

RESEARCH

Open Access



Development and validation of a survival prediction model in elder patients with community-acquired pneumonia: a MIMIC-population-based study

Na Li¹ and Wenli Chu^{2*}

Abstract

Background To develop a prediction model predicting in-hospital mortality of elder patients with community-acquired pneumonia (CAP) admitted to the intensive care unit (ICU).

Methods In this cohort study, data of 619 patients with CAP aged ≥ 65 years were obtained from the Medical Information Mart for Intensive Care III (MIMIC III) 2001–2012 database. To establish the robustness of predictor variables, the sample dataset was randomly partitioned into a training set group and a testing set group (ratio: 6.5:3.5). The predictive factors were evaluated using multivariable logistic regression, and then a prediction model was constructed. The prediction model was compared with the widely used assessments: Sequential Organ Failure Assessment (SOFA), Pneumonia Severity Index (PSI), systolic blood pressure, oxygenation, age and respiratory rate (SOAR), CURB-65 scores using positive predictive value (PPV), negative predictive value (NPV), accuracy (ACC), area under the curve (AUC) and 95% confidence interval (CI). The decision curve analysis (DCA) was used to assess the net benefit of the prediction model. Subgroup analysis based on the pathogen was developed.

Results Among 402 patients in the training set, 90 (24.63%) elderly CAP patients suffered from 30-day in-hospital mortality, with the median follow-up being 8 days. Hemoglobin/platelets ratio, age, respiratory rate, international normalized ratio, ventilation use, vasopressor use, red cell distribution width/blood urea nitrogen ratio, and Glasgow coma scales were identified as the predictive factors that affect the 30-day in-hospital mortality. The AUC values of the prediction model, the SOFA, SOAR, PSI and CURB-65 scores, were 0.751 (95% CI 0.749–0.752), 0.672 (95% CI 0.670–0.674), 0.607 (95% CI 0.605–0.609), 0.538 (95% CI 0.536–0.540), and 0.645 (95% CI 0.643–0.646), respectively. DCA result demonstrated that the prediction model could provide greater clinical net benefits to CAP patients admitted to the ICU. Concerning the pathogen, the prediction model also reported better predictive performance.

Conclusion Our prediction model could predict the 30-day hospital mortality in elder patients with CAP and guide clinicians to identify the high-risk population.

Keywords Survival prediction model, Elder patients, Community-acquired pneumonia, MIMIC

*Correspondence:

Wenli Chu

chuwenlishanxi@outlook.com

¹ Department of Clinical Medicine, College of Medicine, Pingdingshan University, Pingdingshan 467000, People's Republic of China

² Department of Respiratory and Critical Care Medicine, The Second Affiliated Hospital of Xi'an Medical College, No. 167 Fangdong Street,

Baqiao District, Xi'an 710038, People's Republic of China



© The Author(s) 2023. **Open Access** This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit <http://creativecommons.org/licenses/by/4.0/>. The Creative Commons Public Domain Dedication waiver (<http://creativecommons.org/publicdomain/zero/1.0/>) applies to the data made available in this article, unless otherwise stated in a credit line to the data.

Introduction

Community-acquired pneumonia (CAP), defined as pneumonia acquired outside the hospital, is one of the most common infectious diseases in clinical practice [1, 2]. The incidence of pneumonia increases with age, with a 10 times higher hospitalization rate in patients aged 65 years and older (about 2000 per 100,000 per year) than in the younger population [3, 4]. CAP remains a common cause of intensive care unit (ICU) admissions and in-hospital mortality in the elderly [5, 6]. Approximately 75% of CAP patients require hospitalization, up to 10% of them need to be admitted to the ICU, and the in-hospital mortality from 4 to 20.9% in these patients, which poses a huge burden on families and society [7, 8]. Therefore, early identification of elderly CAP patients with high in-hospital mortality is crucial to timely and effective intervention for prognosis improvement.

Several pneumonia severity scores include the Sequential Organ Failure Assessment (SOFA), Pneumonia Severity Index (PSI), CURB-65, and systolic blood pressure, oxygenation, age and respiratory rate (SOAR) have been developed and used to predict outcomes in patients with CAP [9–11]. These scores are useful in the management of patient risk stratification, but there is still a lack of accurate assessment with regard to patient mortality [12]. Moreover, a common limitation of the above score systems is that a lot of variables cannot be obtained within the first 24 h after admission [13]. In addition to the scoring methods, in recent years, many blood biomarkers have been shown to play crucial roles in the early diagnosis and prognosis of pneumonia, including CAP [14, 15]. Serum albumin (ALB) level was reported to be associated with in-hospital mortality in patients with CAP [12]. The value of the red cell distribution width (RDW) has also been found in predicting the prognosis in critically ill patients [15]. A study demonstrated that the ALB-RDW score is the independent factor of 90-day mortality in patients with severe CAP [16]. Another study indicated neutrophil to lymphocyte (NLR) ratio was a promising candidate predictor of unfavorable outcomes in CAP patients [17]. However, there is a lack of research establishing prediction models to predict in-hospital mortality in CAP patients based on these biomarkers. Therefore, it is necessary to incorporate these biomarkers and develop new prediction models to achieve early assessment of in-hospital mortality risk in elderly CAP patients and guide clinical decision-making.

Herein, this study aimed to conduct a prediction model to predict the in-hospital mortality in elderly CAP patients and to compare the predictive value of the prediction model with SOFA, PSI, SOAR, and CURB-65 scoring system. We developed a simpler prediction

model that may be beneficial to the decrease of in-hospital mortality in elder patients with CAP.

Methods

Study design and population

This study was a retrospective cohort study, and all data were obtained from the Medical Information Mart for Intensive Care III (MIMIC-III) 2001–2012. The MIMIC-III is a large, single-center, freely available database, which contained the comprehensive and high-quality medical records of 50,000 patients admitted to ICU at the Beth Israel Deaconess Medical Center between 2001 and 2012 [18]. Study inclusion criteria were (1) aged ≥ 65 years old; (2) population diagnosed with CAP at the time of admission to ICU. The exclusion criteria of this study were as follows: (1) the number of predictive factors that were not recorded during the first 24 h of the ICU stay exceeds 30% of the total number of predictive factors. Since the clinical data in this study were collected from a publicly available database, there were no local or state ethical issues.

Data collection

All the patients were inquired the clinical data, including (1) baseline characteristics: age (years), gender, marital status, ethnicity; (2) vital signs: heart rate (times/min), respiratory rate (breaths/min), temperature ($^{\circ}\text{C}$), systolic blood pressure (SBP, mmHg), diastolic blood pressure (DBP, mmHg), mean arterial pressure (MAP, mmHg); (3) comorbidities: liver cirrhosis, congestive heart-failure (CHF), renal failure, chronic obstructive pulmonary disease (COPD), septic shock, effusion, emphysema, lung cancer, heart disease, diabetes mellitus (DM), respiratory failure, atrial fibrillation (AF), hyperlipidemia, malignant cancer; (4) scoring systems: SOFA score, Simplified Acute Physiology Score (SAPSII), SOAR score, PSI, CURB-65 score, Glasgow coma scales (GCS), International normalized ratio (INR), Elixhauser comorbidity score; (5) laboratory parameters: red blood cell (RBC, m/uL), white blood cells (WBC, K/uL), mean corpuscular volume (MCV, μm^3), blood urea nitrogen (BUN), sodium (mEq/L), haematocrit, potassium (mEq/L), phosphate (mg/dL), calcium (mg/dL), magnesium (mg/dL), lactate (mmol/L), creatine kinase (IU/L), arterial pH, oxygen saturation (SpO_2 , %), partial carbon dioxide pressure (PCO_2), partial oxygen pressure (PO_2), fraction of inspired oxygen (FiO_2); (6) pathogen: *Streptococcus pneumoniae*, *Klebsiella pneumoniae*, *Legionella pneumophila*, other *Streptococcus*, *Staphylococcus*, *E. coli*, *Candida*, *Acinetobacter*, *Clostridium*, *Citrobacter*, *Enterococcus*, *Pneumocystis pneumonia* (PCP), other bacteria, virus, fungus, yeast; (7) treatments: invasive ventilation, ventilation, vasopressor; (8) inflammatory biomarker:

NLR, platelet–lymphocyte ratio (PLR), prognostic nutritional index (PNI), anion gap, hemoglobin/platelets ratio (HPR), RDW/BUN ratio, absolute neutrophil count/(white blood cell count–neutrophil count) (dNLR), BUN/ALB ratio, platelet count*(lymphocytes/neutrophil) (SII). Blood tests, pathogen detections, and scoring systems were performed on the first day after admission.

Variable definitions and outcome

CAP was defined as evidence of a pulmonary infiltrate on the chest radiograph and symptoms of lower respiratory infection, including cough, dyspnea, fever, and/or pleuritic chest pain, which were not acquired in a hospital or a nursing home.

PNI referred to $10 \times \text{ALB (g/dL)} + 0.005 \times \text{lymphocytes count}$. SOFA score uses $\text{SBP} \leq 100 \text{ mmHg}$, respiratory rate $\geq 22/\text{min}$, and altered cognitive state to identify high risk patients. The SOAR score identifies severe CAP using the following criteria (definitions of variables for data extraction are also listed below): $\text{SBP} < 90 \text{ mmHg}$, $\text{PaO}_2/\text{FiO}_2 \text{ ratio} < 250$, $\text{age} \geq 65$, and respiratory rate $\geq 30 \text{ breaths/min}$. The CURB-65 index identifies high risk patients using the following criteria (definitions of variables for data extraction are also listed below): confusion, $\text{BUN} \geq 20 \text{ mg/dl}$, respiratory rate $\geq 30 \text{ breaths/min}$, $\text{SBP} < 90 \text{ mmHg}$ or $\text{DBP} \leq 60 \text{ mmHg}$, and $\text{age} \geq 65$.

