Zhang Q et al. (2024) PROGNOSTIC VALUE OF BIOMARKER MONITORING AND STATISTICAL MODELING IN SEVERE PNEUMONIA-ASSOCIATED SEPSIS: IMPLICATIONS FOR RECOVERY AND PHYSICAL REHABILITATION IN ATHLETES. Revista Internacional de Medicina y Ciencias de la Actividad Física y el Deporte vol. 24 (98.1) pp. 131-146.
DOI: https://doi.org/10.15366/rimcafd2024.98.1.009

ORIGINAL

PROGNOSTIC VALUE OF BIOMARKER MONITORING AND STATISTICAL MODELING IN SEVERE PNEUMONIA-ASSOCIATED SEPSIS: IMPLICATIONS FOR RECOVERY AND PHYSICAL REHABILITATION IN ATHLETES

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Recibido 13 de abril de 2024 **Received** April 13, 2024
Aceptado 10 de diciembre de 2024 **Accepted** December 10, 2024

ABSTRACT

To evaluate the prognostic value of multivariate logistic regression analysis combined with amyloid A and lactic acid monitoring in patients with severe pneumonia-associated sepsis, with a focus on its implications for recovery, physical rehabilitation, and the maintenance of physical performance. **Methods:** This retrospective study analyzed clinical data from patients diagnosed with severe pneumonia-associated sepsis. Key biomarkers, including serum amyloid A (SAA) and lactic acid, were monitored alongside multivariate logistic regression analysis to assess their predictive value for patient outcomes. Biomarker trends and regression results were correlated with clinical recovery metrics, focusing on functional capacity and readiness for physical rehabilitation. **Results:** Serum amyloid A and lactic acid levels were significantly elevated in patients with severe pneumonia-associated sepsis, correlating with worse clinical outcomes. Multivariate logistic regression analysis identified these biomarkers as independent predictors of mortality and prolonged recovery time ($P < 0.05$). Patients with lower biomarker levels showed improved physical performance, shorter rehabilitation durations, and greater readiness to re-engage in physical activities compared to those with elevated levels. **Conclusion:** The combination of multivariate logistic regression analysis with amyloid A and lactic acid monitoring provides valuable

prognostic insights in severe pneumonia-associated sepsis. These tools not only enhance clinical decision-making but also inform personalized rehabilitation strategies, ensuring effective recovery and the restoration of physical performance. This approach has significant implications for individuals, including athletes, recovering from critical illnesses, emphasizing the need for integrated care models that bridge acute treatment and physical rehabilitation. Future research should explore the long-term effects of biomarker-guided interventions on physical activity levels and overall functional outcomes.

KEYWORDS: Severe Pneumonia in the Elderly; Sepsis; Multivariate Analysis; Lactic Acid; Amyloid A

1. INTRODUCTION

Severe pneumonia-associated sepsis is a life-threatening condition characterized by systemic inflammation, organ dysfunction, and high mortality rates. The recovery process is often prolonged and marked by significant physical and functional impairments, which can severely limit a patient's ability to engage in physical activity and rehabilitation. For athletes and physically active individuals, sepsis-related complications not only hinder their immediate health but also compromise their long-term physical performance and recovery potential(Florin et al., 2021; Font, Thyagarajan, & Khanna, 2020). Understanding the prognostic factors that influence recovery can pave the way for tailored rehabilitation strategies, enhancing the chances of a full return to physical functionality and activity (Florin et al., 2021; Font et al., 2020). Biomarkers such as serum amyloid A (SAA) and lactic acid have emerged as critical indicators of inflammation, metabolic dysfunction, and disease severity in sepsis. These markers provide valuable insights into the progression of the condition and the body's response to treatment (Alexander et al., 2021; Angus & Van der Poll, 2013). In parallel, multivariate logistic regression analysis serves as a robust statistical tool to integrate clinical and biomarker data, enabling precise predictions of patient outcomes. When combined, these approaches have the potential to guide clinical decisions and rehabilitation planning, bridging the gap between acute medical care and long-term physical recovery. In the context of sports and physical performance, timely and accurate prognostic evaluation is essential for developing personalized rehabilitation protocols that address both physical and psychological needs. Monitoring biomarkers and leveraging advanced statistical analyses can inform strategies to optimize recovery (Kalil & Thomas, 2019; Pierrakos, Velissaris, Bisdorff, Marshall, & Vincent, 2020), mitigate muscle deconditioning (Copaescu, Smibert, Gibson, Phillips, & Trubiano, 2020; da Silva Ramos, de Freitas, & Machado, 2021), and restore cardiovascular and metabolic health, ensuring that individuals can safely resume physical activity (Hwang, Shimizu, & Lee, 2022; Lanks, Musani, & Hsia, 2019). This study explores the prognostic value of multivariate logistic regression analysis and amyloid A/lactic acid monitoring

