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Association between prognostic nutritional index and mortality risk in patients with community-acquired pneumonia: a retrospective study

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Abstract

Background The prognostic nutritional index (PNI), reflecting the body's immune-nutritional status, has been established as a correlate of prognosis across various diseases. However, its significance in community-acquired pneumonia (CAP) remains unclear. This study investigated the relationship between PNI and clinical outcomes in CAP patients.

Methods In this retrospective cohort study, we aimed to evaluate the prognostic value of the PNI in adults with CAP admitted to the ICU. Participants were selected from the Medical Information Mart for Intensive Care IV (MIMIC-IV) database and categorized into quartiles (Q1–Q4) according to their PNI values. We employed Kaplan-Meier survival analysis, multivariate Cox regression, and restricted cubic spline (RCS) models to explore the association between PNI and the clinical outcomes of these CAP patients.

Results In this study, we included 1,608 patients with CAP. The observed 30-day and 90-day mortality rates stood at 30.85% and 39.99%, respectively. Patients with higher PNI levels exhibited a reduced risk of both 30-day and 90-day mortality. Following adjustment for confounders, PNI showed a significant negative association with 30-day mortality [HR, 0.93 (0.91–0.94), $P < 0.001$] and 90-day mortality [HR, 0.94 (0.92–0.95), $P < 0.001$]. RCS analysis revealed a consistent trend of declining all-cause mortality risk corresponding to increasing PNI values. PNI demonstrated predictive value for 30-day and 90-day mortality in CAP patients, with AUCs of 0.71 and 0.68, respectively. Combining PNI with CURB-65 enhanced the predictive value of CURB-65.

Conclusion Our investigation identified a significant negative association between the PNI and the risk of mortality in patients with CAP. Additionally, the PNI demonstrated superior predictive value for mortality risk in CAP patients when compared to the CURB-65 scoring system.

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Introduction

Community-acquired pneumonia (CAP) represents a significant global health challenge, often necessitating admission to intensive care units (ICUs) and ranking as the foremost infectious disease-related cause of hospitalization worldwide [1]. Annually, approximately 4 to 5 million new cases of CAP are identified globally [2, 3]. The mortality rate for hospitalized CAP patients is about 13%, rising to over 35% for severe cases [4]. Despite advancements in antimicrobial treatments and preventive strategies, CAP remains a significant challenge for healthcare systems worldwide. Timely identification of individuals at heightened risk for adverse outcomes is crucial in the effective management of CAP.

The prognostic nutritional index (PNI) was initially devised to evaluate the nutritional and immunological status of surgical patients [5]. Albumin serves as an indicator of the body's nutritional state and has antioxidant and anti-inflammatory functions [6]. Lymphocytes, a subtype of white blood cells, are integral to the immune system, playing key roles in resisting infections, regulating immune responses, and developing immune memory. The PNI offers a comprehensive assessment of both nutritional and immune status and is easily obtainable, rendering it a valuable tool for prognostication in patient care. PNI has been proven to possess significant predictive value for various types of cancer [7–9]. Additionally, researches indicated that PNI is also effective in predicting outcomes for patients with non-neoplastic diseases, such as cardiovascular diseases, autoimmune diseases, chronic pulmonary diseases, and cerebrovascular diseases [10]. However, the prognostic relevance of PNI in CAP patients, particularly those requiring ICU admission, remains uncertain. Therefore, further elucidation is vital to ascertain any potential association between PNI and the prognosis of CAP patients.

In this study, we aimed to identify potential associations between the PNI and patient prognosis, thereby providing new insights for the early prediction of clinical outcomes in patients with CAP.

Materials and methods

Database introduction

All date were sourced from the MIMIC-IV (version 2.2) database, an extensive repository developed and curated by the Massachusetts Institute of Technology Laboratory for Computational Physiology. MIMIC-IV contains a diverse array of data extracted from the Beth Israel Deaconess Medical Center in Boston, Massachusetts, spanning the period from 2008 to 2019 [11]. It includes demographic, clinical, laboratory, and outcome data for over 70,000 patients, providing a rich resource for medical research. The first author, Guangdong Wang (certification number: 60106105), was authorized to access the MIMIC-IV database.

Population selection criteria

A total of 6,333 CAP patients were initially considered for this study based on the ICD criteria. The exclusion criteria comprised the following: (1) Age under 18 years old (n=0); (2) Non-first ICU admission (n=988); (3) ICU stay less than 24 h (n=726); (4) Absence of a PNI (n=2,803); (5) Incomplete clinical data (n=208). Consequently, the final cohort consisted of 1,608 patients, who were subsequently categorized into four groups based on quartiles of the PNI (Fig. 1).

Data extraction and PNI

Data extraction from the MIMIC-IV database was performed using PostgreSQL. The clinical data primarily included: (1) Basic demographic information such as gender, age, and race. (2) Vital signs, including heart rate, mean blood pressure (MBP), respiratory rate, and blood oxygen saturation (SpO2). (3) Comorbidities, including chronic pulmonary disease, diabetes, hypertension, renal disease, and malignant cancer. (4) Laboratory parameters such as red blood cell distribution width (RDW), platelets, lymphocytes, white blood cells (WBC), hemoglobin, albumin, blood urea nitrogen (BUN), creatinine, sodium, international normalized ratio (INR), and prothrombin time (PT). Clinical scores and indices, including the Charlson Comorbidity Index, Glasgow Coma Scale (GCS), CURB-65 score, Sequential Organ Failure Assessment (SOFA) score, and Acute Physiology Score III (APS III) were collected. Pathogen detection data included the presence of bacterial infection, fungal infection, Methicillin-resistant *Staphylococcus aureus*(MRSA), *Klebsiella pneumoniae*, and blood culture results. Additionally, therapies administered, including the use of antibiotics, vasoactive agents, and mechanical ventilation, were documented. The PNI was calculated using the formula: =(10×serum albumin [g/dL])+(0.005×lymphocytes [μL]). All data were retrieved from records generated within the first 24 h following the patient's admission to the ICU.

Primary outcomes and secondary outcomes

The clinical outcomes of the patients were documented. Primary outcomes focused on 30-day and 90-day mortality rates. Secondary outcomes included hospital mortality and the lengths of hospital and ICU stays.

Management of missing data

All variables had less than 10% missing data, as detailed in Table S1. Missing data for variables with less than 5% were imputed using mean or median value. For variables with more than 5% missing data, multiple imputation was performed using the mice package in R software.

