

Mortality rate analysis of patients on invasive mechanical ventilation in the intensive care unit on day 28

SONG ZHONG, HAOHAO YANG and ZHEREN ZHAO

Department of Intensive Care Unit, Renhe Hospital, Shanghai 200431, P.R. China

Received February 1, 2024; Accepted May 31, 2024

DOI: 10.3892/br.2024.1828

Abstract. Outcomes in patients receiving invasive mechanical ventilation (IMV) are currently unclear. The present study aimed to explore the prognostic factors of the mortality rate on day 28 in patients treated in the intensive care unit (ICU) and undergoing IMV. The IMV Mortality Prediction Score (IMPRES) of 129 patients in the ICU receiving IMV after emergency (or selective) endotracheal intubation from March 2018 to August 2020 was calculated. The patients were divided into survival (n=73) and death groups (n=56) on day 28. The predictive factors of independent and combined mortality rates were determined using a receiver operating characteristic (ROC) curve and the area under the ROC curve (AUC). The AUC of the IMPRES for predicting patient death on day 28 was 0.785 (95% confidence interval (CI): 0.704-0.864, $P<0.01$). When the IMPRES cut-off was 4.50, the Youden index was at its maximum (0.487) with a sensitivity of 85.7% and a specificity of 63.0%. The AUC of the ventilator use time (days) at 12.5 days cut-off was 0.653 (95% CI: 0.56-0.746, $P<0.01$), the Youden index was 0.235 with a sensitivity of 52.1% and a specificity of 71.4%. The AUC of the IMPRES combined with the duration of ventilator use was 0.856 (95% CI: 0.789-0.922, $P<0.001$), the Youden index was 0.635 with a sensitivity of 84.9% and a specificity of 78.6%. The IMPRES was observed to be the main factor influencing the mortality

rate of patients receiving IMV at the ICU on day 28, and the IMPRES combined with the duration of ventilator use had a significant predictive value for the 28-day mortality rates of these patients.

Introduction

Invasive mechanical ventilation (IMV) is one of the most critical methods for determining patient outcomes in the Intensive Care Units (ICUs) (1). IMV is frequently used to treat patients with severe injuries, poisoning, infectious diseases, neuromuscular diseases, chronic obstructive pulmonary disease (COPD) and interstitial lung diseases (2-4). IMV is associated with a mortality rate of up to 13.1-51.0% (5-7). Although IMV is helpful to decrease the mortality rate, the ultimate patient outcomes often do not change significantly. When patients are admitted to the ICU, attending physicians must quickly decide whether to initiate IMV, as time is of the essence. For this purpose, the IMV Mortality Prediction Score (IMPRES) may represent a good method to help physicians with decision-making (8,9). IMPRES is a comprehensive index based on various clinical factors that have been observed to be associated with the mortality rate in ICU patients.

IMPRES considers factors such as patient age, reasons for ICU admission, the severity of illness as measured by scores such as the Acute Physiology and Chronic Health Evaluation (APACHE)II or III score, and the number of days the patient has been on mechanical ventilation (10-12). By assessing these factors, IMPRES can provide physicians with a valuable tool to estimate the likelihood of patient survival. Furthermore, it helps to guide decision-making regarding treatment options and care goals. However, the predictive value of the IMPRES has remained to be defined. Therefore, the present study aimed to explore the predictive value of the IMPRES and the duration of IMV use for the mortality rate in patients with IMV use on day 28.

Patients and methods

Patients. The present study was a retrospective cross-sectional cohort study conducted in a single medical center. All data were obtained from the patient information database of the Department of ICU of Renhe Hospital (Shanghai, China) between March 2018 and August 2020. A total of 129 patients were admitted to the ICU of the hospital and received IMV

Correspondence to: Dr Song Zhong, Department of Intensive Care Unit, Renhe Hospital, 1999 Changjiang West Road, Baoshan, Shanghai 200431, P.R. China
E-mail: zhong19742006@126.com

Abbreviations: IMV, invasive mechanical ventilation; ICU, intensive care unit; IMPRES, IMV Mortality Prediction Score; ROC, receiver operating characteristic; AUC, area under the ROC curve; CI, confidence interval; COPD, chronic obstructive pulmonary disease; SOFA, sequential organ failure assessment; APACHEII, Acute Physiology and Chronic Health Evaluation II; RR, respiratory rate; SaO₂, oxygen saturation; SOFA, Sequential Organ Failure Assessment; HR, heart rate; MAP, mean arterial pressure; S.D, standard deviation; OS, overall survival

