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Correlation between hemoglobin, albumin, lymphocyte, and platelet score and short-term mortality in critically ill patients

Chong Zhang[1,2,3,4,5†], Wenjin Peng[1,2,3,4,5†], Meng Ning[1,2,3,4,5†], Weiru Liang[6], Bin Su[1,2,3,4,5], Tingting Guo[1,2,3,4,5], Kun Hu[1,2,3,4,5], Wei Su[1,2,3,4,5], Yi Chen[1,2,3,4,5] and Yingwu Liu[1,2,3,4,5*]

Abstract

Background Hemoglobin, albumin, lymphocyte and platelet (HALP) score is derived from the counts of hemoglobin, albumin, lymphocytes, and platelets. It serves as a valuable tool for assessing both inflammation and nutritional status in critically ill patients. However, there hasn't been a specific study exploring the role of the HALP score in critically ill patients. Additionally, whether the HALP score exhibits an incremental effect on the Sequential Organ Failure Assessment (SOFA) score remains unknown.

Methods In this study, we used the Medical Information Mart for Intensive Care (MIMIC-IV) version 2.2 database to evaluate the predictive value of HALP score for critically ill patients. The primary outcome investigated was intensive care unit (ICU) death, and the secondary outcomes included in-hospital mortality, ICU length of stay (LOS), hospital LOS, and 28-day mortality.

Results We analyzed 20,083 critically ill patients. In logistic regression, a low HALP score (HALP score < 3.56) showed higher risk of ICU death (adjusted odds ratio: 1.41, 95% confidence interval [CI]: 1.25 to 1.59). Additionally, the HALP score improved the predictive ability of the SOFA score (ΔArea under curve: 0.009, $p < 0.001$). In Cox proportional hazards models, a low HALP score (HALP score < 3.2) was also associated with a higher risk of 28-day mortality (adjusted hazard ratio: 1.52, 95% CI: 1.33 to 1.74).

Conclusion HALP score is associated with short-term mortality. Additionally, HALP score showed an incremental effect on SOFA score in predicting short-term mortality.

Keywords Hemoglobin, albumin, lymphocyte and platelet score, Prognostic nutritional index, Sequential organ failure assessment score, Short-term mortality

†Chong Zhang, Wenjin Peng and Meng Ning contributed equally to this work.

*Correspondence:
Yingwu Liu
liuyingwu3zx@sina.com
[1]The Third Central Clinical College of Tianjin Medical University, Tianjin 300170, China
[2]Tianjin Key Laboratory of Extracorporeal Life Support for Critical Diseases, Tianjin 300170, China
[3]Artificial Cell Engineering Technology Research Center, Tianjin 300170, China
[4]Tianjin Institute of Hepatobiliary Disease, Tianjin 300170, China
[5]Department of Heart Center, The Third Central Hospital of Tianjin, No. 83, Jintang Road, Hedong District, Tianjin 300170, China
[6]State Key Laboratory of Experimental Hematology, Haihe Laboratory of Cell Ecosystem, Institute of Hematology & Blood Diseases Hospital, National Clinical Research Center for Blood Diseases, Chinese Academy of Medical Sciences & Peking Union Medical College, Tianjin 300020, China

Introduction

Inflammation and nutritional status are associated with the progression of illness in critically ill patients [1, 2]. Critically ill patients are at an elevated risk of malnutrition and short-term mortality due to inflammation and the catabolic state induced by stress. The hemoglobin, albumin, lymphocyte and platelet (HALP) score calculated from hemoglobin (HGB), albumin (ALB), lymphocyte counts, and platelet counts, can better assess the inflammation and nutritional status compared to the individual inflammation biomarker and nutrition risk score [3]. Recent studies have demonstrated that a low HALP score is associated with an increased risk of mortality for patients with tumors [4], recurrent stroke and long-term mortality for patients with acute ischemic stroke [5], and long-term mortality for the general population [6]. However, no study has specifically investigated the impact of the HALP score on short-term mortality in critically ill patients. Furthermore, prior research has indicated that a high prognostic nutritional index (PNI) is linked to lower Sequential Organ Failure Assessment (SOFA) scores and better short-term prognosis for critically ill patients [7]. Although SOFA scores, which consider the physiological state of each organ, and inflammation biomarkers showed better predictive ability for critically ill patients [8], it remains unclear whether the nutrition risk score has an incremental effect on the SOFA score, particularly in relation to the new biomarker of HALP score.

In this study, we used the Medical Information Mart for Intensive Care IV (MIMIC-IV) 2.2 database to investigate the following questions: (1) the association between HALP score and short-term mortality for critically ill patients; (2) comparing the incremental effect of the HALP score and PNI on the predictive ability for SOFA score.