in patients with severe pneumonia-associated sepsis. By focusing on recovery metrics relevant to physical performance and rehabilitation, this research highlights the importance of integrating clinical tools with sports medicine principles to enhance patient outcomes and support a successful return to physical activity (Póvoa, Coelho, & Salluh, 2021; Sharma et al., 2020). Severe pneumonia has an acute initiation, rapid progression and poor prognosis. An imbalance between pro-inflammatory and anti-inflammatory responses has been found to be key to the development of severe pneumonia (Yaghoobi, Taher, Seifrabie, Sabahi, & Rahimi-Bashar, 2019). Therefore, predicting the level of inflammatory factors in patients is important to block the inflammatory cascade response and improve the prognosis. Clinical routine evaluation of inflammatory indexes of severe pneumonia includes C-reactive protein (CRP), procalcitonin (PCT), interleukin-6 (IL-6) and so on. However, these indexes are easily influenced by external factors, resulting in a wide range of physiological fluctuations, which affects the accuracy of test results. Serum amyloid A (SAA) is an acute reaction protein. Trauma, inflammation, infection, and other causes can stimulate the body to regulate various inflammatory factors to promote the expression of SAA, which makes SAA rapidly increase by 1000 times within 24-36h of inflammation (Jacobs et al., 2022; Ludwick et al., 2022). In addition, some studies have pointed out that patients with septic shock and ARDS have acid-base balance disorder in the early stage, and the acid-base balance disorder may be one of the important factors in the progress of the disease (Claverias et al., 2022). Blood lactic acid (BLA) is an important index to reflect the disorder of acid-base balance, which can be detected by blood gas analysis. Blood lactic acid has become a biological marker of many severe diseases (Weiss et al., 2020). It is, however, unclear whether this test can accurately predict patients' prognoses with severe pneumonia complicated by sepsis. There are few reports on the prognostic value of amyloid A/lactate level monitoring in patients with severe pneumonia complicated with sepsis, and its specific correlation remains to be further clarified. This study aimed to analyze 412 patients with severe pneumonia who were treated at our hospital between August 2021 and August 2022. The purpose of this study is to explore the pathogenic factors of sepsis and the value of amyloid A/lactic acid level in the evaluation of prognosis in patients with severe pneumonia.

2. Patients and Methods

2.1 General Information

During August 2021 to January 2023, 412 patients with severe pneumonia cured in our hospital were included in the study. A summary of the general data regarding the patients can be found in Table 1. The Medical Ethics Review Committee of our hospital has reviewed this study. Diagnostic criteria of severe sepsis: previous clinical symptoms, signs, medication records and discharge diagnosis according to the patient's history. The patient would

evaluate for sepsis at admission. Severe sepsis is defined as sepsis with at least one organ failure, severe sepsis, creatinine greater than 2mg/dL or systolic blood pressure less than 90mmHg (Angus & Van der Poll, 2013).

Inclusion criteria: (1) all patients in the group meet the diagnostic criteria of severe pneumonia (Wongsurakiat & Chitwarakorn, 2019)f, with symptoms and signs of severe pneumonia; (2) the age of patients is above 60 years; (3) patients with complete clinical data.

Exclusion criteria: (1) leukopenia or neutropenia caused by extrapulmonary causes; (2) patients with severe immunosuppression or immunodeficiency, such as patients with positive human immunodeficiency virus; (3) recent treatment with corticosteroids or other immunosuppressive drugs; (4) patients with malignant tumor, mental illness, and respiratory failure; (5) hemodynamic instability; (6) elevated intracranial pressure.