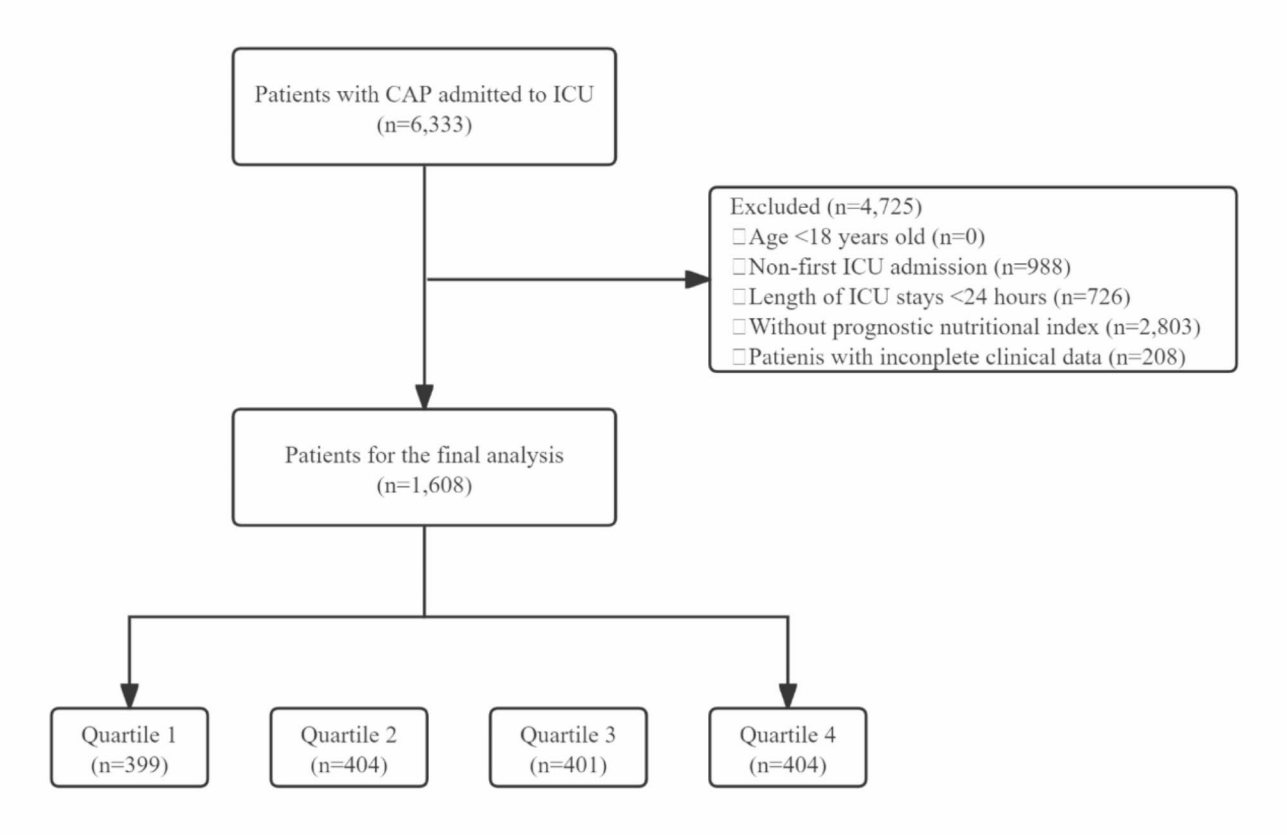

Fig. 1 Flowchart of the study. CAP, community-acquired pneumonia; ICU, intensive care unit

Statistical analysis

Continuous variables were summarized as means ± standard deviation for data following a normal distribution, or as medians with interquartile ranges for non-normally distributed data. Parametric tests, such as the t-test or ANOVA, were applied to normally distributed variables, whereas non-parametric tests, including the Mann-Whitney U test and Kruskal-Wallis test, were applied for those with skewed distributions. Categorical variables were presented as frequencies and percentages and were analyzed using the Chi-square test.

Kaplan-Meier survival analysis was employed to assess the incidence of endpoints across various levels of the PNI, with survival curves compared using the log-rank test. The relationship between PNI and mortality outcomes was analyzed using multivariate Cox regression, adjusting for confounders identified in univariate Cox analyses. The results were expressed as hazard ratios (HR) with 95% confidence intervals (CIs). Additionally, P for trend values were calculated to assess the significance of trends across ordered groups. To explore potential non-linear relationships between baseline PNI and all-cause mortality, restricted cubic spline (RCS) regression models were implemented. Receiver operating characteristic (ROC) analysis was conducted to evaluate the predictive utility of the PNI and CURB-65 for all-cause mortality. To assess the combined predictive value of PNI and CURB-65, PNI was stratified based on optimal cutoff values: PNI < 31.55 for predicting 30-day mortality and PNI < 34.85 for predicting 90-day mortality. We subsequently calculated the predictive value of these combinations (PNI < 31.55 plus CURB-65 and PNI < 34.85 plus CURB-65) for mortality outcomes. Subgroup analyses were performed to examine the consistency of PNI's prognostic value across different patient groups, including variations by age, gender, chronic pulmonary disease, diabetes, hypertension, renal disease, and malignant cancer.

All data analyses were carried out using R software, version 4.3.2, and SPSS version 26.0, with statistical significance set at a two-sided p-value of less than 0.05.

Results

Patient characteristics

In this study, 1,608 patients with CAP were included. The median PNI was 35.70 (IQR: 31.05–40.75). The 30-day mortality rate was 30.85%, and the 90-day mortality rate was 39.99%. Patient characteristics, divided by PNI quartiles, were displayed in Table 1. Patients were stratified into four groups based on their PNI values: Quartile (Q)