Methods

Study population

This is a retrospective study that sourced data from MIMIC-IV 2.2 database. The MIMIC-IV database, managed by the Massachusetts Institute of Technology, encompasses medical records from the Beth Israel Deaconess Medical Center (Boston, MA, USA) spanning the years 2008 to 2019. One of the authors involved in this study (C.Z.) had authorized access to and permission for utilizing the database (Record ID 51185766). Importantly, the MIMIC-IV database is publicly accessible without requiring ethical approval statements or informed consent.

We conducted an analysis on a total of 73,181 critically ill patients, aged 18 years or above. The following patients were excluded from the study: (1) patients who were not initially admitted to the intensive care unit (ICU); (2) patients with missing HALP score data. Finally, we analyzed the data of 20,083 patients (Fig. 1).

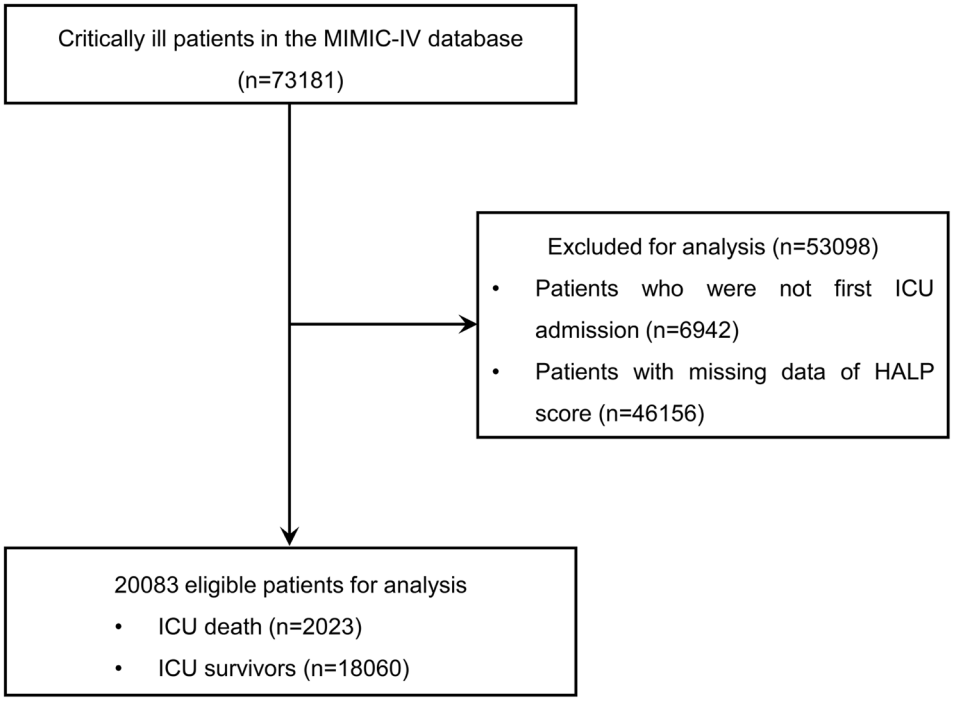

Fig. 1 Study flow chart. Abbreviations: HALP, hemoglobin, albumin, lymphocyte and platelet; ICU, intensive care unit; MIMIC-IV, Medical Information Mart for Intensive Care IV

Study variables

PostgreSQL Version 14.5 was used to extract data from the MIMIC-IV database. This study included the following covariates: (1) demographic characteristics, including age, sex, length of stay (LOS) in ICU, SOFA score, ICU types; (2) medical history, including hypertension (HTN), acute myocardial infarction (AMI), congestive heart failure (CHF), cerebrovascular disease (CVD), chronic lung disease (CLD), chronic kidney diseases (CKD), diabetes mellitus (DM); (3) vital signs, including systolic blood pressure (SBP), diastolic blood pressure (DBP), heart rate (HR); (4) laboratory values, including, ALB, lymphocyte count, HGB, platelet count, white blood cell count (WBC), HALP score, PNI, systemic immune-inflammation index (SII), estimated glomerular filtration rate (eGFR), glucose (Glu). The HALP score was calculated using the following equation: HGB (g/L) × ALB (g/L) × lymphocyte (10^9/L)/platelet (10^9/L) [9]. The PNI was calculated as ALB (g/L) + 5 × lymphocyte count (10^9/L). The eGFR was calculated using the Chronic Kidney Disease Epidemiology Collaboration equation [10]. The SII was calculated using the equation: platelet (10^9/L) × neutrophils (10^9/L)/lymphocytes (10^9/L) [11]. The SOFA score evaluates the severity of organ dysfunction across six systems: respiratory, cardiovascular, hepatic, renal, coagulation, and neurological. Each system is scored from 0 to 4 based on dysfunction severity, with higher scores indicating greater dysfunction [8].

