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Original Article

The Predictive Values of Different Scoring Systems for Mortality of Older Patients with Community-Acquired Pneumonia Who Underwent Invasive Mechanical Ventilation

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SUMMARY

Objective: To evaluate the performance of the pneumonia severity index (PSI), acute physiology and chronic health evaluation II (APACHE II), and simplified acute physiology score III (SAPS III) in predicting mortality in patients with community-acquired pneumonia (CAP) who underwent invasive mechanical ventilation (IMV) in the emergency intensive care unit (EICU).
Methods: A retrospective study was performed using the clinical data of older patients with CAP (who underwent IMV in the EICU), analyzed using APACHE II, SAPS III, and PSI. Logistic regression was used to analyze independent risk factors for mortality in these patients. The predictive values of APACHE II, SAPS III, and PSI for mortality were evaluated by the receiver operating characteristic (ROC) curves.
Results: In total, 101 patients were enrolled. The logistic regression analysis showed that APACHE II was an independent risk factor for mortality in the older patients with CAP who underwent IMV (OR = 1.42, 95% confidence intervals (CI): 1.23–1.63, $p < 0.001$). The areas under the ROC curve (AUROC) corresponding to PSI, APACHE II, and SAPS III were 0.733, 0.837, and 0.700, respectively, and the AUROC of APACHE II was significantly higher than those of PSI and SAPS III ($p < 0.05$). The maximum Youden index of APACHE II was 0.548, and the corresponding score was 18.5. The sensitivity and specificity of APACHE II in predicting mortality were 88.1% and 66.7%, respectively.
Conclusion: Compared to PSI and SAPS III, APACHE II had an optimal effect on predicting mortality in older patients with CAP who underwent IMV.

1. Introduction

Community-acquired pneumonia (CAP) commonly occurs in all age groups worldwide and leads to high morbidity and mortality in older patients.[1–3] Moreover, the mortality rate for patients hospitalized with CAP is 20% and 50% for patients in the intensive care unit.[4] To treat older patients with CAP and co-existing diseases at significant mortality risk in the emergency intensive care unit (EICU), invasive mechanical ventilation (IMV) has been commonly utilized as an effective strategy.[5] The clinical application of IMV suggests a significant mortality risk for patients hospitalized with severe CAP who may die within a short period. In such cases, the effectiveness of predicting CAP severity is critical for deciding whether to treat patients with IMV.

Several tools are available for the outcome prediction of critical illnesses. The Acute Physiology and Chronic Health Evaluation II (APACHE II, total score of 71) consists of acute physiology, age, and chronic health scores, with a total score greater than 20 indicating a severe risk of mortality. The simplified acute physiology score III (SAPS III) consists of 20 variables divided into physiological parameters, demographic data, and reasons for ICU admission. Pneumonia severity index (PSI) uses demographics, coexistence of comorbid illnesses, physical examination findings, and essential laboratory findings to stratify patients into five risk classes: I–V. The PSI is a useful scoring system that can assess the severity of CAP and has been reported to be significantly associated with mortality in a retrospective cohort study of hospitalized patients with viral CAP.[6] APACHE II and SAPS III are both prognostic tools for intra-ICU and in-hospital mortality.[7,8] The APACHE II and SAPS III scores were created based on data from hospitals in the US Europe, and North America, respectively.[8] Among all versions of both scores verified in terms of their diagnostic accuracy, APACHE II and SAPS III are the gold standards for prognostication of severely ill patients in ICUs worldwide. The performance of APACHE II and SAPS III has been verified for mortality prediction with various diagnoses.[8–16]

Mortality prediction accuracy is critical for IMV-treated patients with CAP, who face a very high mortality risk and require highly intense monitoring. To optimize mortality prediction accuracy, we investigated the predictive value of the PSI, APACHE II, and SAPS III scoring systems for the mortality of older patients with CAP who underwent IMV. A retrospective study was performed based on the clinical data of older patients with CAP who underwent IMV in the EICU between August 2016 and August 2019 and were analyzed by APACHE II, SAPS III, and PSI. Logistic regression was used to analyze the independent risk factors for mortality, and receiver operating charac-

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teristic (ROC) curve analysis was used to evaluate the predictive value of the three scores by the ROC curve.