Key words: invasive mechanical ventilation, mortality prediction score, mortality, intensive care units, predictors

over this period. The inclusion criteria were as follows: i) Age >18 years; ii) deterioration of the patient's condition despite being active; iii) disturbance of consciousness; iv) aberrant breathing pattern, including respiratory rate (RR) >35-40/min or <6-8/min, abnormal breathing rhythm, and weak or absent spontaneous breathing; v) severe ventilation and oxygenation disturbances revealed by blood gas analysis or arterial partial pressure of <50 mmHg despite full oxygen therapy; vi) progressive rise in arterial partial pressure of carbon dioxide; and vii) progressive decrease in blood pH. The exclusion criteria were as follows: i) Transfer to the routine resuscitation of the intensive care medicine department after surgery; ii) intubation for mechanical ventilation to treat cardiac arrest; iii) patients who refused treatment and were self-discharged. The study protocol was reviewed and approved by the Ethics Committee of Shanghai Renhe Hospital (Shanghai, China; approval no. KY2022-01). Written informed consent was obtained from the patients that were willing to provide their medical records. Data were collected following international Conventions and guidelines on research involving human subjects, such as the Declaration of Helsinki.

Data collection. The present study and data collection were performed by the ICU specialists. Data were obtained from medical records, medical histories and telephone follow-up records. They included the anonymized name, which was recorded and given a code number, age, sex, underlying diseases, Sequential Organ Failure Assessment (SOFA) score (13), Acute Physiology and Chronic Health Evaluation II (APACHEII) scores (14) at admission and before incubation, analgesia or sedation drugs use and vasopressor use. The RR, heart rate (HR), oxygen saturation (SaO₂), systolic blood pressure, diastolic pressure, mean arterial pressure (MAP) and duration of ventilator use (days) on day 28 in the ICU were recorded.

IMPRES evaluation. After collecting the above data, the individual IMPRES following the literature descriptions (8) was calculated based on parameters provided in Table I.

Outcome classification. Patients who survived for 28 days in the ICU were assigned to the live group and those who had deceased to the dead group. Critical factors for survival and death were determined and compared.

Statistical analysis. Continuous variables are presented as the mean \pm standard deviation (SD) or the median with interquartile ranges (IQR). Categorical variables are presented as percentages and frequencies. The t-test and χ^2 test were used to compare continuous and categorical variables, respectively. Multivariate Cox proportional hazards regression analysis was used to determine the most impactful factors for model construction. A receiver operating characteristic curve (ROC) analysis was performed and the area under the ROC curve (AUC) was calculated to determine the most impactful factors for predicting survival on day 28 in the ICU. The Kaplan-Meier curves with the log-rank test were used to compare overall survival (OS) on day 28 in the ICU. All statistical analyses were performed using SPSS version 21.0 (IBM Corp.). $P < 0.05$ was considered to indicate statistical significance.

Table I. Clinical parameters and Invasive Mechanical Ventilation Mortality Prediction Score of patients.

Variable	Score
Age 70 years	1.6
Pulmonary edema	-0.5
COPD	-0.6
Interstitial lung disease	11.9
Acute kidney injury	1.7
Sepsis	2.2
Metabolic encephalopathy	-0.3
Neurodegenerative disease	-0.2
ICU-level monitoring required	16.7
Type III pulmonary failure	-0.3
Heart failure	-0.7
Lung cancer	3.7
Cardiac arrest	1.9
Lack of treatment opportunities to prolong survival	2.3
Serious comorbidities (at least one)	2.3
Expected survival time is <6 months	3
Permanent organ failure	2.4
Despite benefit from treatment, little chance of recovery	1.69
High cost of treatment to benefit	-0.3
End stage of chronic diseases and malignancies	2.8

COPD, chronic obstructive pulmonary disease; ICU, intensive care unit.

Results

Clinicopathological characteristics. A total of 129 patients who received IMV treatment in the ICU were enrolled in the present study. Their clinicopathological characteristics are presented in Table II. This study included 70 males and 59 females. The patients were divided into dead and live groups based on their statuses on day 28 in the ICU, and the cohort included 56 dead and 73 live cases. The median age of the dead and live groups was 85.0 years (range, 34-101 years) and 81.0 years (range, 24-100 years, Table II), respectively. Compared to the patients in the dead group, patients in the live group had a significantly lower APACHEII score at intubation, as well as SOFA and IMPRES scores ($P < 0.01$). By contrast, there were no marked differences in age, sex and APACHEII scores at admission between the two groups ($P > 0.05$). There were no significant differences ($P = 0.058$) between the intubation rate in the live group (69.9%, 51/73) and the dead group (53.6%, 30/56) in the first 24 h of admission. The average ICU hospitalization time (31 days) in the live group was significantly longer than that in the dead group (20 days; $P = 0.002$) because of early death by day 28 in the ICU in the latter group.