Calculation formula of sample size:

$$n_1 = \frac{[Z_{\alpha/2}\sqrt{p(1-p)(1+c)/c} + Z_{\beta}\sqrt{p_1(1-p_1)+p_2(1-p_2)/c}]^2}{(p_1-p_2)^2}$$

Bilateral α is 0.05 and β is 0.20. The incidence of sepsis in severe pneumonia patients in China is taken as the effect index, the parameter settings are P1=0.93 and P2=0.73. The calculated sample size should be 374 cases, and the shedding rate is 10%, so 412 patients should be included.

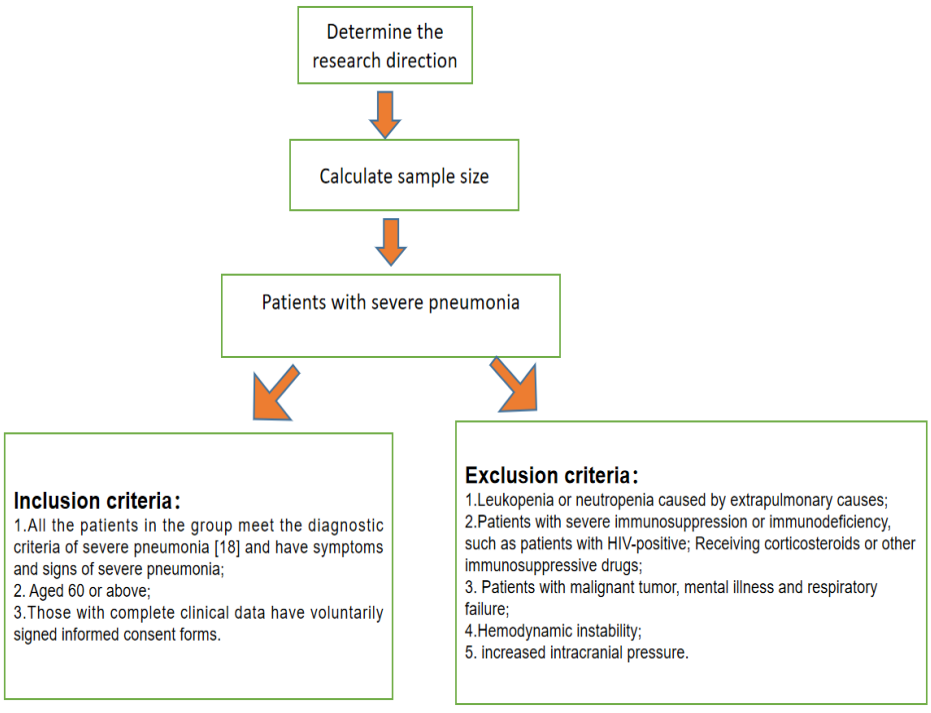

Figure 1: Schematic Diagram of Patients Selected into the Group

2.2 Treatment Methods

2.2.1 Laboratory Examination

In addition to collecting fasting venous blood upon admission, our hospital's laboratory completed routine blood tests. Enzyme-linked immunosorbent assay (ELISA) was used to detect the SAA levels of all subjects. Specific operations were carried out according to instructions for a SAA detection kit manufactured by Qiyi Biotechnology (Shanghai) Co., Ltd. The level of BLA was detected by Danish Ledu ABL825FLEX automatic blood gas analyzer. If a patient was infected, a blood sample was promptly harvested at the time of infection and the above tests were completed by our Laboratory Department.

2.2.2 Etiological Detection

Clinical samples from all patients should be taken separately within 24, 36, and 72 hours of admission to the ICU, taking into account the individual course of the patient's illness, and labeled using a unified method. All patients underwent etiological tests, including sputum culture, blood culture, urine antigens (such as Legionella pneumophila), serological tests (such as Chlamydia pneumoniae, Mycoplasma pneumoniae, Coxiella burnetii and Legionella pneumophila), nasopharyngeal swabs, bronchoscopy (such as bronchoalveolar lavage) and pleural effusion.