Table 1 Baseline characteristics according to PNI quartiles

Variables	Total ($n=1,608$)	Q1 ($n=399$)	Q2 ($n=404$)	Q3 ($n=401$)	Q4 ($n=404$)	*P*
Age (year)	67 (55, 79)	67 (55,79)	68 (57,79)	67 (56,81)	66 (53,80)	0.317
Gender, n(%)						0.765
Female	688 (42.79)	162 (40.60)	173 (42.82)	176 (43.89)	177 (43.81)	
Male	920 (57.21)	237 (59.40)	231 (57.18)	225 (56.11)	227 (56.19)	
Race, n(%)						0.015
Other	1,068 (66.42)	259 (64.91)	276 (68.32)	286 (71.32)	247 (61.14)	
White	540 (33.58)	140 (35.09)	128 (31.68)	115 (28.68)	157 (38.86)	
Vital signs						
MBP (mmHg)	74 (68, 82)	71 (67,77)	74 (68,80)	75 (69,85)	78 (71,86)	< 0.001
Heart rate (beats/min)	91 (79, 102)	94 (82,105)	91 (78,103)	90 (79,101)	88 (78,99)	< 0.001
Respiratory rate (beats/min)	21 (18, 24)	21 (18,25)	20 (18,24)	21 (18,24)	20 (18,24)	0.117
SpO2	96.47 ± 2.46	96.22 ± 2.69	96.58 ± 2.37	96.57 ± 2.44	96.50 ± 2.31	0.121
Comorbidities						
Chronic pulmonary disease, n(%)	602 (37.44)	140 (35.09)	153 (37.87)	149 (37.16)	160 (39.60)	0.616
Diabetes, n(%)	465 (28.92)	93 (23.31)	129 (31.93)	133 (33.17)	110 (27.23)	0.007
Hypertension, n(%)	625 (38.87)	137 (34.34)	151 (37.38)	164 (40.90)	173 (42.82)	0.066
Renal disease, n(%)	426 (26.49)	100 (25.06)	114 (28.22)	112 (27.93)	100 (24.75)	0.554
Malignant cancer, n(%)	323 (20.09)	105 (26.32)	94 (23.27)	64 (15.96)	60 (14.85)	< 0.001
Score						
Charlson index	6 (4, 8)	6 (4,8)	6 (4,8)	5 (4,8)	5 (3,7)	< 0.001
GCS	15 (13, 15)	15 (13,15)	15 (13,15)	15 (13,15)	15 (13,15)	0.438
CURB-65	2 (1, 3)	2 (2,3)	2 (1,3)	2 (1,3)	2 (1,3)	< 0.001
SOFA	6 (4, 9)	7 (5,10)	6 (4,9)	5 (3,8)	5 (3,7.25)	< 0.001
APSIII	53 (40, 69)	64 (51.50,82)	52 (42,68)	49 (38,64)	45 (34,60)	< 0.001
Laboratory tests						
RDW (%)	15.6 (14.2, 17.4)	16.3 (15.1,18.4)	15.6 (14.2,17.4)	15.4 (14.3,17.1)	14.9 (13.8,16.6)	< 0.001
Neutrophils (K/uL)	9.1 (5.6, 13.2)	9.0 (4.9,14.7)	8.5 (5.0,12.5)	9.5 (6.1,13.2)	9.0 (6.1,12.9)	0.139
Hemoglobin (g/L)	9.8 (8.3, 11.3)	8.8 (7.7,10.0)	9.6 (8.3,11.2)	10.1 (8.5,11.2)	10.9 (9.3,12.4)	< 0.001
Platelets (K/uL)	180 (118, 262)	150 (75,253)	179 (116,265)	205 (138,288)	193 (141,252)	< 0.001
WBC (K/uL)	9.7 (6.5, 13.6)	9.2 (5.7,15.5)	8.8 (6.1,13.2)	10.1 (7.0,13.6)	10.0 (7.4,13.3)	0.020
BUN (mg/dL)	24 (14, 39)	30 (18, 46)	26 (15,41)	22 (14,37)	20 (12,32)	< 0.001
Creatinine (mg/dL)	1.0 (0.7, 1.8)	1.1 (0.7,2.1)	1.0 (0.7,1.8)	1.0 (0.7,1.6)	1.0 (0.7,1.5)	0.134
Sodium (mEq/L)	137 (133, 140)	136 (132,140)	137 (133,140)	137 (133,140)	137 (134,140)	0.066
Potassium (mEq/L)	3.8 (3.4, 4.2)	3.8 (3.4,4.2)	3.8 (3.4,4.3)	3.8 (3.4,4.2)	3.8 (3.5,4.2)	0.899
INR	1.3 (1.1, 1.6)	1.4 (1.2,1.8)	1.3 (1.1,1.6)	1.3 (1.1,1.5)	1.2 (1.1,1.4)	< 0.001
PT (s)	14.1 (12.6, 17.4)	15.3 (13.3,19.1)	14.3 (12.7,17.6)	14.0 (12.5,16.4)	13.3 (12.1,15.3)	< 0.001
Pathogen detection						
Bacterial infection, n(%)	1,310 (81.47)	301 (75.44)	335 (82.92)	331 (82.54)	343 (84.90)	0.003
Fungal infection, n(%)	297 (18.47)	95 (23.81)	71 (17.57)	69 (17.21)	62 (15.35)	0.013
MRSA, n(%)	156 (9.70)	48 (12.03)	39 (9.65)	27 (6.73)	42 (10.40)	0.081
Klebsiella pneumoniae, n(%)	109 (6.78)	21 (5.26)	31 (7.67)	26 (6.48)	31 (7.67)	0.470
Blood culture positive, n(%)	188 (11.69)	61 (15.29)	52 (12.87)	38 (9.48)	37 (9.16)	0.019
Therapy						
Antibiotic, n(%)	1,527 (94.96)	384 (96.24)	390 (96.53)	382 (95.26)	371 (91.83)	0.008
Vasoactive agent, n(%)	710 (44.15)	217 (54.39)	198 (49.01)	153 (38.15)	142 (35.15)	< 0.001
Mechanical ventilation, n(%)	550 (34.20)	162 (40.60)	132 (32.67)	136 (33.92)	120 (29.70)	0.010
Clinical outcomes						
Hospital stay(days)	9.97 (5.94, 16.97)	10.69 (5.85,18.27)	10.64 (6.02,17.66)	10.48 (6.03,16.73)	9.05 (5.82,15.86)	0.322
ICU stay(days)	3.98 (2.13, 8.58)	4.66 (2.29,9.51)	3.87 (2.21,8.93)	4.03 (2.14,8.39)	3.56 (1.95,7.49)	0.025
Hospital mortality, n(%)	415 (25.81)	187 (46.87)	97 (24.01)	78 (19.45)	53 (13.12)	< 0.001

Table 1 (continued)

Variables	Total (*n* = 1,608)	Q1 (*n* = 399)	Q2 (*n* = 404)	Q3 (*n* = 401)	Q4 (*n* = 404)	*P*
30-day mortality, n(%)	496 (30.85)	220 (55.14)	121 (29.95)	94 (23.44)	61 (15.10)	< 0.001
90-day mortality, n(%)	643 (39.99)	246 (61.65)	166 (41.09)	136 (33.92)	95 (23.51)	< 0.001

Abbreviations: MBP, mean blood pressure; SpO2, blood oxygen saturation; GCS, Glasgow Coma Scale; SOFA, Sepsis-Related Organ Failure Assessment Score; APSIII, Acute Physiology Score III; RDW, red blood cell distribution width; WBC, white blood cells; BUN, blood urea nitrogen; INR, international normalized ratio; PT, prothrombin time; MRSA, Methicillin-resistant *Staphylococcus aureus*

1: 14.35–31.05; Q2: 31.05–35.70; Q3: 35.70–40.75; Q4: 40.75–77.35. Those in the higher PNI quartiles typically had lower levels of RDW, BUN, INR, PT, and presented with lower disease severity scores at admission compared to those in lower quartiles. The prevalence of malignant cancer was higher in lower PNI quartiles ($P<0.001$). Pathogen detection and therapy characteristics also varied across PNI quartiles. Bacterial infection rates were higher in higher PNI quartiles ($P=0.003$), while fungal infections and blood culture positivity were lower ($P=0.013$ and $P=0.019$, respectively). The use of antibiotic, vasoactive agents and mechanical ventilation was lower in higher PNI quartiles ($P=0.008$, $P<0.001$, and $P=0.010$, respectively). Patients in the highest PNI quartile experienced shorter ICU stays (3.56 days vs. 4.03, 3.87, and 4.66 days, $P=0.025$) and had lower rates of hospital mortality (13.12% vs. 19.45%, 24.01%, and 46.87%, $P<0.001$) compared to those in the lower quartiles.

Table 2 presents the baseline characteristics of the 90-day survivor and mortality groups. Non-survivors were older and had higher rates of renal disease and malignant cancer. They also exhibited lower MBP, higher heart rates, and more severe illness scores. Laboratory tests revealed higher RDW, WBC, BUN, creatinine, INR, and PT, alongside lower hemoglobin and platelet counts. Fungal infections and positive blood cultures were more common in non-survivors, who also required more frequent use of vasoactive agents and mechanical ventilation. The PNI was significantly lower in the mortality group(32.95 vs. 37.45, $P<0.001$). The distribution of PNI levels across survival statuses at both 30 and 90 days was depicted in Figure S1.