2. Materials and methods

2.1. Research design and case selection

This single-center retrospective observational study was conducted at the Sixth People's Hospital, affiliated with Shanghai Jiaotong University, Shanghai, China. This study included 101 older inpatients with CAP admitted to the EICU who received IMV treatment between August 2016 and August 2019. The eligible patients were selected based on the following exclusion criteria: (1) < 18 years old; (2) In severe immunosuppressive status; (3) Thoracic deformities; (4) Received IMV treatment for < 24 h; (5) During pregnancy; (6) Due to incomplete clinical data. This study was approved by the Medical Ethics Committee of the Sixth People's Hospital affiliated with Shanghai Jiaotong University (2021-KY-005(K)).

2.2. Data collection

Patients' clinical data were collected from the patient database of the hospital's electronic medical records, including the following information: (1) Demographic data (n = 2); (2) Comorbidity and sepsis records on admission; (3) PSI, APACHE II, SAPS III, sequential organ failure assessment, and Glasgow coma scale (GCS) scores were recorded within the first 24 hours of EICU admission; (4) Vital signs recorded on admission; (5) Clinical and laboratory data were collected within the first 24 hours after admission. The eligible patients were divided into survivor and non-survivor groups according to their mortality status during hospitalization.

2.3. Statistical analysis

Normally distributed continuous variables were expressed as mean ± standard deviation (SD) and were compared using an independent samples t-test. Non-normally distributed continuous variables are expressed as median and interquartile range (IQR, 25th to 75th percentile) and compared using the Mann-whitney U-test. Categorical variables are described as frequency and percentage (n %) and were compared using the chi-square test or Fisher's exact test. Significant variables between the survivor and non-survivor groups were analyzed using univariate and multivariate logistic regression models (enter method) to identify independent risk factors for mortality in patients with CAP receiving IMV treatment. To determine the performance of each scoring system for mortality prediction, ROC curves were generated using *MedCalc* 20.0, program (*MedCalc* Software, Belgium), and the area under the ROC curve (AUROC) with exact binominal 95% confidence intervals (CI) was compared among the three scoring systems using the *Z*-test. Diagnostic accuracy was defined as poor if an AUROC was 0.6–0.69, acceptable if an AUROC was 0.7–0.79 and excellent if an AUROC was at least 0.8. Calibration was verified using calibration curves and the Hosmer–Lemeshow goodness-of-fit test, and the appropriate chi-squared values were calculated. Calibration curves were drawn by plotting predicted against actual mortality for groups of the patient population stratified by 10% increments of predicted mortality (i.e., by deciles). Chi-squared values with p > 0.05 indicated a good fit. Subsequently, the threshold, sensitivity, specificity, accuracy, positive likelihood ratio, and negative likelihood ratio were calculated. *SPSS* version 19.0 (IBM *SPSS* Statistics, USA) was used for statistical analysis, and a two-sided *p* value of < 0.05 was considered significantly different.

3. Results

3.1. Patient characteristics

We assessed 121 patients and selected 101 patients for further analysis according to the exclusion criteria (Figure 1). Eight patients were excluded because their IMV treatment was less than 24 h, and 12 patients were excluded because of incomplete clinical information. The average age of the patients was over 72 (72.73 ± 12.85) years. Most of the patients carried severe co-existing diseases including: (1) Respiratory disease (Chronic bronchitis, bronchial asthma, or chronic obstructive pulmonary disease); (2) Chronic heart failure (NYHA grade III or IV); (3) Neurological disease with history of cerebral hemorrhage or cerebral infarction; (4) Diabetes; (5) Chronic kidney disease (Stage 3–5). No significant differences were observed among the groups in terms of age (p = 0.515) or sex (p = 0.794). Most patients were admitted to the hospital with septic shock. Due to their severe morbidity, the overall mortality rate was 58.42% (59 101 EICU death). The basic characteristics and outcomes of the patients were detailed in Table 1, including a comparison of clinical and laboratory features between survivors and non-survivors in the EICU (Table 1). There were significant differences between the non-survivor and the survivor groups in APACHE II scores (mean 22.88 ± 3.91 vs. 17.26 ± 4.14, p < 0.001), SAPS III scores (mean 64.27 ± 8.21 vs. 58.40 ± 7.24, p < 0.001), PSI (mean 149.63 ± 32.23 vs. 123.17 ±