Definitions of outcomes

The primary outcome was ICU death, and the secondary outcomes included in-hospital mortality, ICU LOS, hospital LOS, 28-day mortality. After excluding the data of patients who experienced in-hospital mortality, there were 16,989 patients who survived to discharge. 28 days survival information for discharged patients were sourced from the United States Social Security Death Index in the MIMIC-IV database.

Statistical analysis

Continuous variables that conform to a normal distribution are represented as the mean ± standard deviation (SD). Conversely, continuous nonparametric variables are summarized using median values and interquartile ranges (from the 25th to the 75th percentile). Categorical variables are depicted as frequencies and percentages. To assess the differences between groups in terms of continuous and categorical variables, appropriate statistical tests such as unpaired Student's *t*-test, Mann–Whitney U-test, and chi-squared test (χ^2 test) were applied.

Given that the HALP score do not follow a normal distribution, a logarithmic transformation was applied to achieve data normality, which was then used for subsequent analyses. Univariate and multivariable logistic regression were used to explore the relationship between HALP score and outcomes. Logistic regression models with five knots in restricted cubic splines (RCS) models were used to explore the dose-response relationship between HALP score and ICU-death, and Cox regression models with five knots in RCS models were used to explore the relationship between HALP score and 28-day mortality. Multiple linear regression was used to estimate the relationship between HALP score and ICU LOS and hospital LOS. Spearman's correlation analysis was used to test the relationship between SII and HALP score after logarithmic transformation. In the sensitivity analysis with inverse probability of treatment weighting (IPTW), the relationship between HALP score and ICU death was estimated after excluding the following patients: (1) death within 24 h on admission; (2) death within 48 h on admission; (3) ICU LOS less than 24 h on admission; (4) ICU LOS more than 30 days. In receiver operating characteristic (ROC) curve analysis, the area under the curve (AUC) was used to determine the incremental effect of the HALP score on SOFA score for ICU death. Additionally, AUC was used to compare the predictive value of HALP score combined with SOFA score and PNI combined with SOFA score. Kaplan–Meier survival analysis and Cox proportional hazards models were used to estimate the relationship between the HALP score and 28-day mortality. Adjusted variables of statistical significance between the ICU death group and ICU survivor group, included age, ICU types, eGFR, Glu, SBP, DBP, HR, SOFA score, HTN, AMI, CHF, CVD, CLD, CKD, and DM. Subgroup analyses were used to show the relationship between the HALP score and ICU death among subgroups (including age, ICU types, gender, HTN, AMI, CHF, CLD, DM). All statistical analyses were performed using Stata version 17.0 (StataCorp, College Station, TX, USA), with statistical significance defined as a two-tailed p-value < 0.05.

Results

Baseline characteristics

A total of 20,083 critically ill patients were included in this study. Among them, 2,023 patients (10.1%) experienced ICU death, while 3,094 patients (15.4%) had in-hospital mortality. Compared to the ICU survivor group, the ICU death group exhibited lower HALP scores, PNI, higher SII levels, elevated SOFA scores, and a greater proportion of comorbidities (as shown in Table 1). The baseline characteristics between HALP score and missing values groups were shown in Table S1.

Relationship between HALP score and outcomes

After applying a logarithmic transformation to the HALP score, RCS with logistic regression analysis was conducted. The findings revealed a negative association