The distribution of major diseases upon ICU admission was reviewed (Table III). The results indicated that 69 patients (53.5%) had lung infections when they were admitted to the ICU. The next most common conditions were cerebral infarction ($n=15$, 11.6%), followed by septic shock ($n=12$,

Table II. Clinicopathological characteristics of patients receiving invasive mechanical ventilation treatment in the ICU on day 28.

Variable	Dead (n=56)	Live (n=73)	z/χ^2	P-value
Age, years	85.00 (75.25, 90.00)	81.00 (69.50, 87.00)	-1.760	0.078
APACHEII score at admission	29.50 (22.00, 33.75)	26.00 (22.00, 31.50)	-1.432	0.157
APACHEII score at intubation	33.00 (30.25, 36.75)	28.00 (24.50, 32.50)	-3.901	<0.001
Sofa score	12.00 (10.00, 15.00)	10.00 (7.50, 12.00)	-3.025	0.002
IMPRES	6.30 (4.60, 8.53)	3.80 (1.60, 5.70)	-5.548	<0.001
Male sex	30 (53.60)	40 (54.80)	0.019	0.890
Intubation in 24 h	30 (53.60)	51 (69.90)	3.600	0.058
Time at ICU, days	19.50 (11.50, 28.00)	31.00 (15.50, 46.00)	-3.066	0.002

Values are expressed as n (%) or the median (interquartile range). IMV, invasive mechanical ventilation; ICU, intensive care unit; APACHEII, Acute Physiology and Chronic Health Evaluation II; SOFA, Sequential Organ Failure Assessment; IMPRES, IMV Mortality Prediction Score.

Table III. Main disease distribution on admission to the intensive care unit.

Disease	n (%)
Lung infection	69 (53.5)
Cerebral infarction	15 (11.6)
Septic shock	12 (9.3)
Gastrointestinal bleeding	8 (6.2)
Hyperosmolar coma	5 (3.9)
COPD	3 (2.3)
Cerebral hemorrhage	3 (2.3)
Myocardial infarction	3 (2.3)
Sleeping pill poisoning	2 (1.6)
Cervical spine injury	2 (1.6)
Traumatic brain injury	1 (0.8)
Chest trauma	1 (0.8)
Heat stroke	1 (0.8)
Heart failure	1 (0.8)
Pneumothorax	1 (0.8)
Lung cancer	1 (0.8)
Renal failure	1 (0.8)

COPD, chronic obstructive pulmonary disease.

9.3%), gastrointestinal bleeding (n=8, 6.2%), hyperosmolar coma (n=5, 3.9%), COPD (n=3, 2.3%), cerebral hemorrhage (n=3, 2.3%), myocardial infarction (n=3, 2.3%), sleeping pill poisoning (n=2, 1.6%) and cervical spine injury (n=2, 1.6%). Other conditions included chest trauma, heat stroke, heart failure, pneumothorax, lung cancer and renal failure (n=1, 0.8%).

Management comparison. To narrow the critical factors for predicting the outcomes of ICU patients, their management and performances in the ICU at day 28 were compared (Table IV). Vasopressor use before intubation, HR, MAP at intubation, duration of ventilator use (days) and ICU stay (days) were significantly different between the dead and live groups

($P<0.05$). By contrast, non-invasive ventilation before intubation, analgesia and sedation before intubation, SaO_2 and RR at intubation did not differ significantly between the two groups ($P>0.05$). In addition, underlying diseases were compared and no significant differences were observed between the two groups (Table SI). These results revealed that vasopressor use before intubation, HR, MAP at intubation, as well as the duration of ventilator use and ICU stay, were the main determining factors for ICU patient outcomes.

Binary logistic regression analysis. To evaluate the critical factors for OS of ICU patients on day 28, binary logistic regression analysis was performed using the variables that differed significantly between the dead and live groups. The IMPRES and duration of ventilator use were identified as two independent factors for OS in ICU patients on day 28 ($P<0.05$; Table V). Among these two key factors, the IMPRES showed a negative association with OS on day 28 ($B=-0.417$). By contrast, the duration of ventilator use was positively associated with OS on day 28 ($B=0.061$). This result confirmed that the IMPRES was a critical factor affecting OS in ICU patients receiving IMV on day 28.

Predictive value of OS in ICU using an independent factor combined predictive model. To more accurately predict the OS of ICU patients with IMV on day 28, ROC curve analysis was performed and the AUC was calculated using the two independent variables mentioned above (Table VI). The IMPRES showed the following results at a cut-off of 4.50: AUC, 0.785; 95% CI, 0.706-0.864; $P<0.001$; sensitivity, 63.0%; specificity, 85.7%; and Youden index, 0.487. When the IMPRES score was <4.50, OS was higher on day 28. Regarding the duration of ventilator use (days), the results were as follows with 12.50 days as the cut-off: AUC, 0.653; 95% CI, 0.560-0.746; $P=0.003$ sensitivity, 52.1%; specificity, 71.4%, and Youden index, 0.235. When the duration of ventilator use was <12.5 days, the OS of ICU patients with IMV was lower. The OS of ICU patients with IMV on day 28 divided into high and low groups according to the cut-off of the IMPRES score and duration of ventilator use is shown in Figs. 1-3. If survival fractions were compared in the dead and live groups using an IMPRES of 4.5 as the cut-off, the number of patients with IMPRES 4.5 vs. <4.5 in the dead

Table IV. Management and performance of patients at the ICU on day 28.