All-cause mortality in different PNI groups

According to the PNI level, the mortality rates in Q1 to Q4 groups were 55.14%, 29.95%, 23.44%, and 15.10% at 30 days, and 61.65%, 41.09%, 33.92%, and 23.51% at 90 days, respectively. The mortality rate decreased with increasing PNI level. This relationship was further demonstrated by the Kaplan-Meier curves(Fig. 2).

Association between all-cause mortality and PNI

Factors exhibiting a P value < 0.05 in Table S2 will be considered confounders in predicting both 30-day and 90-day mortality using PNI. The findings revealed a correlation between higher PNI and reduced risks of 30-day mortality across various models: unadjusted [HR, 0.91 (0.89–0.92), $P<0.001$], partly adjusted [HR, 0.92 (0.91–0.94), $P<0.001$], and fully adjusted [HR, 0.93 (0.91–0.94), $P<0.001$] when PNI was treated as a continuous variable. Similarly, PNI showed a correlation with 90-day mortality across the unadjusted [HR, 0.92 (0.91–0.93), $P<0.001$], partly adjusted [HR, 0.93 (0.92–0.94), $P<0.001$], and fully adjusted [HR, 0.94 (0.92–0.95), $P<0.001$] models(Table 3). Furthermore, when PNI was categorized as a nominal variable, individuals in the highest quartile demonstrated significantly lower risk of 30-day and 90-day mortality in all three model. Additionally, RCS indicated that a higher PNI (>35.63) was associated with reduced risks of both 30-day and 90-day mortality (Fig. 3).

Comparative predictive value of PNI and CURB-65 for mortality in CAP

Figure 4; Table 4 demonstrate that the PNI has a superior predictive value for both 30-day and 90-day mortality in patients with CAP compared to CURB-65. For 30-day mortality, PNI had an AUC of 0.71, while CURB-65 had an AUC of 0.63. The combined use of PNI and CURB-65 resulted in an AUC of 0.68. For 90-day mortality, PNI alone had an AUC of 0.68, CURB-65 had an AUC of 0.63, and their combination yielded an AUC of 0.67.

Subgroup analysis

Subgroup analysis of the PNI across diverse demographic and clinical contexts demonstrated a consistent association with reduced 30-day and 90-day mortality among patients with CAP (Fig. 5). Notably, significant interactions were observed in the age subgroup for 90-day mortality ($P=0.03$), suggesting age-related differences in mortality risk prediction.

Discussion

CAP has brought a huge burden of disease to society, yet the absence of straightforward and effective biomarkers for prognostication remains a challenge. Our analysis, based on a cohort of 1,608 CAP patients, revealed substantial 30-day and 90-day mortality rates of 30.85% and 39.99%, respectively. After adjusting for confounders, PNI showed a significant negative association with 30-day mortality [HR, 0.93 (0.91–0.94), $P<0.001$] and 90-day mortality [HR, 0.94 (0.92–0.95), $P<0.001$]. The

Table 2 Baseline characteristics of the 90-day survivor and 90-day mortality group

Variables	Total ($n=1,608$)	90d-survivor ($n=965$)	90d-mortality ($n=643$)	*P*
Age(year)	67 (55, 79)	65 (53, 76)	72 (61, 83)	< 0.001
Gender, n(%)				0.599
Female	688 (42.79)	418 (43.32)	270 (41.99)	
Male	920 (57.21)	547 (56.68)	373 (58.01)	
Race, n(%)				0.278
Other	1,068 (66.42)	651 (67.46)	417 (64.85)	
White	540 (33.58)	314 (32.54)	226 (35.15)	
Vital signs				
MBP (mmHg)	74 (68, 82)	76 (70, 84)	72 (67, 79)	< 0.001
Heart rate (beats/min)	91 (79, 102)	89 (79, 101)	92 (80, 104)	0.001
Respiratory rate (beats/min)	21 (18, 24)	20 (18, 24)	21 (18, 24)	0.088
SpO2	96.47 ± 2.46	96.50 ± 2.24	96.42 ± 2.75	0.541
Comorbidities				
Chronic pulmonary disease, n(%)	602 (37.44)	363 (37.62)	239 (37.17)	0.856
Diabetes, n(%)	465 (28.92)	287 (29.74)	178 (27.68)	0.373
Hypertension, n(%)	625 (38.87)	382 (39.59)	243 (37.79)	0.470
Renal disease, n(%)	426 (26.49)	233 (24.15)	193 (30.02)	0.009
Malignant cancer, n(%)	323 (20.09)	137 (14.20)	186 (28.93)	< 0.001
Score				
Charlson index	6 (4, 8)	5 (3, 7)	7 (5, 8)	< 0.001
GCS	15 (13, 15)	15 (14, 15)	15 (12, 15)	0.003
CURB-65	2 (1, 3)	2 (1, 3)	3 (2, 3)	< 0.001
SOFA	6 (4, 9)	5 (3, 8)	7 (4, 10)	< 0.001
APSIII	53 (40, 69)	48 (37, 62)	62 (48, 80)	< 0.001
Laboratory tests				
RDW (%)	15.6 (14.2, 17.4)	15.3 (14.0, 16.9)	16.2 (14.7, 18.3)	< 0.001
Neutrophils (K/uL)	9.1 (5.6, 13.2)	8.8 (5.6, 12.9)	9.4 (5.5, 14.1)	0.067
Hemoglobin (g/L)	9.8 (8.3, 11.3)	10.1 (8.5, 11.6)	9.4 (8.1, 10.8)	< 0.001
Platelets (K/uL)	180 (118, 262)	184 (126, 255)	175 (105, 271)	0.044
WBC (K/uL)	9.7 (6.5, 13.6)	9.4 (6.6, 13.2)	10.1 (6.5, 14.7)	0.028
BUN (mg/dL)	24 (14, 39)	21 (13, 35)	30 (18, 49)	< 0.001
Creatinine (mg/dL)	1.0 (0.7, 1.8)	0.9 (0.7, 1.5)	1.2 (0.7, 2.1)	< 0.001
Sodium (mEq/L)	137 (133, 140)	137 (133, 140)	137 (133, 140)	0.870
Potassium (mEq/L)	3.8 (3.4, 4.2)	3.8 (3.4, 4.2)	3.8 (3.4, 4.3)	0.117
INR	1.3 (1.1, 1.6)	1.2 (1.1, 1.5)	1.4 (1.1, 1.7)	< 0.001
PT (s)	14.1 (12.6, 17.4)	13.7 (12.3, 16.2)	15.1 (13.0, 18.9)	< 0.001
PNI	35.7 (31.1, 40.8)	37.5 (32.9, 42.2)	33.0 (28.2, 37.8)	< 0.001
Pathogen detection				
Bacterial infection, n(%)	1,310 (81.47)	801 (83.01)	509 (79.16)	0.052
Fungal infection, n(%)	297 (18.47)	162 (16.79)	135 (21.00)	0.033
MRSA, n(%)	156 (9.70)	88 (9.12)	68 (10.58)	0.334
Klebsiella pneumoniae, n(%)	109 (6.78)	63 (6.53)	46 (7.15)	0.625
Blood culture positive, n(%)	188 (11.69)	93 (9.64)	95 (14.77)	0.002
Therapy				
Antibiotic, n(%)	1,527 (94.96)	910 (94.30)	617 (95.96)	0.137
Vasoactive agent, n(%)	710 (44.15)	367 (38.03)	343 (53.34)	< 0.001
Mechanical ventilation, n(%)	550 (34.20)	282 (29.22)	268 (41.68)	< 0.001