Table 1 Baseline characteristics between the ICU survival and ICU death groups

Categories	ICU survival group *n* = 18,060	ICU death group *n* = 2023	*P* value
Demographic characteristics			
Age, year	64 ± 18	69 ± 15	< 0.001
Sex, male, n (%)	10,248 (56.7)	1118 (55.3)	0.20
SOFA score	4.0 (2.0, 6.0)	8.0 (5.0, 10.0)	< 0.001
ICU LOS, days	2.0 (1.1, 3.9)	3.9 (1.8, 8.1)	< 0.001
Comorbidities, n (%)			
AMI	2779 (15.4)	429 (21.2)	< 0.001
Renal disease	4146 (23.0)	593 (29.3)	< 0.001
CLD	4402 (24.4)	566 (28.0)	< 0.001
HTN	10,935 (60.5)	1307 (64.6)	< 0.001
DM	5577 (30.9)	673 (33.3)	0.028
CVD	2690 (14.9)	404 (20.0)	0.002
Dementia	1496 (11.4)	173 (11.1)	< 0.001
CHF	5066 (28.1)	727 (35.9)	< 0.001
Laboratory tests in the first 24 h			
eGFR, mL/min/1.73m^2	60.4 (31.8, 90.5)	36.4 (19.1, 66.0)	< 0.001
Glu, mg/dL	147.0 (117.0, 202.0)	169.0 (128.0, 241.0)	< 0.001
SII	1544 (726, 3179)	1920 (900, 3895)	< 0.001
PNI	41.0 (35.0, 47.0)	37.0 (31.0, 43.0)	< 0.001
HALP score	21.6 (11.5, 38.1)	17.3 (8.9, 32.1)	< 0.001
HALP score (Log)	3.0 ± 0.9	2.8 ± 1.0	< 0.001
Albumin, g/L	34.0 (29.0, 39.0)	31.0 (25.0, 36.0)	< 0.001
HGB, mg/dL	11.4 (9.8, 13.2)	11.0 (9.4, 12.7)	< 0.001
Plt, K/μL	217.0 (152.0, 292.0)	201.0 (128.0, 284.0)	< 0.001
Lymphocyte count, K/μL	1.2 (0.7, 1.8)	1.0 (0.6, 1.7)	< 0.001
WBC, K/μL	12.0 (8.4, 17.0)	15.1 (9.8, 21.3)	< 0.001
ICU type, n (%)			0.002
CVICU	990 (5.5)	80 (4.0)	
CCU	1764 (9.8)	222 (11.0)	
MICU/SICU	12,774 (70.7)	1466 (72.5)	
NSICU	1121 (6.2)	98 (4.8)	
TSICU	1411 (7.8)	157 (7.8)	
Vital signs			
HR, bpm	86.0 (75.0, 98.0)	90.0 (77.0, 104.0)	< 0.001
SBP, mmHg	118.0 (108.0, 131.0)	111.0 (102.0, 124.0)	< 0.001
DBP, mmHg	64.0 (57.0, 72.0)	60.0 (53.0, 68.0)	< 0.001

Abbreviations: AMI, acute myocardial infarction; CHF, congestive heart failure; CLD, chronic pulmonary disease; CVD, cerebrovascular disease; DBP, diastolic blood pressure; DM, diabetes mellitus; eGFR, estimated glomerular filtration rate; Glu, glucose; HALP, hemoglobin, albumin, lymphocyte and platelet; HGB, hemoglobin; HR, heart rate; HTN, hypertension; ICU, intensive care unit; LOS, length of stay; Plt, platelet; PNI, prognostic nutrition index; SBP, systolic blood pressure; SII, systemic immune-inflammation index; SOFA, Sequential Organ Failure Assessment; WBC, white blood cell

between the HALP score and ICU death, with a threshold value of 3.56 (as shown in Fig. 2A). The HALP score was then transformed into a binary variable according to the threshold value 3.56. In the subsequent logistic regression models, it was evident that low HALP score was associated with a higher risk of ICU death (adjusted odds ratio [OR] 1.41, 95% confidence interval [CI] 1.25 to 1.59), in-hospital mortality (adjusted OR 1.41, 95% CI: 1.27 to 1.57), ICU LOS (adjusted Coefficient – 0.49, 95% CI: -0.56 to -0.41), and hospital LOS (adjusted Coefficient – 1.40, 95% CI: -1.58 to -1.23) (as shown in Table 2). Moreover, HALP score change that defined by the log of difference between the first HALP score and the mean HALP score during hospitalization was associated with higher risk of ICU death, which was statistical significance in the lowest tertile of HALP score change (0.14–4.38) (Table S2). In Spearman's correlation analysis, SII was used to evaluate the level of inflammation and it was found that the HALP score showed a negative correlation with SII (correlation coefficient was – 0.691, $p < 0.001$) (as shown in Figure S1). In sensitivity analysis IPTW, the relationship between the HALP score and ICU death was estimated, and it was found that a low HALP score remained associated with a high risk of ICU death even after excluding specific patients (as shown in Figure S2).