Variable	Death (n=56)	Live (n=73)	z/χ^2	P-value
Intubation in 24 h	30 (53.6)	51 (69.9)	3.600	0.058
Vasopressor use before intubation	14 (25.0)	7 (9.6)	5.522	0.019
Non-invasive ventilation before intubation	15 (26.8)	19 (26.0)	0.009	0.923
Analgesia and sedation before intubation	7 (12.5)	7 (9.6)	0.278	0.598
HR at intubation (normal range, 75-128 bpm)	97.0 (76.0, 110.8)	105.0 (88.0, 125.0)	-2.455	0.014
Oxygen saturation during intubation (normal range, 95-100%)	87.5 (71.3, 94.3)	89.0 (72.5, 96.5)	-1.120	0.263
RR at intubation (normal range, 12-20 breaths/min)	23.0 (18.0, 30.0)	22.0 (16.0, 30.0)	-0.019	0.985
MAP at intubation, mmHg	74.2 (54.4, 87.7)	88.0 (72.3, 100.7)	-3.583	<0.001
Duration of ventilator use, days	8.5 (3.0, 13.0)	13.0 (5.0, 34.5)	-2.971	0.003
ICU time, days	20.0 (11.5, 28.00)	31.0 (15.5, 46.0)	-3.066	0.002

Values are expressed as n (%) or the median (interquartile range). HR, heart rate; RR, respiratory rate; bmp, beats per min; MAP, mean arterial pressure (range); ICU, intensive care unit.

Table V. Binary logistic regression analysis of overall survival on day 28 of patients receiving invasive mechanical ventilation in the ICU.

Parameter	B	S.E.	Wald	P-value	Exp (B)	95% CI of EXP(B)
SOFA score	-0.002	0.087	0.001	0.980	0.998	0.842-1.182
IMPRES	-0.417	0.105	15.829	0.000	0.659	0.536-0.809
Times in ICU	-0.008	0.014	0.384	0.536	0.992	0.966-1.018
Age	-0.022	0.020	1.220	0.269	0.978	0.941-1.017
APACHEII score at intubation	-0.027	0.049	0.300	0.584	0.974	0.885-1.071
Early intubation	0.887	0.527	2.831	0.092	2.429	0.864-6.828
Duration of ventilator use	0.061	0.026	5.713	0.017	1.063	1.011-1.118
Vasopressor	-0.455	0.683	0.443	0.506	0.635	0.166-2.421
HR at intubation	0.003	0.010	0.059	0.808	1.003	0.982-1.023
MAP at intubation	0.011	0.012	0.892	0.345	1.011	0.988-1.035

Wald is a test of whether the independent variable has an influence on the dependent variable. ICU, intensive care unit; B, independent variable coefficient; S.E., standard error; Exp (B), the odds ratio (also known as relative risk); CI, confidence interval; SOFA, Sequential Organ Failure Assessment; IMPRES, Invasive Mechanical Ventilation Mortality Prediction Score; APACHEII, Acute Physiology and Chronic Health Evaluation II; HR, heart rate; MAP, mean arterial pressure.

and live groups was 48/8 (37.21 vs. 6.20%) and 27/46 (20.93 vs. 35.66%), respectively. There were significant differences ($P<0.001$) in the number of patients with IMPRES 4.5 between the dead and live groups (Fig. 1). Furthermore, the number of patients at a cut-off for ventilator time of 12.5 days in the dead and live groups was 40/16 (30.01 vs. 12.40%) and 35/38 (27.1 vs. 29.5%, $P=0.782$), respectively (Fig. 2). The analysis was then performed using the combination of an IMPRES of 4.5 combined with ventilator use for <12.5 days, and it was observed that the number of patients with IMPRES 4.5 combined with ventilator use <12.5 days, and the respective other group, which included patients with IMPRES not 4.5 and ventilator use not <12.5 days, in the dead and live groups was 37/19 (28.68 vs. 14.73%, $P<0.01$) and 10/63 (7.75 vs. 48.84%), respectively (Fig. 3). By contrast, the number (10/129, 7.75%) of patients with IMPRES 4.5 combined with ventilator use <12.5 days in the live group was markedly lower than number

of patients in the other group (63/129, 48.84%, $P<0.001$). These data indicated a strong differentiation in the outcomes of ICU patients using the IMPRES and duration of ventilator use with cut-off values of 4.5 and <12.5 days, respectively.