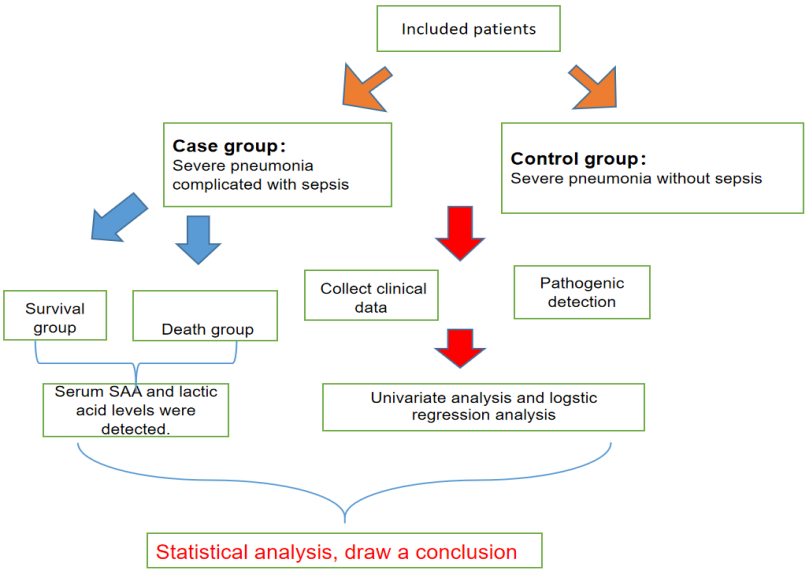

Figure 2: Research Technology Roadmap

2.3 Observation Index

The clinical data such as sex, body mass index (BMI), years of education, age, drinking history, complications (diabetes, coronary heart disease,

abnormal liver function), pleural effusion, etiological test results, history of antibiotic treatment and pneumonia severity index on admission (PSI) were collected. There were Ⅰ - V levels of PSI. The higher the level, the higher the risk of death, the lower the risk of PSI less than Ⅲ, and the higher the risk of PSI more than Ⅲ.

2.4 Statistical Analysis

The statistical analysis was conducted using SPSS22.0 software. The normally distributed data with uniform variance were presented as mean ± standard deviation ($\bar{x}$ ±s). Independent sample t-tests were performed to compare differences between groups, while categorical data were presented as frequency and percentage (n%) and analyzed by chi-square test (χ^2). The risk factors for sepsis in patients with severe pneumonia were analyzed using multivariate logistic regression analysis, with sepsis as the dependent variable and the selected risk factors as the independent variables. ROC was adopted to analyze the prognostic value of serum SAA and BLA levels alone and combined monitoring in patients with sepsis. Statistically noticeable differences were observed ($P < 0.05$).

3. Results

3.1 The General Situation

Between August 2021 and August 2022, 412 patients with severe pneumonia were classified into two groups: those with sepsis (n = 110) and those without sepsis (n = 302). The incidence of sepsis in this study was 26.70%. No noticeable difference was found in gender, BMI index, years of education, history of hypertension, drinking, smoking, and abnormal liver function ($P > 0.05$). There were statistically noticeable differences in age, history of diabetes, history of coronary heart disease, history of antibiotic treatment, complicated pleural effusion, PSI and pathogen detection results ($P < 0.05$). In Table 1, you can see all the results.

Table 1 (a): The General Situation

VARIABLE	SEPSIS GROUP（N=110）	NON-SEPSIS GROUP（N=302）	*T/X²*	*P*
AGE (YEARS)	73.49±9.03	68.42±10.07	4.643	＜0.05
GENDER (MALE / FEMALE)			0.018	＞0.05
MALE	58（52.73）	157（51.99）		
FEMALE	52（47.27）	145（48.01）		
BMI INDEX（kg/m²）	23.31±2.59	23.20±2.52	0.389	＞0.05