The study outcome was the 30-day in-hospital mortality rate. When the patient died in the hospital, the follow-up period ended. The median follow-up was 8 days.

Statistics analysis

The t-test was used to evaluate the normally distributed data which was presented as mean \pm standard deviation (Mean \pm SD). Mann Whitney U test was used to evaluate the non-normally distributed variables and data were presented as median and quartile M (Q_1 , Q_3). Fisher's exact test was used to analyze the enumeration data and data were described as the number of cases and constituent ratio N (%). Multiple imputation was performed by "mice" R package for missing values. Sensitivity analysis was performed by comparing the data before and after imputation.

To establish the robustness of predictor variables, the sample dataset was randomly partitioned into the training set group and the testing set group (ratio: 6.5:3.5). $P < 0.05$ was considered statistically significant. To determine the predictive factors, variables achieving a significance level were selected for multivariable Logistic analysis and other variables that are significant in other studies were included. Then stepwise regression was performed to construct the final prediction model. The performance of the prediction model was evaluated by the Hosmer–Lemeshow (H–L) goodness-of-fit

test, using positive predictive value (PPV), negative predictive value (NPV), accuracy (ACC), area under the curve (AUC), and 95% confidence interval (CI). To compare the performance of our prediction model with the SOFA, PSI, SOAR, and CURB-65, the DeLong test was applied. In addition, the decision curve analysis (DCA) was used to assess the net benefit of the prediction model and SOFA, PSI, SOAR, CURB-65. The total population was divided into subgroups to verify our prediction model.

Multiple imputation, DCA curve, and Logistic regression were performed using R Software (version 4.0.3; The R Project for Statistical Computing, TX, USA). ROC curves and prediction results were completed using Python 3.8. All remaining analyses were performed using SAS software (version 9.4; SAS Institute Inc., Cary, NC, USA).

Results

Characteristics of the included patients

In total, 619 patients with CAP aged over 65 years were included in this study, with 217 patients in the testing set and 402 patients in the training set. The median follow-up was 8 days. The flow chart of the participants' selection is shown in Fig. 1. The characteristics of the included patients between the testing set and the training set groups are described in Table 1. Among 402 patients in the training set, 90 (24.63%) elderly CAP patients suffered from 30-day in-hospital mortality; 41.41% (41 of 99) of the patients were male, while 58.59% (58 of 99) were women. The baseline and clinical characteristics between in-hospital mortality and non-in-hospital mortality are present in Table 2.

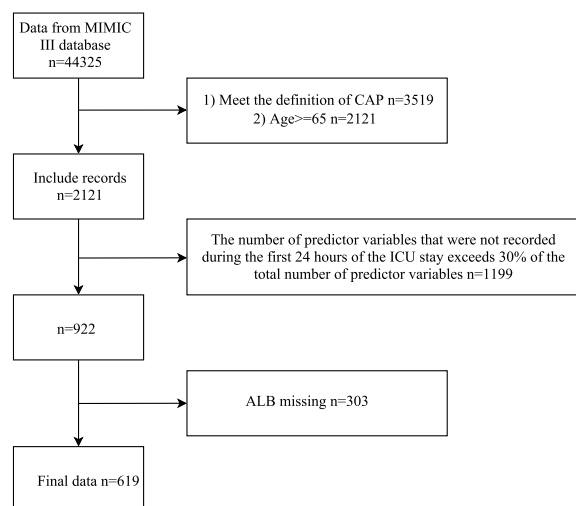


Fig. 1 Flow chart of the participants selection

Table 1 Characteristics of the included patients between the testing set and the training set groups

Variables	Total (n = 619)	Testing set (n = 217)	Training set (n = 402)	Statistics	P
Age, years, Mean ± SD	78.44 ± 7.76	78.97 ± 7.47	78.16 ± 7.91	t = 1.24	0.217
Gender, n (%)				$\chi^2 = 1.105$	0.293
Female	296 (47.82)	110 (50.69)	186 (46.27)		
Male	323 (52.18)	107 (49.31)	216 (53.73)		
Marital status, n (%)				$\chi^2 = 1.536$	0.820
Divorced	34 (5.49)	15 (6.91)	19 (4.73)		
Married	298 (48.14)	105 (48.39)	193 (48.01)		
Separated	3 (0.48)	1 (0.46)	2 (0.50)		
Single	111 (17.93)	39 (17.97)	72 (17.91)		
Widowed	173 (27.95)	57 (26.27)	116 (28.86)		
Ethnicity, n (%)				$\chi^2 = 7.042$	0.134
Asian	29 (4.68)	12 (5.53)	17 (4.23)		
Black	62 (10.02)	19 (8.76)	43 (10.70)		
Hispanic	15 (2.42)	7 (3.23)	8 (1.99)		
Other	14 (2.26)	9 (4.15)	5 (1.24)		
White	499 (80.61)	170 (78.34)	329 (81.84)		
Respiratory rate, times/min, Mean ± SD	22.61 ± 6.94	22.41 ± 7.13	22.71 ± 6.84	t = -0.52	0.606
Temperature, °C, Mean ± SD	36.80 ± 1.00	36.79 ± 0.99	36.80 ± 1.01	t = -0.19	0.850
Heart rate, beats/min, Mean ± SD	95.65 ± 20.71	93.55 ± 20.03	96.79 ± 21.01	t = -1.86	0.064
SBP, mmHg, Mean ± SD	121.75 ± 24.48	120.47 ± 26.35	122.45 ± 23.42	t = -0.93	0.353
DBP, mmHg, Mean ± SD	61.67 ± 17.38	60.40 ± 17.73	62.36 ± 17.17	t = -1.34	0.181
MAP, mmHg, M (Q ₁ , Q ₃)	76.00 (67.00, 88.00)	74.00 (65.00, 88.00)	77.00 (67.67, 88.00)	Z = -1.035	0.301
SpO ₂ , % Mean ± SD	95.85 ± 6.33	95.69 ± 7.55	95.94 ± 5.57	t = -0.43	0.666
WBC, K/UI, M (Q ₁ , Q ₃)	12.30 (8.70, 17.50)	12.90 (8.80, 18.30)	12.00 (8.50, 17.10)	Z = 1.510	0.131
RBC, m/uL, Mean ± SD	3.84 ± 0.72	3.79 ± 0.73	3.87 ± 0.71	t = -1.17	0.243
Sodium, mEq/L, Mean ± SD	138.02 ± 6.19	137.95 ± 6.49	138.05 ± 6.03	t = -0.19	0.851
Potassium, mEq/L, Mean ± SD	4.52 ± 0.89	4.54 ± 0.83	4.51 ± 0.93	t = 0.39	0.700
Phosphate, mg/dL, M (Q ₁ , Q ₃)	3.50 (2.90, 4.30)	3.50 (3.00, 4.50)	3.40 (2.80, 4.20)	Z = 1.840	0.066
Calcium, mg/dL, Mean ± SD	8.46 ± 0.91	8.53 ± 0.83	8.42 ± 0.95	t = 1.46	0.144
pH, Mean ± SD	7.36 ± 0.11	7.36 ± 0.11	7.37 ± 0.11	t = -1.07	0.286
Lactate, mmol/L, M (Q ₁ , Q ₃)	2.00 (1.50, 2.90)	1.90 (1.40, 2.90)	2.00 (1.50, 2.90)	Z = -0.634	0.526
INR, M (Q ₁ , Q ₃)	1.20 (1.10, 1.60)	1.20 (1.10, 1.60)	1.30 (1.10, 1.60)	Z = -0.195	0.845
MCV, μm^3 , Mean ± SD	91.10 ± 7.26	91.26 ± 7.64	91.01 ± 7.05	t = 0.41	0.680
magnesium, mg/dL, Mean ± SD	1.94 ± 0.39	1.96 ± 0.42	1.93 ± 0.37	t = 1.09	0.274
BUN, mg/dL, M (Q ₁ , Q ₃)	29.00 (20.00, 43.00)	29.00 (20.00, 46.00)	29.00 (20.00, 43.00)	Z = 0.464	0.643
Creatine kinase, IU/L, M (Q ₁ , Q ₃)	76.00 (38.00, 161.00)	63.00 (34.00, 137.00)	80.50 (40.00, 181.00)	Z = -2.829	0.005
Hematocrit, %, Mean ± SD	34.79 ± 6.13	34.40 ± 6.12	35.00 ± 6.14	t = -1.16	0.244
PO ₂ , M (Q ₁ , Q ₃)	84.00 (63.00, 133.00)	81.00 (62.00, 135.00)	85.50 (63.00, 129.00)	Z = -0.492	0.623
Hemoglobin, g/dL, Mean ± SD	11.45 ± 2.07	11.30 ± 2.05	11.54 ± 2.08	t = -1.38	0.169
PCO ₂ , M (Q ₁ , Q ₃)	42.00 (35.00, 52.00)	43.00 (35.00, 54.00)	42.00 (34.00, 51.00)	Z = 0.699	0.485
RDW, %, Mean ± SD	15.47 ± 2.19	15.55 ± 2.24	15.43 ± 2.16	t = 0.64	0.520
COPD, n (%)				$\chi^2 = 0.000$	0.987
No	479 (77.38)	168 (77.42)	311 (77.36)		
Yes	140 (22.62)	49 (22.58)	91 (22.64)		
Lung cancer, n (%)				$\chi^2 = 3.392$	0.066
No	592 (95.64)	212 (97.70)	380 (94.53)		
Yes	27 (4.36)	5 (2.30)	22 (5.47)		
AF, n (%)				$\chi^2 = 0.395$	0.530
No	350 (56.54)	119 (54.84)	231 (57.46)		

Table 1 (continued)