The parameters from the ROC curve to predict patient survival based on the IMPRES combined with ventilator use are provided in Tables V and VI. The results indicated a maximum AUC (0.856) and 95% CI (0.789-0.922, $P<0.01$) with the combination of the IMPRES plus the duration of ventilator use (Fig. 4). The sensitivity and specificity were 84.9 and 78.6%, respectively. This result confirmed that the combination of the IMPRES score and duration of ventilator use showed the greatest efficacy for accurately predicting survival of ICU patients.

Comparison of OS of hospitalized patients by the Kaplan-Meier method. To further investigate the survival conditions

Table VI. Comparison of AUC, Youden index, sensitivity and specificity of independent risk factors in the ROC analysis.

Parameter	AUC	S.D.	P-value	95% CI	Cut-off	Youden index	Sensitivity	Specificity
IMPRES	0.785	0.040	<0.001	0.706-0.864	4.50	0.487	0.857	0.630
Duration of ventilator use, days	0.653	0.048	0.003	0.560-0.746	12.50	0.235	0.521	0.714
IMPRES + duration of ventilator use, days	0.856	0.034	<0.001	0.789-0.922	4.5 + 12.5	0.635	0.849	0.786

AUC, area under ROC curve; ROC, receiver operating characteristic; S.D., standard deviation; CI, confidence interval; IMPRES, Invasive Mechanical Ventilation Mortality Prediction Score.

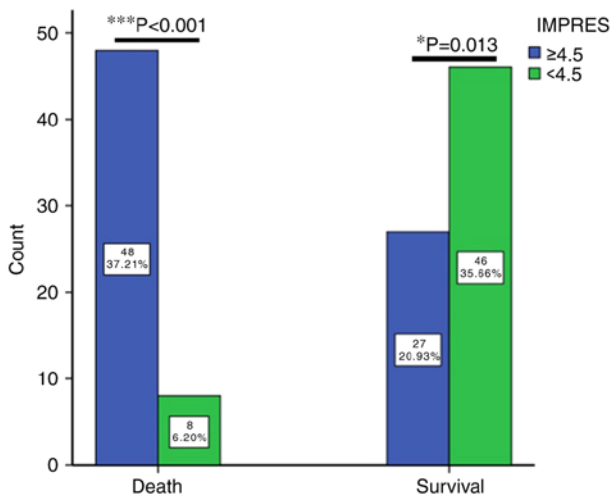


Figure 1. Comparison of dead and live patients on day 28 according to their IMPRES. The graph was created using the IMPRES at a cut-off of 4.5. IMPRES, Invasive Mechanical Ventilation Mortality Prediction Score. *P<0.05; ***P<0.001.

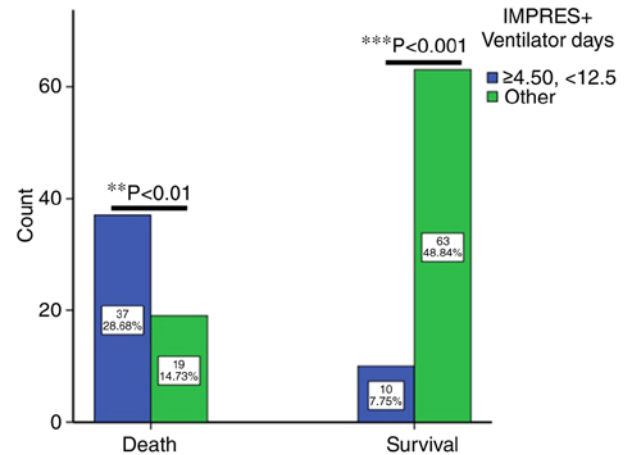


Figure 3. Comparison of dead and live patients on day 28 according to IMPRES plus duration of ventilator use. The graph was created using the IMPRES at a cut-off of 4.5 plus the duration of ventilator use with a cut-off of 12.5 days in combination. Other included patients with IMPRES not 4.5 and ventilator use not <12.5 days. IMPRES, Invasive Mechanical Ventilation Mortality Prediction Score. **P<0.01; ***P<0.001.