Table 1 (b): The General Situation

VARIABLE	SEPSIS GROUP (N=110)	NON-SEPSIS GROUP (N=302)	T/X^2	P
NUMBER OF YEARS OF EDUCATION (YEARS)	9.45±1.20	9.50±1.24	0.365	＞0.05
HIGH BLOOD PRESSURE			0.014	＞0.05
YES	63（57.27）	171（56.62）		
NONE	47（42.73）	131（43.38）		
DIABETES			73.985	＜0.05
YES	92（83.64）	108（35.76）		
NONE	18（16.36）	194（64.24）		
CORONARY ARTERY DISEASE			76.447	＜0.05
YES	87（79.09）	93（30.79）		
NONE	23（20.91）	209（69.21）		
HISTORY OF DRINKING			0.879	＞0.05
YES	64（58.18）	160（52.98）		
NONE	46（41.82）	142（47.02）		
SMOKING HISTORY			1.758	＞0.05
YES	66（60.00）	159（52.65）		
NONE	44（40.00）	143（47.35）		
HISTORY OF ANTIBIOTIC TREATMENT			75.311	＜0.05
YES	87（79.09）	94（31.13）		
NONE	23（20.91）	208（68.87）		
ABNORMAL LIVER FUNCTION			0.260	＞0.05
YES	36（32.73）	107（35.43）		
NONE	74（67.27）	195（64.57）		
PLEURAL EFFUSION			120.923	＜0.05
YES	94（85.45）	76（25.17）		
NO	16（14.55）	226（74.83）		
PSI			33.870	＜0.05
LOW RISK	43（39.09）	213（70.53）		
HIGH RISK	67（60.91）	89（29.47）		
RESULTS OF ETIOLOGICAL EXAMINATION			24.323	＜0.05
GRAM-NEGATIVE BACTERIA	19（17.27）	73（24.17）		
GRAM-NEGATIVE BACTERIA	41（37.27）	56（18.54）		
VIRUS	6（5.45）	60（19.87）		
MIXED INFECTION	36（32.73）	52（17.22）		
ATYPICAL PATHOGEN	8（7.27）	60（19.87）		

3.2 Analysis of Multiple Factors Affecting Sepsis in Patients with Severe Pneumonia

We take the statistically noticeable factors of univariate analysis as independent variables to fit the multi-factor logistic regression model of the corresponding variables of the influencing factors. In Table 2, you can see the specific assignment table. The results indicated that older age, diabetes, coronary heart disease, history of antibiotic treatment, high risk of PSI, gram-negative bacterial infection, gram-positive bacterial infection, and mixed infection were independent risk factors for sepsis in patients with severe pneumonia ($P < 0.05$). In Table 3, you can see all the results.

Table 2: Analysis of Influencing Factors of Sepsis in Patients with Severe Pneumonia

RELATED FACTORS	VARIABLE NAME	VARIABLE ASSIGNMENT
AGE	X_1	Actual value
DIABETES	X_2	1= Yes，0= None
CORONARY ARTERY DISEASE	X_3	1= Yes，0= None
HISTORY OF ANTIBIOTIC TREATMENT	X_4	1= Yes，0= None
PSI	X_5	1= High risk，0= Low risk
RESULTS OF ETIOLOGICAL EXAMINATION	X_6	Actual value

Table 3: Logistic Regression Analysis of Factors Related to Sepsis in Patients with Severe Pneumonia

VARIABLE	B	S.E.	WALDX^2	P VALUE	OR VALUE（95%CI）
AGE	0.389	0.131	8.818	0.003	1.476(1.141~1.907)
DIABETES	0.571	0.093	37.697	0.000	1.770(1.475~2.124)
CORONARY ARTERY DISEASE	1.321	0.203	42.346	0.000	3.747(2.517~5.578)
HISTORY OF ANTIBIOTIC TREATMENT	1.082	0.112	93.329	0.000	2.951(2.369~3.675)
PSI	2.538	1.113	5.200	0.023	12.654(1.428~112.110)
RESULTS OF ETIOLOGICAL EXAMINATION	0.722	0.151	22.862	0.000	2.059(1.531~2.768)

3.3 The Serum SAA and BLA Levels in Patients with Different Prognosis

Patients in sepsis group were followed up for 3 months. Patients were classified into death groups (n = 43) and survival groups (n = 67) based on their prognosis. Of the 110 patients with sepsis, 43 cases died with a mortality rate of 39.09%. Results indicated that serum SAA and BLA levels were noticeably

higher in the death group (P < 0.05). All the results are shown in Table 4.