Variables	Total (n = 619)	Testing set (n = 217)	Training set (n = 402)	Statistics	P
Yes	269 (43.46)	98 (45.16)	171 (42.54)		
Liver cirrhosis, n (%)				$\chi^2 = 0.910$	0.340
No	604 (97.58)	210 (96.77)	394 (98.01)		
Yes	15 (2.42)	7 (3.23)	8 (1.99)		
CHF, n (%)				$\chi^2 = 0.149$	0.700
No	293 (47.33)	105 (48.39)	188 (46.77)		
Yes	326 (52.67)	112 (51.61)	214 (53.23)		
Heart disease, n (%)				$\chi^2 = 2.605$	0.107
No	514 (83.04)	173 (79.72)	341 (84.83)		
Yes	105 (16.96)	44 (20.28)	61 (15.17)		
DM, n (%)				$\chi^2 = 0.001$	0.973
No	474 (76.58)	166 (76.50)	308 (76.62)		
Yes	145 (23.42)	51 (23.50)	94 (23.38)		
Respiratory failure, n (%)				$\chi^2 = 0.801$	0.371
No	243 (39.26)	80 (36.87)	163 (40.55)		
Yes	376 (60.74)	137 (63.13)	239 (59.45)		
Hyperlipidemia, n (%)				$\chi^2 = 0.018$	0.893
No	393 (63.49)	137 (63.13)	256 (63.68)		
Yes	226 (36.51)	80 (36.87)	146 (36.32)		
Renal failure, n (%)				$\chi^2 = 0.110$	0.740
No	268 (43.30)	92 (42.40)	176 (43.78)		
Yes	351 (56.70)	125 (57.60)	226 (56.22)		
Malignant cancer, n (%)				$\chi^2 = 0.009$	0.926
No	395 (63.81)	139 (64.06)	256 (63.68)		
Yes	224 (36.19)	78 (35.94)	146 (36.32)		
SAPSI, Mean \pm SD	44.65 \pm 13.24	44.78 \pm 13.09	44.58 \pm 13.34	t = 0.18	0.859
SOFA, M (Q ₁ , Q ₃)	5.00 (3.00, 7.00)	5.00 (3.00, 7.00)	5.00 (3.00, 7.00)	Z = 1.165	0.244
Septic shock, n (%)				$\chi^2 = 0.492$	0.483
No	500 (80.78)	172 (79.26)	328 (81.59)		
Yes	119 (19.22)	45 (20.74)	74 (18.41)		
Ventilation, n (%)				$\chi^2 = 0.153$	0.696
No	269 (43.46)	92 (42.40)	177 (44.03)		
Yes	350 (56.54)	125 (57.60)	225 (55.97)		
Vesopressor, n (%)				$\chi^2 = 0.889$	0.346
No	583 (94.18)	207 (95.39)	376 (93.53)		
Yes	36 (5.82)	10 (4.61)	26 (6.47)		
<i>Streptococcus pneumoniae</i> , n (%)				$\chi^2 = 1.083$	0.298
No	597 (96.45)	207 (95.39)	390 (97.01)		
Yes	22 (3.55)	10 (4.61)	12 (2.99)		
<i>Klebsiella pneumoniae</i> , n (%)				$\chi^2 = 0.019$	0.891
No	583 (94.18)	204 (94.01)	379 (94.28)		
Yes	36 (5.82)	13 (5.99)	23 (5.72)		
Virus, n (%)				$\chi^2 = 1.020$	0.312
No	602 (97.25)	213 (98.16)	389 (96.77)		
Yes	17 (2.75)	4 (1.84)	13 (3.23)		
Emphysema, n (%)				$\chi^2 = 0.219$	0.640
No	593 (95.80)	209 (96.31)	384 (95.52)		
Yes	26 (4.20)	8 (3.69)	18 (4.48)		
Pneumothorax, n (%)				$\chi^2 = 0.008$	0.927

Table 1 (continued)

Variables	Total (n = 619)	Testing set (n = 217)	Training set (n = 402)	Statistics	P
No	608 (98.22)	213 (98.16)	395 (98.26)		
Yes	11 (1.78)	4 (1.84)	7 (1.74)		
Effusion, n (%)				$\chi^2 = 0.350$	0.554
No	544 (87.88)	193 (88.94)	351 (87.31)		
Yes	75 (12.12)	24 (11.06)	51 (12.69)		
Yeast, n (%)				$\chi^2 = 0.479$	0.489
No	414 (66.88)	149 (68.66)	265 (65.92)		
Yes	205 (33.12)	68 (31.34)	137 (34.08)		
Staphylococcus, n (%)				$\chi^2 = 1.446$	0.229
No	432 (69.79)	158 (72.81)	274 (68.16)		
Yes	187 (30.21)	59 (27.19)	128 (31.84)		
EColi, n (%)				$\chi^2 = 7.523$	0.006
No	583 (94.18)	212 (97.70)	371 (92.29)		
Yes	36 (5.82)	5 (2.30)	31 (7.71)		
Other bacteria, n (%)				$\chi^2 = 0.017$	0.895
No	447 (72.21)	156 (71.89)	291 (72.39)		
Yes	172 (27.79)	61 (28.11)	111 (27.61)		
Another streptococcus, n (%)				$\chi^2 = 0.831$	0.362
No	586 (94.67)	203 (93.55)	383 (95.27)		
Yes	33 (5.33)	14 (6.45)	19 (4.73)		
Candida, n (%)				$\chi^2 = 1.499$	0.221
No	587 (94.83)	209 (96.31)	378 (94.03)		
Yes	32 (5.17)	8 (3.69)	24 (5.97)		
Acinetobacter, n (%)				–	1.000
No	613 (99.03)	215 (99.08)	398 (99.00)		
Yes	6 (0.97)	2 (0.92)	4 (1.00)		
Clostridium, n (%)				$\chi^2 = 0.744$	0.388
No	596 (96.28)	207 (95.39)	389 (96.77)		
Yes	23 (3.72)	10 (4.61)	13 (3.23)		
Citrobacter, n (%)				–	1.000
No	617 (99.68)	216 (99.54)	401 (99.75)		
Yes	2 (0.32)	1 (0.46)	1 (0.25)		
Enterococcus, n (%)				$\chi^2 = 0.088$	0.767
No	562 (90.79)	196 (90.32)	366 (91.04)		
Yes	57 (9.21)	21 (9.68)	36 (8.96)		
PCP, n (%)				$\chi^2 = 1.730$	0.188
No	617 (99.68)	217 (100.00)	400 (99.50)		
Yes	2 (0.32)	0 (0.00)	2 (0.50)		
Fungus, n (%)				–	0.615
No	615 (99.35)	215 (99.08)	400 (99.50)		
Yes	4 (0.65)	2 (0.92)	2 (0.50)		
CURB-65, Mean \pm SD	2.55 \pm 0.81	2.60 \pm 0.82	2.52 \pm 0.80	t = 1.17	0.244
PSI, Mean \pm SD	136.63 \pm 27.27	136.91 \pm 28.73	136.48 \pm 26.49	t = 0.19	0.850
NLR, M (Q ₁ , Q ₃)	10.40 (5.99, 18.52)	10.71 (6.20, 17.40)	9.92 (5.97, 19.98)	Z = -0.037	0.971
PLR, M (Q ₁ , Q ₃)	2.78 (1.70, 4.61)	2.90 (1.77, 4.30)	2.75 (1.69, 4.74)	Z = 0.112	0.911
SOAR, M (Q ₁ , Q ₃)	2.00 (1.00, 2.00)	2.00 (1.00, 2.00)	2.00 (1.00, 2.00)	Z = -0.671	0.502
HPR, M (Q ₁ , Q ₃)	0.04 (0.03, 0.06)	0.04 (0.03, 0.06)	0.05 (0.03, 0.06)	Z = -2.377	0.017
Elixhauser comorbidity score, M (Q ₁ , Q ₃)	20.00 (12.00, 29.00)	21.00 (14.00, 29.00)	20.00 (12.00, 29.00)	Z = 0.767	0.443
PNI, Mean \pm SD	31.63 \pm 8.01	31.58 \pm 6.04	31.65 \pm 8.90	t = -0.13	0.899

Table 1 (continued)

Variables	Total (n = 619)	Testing set (n = 217)	Training set (n = 402)	Statistics	P
RDW/BUN ratio, Mean ± SD	5.29 ± 1.54	5.25 ± 1.45	5.32 ± 1.59	t = -0.50	0.619
dNLR, Mean ± SD	-1.01 ± 0.07	-1.01 ± 0.01	-1.01 ± 0.09	t = -0.15	0.885
BUN/ALB ratio, M (Q ₁ , Q ₃)	9.71 (6.28, 14.44)	10.00 (6.32, 14.62)	9.63 (6.21, 14.40)	Z = 0.392	0.695
ALB, Mean ± SD	3.07 ± 0.62	3.09 ± 0.60	3.06 ± 0.64	t = 0.61	0.545
Anion gap, Mean ± SD	63.03 ± 9.69	63.22 ± 10.35	62.93 ± 9.32	t = 0.36	0.721
ICU LOS, M (Q ₁ , Q ₃)	3.20 (1.73, 7.58)	3.13 (1.77, 7.58)	3.25 (1.72, 7.43)	Z = -0.409	0.682
In hospital mortality, n (%)				χ ² = 0.104	0.747
No	464 (74.96)	161 (74.19)	303 (75.37)		
Yes	155 (25.04)	56 (25.81)	99 (24.63)		