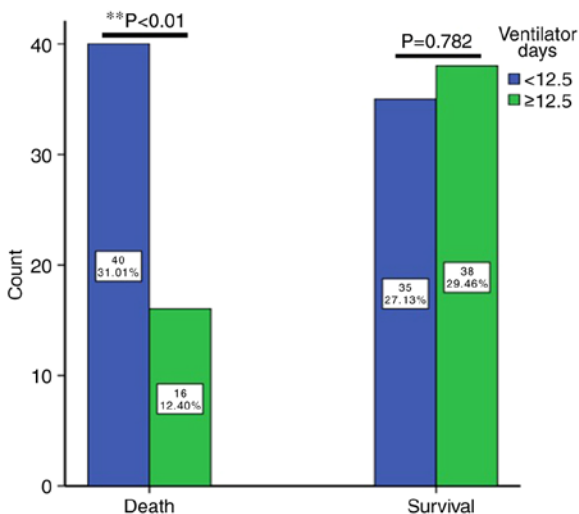


Figure 2. Comparison of dead and live patients on day 28 according to the duration of ventilator use (days). The graph was created using the length of ventilator use of 12.5 days as the cut-off. **P<0.01.

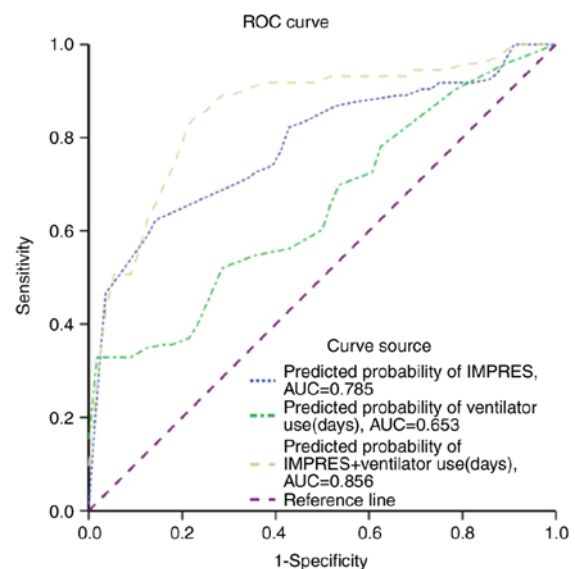


Figure 4. ROC curve of probability rate in the dead and live patients on day 28. The graph was generated using the IMPRES at a cut-off of 4.5 plus the duration of ventilator use with a cut-off of 12.5 days, and both factors in combination. IMPRES, Invasive Mechanical Ventilation Mortality Prediction Score; ROC, receiver operating characteristic; AUC, area under ROC curve.

at the time of hospitalization, the follow-up period was lengthened up to 100 days and an OS analysis was performed using

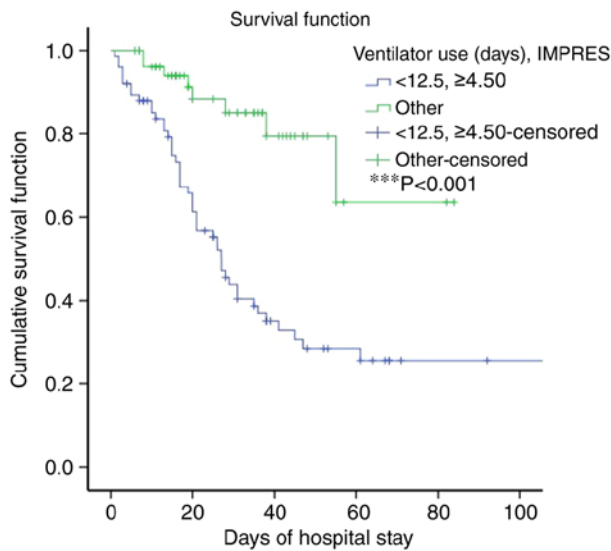


Figure 5. The Kaplan-Meier curves displaying the cumulative survival function in the dead and live patients over 100 days. The graph was generated by the Kaplan-Meier method using the IMPRES score at a cut-off of 4.5 plus the length of ventilator use with a cut-off of 12.5 days, in combination. IMPRES, Invasive Mechanical Ventilation Mortality Prediction Score. *** $P<0.001$.

the Kaplan-Meier method, based on the number of live and dead patients (Fig. 5). The mortality rate (78.7%) of patients with $\text{IMPRES} \geq 4.5$ and <12.5 days of ventilator use was much higher than that in the other groups (23.2%, $P<0.001$). This result demonstrated that $\text{IMPRES} \geq 4.50$ plus <12.5 days of ventilator use in combination has a high predictive value for favorable outcomes for ICU patients with IMV.

Discussion

The mortality rate of ICU patients receiving IMV is excessively high. Predicting critical factors for patient survival can significantly improve outcomes in this patient group. Our data indicated that the IMPRES and the length of ventilator use (days) were two major independent factors for ICU patient survival on day 28. Among these factors, the IMPRES is an important factor for predicting OS. However, the IMPRES plus length of ventilator use had a greater predictive value for ICU patient survival than either factor alone.