Table 4: The Serum SAA and Lactic Acid Levels in Patients with Different Prognosis (X±S)

GROUPING	N	SAA（mg/L）	BLA (mmol/L)
DEATH GROUP	43	394.53±35.28	7.61±2.09
SURVIVAL GROUP	67	124.23±18.47	4.23±1.35
T		52.566	10.315
P		＜0.05	＜0.05

3.4 Prognostic Value of Single and Combined Detection of Serum SAA and BLA Levels in Patients with Severe Pneumonia Complicated with Sepsis

The results of ROC curve study indicated that the AUC of serum SAA and BLA alone and in combination were 0.815 (95%CI = 0.7237-0.9070), 0.735 (95%CI = 0.6317-0.8371) and 0.924 (95%CI = 0.8626-0.9858), respectively, the AUC of combined diagnosis was noticeably higher compared to predicted by single factor (P<0.05). Predictive value was combined detection > ＞SAA ＞ > lactic acid. See Fig.3-5 and Table 5 for details.

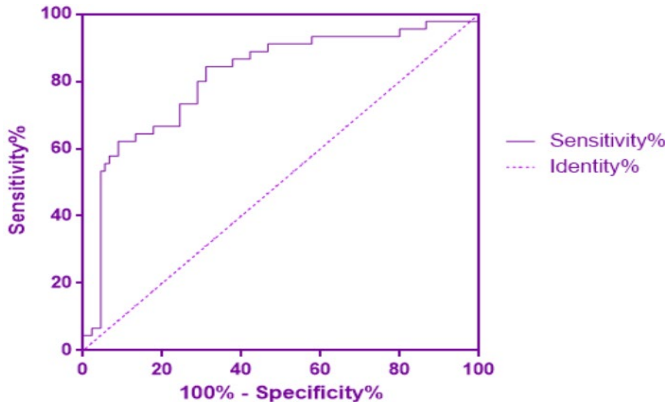

Figure 3: ROC Curve of Serum SAA Level Predicting Prognosis in Patients with Severe Pneumonia Complicated with Sepsis

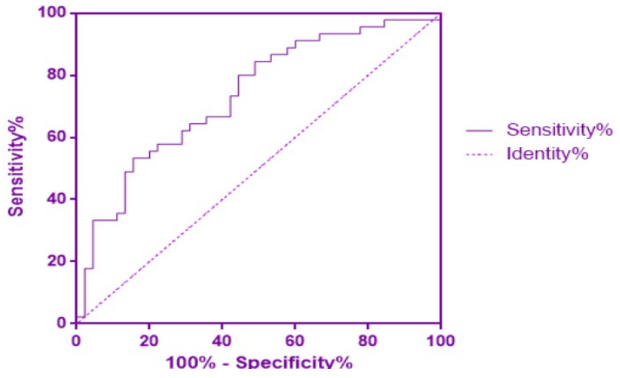

Figure 4: ROC Curve of Serum BLA Level Predicting Prognosis in Patients with Severe Pneumonia Complicated with Sepsis

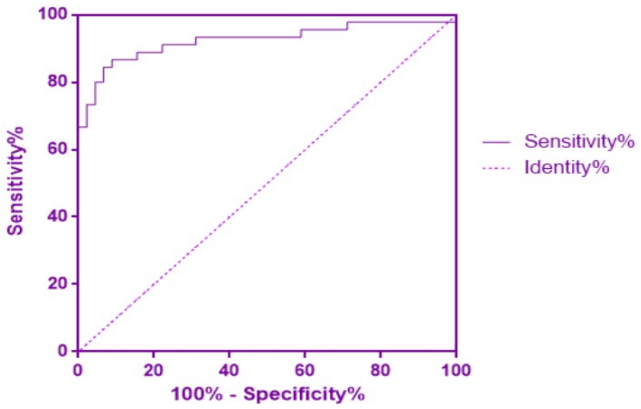

Figure 5: ROC Curve of Combined Detection of Two Serum Factors to Predict the Prognosis of Severe Pneumonia Complicated with Sepsis