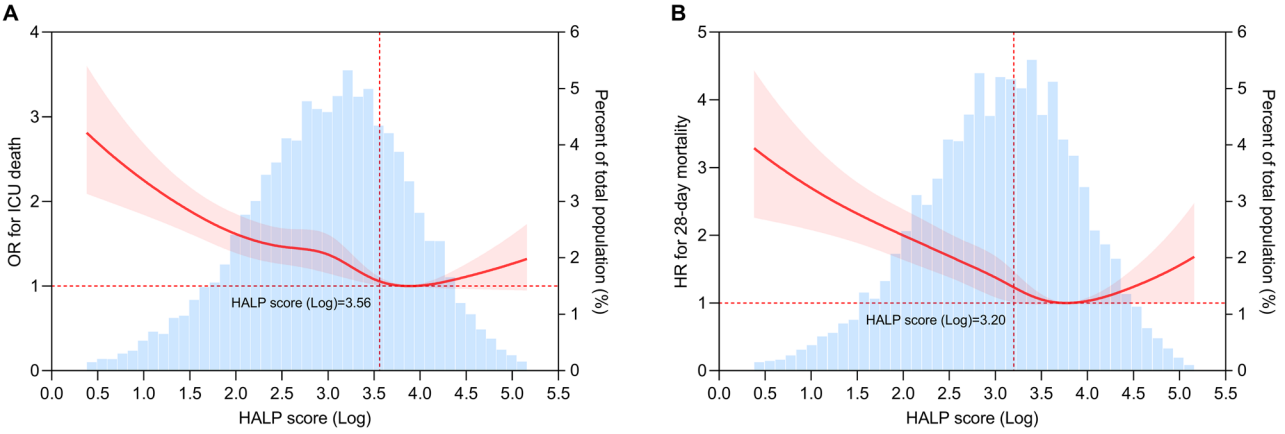

Fig. 2 Relationship between HALP score and ICU-death and 28-day mortality. **A**: Relationship between HALP score and ICU-death in RCS with multivariable logistic regression; **B**: Relationship between HALP score and 28-day mortality in RCS with multivariable Cox proportional hazards model. The horizontal dotted red line indicates the OR/HR of 1.0. The vertical dotted red line indicates the threshold values of the HALP score (Log) in RCS models. Blue histogram represents the percent of density distribution of the HALP score (Log). Heavy central line represents OR/HR with shaded ribbons denoting 95% CI. Note: HALP score is presented after logarithmic transformation. Abbreviations: HALP, hemoglobin, albumin, lymphocyte and platelet; HR, hazard ratio; ICU, intensive care unit; OR, odds ratio; RCS, restricted cubic splines

Table 2 Association between HALP score (log) and outcomes

Outcomes	Crude model		Adjusted model	
	OR/Coef. and 95%CI	*P* value	OR/Coef. and 95%CI	*P* value
ICU death	1.38 (1.23 to 1.54)	< 0.001	1.41 (1.25 to 1.59)	< 0.001
In-hospital mortality	1.37 (1.25 to 1.50)	< 0.001	1.41 (1.27 to 1.57)	< 0.001
ICU LOS	-0.37 (-0.45 to -0.30)	< 0.001	-0.49 (-0.56 to -0.41)	< 0.001
Hospital LOS	-1.32 (-1.49 to -1.14)	< 0.001	-1.40 (-1.58 to -1.23)	< 0.001

Abbreviations: CI, confidence interval; Coef., coefficient; HALP, hemoglobin, albumin, lymphocyte and platelet; ICU, intensive care unit; LOS, length of stay; OR, odds ratio

Note: Covariates for the adjusted model are described in the "Statistical Analysis" section

Table 3 Added value of HALP score for SOFA score in predicting ICU death

Models	AUC and 95% CI	*P* value[a]	*P* value[b]
Model 1: SOFA score	0.755 (0.744 to 0.766)	Ref.	—
Model 2: SOFA score + PNI	0.761 (0.750 to 0.771)	< 0.001	Ref.
Model 3: SOFA score + HALP score (Log)	0.764 (0.753 to 0.775)	< 0.001	0.002

Abbreviations: AUC, area under curve; CI, confidence interval; HALP, hemoglobin, albumin, lymphocyte and platelet; ICU, intensive care unit; PNI, prognostic nutritional index; SOFA, Sequential Organ Failure Assessment

Note: [a] the *p* values show the statistical difference for ΔAUC of Model 2–3 compared with Model 1 (Ref.) respectively; [b] the *p* values show the statistical difference for ΔAUC of Model 3 compared with Model 2 (Ref.)

Additionally, SOFA score showed a negative correlation with HALP score in Spearman's correlation analysis (correlation coefficient was − 0.132, $p = 0.001$). Furtherly, the incremental effect of the HALP score on the SOFA score for predicting ICU death was tested, and the results showed that the HALP score improved the predictive ability of the SOFA score (ΔAUC 0.009, $p < 0.001$), as shown in Table 3. The predictive ability of the SOFA score combined with PNI and the SOFA score combined with HALP score was compared, and it was found that the SOFA score combined with HALP score showed a higher predictive ability for ICU death compared to the SOFA score combined with PNI (ΔAUC 0.003, $p = 0.002$).