The mortality rate of adult ICU patients ranges between 10.1-45.1% and is related to acute organ dysfunctions (15,16). By contrast, the mortality rate of ICU patients with IMV is higher than that of patients without IMV because IMV use is frequently associated with organ failure (17) and prolonged intubation markedly increases ventilator-acquired pneumonia (18). Therefore, numerous studies have attempted to predict the mortality rate of ICU patients using different strategies (19-21). However, these evaluation systems have certain limitations. For example, patients with cancer or organ transplantation have relatively low mortality rates according to the Simplified Acute Physiology Score 3 system (22). By contrast, the SOFA score is more helpful for predicting the mortality of patients with sepsis (22-24). Currently, most physicians use the APACHE score to predict the severity of disease. However, this score has a relatively low predictive value in patients undergoing neurosurgery (25). Another report

revealed that the APACHEIII score and surgery type were strong predictors of mortality in ICU patients (26). Recently, machine learning models were used to predict the mortality rate at 30 days after IMV use (9,27) and higher AUC values were reported for this approach compared to conventional scoring systems. Chan *et al* (27) reported on 30-day, 90-day and 1-year mortality prediction in ICU patients, indicating higher AUC values in short-term follow-up using independent predictive factors. Another study showed that the intensity of oxygen exposure in ICU patients receiving IMV were a critical factor for their outcomes on day 28 (5). Therefore, day 28 was selected as the cut-off time in the present study. The current study aimed to determine the critical factors for predicting survival in ICU patients on IMV on day 28. It was observed that the APACHEII and SOFA score were not determining factors for the survival rate on day 28, although the APACHEII and SOFA score in the dead group were significantly higher than those in the live group. This bias may have occurred because all of the patients with high APACHEII and SOFA scores underwent IMV.

To the best of our knowledge, the present study was the first to use individual variables to evaluate the key factors for predicting mortality in ICU patients receiving IMV on day 28. Binary logistic regression and ROC curve analysis were used to narrow down the critical factors related to outcomes in this patient group. It was observed that the IMPRES and length of ventilator use were the two most critical factors for this application. Ozlu *et al* (8) analyzed the mortality rate of 1,463 cases in 41 ICUs using the IMPRES method, including 583 patients on IMV and 880 patients who did not receive IMV. Their results showed that the IMPRES helped to predict outcomes in the ICU patients on IMV. They selected 20 variables from the initial 158 variables and established evaluation criteria using different mortality risk values. Compared to other mortality predictive methods in the ICU patients, the IMPRES utilizes not only available clinical data, but also takes into account the physician's subjective anticipation. The results provided a more accurate prediction than other methods such as the APACHEII or SOFA scores (8). This method may be a superior measure for short-term mortality prediction because the physician makes a decision based on bedside data collection for patients at the ICU receiving IMV. Their results showed that 76.3% of patients with an IMPRES of 5.1 died. The present study showed that patients with an IMPRES of 4.50 had a mortality rate of 78.7% on day 28. The present result thus confirmed that the IMPRES was a critical variable for predicting mortality in ICU patients on IMV.

The mortality rate of ICU patients on IMV can be impacted by various factors, such as pneumonia caused by ventilator use (28). One study reported that the duration of ventilator use represented another critical factor for predicting outcomes in ICU patients on IMV, as longer ventilator use could cause nosocomial infection, raising both ethical and legal concerns (29). Therefore, the optimal length of ventilator use represents another key issue for predicting mortality in ICU patients. In the present study, binary logistic regression and ROC curve analyses were used to determine the critical factors affecting the outcomes of ICU patients on IMV. The present results indicated that patients with $\text{IMPRES} < 4.5$ or duration of ventilator use < 12.5 days have a probability of long survival. Otherwise,

patients' survival probability was low. In addition, the combination of IMPRES and length of ventilator use <12.5 days had a greater predictive ability than either factor alone.

The present study had several key limitations worth noting. First, the sample size was relatively small. Furthermore, it was a retrospective study and certain data may have been missed. In addition, the data were from a single center and may have been affected by the physicians' experiences. Therefore, a prospective study with a large sample size across multiple centers may further confirm our observations.

In conclusion, the present study confirmed that the IMPRES and duration of ventilator use represent two critical factors for predicting mortality in ICU patients receiving IMV. Those patients with an IMPRES of 4.5 or <12.5 days of ventilator use had high mortality rates in the present study cohort. The combination of the IMPRES and duration of ventilator use exhibited a greater predictive power than either factor alone. This conclusion will be helpful in assisting ICU physicians with clinical decision-making.

Acknowledgements

Not applicable.

Funding

No funding was received.

Availability of data and materials

The datasets are not publicly available due to ethical restrictions but may be requested from the corresponding author.