Table 5: Prognostic Efficacy of Single and Combined Detection of Serum SAA and Lactic Acid Levels in Patients with Sepsis

VARIABLE	AUC	SENSITIVITY（%）	SPECIFICITY DEGREE（%）	YODEN INDEX	95%CI
SAA	0.815	78.28	84.21	0.323	0.7237-0.9070
BLA	0.735	61.29	57.37	0.121	0.6318-0.8371
JOINT DIAGNOSIS	0.9242	90.04	91.84	0.536	0.8626-0.9858

4. Discussion

The condition of patients with severe pneumonia is more serious, often complicated with more basic diseases, and sepsis can lead to aggravation of dyspnea, decreased immunity, multiple organ dysfunction, progression to severe sepsis, threatening the lives of patients. Sepsis is a noticeable contributor to mortality in patients with severe pneumonia, particularly in intensive care units, and can lead to treatment failure in severe pneumonia (Bartoš & Džupová, 2020; Ferreira-Coimbra, Sarda, & Rello, 2020). Identifying the risk factors for sepsis in patients with severe pneumonia is crucial for clinical assessment, prevention, and early treatment of sepsis. The results of this study indicated that 26.70% (110/412) patients with severe pneumonia are complicated with severe sepsis, which should be paid enough attention by clinicians. Elderly patients with severe pneumonia complicated with basic diseases (such as coronary heart disease, and diabetes) and pleural effusion are more likely to develop severe sepsis. Clinically, we should pay attention to prevention for such patients, and actively treat them after sepsis to prevent them from further developing into severe sepsis. In this study, it was found that older age, coronary heart disease or diabetes, high risk of PSI at admission, administration of antibiotics, gram-negative bacteria, gram-positive bacterial infection or mixed infection of pathogens were independent risk factors for severe sepsis in patients with severe pneumonia. The results suggest that for

the elderly patients with severe pneumonia complicated with underlying diseases, we should formulate targeted prevention strategies and closely monitor the patient's condition in order to quickly identify signs of sepsis. The infection rate of Streptococcus pneumoniae is the highest in patients with severe pneumonia, and mixed infection is the second most common cause of community-acquired pneumonia (Chisti et al., 2021; Haggie, Barnes, Selvadurai, Gunasekera, & Fitzgerald, 2022). Our study supports the effect of pathogenic microorganisms on the severity of sepsis. Patients with severe sepsis should optimize the detection of pathogenic microorganisms before starting a combination of antibiotics. Antibiotics may increase the drug resistance of patients with severe pneumonia, so they are more cautious about their use. In the early stage of pneumonia, a variety of cytokines and inflammatory chemokines are produced in alveolar macrophages, which stimulate neutrophils to produce immune response (Goh et al., 2020). Severe pneumonia can induce immune cell infiltration, secondary immunity *in vivo*, promote the rapid release of cytokines and inflammatory chemokines, and induce pathological changes and necrosis of various tissues and organs (Gitonga, Wang, Yu, Wu, & Shen, 2020; Noguchi et al., 2019). At present, the most representative inflammatory cytokines include CRP, PCT, IL-6, Tumor Necrosis Factor-α (TNF- α) and so on. The excessive release of these factors can directly participate in the injury process of alveolar epithelial tissue. CRP secretion begins within 4-6 hours after infection or inflammatory stimulus and peaks within 36-50 hours. In asymptomatic patients with infection CRP may not change noticeably and lacks specificity (Kaneta et al., 2022). Therefore, actively exploring the serum indexes with high sensitivity and specificity is particularly important in early identification of severe pneumonia and improving prognosis. In this study, the serum SAA level of septic shock patients was noticeably higher compared to the control group, suggesting that SAA level is relevant to the initiation and development of septic shock. Furthermore, SAA is expected to be a monitoring index and therapeutic target for the dynamic development of septic shock. SAA is an acute phase reaction protein existing in plasma, and it is a commonly used inflammatory detection index in clinic, which is involved in immune response, lipid metabolism and inflammatory defense (Hermann et al., 2020). Levels of SAA are low in healthy humans, and bacterial or viral infections can cause elevated levels of SAA. The secretion of SAA by the liver is noticeably increased by the induction of IL-1, IL-6 and TNF-α, peaking at 8-12 hours and reaching levels up to 1000 times the normal value in severe cases (Malinverni et al., 2022). The content of SAA increases rapidly after infection, so dynamic monitoring of SAA levels is helpful for the early diagnosis of septic shock. Inflammation is a complex process that involves various signals that can contribute to the development of tumors and autoimmune diseases. Some scholars have detected the level of SAA in shock patients (Palma Medina et al., 2023). The results indicated that SAA in shock group was noticeably higher than that in other infection groups. The results of this study indicated that the levels