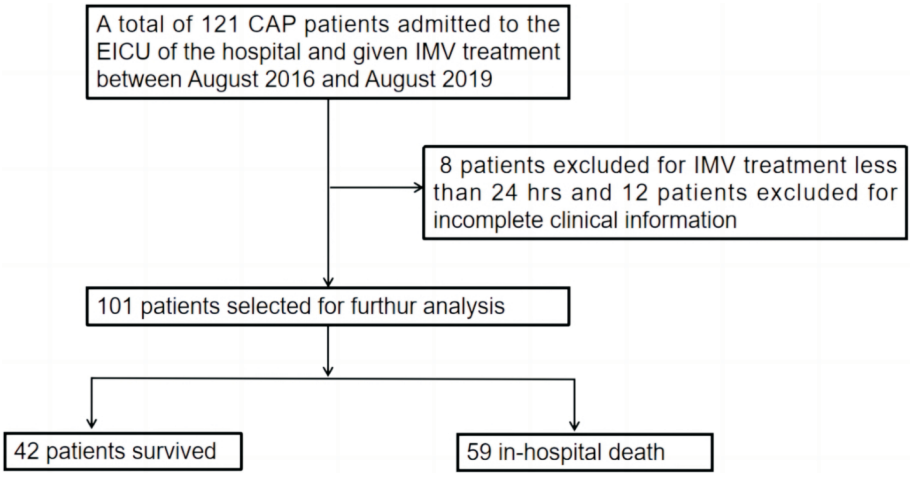


Figure 1. The participant flow diagram.

29.98, p < 0.001), GCS (mean 9.31 ± 2.73 vs. 11.33 ± 3.37, p < 0.001), HR (mean 94.76 ± 15.49 vs. 86.62 ± 14.52, p < 0.001), WBC (mean 13.71 ± 6.18 vs. 11.33 ± 4.66, p = 0.030), and the serum albumin concentration (ALB, mean 27.07 ± 5.02 vs. 29.48 ± 5.24, p = 0.022). However, other variables, such as age, sex, comorbidities, sepsis, oxygenation index, and platelet count, showed no significant differences between the two groups (all p > 0.05).

3.2. Univariate and multivariate logistic regression analysis

Based upon the univariate logistic regression analysis between the survivor and the non-survivor groups, significant differences were observed in APACHE II scores (β = 0.348, OR = 1.42, 95% CI: 1.23–1.63, p < 0.001), GCS (β = -0.216, OR = 0.81, 95% CI: 0.70–0.92, p < 0.001), SAPS III scores (β = 0.095, OR = 1.10, 95% CI: 1.04–1.16, p < 0.001), PSI (β = 0.028, OR = 1.03, 95% CI: 1.01–1.04, p < 0.001), HR (β = 0.037, OR = 1.04, 95% CI: 1.01–1.07, p = 0.012), WBC (β = 0.081, OR = 1.08, 95% CI: 1.00–1.17, p = 0.043) and ALB (β = -0.093, OR = 0.91, 95% CI: 0.84–0.99, p = 0.026), respectively.

Multivariate logistic regression analysis showed that APACHE II scores (β = 0.348, OR = 1.42, 95% CI: 1.23–1.63, p < 0.001) were associated with the death of the IMV-treated patients in EICU, suggesting that APACHE II score was the independent risk indicator that was associated with EICU mortality of the older patients with CAP who underwent IMV (Table 2).