ICU, intensive care unit; LOS, length of stay; SBP, systolic blood pressure; DBP, diastolic blood pressure; MAP, mean arterial pressure; SpO₂, oxygen saturation; WBC, white blood cells; RBC, red blood cell; INR, International normalized ratio; MCV, mean corpuscular volume; BUN, blood urea nitrogen; PO₂, partial oxygen pressure; PCO₂, partial carbon dioxide pressure; COPD, chronic obstructive pulmonary disease; AF, atrial fibrillation; CHF, congestive heart-failure; DM, diabetes mellitus; SOFA, Sequential Organ Failure Assessment; SAPSII, Simplified Acute Physiology Score; PCP, Pneumocystis pneumonia; PSI, Pneumonia Severity Index; NLR, neutrophil to lymphocyte; PLR, platelet-lymphocyte ratio; SOAR, systolic blood pressure, oxygenation, age and respiratory rate; HPR, hemoglobin/platelets ratio; PNI, prognostic nutritional index; RDW, red cell distribution width; dNLR, absolute neutrophil count/(white blood cell count-neutrophil count); ALB, albumin

Identifications of the predictive factors for in-hospital mortality of elderly CAP patients

Factors achieving a significance level in the comparison of the in-hospital mortality and non-in-hospital mortality groups were septic shock ($P=0.003$), respiratory failure ($P=0.009$), respiratory rate ($P=0.027$), SOFA score ($P<0.001$), SAPSII score ($P<0.001$), SOAR ($P<0.001$), CURB-65 score ($P<0.001$), GCS ($P<0.001$), INR ($P=0.002$), other bacteria ($P=0.001$), yeast ($P=0.006$), MCV ($P=0.038$), RBC ($P=0.024$), phosphate ($P=0.013$), Ph ($P=0.009$), invasive ventilation ($P<0.001$), ventilation ($P<0.001$), vasopressor ($P<0.001$), PNI ($P=0.002$), RDW/BUN ratio ($P<0.001$), BUN/ALB ratio ($P=0.004$) (Table 2). The above significant variables were included in multivariate logistic regression, and the significant variables in other studies were added to the multivariate model, including HPR, age, gender, ethnicity, anion gap, and Elixhauser comorbidity score. Finally, HPR [risk ratio (RR): 1.429, 95% CI 1.030–1.985, $P>Chi$ -square: 0.033], age (RR: 1.017, 95% CI 0.984–1.05, $P>Chi$ -square: 0.325), respiratory rate (RR: 1.049, 95% CI 1.012–1.087, $P>Chi$ -square: 0.009), INR (RR: 1.363, 95% CI 1.077–1.724, $P>Chi$ -square: 0.010), ventilation (RR: 1.974, 95% CI 1.084–3.592, $P>Chi$ -square: 0.026), vesopressor (RR: 4.201, 95% CI 1.643–10.743, $P>Chi$ -square: 0.003), RDW/BUN (RR: 1.192, 95% CI 1.029–1.38, $P>Chi$ -square: 0.019), GCS (RR: 0.919, 95% CI 0.861–0.982, $P>Chi$ -square: 0.013) were the predictive factors for in-hospital mortality of elderly CAP patients. The predictive factors for in-hospital mortality of elderly CAP patients are shown in Table 3.

Prediction model construction and evaluations

Based on the predictive factors, the prediction model for predicting in-hospital mortality of elderly CAP patients was constructed. Table 3 shows the detailed information of our prediction model. The final prediction model is:

$$y = -4.83 + 0.36 * \text{HPR} + 0.016 * \text{age} + 0.05 * \text{respiratory rate} + 0.31 * \text{INR} + 0.68 * \text{ventilation (yes = 1, no = 0)} + 1.44 * \text{vasopressor (yes = 1, no = 0)} + 0.176 * \text{RDW/BUN} - 0.08 * \text{GCS}.$$

The chi-square and P values of the H–L goodness of fit of our model in the training set and testing set were $\chi^2=3.502$, $P=0.899$, $\chi^2=7.196$, $P=0.516$, respectively, indicating that our model showed good goodness-of-fit. In addition, in the training set, the PPV, NPV, AUC, and ACC of the prediction model were 0.529 (95% CI 0.433–0.626), 0.850 (95% CI 0.810–0.890), 0.751 (95% CI 0.749–0.752), 0.769 (95% CI 0.727–0.810), respectively. The results of the prediction model evaluation are described in Table 4. The DCA results indicated that the prediction model had a good ability for predicting in-hospital mortality of elderly CAP patients. DCA result of the prediction model is shown in Fig. 2.

For the external validation of the prediction model, the result showed that the AUC our prediction model was 0.703, higher than SOFA (AUC: 0.686), SOAR (0.564), PSI (0.613), and CURB-65 (0.570).

Comparison of the predictive performances between the prediction model and SOFA, SOAR, PSI, and CURB-65 scores

We calculated the AUC value of the prediction model and four other scoring systems as shown in Fig. 3. The

Table 2 Characteristics between in-hospital mortality and non-in-hospital mortality among elderly CAP patients

Variables	Total (n = 402)	In-hospital mortality		Statistics	P
		No (n = 303)	Yes (n = 99)		
Age, years, Mean \pm SD	78.16 \pm 7.91	77.94 \pm 7.92	78.82 \pm 7.87	t = -0.96	0.336
Gender, n (%)				$\chi^2 = 1.245$	0.264
Female	186 (46.27)	145 (47.85)	41 (41.41)		
Male	216 (53.73)	158 (52.15)	58 (58.59)		
Marital status, n (%)				Fisher	0.497
Divorced	19 (4.73)	17 (5.61)	2 (2.02)		
Married	193 (48.01)	143 (47.19)	50 (50.51)		
Separate	2 (0.50)	1 (0.33)	1 (1.01)		
Single	72 (17.91)	54 (17.82)	18 (18.18)		
Widowed	116 (28.86)	88 (29.04)	28 (28.28)		
Ethnicity, n (%)				$\chi^2 = 4.822$	0.306
Asian	17 (4.23)	12 (3.96)	5 (5.05)		
Black	43 (10.70)	32 (10.56)	11 (11.11)		
Hispanic	8 (1.99)	8 (2.64)	0 (0.00)		
Other	5 (1.24)	4 (1.32)	1 (1.01)		
White	329 (81.84)	247 (81.52)	82 (82.83)		
Liver cirrhosis, n (%)				$\chi^2 = 0.001$	0.980
No	394 (98.01)	297 (98.02)	97 (97.98)		
Yes	8 (1.99)	6 (1.98)	2 (2.02)		
CHF, n (%)				$\chi^2 = 1.750$	0.186
No	188 (46.77)	136 (44.88)	52 (52.53)		
Yes	214 (53.23)	167 (55.12)	47 (47.47)		
Renal failure, n (%)				$\chi^2 = 2.936$	0.087
No	176 (43.78)	140 (46.20)	36 (36.36)		
Yes	226 (56.22)	163 (53.80)	63 (63.64)		
COPD, n (%)				$\chi^2 = 2.240$	0.134
No	311 (77.36)	229 (75.58)	82 (82.83)		
Yes	91 (22.64)	74 (24.42)	17 (17.17)		
Septic shock, n (%)				$\chi^2 = 8.528$	0.003
No	328 (81.59)	257 (84.82)	71 (71.72)		
Yes	74 (18.41)	46 (15.18)	28 (28.28)		
Effusion, n (%)				$\chi^2 = 0.023$	0.878
No	351 (87.31)	265 (87.46)	86 (86.87)		
Yes	51 (12.69)	38 (12.54)	13 (13.13)		
Emphysema, n (%)				$\chi^2 = 0.698$	0.403
No	384 (95.52)	288 (95.05)	96 (96.97)		
Yes	18 (4.48)	15 (4.95)	3 (3.03)		
Pneumothorax, n (%)				$\chi^2 = 0.461$	0.497
No	395 (98.26)	297 (98.02)	98 (98.99)		
Yes	7 (1.74)	6 (1.98)	1 (1.01)		
Lung cancer, n (%)				$\chi^2 = 0.088$	0.767
No	380 (94.53)	287 (94.72)	93 (93.94)		
Yes	22 (5.47)	16 (5.28)	6 (6.06)		
Heart disease, n (%)				$\chi^2 = 0.426$	0.514
No	341 (84.83)	255 (84.16)	86 (86.87)		
Yes	61 (15.17)	48 (15.84)	13 (13.13)		
DM, n (%)				$\chi^2 = 3.823$	0.051
No	308 (76.62)	225 (74.26)	83 (83.84)		

Table 2 (continued)