of lactic acid and serum SAA in the death group were noticeably higher than those in the survival group, suggesting that the levels of serum lactic acid and SAA can assist the clinical evaluation of the prognosis to some extent. Lactic acid is the metabolite of tissue hypoxia. Patients in septic shock often have insufficient effective circulating blood volume and inadequate systemic tissue perfusion, especially in the microcirculation, leading to tissue hypoxia, accumulation of metabolites such as lactic acid and multi-organ impairment (Rathmann, Jayne, Segelmark, Jönsson, & Mohammad, 2021). The study has found that with the passage of time, the lactate clearance rate is closely related to mortality (Samransamruajkit et al., 2021). The level of lactic acid in the early stage of admission has little significance for the evaluation of prognosis, and the clearance rate of lactic acid for 6 or 12 hours plays a more noticeable role in evaluating the condition and prognosis of patients with sepsis (Hermann et al., 2020). In this study, the predictive efficacy of SAA, BLA, and combined monitoring in predicting the prognosis of patients with severe pneumonia complicated with sepsis was analyzed using the ROC curve. Based on the results, the predictive efficiency of SAA, BLA and combined monitoring was analyzed using ROC curves. Our results indicated that the AUC of serum SAA and BLA were 0.831(95%CI = 0.738~0.924), 0.720(95%CI= = 0.600~0.840) and 0.909 (95%CI = 0.847~0.972) respectively, and the AUC of comminated diagnosis was 0.909. Predictive value was combination detection > SAA > BLA. This suggests that SAA and lactate are expected to be valid predictors of prognosis in patients with severe pneumonia complicated by sepsis, and that combined monitoring is of greater value. There are limitations to this study, including the fact that only one-time point was used to determine serum indicators. Furthermore, the sample size in this study was small and regional in nature, therefore further expansion of the sample size is needed to ensure the accuracy of the results.

5. Conclusion

This study highlights the critical prognostic value of multivariate logistic regression analysis combined with serum amyloid A (SAA) and lactic acid monitoring in patients with severe pneumonia-associated sepsis. These biomarkers, alongside robust statistical modeling, provide valuable insights into the severity of the condition, recovery trajectories, and potential outcomes. The ability to predict patient recovery based on biomarker trends and multivariate analyses allows healthcare providers to implement timely interventions, optimize clinical decision-making, and improve patient care. In the context of physical rehabilitation and sports medicine, the findings underscore the importance of early and precise prognostic evaluations in guiding recovery strategies. Elevated levels of SAA and lactic acid were associated with prolonged recovery times and reduced physical performance, emphasizing the need for personalized rehabilitation plans that address inflammation, metabolic recovery, and physical reconditioning. Patients with lower biomarker levels

demonstrated better functional outcomes and a greater capacity to engage in physical activity, highlighting the potential for biomarker-guided approaches to enhance rehabilitation outcomes. For athletes and physically active individuals recovering from severe pneumonia-associated sepsis, these findings are particularly significant. By integrating biomarker monitoring into rehabilitation protocols, clinicians can identify at-risk individuals, tailor recovery strategies, and promote a safe and effective return to physical activity. This approach not only aids in restoring baseline physical performance but also minimizes the long-term impact of sepsis on overall health and athletic capabilities. Future research should explore the long-term implications of biomarker-guided rehabilitation, particularly in terms of sustained physical performance, muscle strength, and cardiovascular health. Additionally, the potential for integrating these findings into sports medicine frameworks can expand the scope of recovery strategies, ensuring that individuals recovering from critical illnesses are supported holistically in their journey toward full functional and athletic recovery.

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