3.3. Predictive values of PSI, APACHE II and SAPS III

ROC curves were used to validate the predictive values of the PSI, APACHE II, and SAPS III scores for patient death (Figure 2A). The predictive values of PSI, APACHE II, and SAPS III for intra-EICU mortality were evaluated in terms of sensitivity, specificity, AUROC, and the highest Youden index with the optimal cutoff value (Figure 2B). Statistical analysis showed that APACHE II had an AUROC of 0.837 (95% CI: 0.750–0.903) compared with a PSI of 0.733 (95% CI: 0.636–0.817) and SAPS III of 0.700 (95% CI: 0.600–0.787), which verified that all three scoring systems were able to predict mortality for patients with CAP treated with IMV in the EICU (Figure 2B). Further-

Table 1
Baseline IMV-treated CAP patient characteristics, including comparsion between survivors and non-survivors in the EICU observation.

Variable	All patients (n = 101)	Non-survivors (n = 59)	Survivors (n = 42)	*p* value
Age (year)	72.73 ± 12.85	71.74 ± 11.75	73.44 ± 13.64	0.515
Male (n, %)	61 (60.40)	35 (59.32)	26 (61.90)	0.794
APACHE II	20.54 ± 4.86	22.88 ± 3.91	17.26 ± 4.14	**< 0.001**
SAPS III	61.83 ± 8.31	64.27 ± 8.21	58.40 ± 7.24	**< 0.001**
PSI	138.62 ± 33.81	149.63 ± 32.23	123.17 ± 29.98	**< 0.001**
GCS	10.15 ± 3.16	9.31 ± 2.73	11.33 ± 3.37	**< 0.001**
Co-morbidities	1 (1, 2)	1 (1, 2)	1 (1, 2)	0.433
Sepsis (n, %)	90 (89.11)	56 (94.92)	34 (80.95)	0.058
HR (per minute)	91.38 ± 18.55	94.76 ± 15.49	86.62 ± 14.52	**< 0.001**
MAP (mmHg)	93.63 ± 15.38	95.41 ± 15.51	91.13 ± 15.02	0.169
PaO_2/FiO_2	187.50 (150.00, 255.00)	167.50 (137.50, 260.00)	191.25 (170.00, 223.13)	0.175
pH	7.39 ± 0.14	7.37 ± 0.15	7.41 ± 0.11	0.152
Na^+ (mmol/L)	140.02 ± 9.58	139.32 ± 11.53	141.00 ± 5.85	0.341
K^+ (mmol/L)	3.78 ± 0.86	3.87 ± 0.88	3.66 ± 0.82	0.222
Cr (μmol/L)	88.00 (58.00, 146.50)	98.00 (60.00, 176.00)	83.00 (57.25, 118.00)	0.133
WBC ($\times 10^9$/L)	12.72 ± 5.70	13.71 ± 6.18	11.33 ± 4.66	**0.030**
Hb (g/L)	109.47 ± 24.94	105.46 ± 26.20	115.10 ± 22.14	0.055
PLT ($\times 10^9$/L)	168.00 (141.00, 229.50)	161.00 (140.00, 231.00)	183.50 (144.75, 230.25)	0.340
TB (μmol/L)	17.00 (11.00, 32.00)	17.00 (10.00, 37.00)	17.50 (13.75, 26.25)	0.524
ALB (g/L)	28.07 ± 5.23	27.07 ± 5.02	29.48 ± 5.24	**0.022**

Normally distributed continuous variables were expressed as mean ± standard deviation (SD) and were compared using independent samples t-test. Non-normally distributed continuous variables were expressed as the median and interquartile range (IQR, 25th to 75th percentile) and were compared using the Mann-whitney U-test.

ALB, serum albumin concentration; APACHE II, acute physiology and chronic health evaluation II; CAP, community-acquired pneumonia; Cr, serum creatinine concentration; EICU, emergency intensive care unit; FiO_2, inhaled gas and oxygen concentration; GCS, Glasgow coma scale; Hb, hemoglobin concentration; HR, heart rate; IMV, invasive mechanical ventilation; K^+, serum potassium ion concentration; MAP, mean arterial pressure; Na^+, serum sodium ion concentration; PaO_2, arterial blood oxygen partial pressure; pH, arterial blood pH value; PLT, platelet count; PSI, pneumonia severity index; SAPS III, simplified acute physiology score III; TB, serum total bilirubin concentration; WBC, white blood cells.