Variables	Total (n = 402)	In-hospital mortality		Statistics	P
		No (n = 303)	Yes (n = 99)		
Respiratory failure, n (%)				$\chi^2 = 6.901$	0.009
Yes	94 (23.38)	78 (25.74)	16 (16.16)		
No	163 (40.55)	134 (44.22)	29 (29.29)		
Hyperlipidemia, n (%)				$\chi^2 = 2.803$	0.094
Yes	239 (59.45)	169 (55.78)	70 (70.71)		
No	256 (63.68)	186 (61.39)	70 (70.71)		
Malignant cancer, n (%)				$\chi^2 = 2.055$	0.152
Yes	146 (36.32)	117 (38.61)	29 (29.29)		
No	256 (63.68)	187 (61.72)	69 (69.70)		
AF, n (%)				$\chi^2 = 0.829$	0.363
Yes	171 (42.54)	125 (41.25)	46 (46.46)		
No	231 (57.46)	178 (58.75)	53 (53.54)		
Heart rate, beats/min, Mean \pm SD	96.79 \pm 21.01	96.74 \pm 20.98	96.92 \pm 21.21	t = -0.07	0.942
Respiratory rate, times/min, Mean \pm SD	22.71 \pm 6.84	22.28 \pm 6.87	24.03 \pm 6.61	t = -2.22	0.027
Temperature, °C, Mean \pm SD	36.80 \pm 1.01	36.85 \pm 1.02	36.65 \pm 0.99	t = 1.74	0.083
SOFA, M (Q ₁ , Q ₃)	5.00 (3.00, 7.00)	4.00 (2.00, 7.00)	7.00 (4.00, 9.00)	Z = 5.173	<0.001
SAPSII, Mean \pm SD	44.58 \pm 13.34	41.98 \pm 11.77	52.57 \pm 14.70	t = -6.52	<0.001
SOAR, M (Q ₁ , Q ₃)	2.00 (1.00, 2.00)	2.00 (1.00, 2.00)	2.00 (1.00, 2.00)	Z = 3.563	<0.001
PSI, Mean \pm SD	136.48 \pm 26.49	135.61 \pm 27.65	139.13 \pm 22.51	t = -1.27	0.205
CURB-65, Mean \pm SD	2.52 \pm 0.80	2.41 \pm 0.78	2.85 \pm 0.77	t = -4.84	<0.001
GCS, M (Q ₁ , Q ₃)	14.00 (8.00, 15.00)	14.00 (9.00, 15.00)	10.00 (6.00, 15.00)	Z = -3.637	<0.001
INR, M (Q ₁ , Q ₃)	1.30 (1.10, 1.60)	1.20 (1.10, 1.50)	1.40 (1.20, 1.80)	Z = 3.060	0.002
Elixhauser comorbidity score, M (Q ₁ , Q ₃)	20.00 (12.00, 29.00)	20.00 (12.00, 28.00)	23.00 (11.00, 33.00)	Z = 1.640	0.101
<i>Streptococcus pneumoniae</i> , n (%)				$\chi^2 = 0.459$	0.498
Yes	12 (2.99)	10 (3.30)	2 (2.02)		
No	390 (97.01)	293 (96.70)	97 (97.98)		
<i>Klebsiella pneumoniae</i> , n (%)				$\chi^2 = 1.356$	0.244
Yes	23 (5.72)	15 (4.95)	8 (8.08)		
No	379 (94.28)	288 (95.05)	91 (91.92)		
<i>Legionella pneumophila</i> , n (%)				$\chi^2 = 1.356$	0.244
Yes	402 (100.00)	303 (100.00)	99 (100.00)		
No	402 (100.00)	303 (100.00)	99 (100.00)		
Other <i>Streptococcus</i> , n (%)				$\chi^2 = 0.142$	0.706
Yes	19 (4.73)	15 (4.95)	4 (4.04)		
No	383 (95.27)	288 (95.05)	95 (95.96)		
Virus, n (%)				$\chi^2 = 0.018$	0.894
Yes	13 (3.23)	10 (3.30)	3 (3.03)		
No	389 (96.77)	293 (96.70)	96 (96.97)		
Other bacteria, n (%)				$\chi^2 = 10.753$	0.001
Yes	111 (27.61)	71 (23.43)	40 (40.40)		
No	291 (72.39)	232 (76.57)	59 (59.60)		
Yeast, n (%)				$\chi^2 = 7.565$	0.006
Yes	137 (34.08)	92 (30.36)	45 (45.45)		
No	265 (65.92)	211 (69.64)	54 (54.55)		
<i>Staphylococcus</i> , n (%)				$\chi^2 = 0.135$	0.713
Yes	128 (31.84)	95 (31.35)	33 (33.33)		
No	274 (68.16)	208 (68.65)	66 (66.67)		
EColi, n (%)				$\chi^2 = 0.025$	0.874

Table 2 (continued)

Variables	Total (n = 402)	In-hospital mortality		Statistics	P
		No (n = 303)	Yes (n = 99)		
No	371 (92.29)	280 (92.41)	91 (91.92)		
Yes	31 (7.71)	23 (7.59)	8 (8.08)		
<i>Candida</i> , n (%)				$\chi^2 = 0.198$	0.656
No	378 (94.03)	284 (93.73)	94 (94.95)		
Yes	24 (5.97)	19 (6.27)	5 (5.05)		
<i>Acinetobacter</i> , n (%)				Fisher	1.000
No	398 (99.00)	300 (99.01)	98 (98.99)		
Yes	4 (1.00)	3 (0.99)	1 (1.01)		
<i>Clostridium</i> , n (%)				$\chi^2 = 0.260$	0.610
No	389 (96.77)	294 (97.03)	95 (95.96)		
Yes	13 (3.23)	9 (2.97)	4 (4.04)		
<i>Citrobacter</i> , n (%)				Fisher	1.000
No	401 (99.75)	302 (99.67)	99 (100.00)		
Yes	1 (0.25)	1 (0.33)	0 (0.00)		
<i>Enterococcus</i> , n (%)				$\chi^2 = 0.003$	0.957
No	366 (91.04)	276 (91.09)	90 (90.91)		
Yes	36 (8.96)	27 (8.91)	9 (9.09)		
PCP, n (%)				$\chi^2 = 1.134$	0.287
No	400 (99.50)	301 (99.34)	99 (100.00)		
Yes	2 (0.50)	2 (0.66)	0 (0.00)		
Fungus, n (%)				Fisher	0.432
No	400 (99.50)	302 (99.67)	98 (98.99)		
Yes	2 (0.50)	1 (0.33)	1 (1.01)		
MCV, Mean \pm SD	91.01 \pm 7.05	90.59 \pm 7.06	92.28 \pm 6.90	t = -2.08	0.038
Hematocrit, %, Mean \pm SD	35.00 \pm 6.14	35.22 \pm 6.37	34.34 \pm 5.34	t = 1.36	0.176
RBC, m/uL, Mean \pm SD	3.87 \pm 0.71	3.91 \pm 0.73	3.74 \pm 0.62	t = 2.28	0.024
Potassium, mEq/L, Mean \pm SD	4.51 \pm 0.93	4.49 \pm 0.91	4.59 \pm 0.98	t = -0.91	0.364
Phosphate, mg/dL, M (Q ₁ , Q ₃)	3.40 (2.80,4.20)	3.30 (2.80,4.10)	3.70 (3.00,4.50)	Z = 2.480	0.013
Calcium, mg/dL, Mean \pm SD	8.42 \pm 0.95	8.43 \pm 0.96	8.38 \pm 0.93	t = 0.45	0.653
Magnesium, Mean \pm SD	1.93 \pm 0.37	1.93 \pm 0.36	1.91 \pm 0.40	t = 0.42	0.676
Lactate, mmol/L, M (Q ₁ , Q ₃)	2.00 (1.50, 2.90)	1.90 (1.50, 2.80)	2.20 (1.50, 3.70)	Z = 1.886	0.059
Creatine kinase, IU/L, M (Q ₁ , Q ₃)	80.50 (40.00, 181.00)	80.00 (39.00, 183.00)	82.00 (40.00, 167.00)	Z = 0.237	0.813
pH, Mean \pm SD	7.37 \pm 0.11	7.38 \pm 0.10	7.33 \pm 0.14	t = 2.64	0.009
SpO ₂ , Mean \pm SD	95.94 \pm 5.57	95.90 \pm 6.00	96.07 \pm 4.01	t = -0.32	0.749
PO ₂ , M (Q ₁ , Q ₃)	85.50 (63.00,129.00)	84.00 (63.00, 128.00)	89.00 (65.00, 136.00)	Z = 0.343	0.731
PCO ₂ , M (Q ₁ , Q ₃)	42.00 (34.00, 51.00)	42.00 (35.00, 51.00)	39.00 (33.00, 52.00)	Z = -0.757	0.449
Fio ₂ , M (Q ₁ , Q ₃)	35.00 (1.00, 70.00)	35.00 (1.00, 60.00)	40.00 (1.00, 100.00)	Z = 1.280	0.200
Invasive ventilation, n (%)				$\chi^2 = 23.105$	< 0.001
No	218 (54.23)	185 (61.06)	33 (33.33)		
Yes	184 (45.77)	118 (38.94)	66 (66.67)		
Ventilation, n (%)				$\chi^2 = 18.792$	< 0.001
No	177 (44.03)	152 (50.17)	25 (25.25)		
Yes	225 (55.97)	151 (49.83)	74 (74.75)		
Vesopressor, n (%)				$\chi^2 = 29.794$	< 0.001
No	376 (93.53)	295 (97.36)	81 (81.82)		
Yes	26 (6.47)	8 (2.64)	18 (18.18)		
NLR, M (Q ₁ , Q ₃)	9.92 (5.97, 19.98)	9.40 (6.04, 19.60)	11.20 (5.71, 21.28)	Z = 0.789	0.430
PLR, M (Q ₁ , Q ₃)	2.75 (1.69, 4.74)	2.72 (1.68, 4.70)	3.03 (1.78, 4.91)	Z = 0.458	0.647

Table 2 (continued)

Variables	Total (n = 402)	In-hospital mortality		Statistics	P
		No (n = 303)	Yes (n = 99)		
PNI, Mean \pm SD	31.65 \pm 8.90	32.33 \pm 9.33	29.59 \pm 7.12	t = 3.06	0.002
Anion gap, Mean \pm SD	16.39 \pm 3.86	16.33 \pm 3.92	16.58 \pm 3.69	t = -0.55	0.583
HPR, M (Q ₁ , Q ₃)	0.46 (0.32, 0.63)	0.46 (0.32, 0.63)	0.48 (0.35, 0.70)	Z = 1.571	0.116
RDW/BUN, Mean \pm SD	5.32 \pm 1.59	5.16 \pm 1.52	5.79 \pm 1.74	t = -3.47	<0.001
dNLR, Mean \pm SD	-1.01 \pm 0.09	-1.01 \pm 0.06	-1.02 \pm 0.15	t = 0.26	0.793
BUN/ALB, M (Q ₁ , Q ₃)	9.63 (6.21, 14.40)	9.05 (5.71, 14.00)	11.00 (7.35, 16.18)	Z = 2.891	0.004
SII, M (Q ₁ , Q ₃)	24.74 (13.09, 44.68)	26.36 (13.61, 45.36)	21.64 (11.00, 42.32)	Z = -1.723	0.085
LOS, M (Q ₁ , Q ₃)	3.25 (1.72, 7.43)	3.06 (1.66, 7.01)	4.13 (1.95, 9.05)	Z = 1.632	0.103