Abbreviations: MBP, mean blood pressure; SpO2, blood oxygen saturation; GCS, Glasgow Coma Scale; SOFA, Sepsis-Related Organ Failure Assessment Score; APSIII, Acute Physiology Score III; RDW, red blood cell distribution width; WBC, white blood cells; BUN, blood urea nitrogen; INR, international normalized ratio; PT, prothrombin time; PNI, prognostic nutritional index; MRSA, Methicillin-resistant *Staphylococcus aureus*

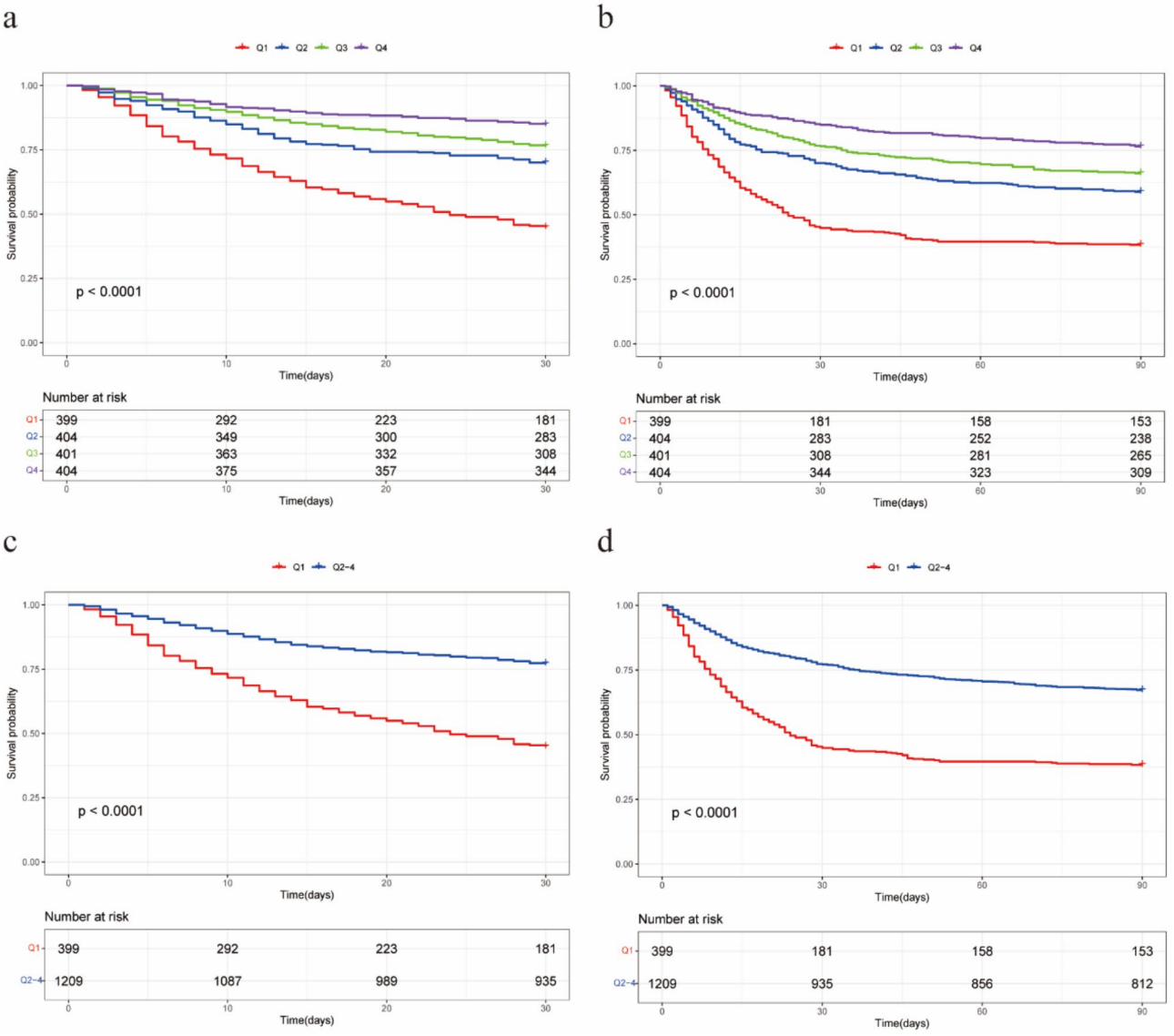

Fig. 2 Kaplan-Meier survival curves for all-cause mortality by PNI Quartiles.(**a**) 30-day and (**b**) 90-day mortality: displays stratification across PNI quartiles (Q1-Q4), showing progressively better survival from lowest to highest quartiles ($P < 0.0001$).(**c**) 30-day and (**d**) 90-day mortality, aggregated groups: compares lowest quartile (Q1) against combined higher quartiles (Q2-4), highlighting significantly lower survival in Q1 ($P < 0.0001$)

PNI demonstrated predictive value for 30-day and 90-day mortality in CAP patients, with AUCs of 0.71 and 0.68, respectively. Moreover, combining PNI with CURB-65 further enhanced the predictive value of CURB-65.

Albumin, the predominant protein in plasma, plays essential roles in several physiological processes. These include maintaining plasma colloid osmotic pressure, providing antioxidation and anticoagulation benefits, regulating immune functions, and preserving the integrity of vascular walls [12, 13]. Low serum albumin levels in patients with CAP are associated with a poor prognosis [14]. Similarly, lymphocyte count serves as a key marker of cellular immunity. A decrease in lymphocytes, primarily due to increased adhesion, redistribution, and accelerated apoptosis, is indicative of weakened immune responses [15]. Lymphopenia is observed in many patients with CAP who have a poor prognosis [16, 17]. Given the complexity of CAP's clinical course, which is influenced by multiple factors, relying on a single predictive indicator often falls short in accurately forecasting clinical outcomes. The PNI addresses this limitation by offering a comprehensive reflection of both the nutritional status and immune function of the body, enhancing the ability to predict the prognosis in CAP patients effectively.