Association between HALP score and 28-day mortality

In survival analysis, data of 16,989 patients who were followed-up for a 28-day period were analyzed, during which 982 patients experienced 28-day mortality. Using RCS with Cox proportional hazards models, a threshold value of 3.2 was identified for the HALP score, below which patients faced a higher risk of 28-day mortality (as shown in Fig. 2B). Specifically, in the Cox proportional hazards models, a low HALP score (HALP score < 3.2) showed a higher risk of 28-day mortality (adjusted hazard ratio 1.52, 95% CI: 1.33 to 1.74). Furthermore, Kaplan–Meier survival analysis demonstrated that patients with a low HALP score had a higher risk of 28-day mortality compared to those with a high HALP score (HALP

score ≥ 3.2) (Log-rank test, $\chi^2 = 684.8$, $p < 0.001$), which is consistent with the Cox survival plot, as shown in Fig. 3A and B.

Subgroup analysis

The relationship between the HALP score and ICU death across various subgroups, including age, ICU types, gender, HTN, AMI, CHF, CLD, and DM was analyzed. Notably, a low HALP score was associated with a higher risk of ICU death in different subgroups, and there was no interaction effect between the HALP score and these subgroups, as shown in Fig. 4.

Discussion

In this study, a lower HALP score was associated with an increased risk of short-term mortality. Additionally, the HALP score showed an incremental effect on the SOFA score for predicting short-term mortality, and showed higher predictive ability than the SOFA score combined with PNI. These results supported the important roles of inflammation and nutritional status in the prognosis of critically ill patients, suggesting that the HALP score may provide better risk stratification compared to traditional biomarkers.

HALP score, calculated from HGB, ALB, lymphocyte counts, and platelet counts could better estimate the inflammation and nutritional status for patients suffering from cancer, patients who had suffered acute ischemic stroke, and the general population compared to individual inflammation factor and nutritional risk scores [3]. Xu et al. included 28 studies involving 13,038 patients with solid tumors, and they found that a lower HALP score was associated with an increased risk of mortality [3]. Tian et al. studied 1,337 patients who had suffered acute ischemic stroke, to explore the association between the HALP score and poor outcomes (including short-term mortality and new stroke event), and they found that a lower HALP score was associated with an increased risk of poor outcomes [5]. Pan et al. studied 21,578 persons from the general population, and they found that a lower HALP score was independently associated with an increased risk of cardiovascular disease and mortality [6]. The above studies showed that HALP score was associated with poor outcomes for patients with solid tumors, patients who had suffered acute ischemic stroke, and the general population, while patients who had been admitted to different ICU types were all at a higher risk of experiencing acute inflammation response and poor nutritional status during hospitalization. The HALP score may also be associated with short-term mortality for critically ill patients. However, there has been no study focused on the impact of HALP score on critically ill patients. In this study, we found that a low HALP score was associated with a higher risk of short-term mortality compared to a high HALP score. Several pathophysiological mechanisms could explain this phenomenon. Firstly, a HALP score that included lower HGB, lower ALB, and lower lymphocyte counts