CAP, community-acquired pneumonia; CHF, congestive heart-failure; COPD, chronic obstructive pulmonary disease; DM, diabetes mellitus; AF, atrial fibrillation; SOFA, sequential Organ Failure Assessment; SAPSII, Simplified Acute Physiology Score; SOAR, systolic blood pressure, oxygenation, age and respiratory rate; PSI, Pneumonia Severity Index; GCS, Glasgow coma scales; INR, International normalized ratio; MCV, mean corpuscular volume; RBC, red blood cell; SpO₂, oxygen saturation; PCO₂, partial carbon dioxide pressure; Fio₂, fraction of inspired oxygen; NLR, neutrophil to lymphocyte; PLR, platelet-lymphocyte ratio; PNI, prognostic nutritional index; HPR, hemoglobin/platelets ratio; RDW, red cell distribution width; BUN, blood urea nitrogen; dNLR, absolute neutrophil count/ (white blood cell count-neutrophil count); SII, platelet count*lymphocytes/neutrophil; LOS, length of stay

Table 3 The predictive factors and prediction model for in-hospital mortality of elderly CAP patients

Variables	Estimate	RR (95% CI)	Standard error	Wald statistics	Pr > Chi-square
HPR	0.357	1.429 (1.03–1.985)	0.167	4.553	0.033
Age	0.016	1.017 (0.984–1.050)	0.017	0.970	0.325
Respiratory rate	0.048	1.049 (1.012–1.087)	0.018	6.839	0.009
INR	0.309	1.363 (1.077–1.724)	0.120	6.639	0.010
Ventilation (Yes)	0.680	1.974 (1.084–3.592)	0.306	4.951	0.026
Vasopressor (Yes)	1.435	4.201 (1.643–10.743)	0.479	8.979	0.003
RDW/BUN	0.175	1.192 (1.029–1.380)	0.075	5.509	0.019
GCS	-0.084	0.919 (0.861–0.982)	0.034	6.183	0.013

CAP, community-acquired pneumonia; HPR, hemoglobin/platelets ratio; RR: risk ratio; CI: confidence interval; INR: International normalized ratio; RDW, red cell distribution width; BUN, blood urea nitrogen; GCS, Glasgow coma scales

AUC value of the prediction model was 0.751 (95% CI 0.749–0.752), while those of the SOFA, SOAR, PSI and CURB-65 scores were 0.672 (95% CI 0.670–0.674), 0.607 (95% CI 0.605–0.609), 0.538 (95% CI 0.536–0.540), and 0.645 (95% CI 0.643–0.646), respectively. PPV, NPV, and ACC were also calculated to compare the predictive performance of the prediction model and SOFA, SOAR, PSI, and CURB-65 scores. Details of the performance are shown in Table 4.

The predictive performances of the prediction model and SOFA, SOAR, PSI, and CURB-65 scores in the subgroup analysis based on the pathogen

Based on bacteria pathogen, the prediction model showed a higher AUC compared with SOFA, SOAR, PSI and CURB-65 scores, with AUC being 0.727 (95% CI 0.725–0.729), 0.632 (95% CI 0.630–0.634), 0.617 (95% CI 0.616–0.619), 0.563 (95% CI 0.561–0.565), 0.640 (95% CI 0.639–0.642), respectively. Concerning other pathogens, the prediction model also reported better predictive

performance. The predictive performances of the prediction model and SOFA, SOAR, PSI, and CURB-65 scores based on the pathogen are shown in Table 5.

Discussion

CAP is a global infectious disease that causes high morbidity and mortality. Accurate and timely identification of patients at high risk of mortality is one of the most important works of physicians. In this study, patients with CAP 30-day mortality rate was 24.63%, slightly higher than the previous related literature reports, this may be because of the large cases included in the ICU, and the age, basic diseases, or a minority of the critically ill patient into the hospital later on. We identified HPR, RDW/BUN ratio, age, respiratory rate, INR, GCS, ventilation use, and vasopressor use were independent predictive factors that were related to the hospital mortality of elderly CAP patients. Based on the predictive factors, our prediction model showed a better predictive performance with an AUC being 0.751. Our model also showed

Table 4 Performances of the prediction model and scoring systems

Indicators	PPV (95% CI)	NPV (95% CI)	AUC (95% CI)	ACC (95% CI)
Training set				
Prediction model	0.529 (0.433–0.626)	0.850 (0.810–0.890)	0.751 (0.749–0.752)	0.769 (0.727–0.810)
SOFA	0.448 (0.348–0.547)	0.817 (0.774–0.860)	0.672 (0.670–0.674)*	0.729 (0.685–0.772)
SOAR	0.302 (0.242–0.362)	0.825 (0.769–0.881)	0.607 (0.605–0.609)*	0.532 (0.484–0.581)
PSI	0.273 (0.225–0.321)	0.875 (0.799–0.951)	0.538 (0.536–0.540)*	0.381 (0.333–0.428)
CURB-65	0.332 (0.267–0.396)	0.843(0.792–0.893)	0.645 (0.643–0.646)*	0.582 (0.534–0.630)
Testing set				
Prediction model	0.475 (0.350–0.601)	0.827 (0.768–0.886)	0.744 (0.742–0.747)	0.728 (0.669–0.787)
SOFA	0.356 (0.216–0.495)	0.767 (0.704–0.831)	0.634 (0.632–0.637)*	0.682 (0.620–0.744)
SOAR	0.360 (0.271–0.450)	0.849 (0.781–0.917)	0.667 (0.665–0.670)	0.599 (0.534–0.664)
PSI	0.301 (0.233–0.369)	0.927 (0.847–1.000)	0.621 (0.618–0.623)*	0.419 (0.354–0.485)
CURB	0.538 (0.347–0.730)	0.780 (0.721–0.839)	0.671 (0.668–0.673)*	0.751 (0.694–0.809)
External validation				
Prediction model	0.467 (0.418–0.516)	0.790 (0.764–0.817)	0.703 (0.672–0.734)	0.692 (0.666–0.717)
SOFA	0.448 (0.403–0.494)	0.801 (0.774–0.828)	0.686 (0.654–0.718)	0.675 (0.649–0.701)
SOAR	0.327 (0.294–0.361)*	0.766 (0.731–0.802)	0.564 (0.533–0.594)*	0.511 (0.484–0.539)*
PSI	0.379 (0.335–0.423)*	0.762 (0.734–0.791)	0.613 (0.580–0.646)*	0.626 (0.599–0.653)*
CURB-65	0.329 (0.295–0.362)*	0.769 (0.734–0.805)	0.570 (0.538–0.601)*	0.511 (0.484–0.539)*

PPV, positive predictive value; NPV, negative predictive value; AUC, area under the curve; ACC, accuracy; CI: confidence interval; SOFA, Sequential Organ Failure Assessment; SOAR, systolic blood pressure, oxygenation, age and respiratory rate; PSI, Pneumonia Severity Index; * is statistically significant compared with the prediction model

good goodness-of-fit. The prediction model also demonstrated better predictive performances than the SOFA, PSI, SOAR, and CURB-65 scoring systems.

The widespread application of scoring systems in clinical practice has brought great benefits to the management of CAP. However, these assessment scales do have limitations. PSI contains 20 variables and is very complex for prediction, these variables are usually not available at the initial visit, which may affect its promotion and implementation in daily practice. The CURB-65 score may not perform a suitable outcome in patients over the age of 70 due to its low sensitivity [19]. The SOFA score is unduly dependent on clinical therapeutic interventions

which fail to be mastered easily [13]. SOAR might be more suitable for assessing disease severity, particularly in the elderly [19]. However, SOAR for in-hospital mortality needs further confirmation. Furthermore, our study showed that these scoring systems have only moderate AUC. Zhang et al. conducted a new prediction model for assessing the clinical outcomes of ICU patients with CAP [20]. However, the AUC of this model was 0.661. Another study with age, congestive heart failure, dementia, respiratory rate and BUN level being predictive factors to develop a prediction model to predict 1-year mortality after hospitalization for CAP. Nevertheless, the C-index was only 0.76. In addition, the model only focuses on out-of-hospital mortality and only focuses on single biomarkers. The variables considered in our prediction model are more complete. Based on the predictive factors including HPR, RDW/BUN ratio, age, respiratory rate, INR, GCS, ventilation use, and vasopressor use, our prediction model was conducted. our prediction model demonstrated a higher AUC than the scoring systems, with an AUC being 0.751. Moreover, our prediction model was constructed based on the predictive factor that has the benefit of being easily calculated and not dependent on operator capacity to correctly gauge the level of confusion in a patient.