The association between the PNI and mortality in CAP patients is multifaceted and profound. Malnutrition, as indicated by a low PNI, impairs immune function,

Table 3 Cox proportional hazard ratios (HRs) for all-cause mortality

Categories	Model1			Model2			Model3		
	HR (95% CI)	*P* value	*P* for trend	HR (95% CI)	*P* value	*P* for trend	HR (95% CI)	*P* value	*P* for trend
30-day mortality									
Continuous	0.91 (0.89–0.92)	< 0.001		0.92 (0.91–0.94)	< 0.001		0.93 (0.91–0.94)	< 0.001	
Quartile			< 0.001			< 0.001			< 0.001
Q1	1.00 (Reference)			1.00 (Reference)			1.00 (Reference)		
Q2	0.46 (0.37–0.57)	< 0.001		0.49 (0.39–0.61)	< 0.001		0.51 (0.41–0.64)	< 0.001	
Q3	0.34 (0.27–0.43)	< 0.001		0.41 (0.32–0.52)	< 0.001		0.43 (0.34–0.56)	< 0.001	
Q4	0.21 (0.16–0.28)	< 0.001		0.27 (0.20–0.36)	< 0.001		0.29 (0.22–0.40)	< 0.001	
90-day mortality									
Continuous	0.92 (0.91–0.93)	< 0.001		0.93 (0.92–0.94)	< 0.001		0.94 (0.92–0.95)	< 0.001	
Quartile			< 0.001			< 0.001			< 0.001
Q1	1.00 (Reference)			1.00 (Reference)			1.00 (Reference)		
Q2	0.53 (0.43–0.64)	< 0.001		0.55 (0.45–0.67)	< 0.001		0.58 (0.47–0.71)	< 0.001	
Q3	0.41(0.33–0.50)	< 0.001		0.48 (0.38–0.59)	< 0.001		0.51 (0.41–0.64)	< 0.001	
Q4	0.27 (0.21–0.34)	< 0.001		0.33 (0.26–0.42)	< 0.001		0.36 (0.28–0.47)	< 0.001	

Model 1: unadjusted

Model 2: adjusted for age, renal disease, malignant cancer, CURB-65, SOFA

Model 3: adjusted for age, MBP, renal disease, malignant cancer, CURB-65, SOFA, RDW, Hemoglobin, WBC, BUN, creatinine, INR, PT, blood culture positive, vasoactive agent, mechanical ventilation

Abbreviations: MBP, mean blood pressure; SpO2, blood oxygen saturation; SOFA, Sepsis-Related Organ Failure Assessment Score; RDW, red blood cell distribution width; WBC, white blood cells; BUN, blood urea nitrogen; INR, international normalized ratio; PT, prothrombin time

making patients more susceptible to severe infections and sepsis [18]. Additionally, malnourished patients often exhibit poorer wound healing and muscle wasting, leading to prolonged hospital stays and increased complications [19]. The systemic inflammation and metabolic stress associated with CAP further exacerbate the nutritional deficiencies, creating a vicious cycle that compromises recovery. Moreover, low PNI is associated with higher rates of comorbid conditions such as malignant cancer and renal dysfunction, which independently elevate mortality risk [20, 21].

Several prior investigations have explored the prognostic significance of the PNI in individuals diagnosed with CAP. For instance, Lisa et al. conducted a retrospective analysis involving 204 adult patients diagnosed with community-acquired bacterial pneumonia (CABP), revealing a notable negative correlation between PNI and mortality [22]. However, their study primarily focused on general hospital admissions without distinguishing the unique challenges faced by critically ill patients admitted to ICU, where our study is centered. In contrast to Lisa et al., our study specifically examines the prognostic value of PNI in a high-risk subgroup—ICU-admitted patients with CAP. This focus is crucial as these patients generally exhibit higher acuity and complexity in their clinical management, making the predictive accuracy of PNI particularly valuable for critical decision-making processes. Our findings demonstrate a significant negative correlation between PNI and all-cause mortality exclusively in this subgroup, underscoring the potential of PNI as a critical tool in managing severe CAP cases. Additionally, other studies, such as those among peritoneal dialysis patients, have highlighted the relationship between PNI and new pneumonia cases but did not delve into mortality or the specific prognosis of pneumonia [23]. Furthermore, extensive research on PNI and its relation to COVID-19 prognosis has been reported [24, 25], yet these studies broadly address respiratory illnesses without zeroing in on the unique ICU setting for CAP patients. Moreover, a study by Shimoyama et al. involved only 33 patients and found no significant difference in PNI between deceased and surviving pneumonia patients, suggesting that their small sample size may have been a limiting factor [26]. Our study addresses this limitation by involving a larger cohort of 1,608 ICU-admitted patients, providing more robust statistical power to validate PNI's prognostic value.

CURB-65 is a widely used clinical prediction rule that assesses the severity of CAP and helps guide decisions regarding hospitalization and treatment [27]. Despite its clinical utility, CURB-65 has limitations. It primarily focuses on clinical parameters and does not account for the patient's nutritional and immunological status, which are critical factors influencing outcomes in CAP. This is where the PNI can complement CURB-65. Our findings indicate that PNI has a superior predictive value for both 30-day and 90-day mortality in CAP patients compared to CURB-65. Specifically, PNI demonstrated an AUC of 0.71 for 30-day mortality and 0.68 for 90-day mortality, while CURB-65 had AUCs of 0.63 for both time points. The combined use of PNI and CURB-65 resulted in an improvement in predictive accuracy, with an AUC of 0.68