Table 2
Univariate and multivariate logistic regression analysis for mortality in IMV-treated CAP patients in EICU.

Variables	Univariate				Multivariate			
	β	OR	95% CI	*p* value	β	OR	95% CI	*p* value
APACHE II	0.348	1.42	1.23–1.63	**< 0.001**	0.348	1.42	1.23–1.63	**< 0.001**
GCS	-0.216	0.81	0.70–0.92	**< 0.001**				
SAPS III	0.095	1.10	1.04–1.16	**< 0.001**				
PSI	0.028	1.03	1.01–1.04	**< 0.001**				
HR	0.037	1.04	1.01–1.07	**0.012**				
WBC	0.081	1.08	1.00–1.17	**0.043**				
ALB	-0.093	0.91	0.84–0.99	**0.026**				

ALB, serum albumin concentration; APACHE II, acute physiology and chronic health evaluation II; CAP, community-acquired pneumonia; CI, confidence intervals; EICU, emergency intensive care unit; GCS, Glasgow coma scale; HR, heart rate; IMV, invasive mechanical ventilation; OR, odds ratio; PSI, pneumonia severity index; SAPS III, simplified acute physiology score III; WBC, white blood cells.

more, to validate the differences among the three AUROC values, the data showed that there was a significant difference between APACHE II and PSI (p = 0.049, Figure 2C), as well as between APACHE II and SAPS III (p < 0.001, Figure 2C), suggesting that APACHE II had the highest predictive power for mortality. However, there was no significant difference between the AUROC values of PSI and SAPS III (p = 0.423, Figure 2C). The sensitivity and specificity of the APACHE II were 88.1% and 66.7%, respectively, according to the highest Youden Index (0.548, Figure 2B) with the optimal cutoff (18.5, Figure 2B).

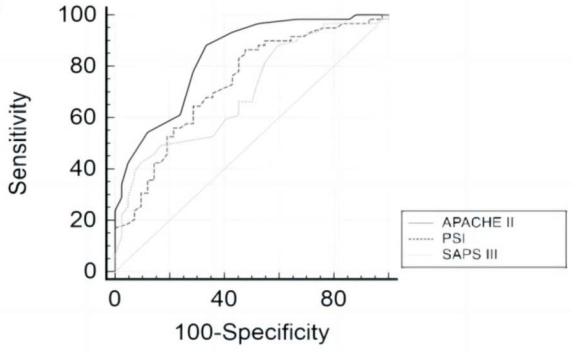
4. Discussion

IMV-treated CAP in older patients is a severe illness associated with substantial mortality.[9] Early recognition and rapid and appropriate treatment of the disease are critical for reducing mortality. Although several mortality prediction scoring systems (APACHE II, PSI, and SAPS III) are available, none have been validated in older patients. APACHE II (total score of 71) consists of acute physiology, age, and chronic health scores, with a total score greater than 20 indicating a severe risk of mortality.[10–12] The recruited patients in this study had average APACHE II score of 20.54 ± 4.86 at average age of 72.73 (±12.85) with mortality rate of 58.42%. Our results indicate that APACHE II score was an independent risk factor associated with EICU mortality in older patients with CAP who underwent IMV. Other studies have shown that APACHE II is an important risk factor for predicting mortality in ventilator-associated pneumonia patients.[12,13] Considering this distinct population, APACHE II may outperform PSI and SAPS III in terms of intra-EICU mortality in IMV-treated older patients. Furthermore, we compared the prognostic abilities of the APACHE II, PSI, and SAPS III for mortality in older patients with CAP who underwent IMV in the EICU. The AUROC is the primary method used to assess the overall diagnostic performance of a test and compare the performance of two or more diagnostic tests. In general, the AUROC curve must be greater than 0.8 to be considered acceptable.[14] Our results showed that the APACHE II system had an AUROC of 0.837 (95% CI: 0.750–0.903) compared with that of PSI (0.733) and SAPS III (0.700), suggesting that APACHE II had the highest predictive power for mortality in older patients with CAP who underwent IMV in the EICU. The Youden index is called the accuracy index and is commonly used to optimize the cutoff point of the ROC curve for the sensitivity and specificity of the test.[15,16] Our analysis showed the highest Youden index for APACHE II (0.548) compared with PSI (0.388) and SAPS III (0.329), suggesting a higher predictive value of APACHE II. Using the highest Youden index with an optimal cutoff of 18.5, the sensitivity for prognostic prediction was superior in APACHE II than in PSI and SAPS III. Therefore, APACHE II could be used as a valuable tool for mortality prediction in older patients with CAP who underwent IMV in the EICU.