Our study demonstrated that RDW/BUN ratio and HPR were associated with in-hospital mortality of elderly CAP patients. The predictive value of the RDW/BUN

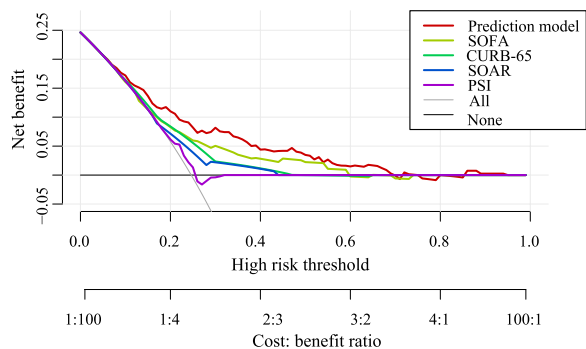


Fig. 2 DCA result of the prediction model, SOFA, SOAR, PSI, and CURB-65 scores

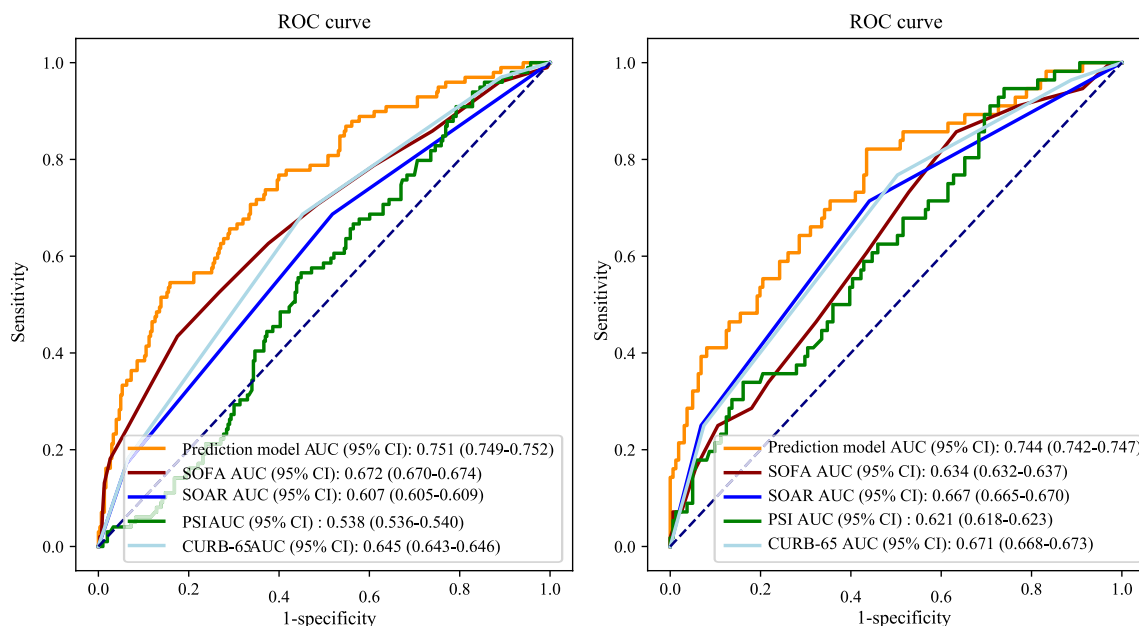


Fig. 3 The AUC values of the prediction model, SOFA, SOAR, PSI, and CURB-65 scores in training set and testing set

Table 5 The predictive performances of the prediction model in the subgroup analysis based on the pathogen

Indicators	PPV (95% CI)	NPV (95% CI)	AUC (95% CI)	ACC (95% CI)
Bacteria				
Prediction model	0.696 (0.563–0.829)	0.764 (0.720–0.809)	0.727 (0.725–0.729)	0.756 (0.714–0.799)
Other pathogen				
Prediction model	0.636 (0.352–0.921)	0.841 (0.792–0.890)	0.751 (0.748–0.753)	0.831 (0.782–0.880)

PPV, positive predictive value; NPV, negative predictive value; AUC, area under the curve; ACC, accuracy; CI: confidence interval

ratio on the in-hospital mortality of elderly CAP patients may be due to the prognostic value of RDW and BUN. The RDW can be obtained immediately from blood routine reports, which has been found to be associated with mortality in patients with CAP [21, 22]. Ge et al. also confirmed that elevated RDW and WBC increased mortality in adult CAP patients [23]. Inflammation and oxidative stress caused by infection were thought to be the mechanisms of RDW and infectious diseases. Erythropoietin regulates myelogenesis, red cell maturation, and survival and was previously considered to be one of the major determinants of RDW [24]. Abnormal production of erythropoietin or the body’s low response to erythropoietin will lead to a gradual increase in RDW value [25]. CAP is a typical infectious disease, during which Inflammation stimulates the release of inflammatory factors, damages the activity of erythropoietin, prevents the maturation of RBCs, leads to the production of ineffective RBCs, increases the heterogeneity of RBC size, and RDW value [26]. Increased RDW values have been reported to

be correlated with inflammatory markers, indicating that C-reactive protein (CRP) and erythrocyte sedimentation rate (ESR) are high when RDW is high [27]. BUN is produced by the metabolism of protein and amino acids in the body, then hydrolyzed by the liver and excreted by the kidney with urine [28]. Due to this complex interplay of modulatory factors, BUN is generally used as a surrogate marker of systemic illness rather than a specific marker of renal dysfunction [29]. $BUN \geq 7$ mmol was one of the CURB-65 scoring criteria for CAP [30]. In a retrospective study by Kang et al. in China that evaluated 4880 patients aged ≥ 65 with CAP, BUN was a prognostic factor for in-hospital mortality [31]. Uematsu et al. reported that elevated BUN had a significantly higher risk of 30-day mortality in CAP patients [32]. RDW/BUN ratio may be a simple and potentially useful prognostic factor of in-hospital mortality in elderly CAP patients. The HPR was calculated based on the hemoglobin and platelet counts. Patients with CAP often exhibit a declining hemoglobin concentration [33]. A study of patients with CAP found

that hemoglobin levels < 10 g/dL were independently associated with 90-day mortality [34]. Abnormal platelet count has previously been related to different complications in patients with CAP admitted to ICU [35]. Rising platelet count throughout hospitalization has been found to be a powerful predictor of better survival, while declining platelet count predicts poor outcomes [36]. Tang et al. found that preoperative HPR can be taken into account as a factor predictive of oncological outcomes for stage 1 and grade 3 bladder cancer, particularly disease progression and mortality outcomes [37]. The HPR can be used as a veritable blood biomarker to predict the in-hospital mortality of elder patients with CAP.

Age, respiratory rate, ventilation use, vasopressor use, GCS could also predict the in-hospital mortality of elderly CAP patients in this study. A study evaluating the prognostic factors in hospitalized CAP identified age, respiratory rate, and mechanical ventilation as prognostic factors of in-hospitalized CAP patients [30]. Braunet al. found that variables associated with an increased risk of 90-day mortality included age ≥ 51 years [38]. A study by Baek et al. found that mechanical ventilation was associated with in-hospital mortality of pneumonia [39]. GCS is the most widely accepted tool for evaluating consciousness [40]. Wang et al. identified GCS as an independent predictor that was closely related to the hospital mortality of severe CAP [13].

Our predictive factors are routinely and rapidly measured in patients in a hospital setting; our prediction model therefore may be a useful early tool in predicting elderly CAP patients with a high risk of in-hospital mortality, who require rapid and timely decision making. There are several limitations to this study. First, considering the retrospective design, and the limitation of the sampling analysis, selection and sampling bias cannot be excluded. Second, this study only included hospitalized patients; therefore, it is difficult to generalize these findings to all CAP patients. Third, as no external validation was conducted in this study, the applicability of the prediction model in clinical practice requires further study. Therefore, the results should be interpreted cautiously when applied in other clinical settings. Further multicenter studies with populations of different geographic areas, a larger number of subjects, and above all, a prospective design are needed to corroborate the additive value of these markers to clinical prediction models to provide a safer and more effective assessment tool for clinicians.

Conclusion

HPR, age, respiratory rate, INR, ventilation use, vasopressor use, RDW/BUN ratio, and GCS can be used as the factors to predict the in-hospital mortality of

elderly CAP patients. The prediction model based on these predictive factors can help clinicians to make clinical decisions timely and early, and decrease the in-hospital mortality of elder patients with CAP admitted to the ICU.

Abbreviations

CAP	Community-acquired pneumonia
ICU	Intensive care unit
SOFA	Sequential Organ Failure Assessment
PSI	Pneumonia Severity Index
ALB	Serum albumin
MIMIC-III	Medical Information Mart for Intensive Care III
SBP	Systolic blood pressure
DBP	Diastolic blood pressure
MAP	Mean arterial pressure
CHF	Congestive heart-failure
COPD	Chronic obstructive pulmonary disease
DM	Diabetes mellitus; atrial fibrillation
SAPSII	Simplified Acute Physiology Score
GCS	Glasgow coma scales
INR	International normalized ratio
RBC	Red blood cell
WBC	White blood cell
MCV	Mean corpuscular volume
BUN	Blood urea nitrogen
SpO ₂	Oxygen saturation
PCO ₂	Partial carbon dioxide pressure
PO ₂	Partial oxygen pressure
FiO ₂	Fraction of inspired oxygen
PCP	Pneumocystis pneumonia
PLR	Platelet-lymphocyte ratio
PNI	Prognostic nutritional index

Acknowledgements

Not applicable.

Author contributions

NL and WC designed the study. NL wrote the manuscript. NL and WC collected, analyzed and interpreted the data. WC critically reviewed, edited and approved the manuscript. All authors read and approved the final manuscript.

Funding

Not applicable.

Availability of data and materials

The datasets generated and/or analyzed during the current study are available in the MIMIC-III database, <https://mimic.mit.edu/docs/gettingstarted/>.

Declarations

Ethics approval and consent to participate

The project was approved by the Institutional Review Boards of Beth Israel Deaconess Medical Center (Boston, MA) and the Massachusetts Institute of Technology (Cambridge, MA). Since the clinical data in this study were collected from a publicly available database, there were no local or state ethical issues. All individuals provided written informed consent before participating in the study. All methods were carried out in accordance with relevant guidelines and regulations (declaration of Helsinki).