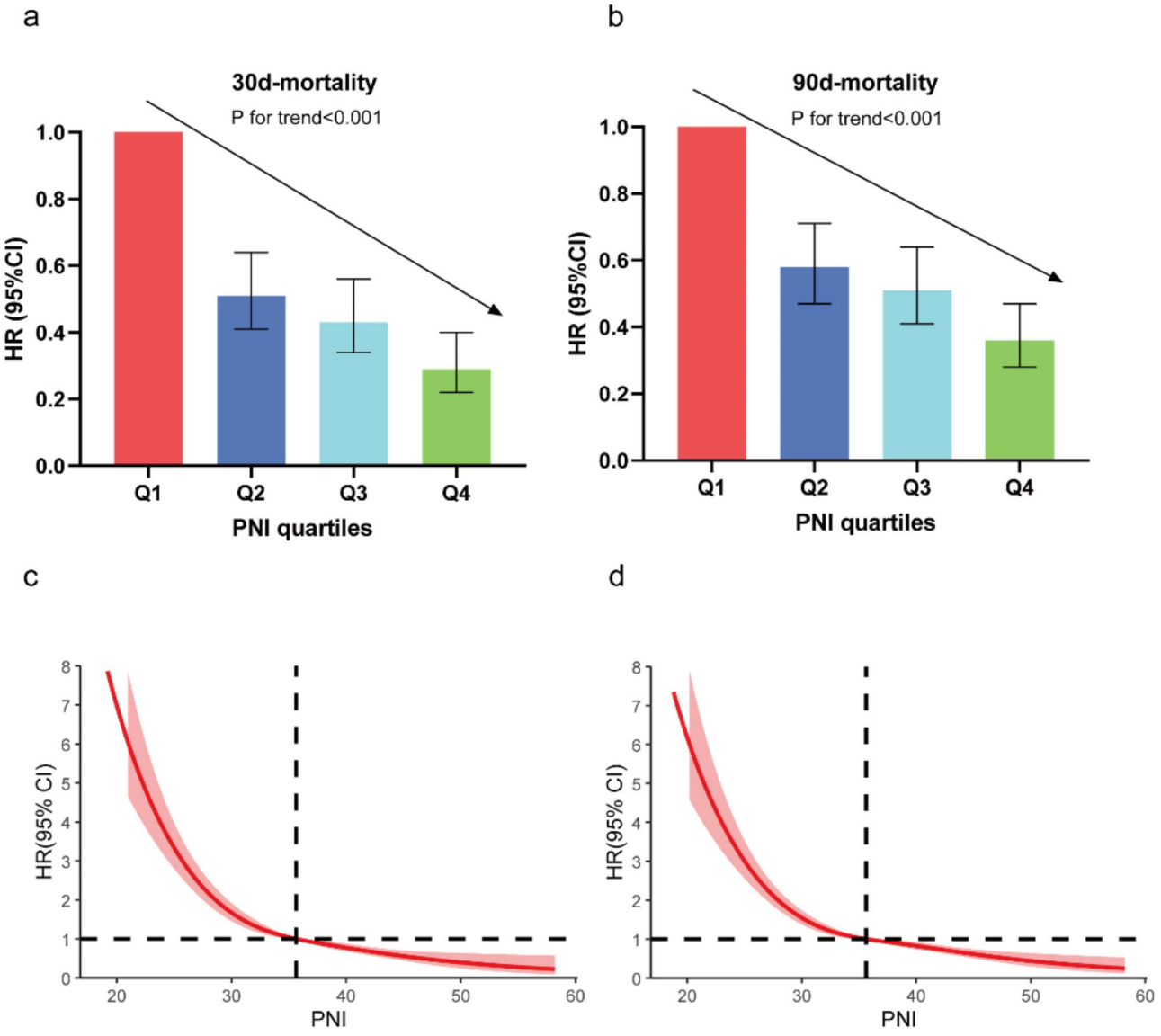

Fig. 3 HR (95% CI) for all-cause mortality according to PNI quartiles after adjusted for age, MBP, renal disease, malignant cancer, CURB-65, SOFA, RDW, hemoglobin, WBC, BUN, creatinine, INR, PT, blood culture positive, vasoactive agent, mechanical ventilation. The Q1 is the reference. (**a**) HR (95% CI) for 30d-mortality according to PNI quartiles. (**b**) HR (95% CI) for 90d-mortality according to PNI quartiles. RCS curve of PNI with all-cause mortality. (**c**) RCS curve for 30-day mortality. (**d**) RCS curve for 90-day mortality. MBP, mean blood pressure; SpO2, blood oxygen saturation; SOFA, Sepsis-Related Organ Failure Assessment Score; RDW, red blood cell distribution width; WBC, white blood cells; BUN, blood urea nitrogen; INR, international normalized ratio; PT, prothrombin time

for 30-day mortality and 0.67 for 90-day mortality. These findings suggest that integrating PNI with CURB-65 can enhance its predictive value. PNI captures the nutritional and immunological status of patients, which are critical factors in the body's response to infection and overall prognosis. The slight improvement in predictive accuracy when combining PNI with CURB-65 underscores the multifaceted nature of mortality risk in CAP patients. While CURB-65 effectively captures clinical severity, PNI adds an additional dimension by accounting for the patient's nutritional and immunological resilience. This holistic approach to risk stratification may better identify high-risk patients who could benefit from more intensive monitoring and therapeutic interventions.

The subgroup analysis confirms the PNI as a stable and robust predictor of both 30-day and 90-day mortality across varied patient demographics and clinical conditions in CAP. However, significant interactions observed in the age subgroup for 90-day mortality ($P=0.03$) warrant further explanation. Patients under 65 years old had an HR of 0.92 (95% CI: 0.90–0.94) for 90-day mortality, whereas those aged 65 years and older had an HR of 0.95

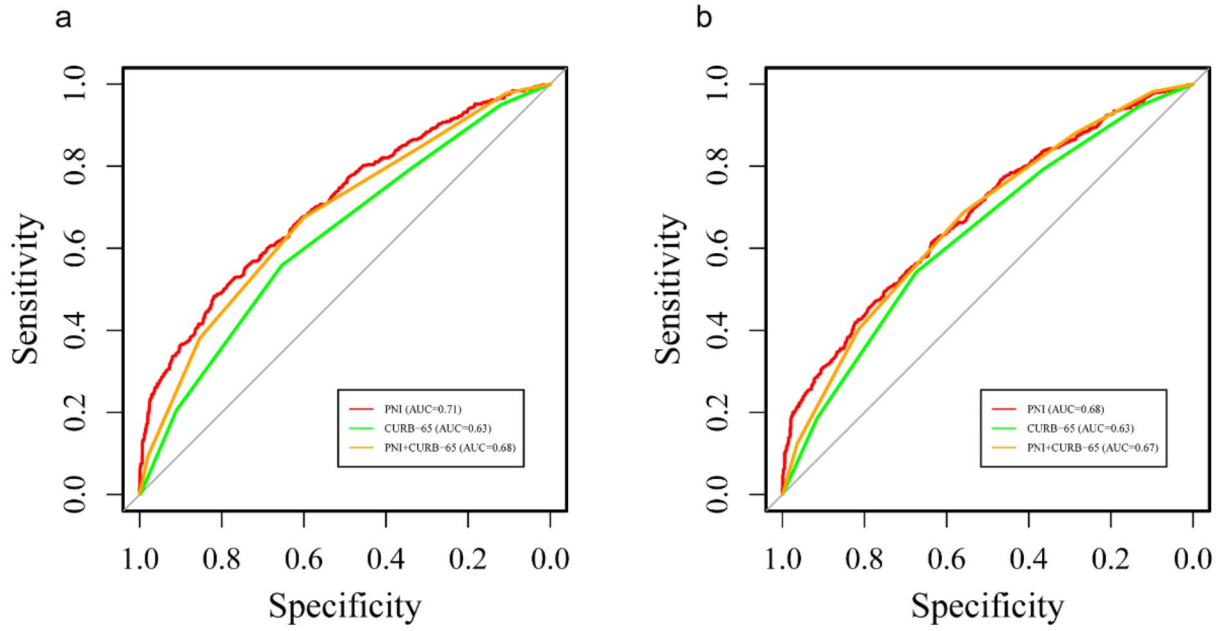

Fig. 4 ROC curves for predicting all-cause mortality. (**a**) ROC curve of PNI, CURB-65, and their combination for predicting 30-day mortality. (**b**) ROC curve of PNI, CURB-65, and their combination for predicting 90-day mortality

Table 4 Prognostic accuracy of the PNI and CURB-65

Prognostic marker	Cut-off	Sensitivity	Specificity	PPV	NPV	AUC(95%CI)
30-day mortality						
PNI	31.55	0.48	0.82	0.54	0.78	0.71 (0.68–0.74)
CURB-65	3	0.56	0.65	0.42	0.77	0.63 (0.60–0.66)
PNI < 31.55 plus CURB-65	< 31.55 plus 3	0.68	0.60	0.43	0.81	0.68 (0.65–0.71)
90-day mortality						
PNI	34.85	0.61	0.64	0.53	0.71	0.68 (0.65–0.71)
CURB-65	3	0.54	0.67	0.53	0.69	0.63 (0.61–0.66)
PNI < 34.85 plus CURB-65	< 34.85 plus 3	0.69	0.56	0.51	0.73	0.67 (0.64–0.69)

Abbreviations: PPV, positive predictive value; NPV, negative predictive value; AUC, area under the curve

(95% CI: 0.93–0.96). This disparity likely arises from several factors. Younger patients typically possess greater physiological resilience, fewer comorbidities, and a more robust immune response, which contribute to their lower HR for 90-day mortality. Conversely, older patients are more likely to have multiple comorbidities, diminished immune function due to immunosenescence, and experience nutritional and functional decline, all of which elevate their risk of mortality. Additionally, frailty and reduced recovery potential further exacerbate this risk in the elderly [28].

