheter removal in patients with PDAP. Their combination outperformed either marker alone in this retrospective cohort and showed acceptable internal performance after bootstrap validation. However, the model should be considered exploratory and requires validation in independent external cohorts before routine clinical application.

Disclosure of conflict of interest

None.

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