The SAPS III consists of 20 variables divided into physiological parameters, demographic data, and reasons for ICU admission.[17] The SAPS III is widely used to assess the severity of patients in ICUs, with the advantage of calculating the probability of death within the first hour of ICU admission and calibrating it according to the world region.[18–20] Our study showed that SAPS III failed to act as an independent risk factor associated with mortality in older patients with CAP who underwent IMV, and was inferior to APACHE II for mortality prognosis.

The PSI uses demographics, coexistence of comorbid illnesses, physical examination findings, and essential laboratory findings to stratify patients into five risk classes, I–V.[21] Risk class I, II, or III pneumonia can be treated at home with oral antibiotics, whereas patients with risk class IV–V pneumonia should be hospitalized for treatment.[22,23] In this case, the PSI was also inferior to APACHE II for mortality prognosis in older patients with CAP who underwent IMV, although a previous study recommended a simple scoring operation.[24]

A



B.

Variable	Cut-off	Youden index	Sensitivity	Specificity	AUROC	95% *CI*
APACHE II	18.5	0.548	88.1%	66.7%	0.837	0.750～0.903
PSI	121.5	0.388	86.4%	52.4%	0.733	0.636～0.817
SAPS III	66.5	0.329	42.4%	90.5%	0.700	0.600～0.787

C.

Variable	*Z value*	*P value*
APACHE II vs. PSI	1.968	0.049
APACHE II vs. SAPS III	2.729	< 0.001
PSI vs. SAPS III	0.801	0.423

Figure 2. ROC curve analysis of three scoring systems for predicting mortality in IMV-treated patients with CAP. A, ROC curves of three scores with intra-EICU mortality as the outcome. B, Three score's area under the receiver operating characteristic (AUROC) and other characteristics for their ROC curves. C, Pairwise comparison of three scores AUROC value.

The present study had some limitations. First, this was a single-center study with a relatively small population. Second, other factors that may influence patient health, such as immune function, nutritional status, pathogenic changes, and antibiotic resistance, were not included. Studies with prospective designs and multiple centers may be more appropriate in the future.

5. Conclusions

In conclusion, this study assessed the predictive values of widely used prognostic scores for mortality of older patients with CAP who underwent IMV in the EICU. The and found that APACHE II exhibited better performance than SAPS III and PSI to aid in decision-making and performance improvements in the ICU. Our data suggest that APACHE II is an independent risk indicator associated with EICU mortality in patients with CAP who undergo IMV. We propose that APACHE II should be used to predict illness severity in older patients with CAP who receive IMV in the ICU.

Author contributions

Shi, Dong-cheng was responsible for designing and running the experiments and writing the manuscript. Li, Yong-xia, Jiang, Jiamei, and Feng, Qiming were responsible for experiments and data analysis. Dr. Zhao, Gang was responsible for the conception, design, and coordination of the study, acquisition and interpretation of the statistical data, and revision of the manuscript.

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Declaration of competing interest

The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. The authors declare no conflicts of interest.

Human research ethics approval

The study was approved by the Medical Ethics Committee of the Sixth People's Hospital affiliated to Shanghai Jiaotong University (2021-KY-005(K)).

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