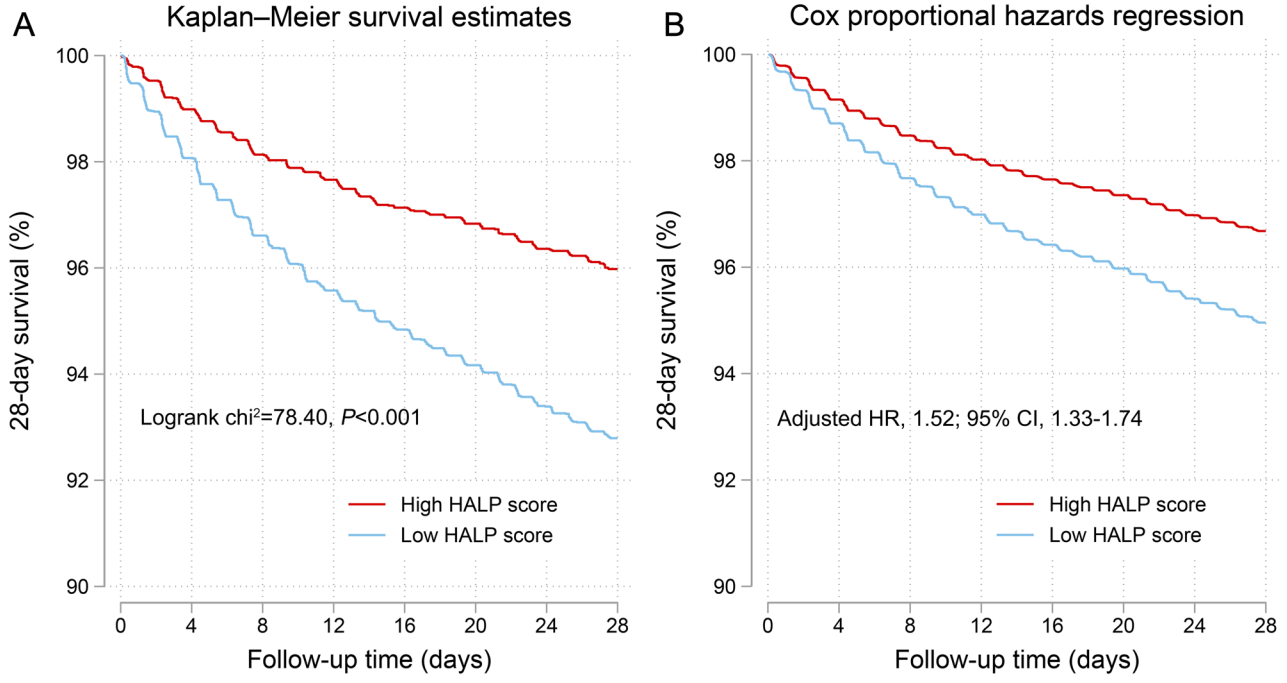

Fig. 3 Association between HALP score and 28-day mortality. **A**: Kaplan–Meier survival analysis for HALP score and 28-day mortality; **B**: Cox survival plot for HALP score and 28-day mortality. Note: HALP score is presented after logarithmic transformation. Abbreviations: CI, confidence interval; HALP, hemoglobin, albumin, lymphocyte and platelet; HR, hazard ratio

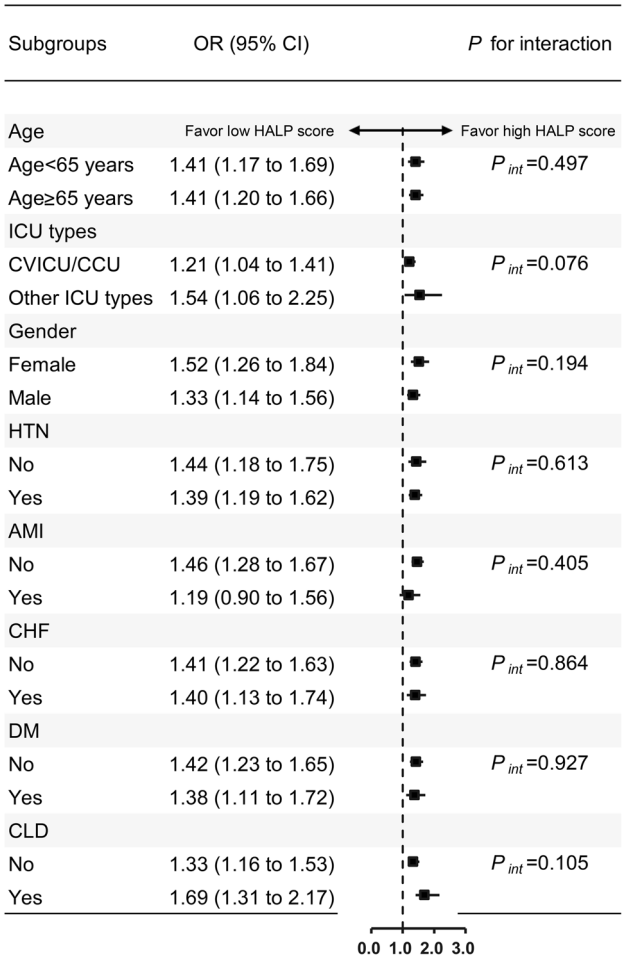

Fig. 4 Subgroup analysis for the association between HALP score and ICU death among different subgroups. Abbreviations: AMI, acute myocardial infarction; CCU, coronary care unit; CHF, congestive heart failure; CI, confidence interval; CLD, chronic pulmonary disease; CVICU, cardiovascular intensive care unit; DM, diabetes mellitus; HALP, hemoglobin, albumin, lymphocyte and platelet; HR, hazard ratio; HTN, hypertension; ICU, intensive care unit; OR, odds ratio

could reflect the nutritional status of critically ill patients, and malnutrition is associated with poor outcomes [12]. Secondly, the HALP score could also reflect the severity of the inflammation response in critically ill patients. Impaired immune state and metabolic status resulted in decreased lymphocyte counts and impaired lymphocytic immunity [13]. Lower lymphocyte counts mean an increase in the level of cytokines released from monocyte/macrophage resulting in lymphocyte depletion [13]. This plays an important role in the elimination and repair of inflammation [14], and increased platelet counts could reflect the acute inflammation response in patients [14]. Considering the above underlying biological mechanisms for HALP score in critically ill patients and the finding that a low HALP score independently predicts short-term mortality, it appears that HALP score may be a better biomarker compared to traditional biomarkers.