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

Received: 5 September 2022 Accepted: 5 January 2023
Published online: 18 January 2023

References

- Cuyppers F, Schäfer A, Skorka SB, Surabhi S, Tölken LA, Paulikat AD, et al. Innate immune responses at the asymptomatic stage of influenza A viral infections of *Streptococcus pneumoniae* colonized and non-colonized mice. *Sci Rep*. 2021;11(1):20609.
- Ghia CJ, Rambhad GS. Systematic review and meta-analysis of comorbidities and associated risk factors in Indian patients of community-acquired pneumonia. *SAGE Open Med*. 2022;10:20503121221095484.
- Divino V, Schranz J, Early M, Shah H, Jiang M, DeKoven M. The annual economic burden among patients hospitalized for community-acquired pneumonia (CAP): a retrospective US cohort study. *Curr Med Res Opin*. 2020;36(1):151–60.
- McLaughlin JM, Khan FL, Thoburn EA, Isturiz RE, Swerdlow DL. Rates of hospitalization for community-acquired pneumonia among US adults: a systematic review. *Vaccine*. 2020;38(4):741–51.
- Huang HR, Cho SJ, Harris RM, Yang J, Bermejo S, Sharma L, et al. RIPK3 activates MLKL-mediated necroptosis and inflammasome signaling during *Streptococcus* infection. *Am J Respir Cell Mol Biol*. 2021;64(5):579–91.
- Brown JD, Harnett J, Chambers R, Sato R. The relative burden of community-acquired pneumonia hospitalizations in older adults: a retrospective observational study in the United States. *BMC Geriatr*. 2018;18(1):92.
- Ma HM, Tang WH, Woo J. Predictors of in-hospital mortality of older patients admitted for community-acquired pneumonia. *Age Ageing*. 2011;40(6):736–41.
- Guo S, Mao X, Liang M. The moderate predictive value of serial serum CRP and PCT levels for the prognosis of hospitalized community-acquired pneumonia. *Respir Res*. 2018;19(1):193.
- Kolditz M, Ewig S, Höffken G. Management-based risk prediction in community-acquired pneumonia by scores and biomarkers. *Eur Respir J*. 2013;41(4):974–84.
- Zhang X, Liu B, Liu Y, Ma L, Zeng H. Efficacy of the quick sequential organ failure assessment for predicting clinical outcomes among community-acquired pneumonia patients presenting in the emergency department. *BMC Infect Dis*. 2020;20(1):316.
- Bradley J, Sbaib N, Chandler TR, Furmanek S, Ramirez JA, Cavallazzi R. Pneumonia severity index and CURB-65 score are good predictors of mortality in hospitalized patients with SARS-CoV-2 community-acquired pneumonia. *Chest*. 2022;161(4):927–36.
- Zhao L, Bao J, Shang Y, Zhang Y, Yin L, Yu Y, et al. The prognostic value of serum albumin levels and respiratory rate for community-acquired pneumonia: a prospective, multi-center study. *PLoS ONE*. 2021;16(3):e0248002.
- Wang X, Jiao J, Wei R, Feng Y, Ma X, Li Y, et al. A new method to predict hospital mortality in severe community acquired pneumonia. *Eur J Intern Med*. 2017;40:56–63.
- Menéndez R, Méndez R, Aldás I, Reyes S, Gonzalez-Jimenez P, España PP, et al. Community-acquired pneumonia patients at risk for early and long-term cardiovascular events are identified by cardiac biomarkers. *Chest*. 2019;156(6):1080–91.
- Jeong JH, Heo M, Lee SJ, Jeong YY, Lee JD, Yoo JW. Clinical usefulness of red cell distribution width/albumin ratio to discriminate 28-day mortality in critically ill patients with pneumonia receiving invasive mechanical ventilation, compared with lactate/albumin ratio: a retrospective cohort study. *Diagnostics (Basel, Switzerland)*. 2021;11(12):2344.
- Chen L, Lu XY, Zhu CQ. Prognostic value of albumin-red cell distribution width score in patients with severe community-acquired pneumonia. *Ann Palliat Med*. 2020;9(3):759–65.
- Lv C, Chen Y, Shi W, Pan T, Deng J, Xu J. Comparison of different scoring systems for prediction of mortality and ICU admission in elderly CAP population. *Clin Interv Aging*. 2021;16:1917–29.
- Johnson AE, Pollard TJ, Shen L, Lehman LW, Feng M, Ghassemi M, et al. MIMIC-III, a freely accessible critical care database. *Sci Data*. 2016;3:160035.
- Subramanian DN, Musonda P, Sankaran P, Tariq SM, Kamath AV, Myint PK. Performance of SOAR (systolic blood pressure, oxygenation, age and respiratory rate) scoring criteria in community-acquired pneumonia: a prospective multi-centre study. *Age Ageing*. 2013;42(1):94–7.
- Zhang S, Zhang K, Yu Y, Tian B, Cui W, Zhang G. A new prediction model for assessing the clinical outcomes of ICU patients with community-acquired pneumonia: a decision tree analysis. *Ann Med*. 2019;51(1):41–50.
- Lee SM, Lee JH, Kim K, Jo YH, Lee J, Kim J, et al. The clinical significance of changes in red blood cell distribution width in patients with community-acquired pneumonia. *Clin Exp Emerg Med*. 2016;3(3):139–47.
- Ren Q, Liu H, Wang Y, Dai D, Tian Z, Jiao G, et al. The role of red blood cell distribution width in the severity and prognosis of community-acquired pneumonia. *Can Respir J*. 2021;2021:8024024.
- Ge YL, Liu CH, Rana MA, Zhu XY, Wang N, Xu J, et al. Elevated red blood cell distribution width combined white blood cell in peripheral blood routine have a better sensitivity than CURB-65 scores in predicting ICU admission and mortality in adult community-acquired pneumonia patients. *Clin Lab*. 2019; 65(3).
- Lippi G, Franchini M, Salvagno GL, Guidi GC. Biochemistry, physiology, and complications of blood doping: facts and speculation. *Crit Rev Clin Lab Sci*. 2006;43(4):349–91.
- Afsar B, Saglam M, Yuceturk C, Agca E. The relationship between red cell distribution width with erythropoietin resistance in iron replete hemodialysis patients. *Eur J Intern Med*. 2013;24(3):e25–9.
- Förhécz Z, Gombos T, Borgulya G, Pozsonyi Z, Prohászka Z, Jánoskúti L. Red cell distribution width in heart failure: prediction of clinical events and relationship with markers of ineffective erythropoiesis, inflammation, renal function, and nutritional state. *Am Heart J*. 2009;158(4):659–66.
- Miyamoto K, Inai K, Takeuchi D, Shinohara T, Nakanishi T. Relationships among red cell distribution width, anemia, and interleukin-6 in adult congenital heart disease. *Circ J*. 2015;79(5):1100–6.
- van Veldhuisen DJ, Ruilope LM, Maisel AS, Damman K. Biomarkers of renal injury and function: diagnostic, prognostic and therapeutic implications in heart failure. *Eur Heart J*. 2016;37(33):2577–85.
- Agarwal M, Joshi M, Gupta M, Bharti N, Chakraborti A, Sonigra M. Role of blood urea nitrogen and serum albumin ratio in predicting severity of community acquired pneumonia (CAP). *Monaldi Arch Chest Dis Archivio Monaldi per le malattie del torace*. 2021; 92(3).
- Ito A, Ishida T, Tokumasu H, Washio Y, Yamazaki A, Ito Y, et al. Prognostic factors in hospitalized community-acquired pneumonia: a retrospective study of a prospective observational cohort. *BMC Pulm Med*. 2017;17(1):78.
- Kang Y, Fang XY, Wang D, Wang XJ. Activity of daily living upon admission is an independent predictor of in-hospital mortality in older patients with community-acquired pneumonia. *BMC Infect Dis*. 2021;21(1):314.
- Uematsu H, Kunisawa S, Sasaki N, Ikai H, Imanaka Y. Development of a risk-adjusted in-hospital mortality prediction model for community-acquired pneumonia: a retrospective analysis using a Japanese administrative database. *BMC Pulm Med*. 2014;14:203.
- Schoorl M, Snijders D, Schoorl M, Boersma WG, Bartels PC. Transient impairment of reticulocyte hemoglobin content and hepcidin-25 induction in patients with community-acquired pneumonia. *Scand J Clin Lab Invest*. 2013;73(1):54–60.
- Reade MC, Weissfeld L, Angus DC, Kellum JA, Milbrandt EB. The prevalence of anemia and its association with 90-day mortality in hospitalized community-acquired pneumonia. *BMC Pulm Med*. 2010;10:15.
- Wool GD, Miller JL. The impact of COVID-19 disease on platelets and coagulation. *Pathobiol J Immunopathol Mol Cell Biol*. 2021;88(1):15–27.
- Gorelik O, Izhakian S, Barchel D, Almozino-Sarafian D, Tzur I, Swarka M, et al. Prognostic significance of platelet count changes during hospitalization for community-acquired pneumonia. *Platelets*. 2017;28(4):380–6.
- Tang G, Zhen Y, Xie W, Wang Y, Chen F, Qin C, et al. Preoperative hemoglobin-platelet ratio can significantly predict progression and mortality outcomes in patients with T1G3 bladder cancer undergoing transurethral resection of bladder tumor. *Oncotarget*. 2018;9(26):18627–36.
- Braun E, Domany E, Kenig Y, Mazor Y, Makhoul BF, Azzam ZS. Elevated red cell distribution width predicts poor outcome in young patients

with community acquired pneumonia. *Crit Care* (Lond, Engl). 2011;15(4):R194.

39. Baek MS, Park S, Choi JH, Kim CH, Hyun IG. Mortality and prognostic prediction in very elderly patients with severe pneumonia. *J Intensive Care Med*. 2020;35(12):1405–10.
40. Suresh V, Yaddanapudi LN, Podder S. Full outline of unresponsiveness score versus glasgow coma scale in critically ill patients with altered sensorium: a comparison of inter-observer variability and outcomes. *Indian J Anaesth*. 2019;63(8):640–7.

Publisher's Note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Ready to submit your research? Choose BMC and benefit from:

- fast, convenient online submission
- thorough peer review by experienced researchers in your field
- rapid publication on acceptance
- support for research data, including large and complex data types
- gold Open Access which fosters wider collaboration and increased citations
- maximum visibility for your research: over 100M website views per year

At BMC, research is always in progress.

Learn more biomedcentral.com/submissions