Patients with CAP who present with low PNI scores upon admission to the ICU represent a particularly vulnerable subgroup, likely to experience worse outcomes. For these patients, a proactive, multidisciplinary approach is crucial. Initial management should focus on aggressive respiratory support and stabilization of hemodynamics. Early high nutritional support has been shown to improve outcomes for critically ill patients [29], emphasizing the importance of nutritional interventions which should be prioritized early. This may include the administration of high-protein diets or supplements to improve immune function and overall nutritional status. Regular monitoring of nutritional markers and adjustments to nutritional support should be guided by repeated PNI assessments throughout the ICU stay. Additionally, these patients might benefit from early and aggressive infection control strategies, including timely antibiotic administration and careful monitoring for signs of sepsis or other complications. By tailoring interventions to address the specific risks associated with low PNI, healthcare providers can potentially mitigate the heightened risk of adverse outcomes and improve the overall prognosis for these patients.

However, several limitations must be acknowledged. Firstly, this study was conducted retrospectively, potentially introducing biases and limitations inherent to observational research. Secondly, key inflammatory

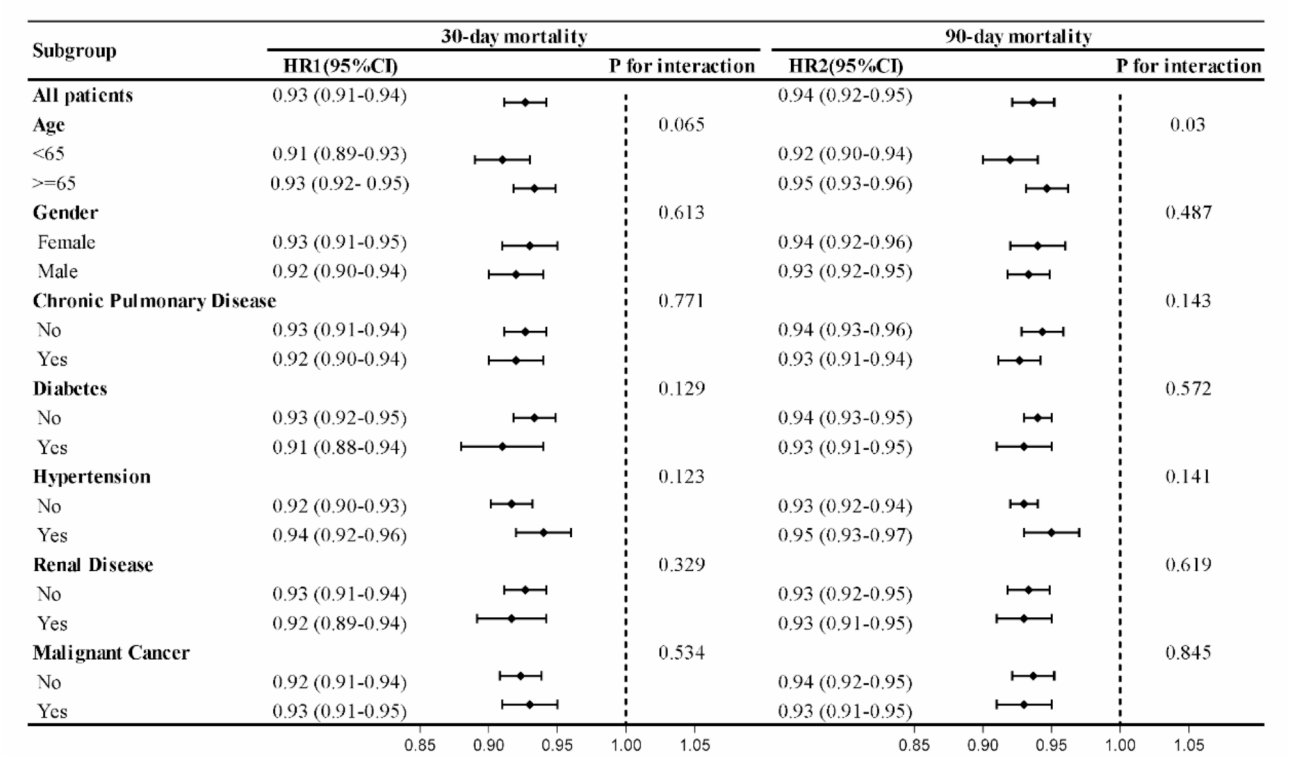

Fig. 5 Forest plot of HRs for the 30-day and 90-day mortality in different subgroups. HRs adjusted for adjusted for age, MBP, renal disease, malignant cancer, CURB-65, SOFA, RDW, Hemoglobin, WBC, BUN, creatinine, INR, PT, blood culture positive, vasoactive agent, mechanical ventilation. MBP, mean blood pressure; SpO2, blood oxygen saturation; SOFA, Sepsis-Related Organ Failure Assessment Score; RDW, red blood cell distribution width; WBC, white blood cells; BUN, blood urea nitrogen; INR, international normalized ratio; PT, prothrombin time

markers, such as C-reactive protein (CRP), interleukin-6 (IL-6), and procalcitonin (PCT), were unavailable, limiting our ability to comprehensively assess the inflammatory and immune status of patients. Thirdly, despite using multiple imputation to address missing values, this limitation remains significant, as imputation cannot fully replace actual data. Finally, specific details regarding nutritional intervention measures were not accounted for, which could influence the interpretation of the PNI's impact on patient outcomes. Future multi-center prospective studies with comprehensive evaluations and detailed treatment assessments are essential to validate our findings and understand the mechanisms linking PNI to mortality in CAP patients.

In conclusion, our study identified a significant negative correlation between the PNI and all-cause mortality in patients with CAP. The PNI shows promise as a predictor of mortality risk in this cohort. However, to confirm these findings, further validation through prospective, large-scale, multi-center studies is essential.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12890-024-03373-3.

Supplementary Material 1

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Author contributions
GW drafted the manuscript and retrieved data from the database (certification number: 60106105). NW, TL, and WJ conducted data preprocessing and statistical analysis. WJ and JS provided manuscript revisions. LL, XY, XC, and ML created all figures for the study. ZS and TH contributed to the study design, critically reviewed, and edited the manuscript. All authors reviewed the manuscript.

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Data availability
The data that support the findings of this study are available from MIMIC-IV. Access to the database can be obtained through PhysioNet at https://mimic.mit.edu/. Researchers wishing to access the MIMIC-IV database must complete the required training and agree to the data use agreement available on the PhysioNet website.

Declarations

Ethics approval and consent to participate
The MIMIC-IV database complies with the principles of the Helsinki Declaration. This database was approved by the Institutional Review Board (IRB) of the Beth Israel Deaconess Medical Center (2001P-001699/14). The IRB assessed the collection of patient data and the development of the research

resource, authorized the data-sharing project, and waived the requirement for informed consent.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

Clinical trial number
Not applicable.

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