Additionally, previous studies have found that lower PNI was associated with higher SOFA scores in critically ill patients [15, 16]. Huang et al. followed 1,180 critically ill patients with AMI and found that PNI could enhance the predictive ability of short-term mortality in relation to SOFA scores [15]. Wei et al. included 395 patients with severe COVID-19, and they found that lower PNI was associated with higher SOFA score and higher mortality [16]. However, no study has directly compared the additional value of the HALP score to SOFA scores, nor has it compared the predictive ability of SOFA scores with that of PNI.

In this study, we found that the HALP score provides added value when combined with SOFA scores and exhibits superior predictive ability for SOFA scores compared to PNI. Critically ill patients often experience an inflammatory response associated with short-term mortality. The HALP score considers both nutritional status and the severity of inflammation, making it a better predictor of poor outcomes than the combination of SOFA scores and PNI. These results also indicate the essential role of nutritional status and inflammation in the prognosis of critically ill patients rather than merely focusing on the severity of multiple organ failure indicated by SOFA scores. Combining the HALP score with SOFA scores may offer a more comprehensive evaluation of critical illness severity and has potential applications in clinical practice.

While this study represents the first exploration of the HALP score in critically ill patients and its added value in predicting short-term mortality compared to the SOFA score, there are several limitations to consider. Firstly, as these results are based on the single-center MIMIC-IV database, their generalizability across ethnicities and healthcare settings is uncertain, requiring validation in diverse populations and clinical contexts. Secondly, due to the MIMIC-IV design, we are unable to accurately determine the admission route of critically ill patients, and future studies are needed to address it. Thirdly, ICU patients often present with varying conditions, including different illnesses, ICU stays, and survival times, which can significantly affect lymphocyte, platelet, and albumin levels. Although multivariable and IPTW sensitivity analyses were performed to reduce confounding, unmeasured or residual confounding may persist.

Conclusion

In conclusion, the HALP score was associated with short-term mortality in critically ill patients and enhanced the SOFA score's predictive ability. Combined, the HALP score and SOFA score outperformed the SOFA score with PNI. These findings suggest the HALP score's potential in risk stratification for short-term mortality, warranting further studies to explore targeted therapies.

Abbreviations

AMI	Acute myocardial infarction
CHF	Congestive heart failure
CLD	Chronic lung disease
CVD	Cerebrovascular disease
DBP	Diastolic blood pressure
DM	Diabetes mellitus
eGFR	Estimated glomerular filtration rate
Glu	Glucose
HALP	Hemoglobin, albumin, lymphocyte and platelet
HGB	Hemoglobin
HR	Heart rate
HTN	Hypertension
ICU	Intensive care unit
LOS	Length of stay
MIMIC-IV	Medical Information Mart for Intensive Care IV
Plt	Platelet
PNI	Prognostic nutrition index
SBP	Systolic blood pressure
SII	Systemic immune-inflammation index
SOFA	Sequential Organ Failure Assessment
WBC	White blood cell

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s41043-025-00759-9.

Supplementary Material 1

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Author contributions

Conception and design of the research: Chong Zhang, Wenjin Peng, Meng Ning, Yingwu Liu. Acquisition of data: Chong Zhang, Wenjin Peng, Meng Ning. Analysis and interpretation of the data: Weiru Liang, Bin Su, Tingting Guo, Kun Hu, Wei Su, Yi Chen. Statistical analysis: Chong Zhang, Wenjin Peng, Meng Ning, Weiru Liang, Yingwu Liu. Writing of the manuscript: Chong Zhang, Wenjin Peng, Meng Ning, Yingwu Liu. Critical revision of the manuscript for intellectual content: Weiru Liang, Bin Su, Tingting Guo, Kun Hu, Wei Su, Yi Chen, Yingwu Liu. All authors read and approved the final draft.

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Data availability

No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate

The human participant studies were conducted in accordance with ethical standards set by the institutional and/or national research committee, as well as the 1964 Helsinki declaration. Approval for use of the MIMIC-IV 2.2 database was granted by both Massachusetts Institute of Technology and Beth Israel Deaconess Medical Center review committees. As the data is publicly available within the MIMIC-IV 2.2 database, no ethical approval statement or informed consent was required for this study. All patient data used has been de-identified and the study complies with relevant data protection and privacy regulations.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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