Authors' contributions

SZ and ZZ conceived and designed the study. SZ and HY were responsible for data collection. HY and ZZ analyzed the results. SZ and ZZ prepared all figures and tables. SZ wrote the initial draft of the manuscript. Each author revised portions of the manuscript, and all authors have read and approved the final manuscript. SZ and ZZ checked and confirmed the authenticity of the raw data.

Ethics approval and consent to participate

The study protocol was reviewed and approved by the Ethics Committee of Shanghai RenHe Hospital (Shanghai, China; approval no. KY2022-01). Written informed consent was obtained from the patients that were willing to provide their medical records. Data were collected in accordance with international conventions and guidelines on research involving human subjects, such as the declaration of Helsinki.

Patient consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

References

1. Wunsch H, Linde-Zwirble WT, Angus DC, Hartman ME, Milbrandt EB and Kahn JM: The epidemiology of mechanical ventilation use in the United States. *Crit Care Med* 38: 1947-1953, 2010.
2. Souza SM, Quintao APC, Soares MCB, Mendes IR, Freitas BAC, Siman AG and Toledo LV: Survival of patients with diabetes mellitus hospitalized for acute respiratory syndrome due to COVID-19. *Rev Inst Med Trop Sao Paulo* 64: e74, 2022.
3. Chen X, Zhang J, Yuan S and Huang H: Remimazolam besylate for the sedation of postoperative patients undergoing invasive mechanical ventilation in the ICU: A prospective dose-response study. *Sci Rep* 12: 19022, 2022.
4. Smith MA, Dinh D, Ly NP, Ward SL, McGarry ME and Zinter MS: Changes in the use of invasive and noninvasive mechanical ventilation in pediatric asthma: 2009-2019. *Ann Am Thorac Soc* 20: 245-253, 2023.
5. Zhu Z, Zhou M, Wei Y and Chen H: Time-varying intensity of oxygen exposure is associated with mortality in critically ill patients with mechanical ventilation. *Crit Care* 26: 239, 2022.
6. Plotnikow GA, Gogniat E, Accoce M, Navarro E and Dorado JH: EpVAR study group: Epidemiology of mechanical ventilation in Argentina. The EpVAR multicenter observational study. *Med Intensiva (Engl Ed)* 46: 372-382, 2022.
7. Fialkow L, Farenzena M, Wawrzyniak IC, Brauner JS, Vieira SR, Vigo A and Bozzetti MC: Mechanical ventilation in patients in the intensive care unit of a general university hospital in southern Brazil: An epidemiological study. *Clinics (Sao Paulo)* 71: 144-151, 2016.
8. Ozlu T, Pehlivanlar Kucuk M, Kaya A, Yazar E, Kirakli SC, Sengoren Dikis O, Kefeli Çelik H, Özkan S, Bektaş Aksoy H and Küçük AO: IMVICAP Study Group: Can we predict patients that will not benefit from invasive mechanical ventilation? A novel scoring system in intensive care: The IMV Mortality Prediction Score (IMPRES). *Turk J Med Sci* 49: 1662-1673, 2019.
9. Kim JH, Kwon YS and Baek MS: Machine learning models to predict 30-day mortality in mechanically ventilated patients. *J Clin Med* 10: 2172, 2021.
10. Sudarsanam TD, Jeyaseelan L, Thomas K and John G: Predictors of mortality in mechanically ventilated patients. *Postgrad Med J* 81: 780-783, 2005.
11. Innocenti F, Lazzari C, Paolucci E, De Paris A, Lagomarsini A, Guerra F, Alleonato P, Casalini L, Buggea M, Caldi F, *et al*: Role of prognostic scores in predicting in-hospital mortality and failure of non-invasive ventilation in adults with COVID-19. *Intern Emerg Med* 17: 2367-2377, 2022.
12. Liang J, Li Z, Dong H and Xu C: Prognostic factors associated with mortality in mechanically ventilated patients in the intensive care unit: A single-center, retrospective cohort study of 905 patients. *Medicine (Baltimore)* 98: e17592, 2019.
13. Vincent JL, Moreno R, Takala J, Willatts S, De Mendonca A, Bruining H, Reinhart CK, Suter PM and Thijs LG: The SOFA (Sepsis-related Organ Failure Assessment) score to describe organ dysfunction/failure. On behalf of the Working Group on Sepsis-Related Problems of the European Society of Intensive Care Medicine. *Intensive Care Med* 22: 707-710, 1996.
14. Knaus WA, Draper EA, Wagner DP and Zimmerman JE. APACHE II: A severity of disease classification system. *Crit Care Med* 13: 818-829, 1985.
15. Depuydt PO, Benoit DD, Vandewoude KH, Decruyenaere JM and Colardyn FA: Outcome in noninvasively and invasively ventilated hematologic patients with acute respiratory failure. *Chest* 126: 1299-1306, 2004.
16. Azoulay E, Mokart D, Rabbat A, Pene F, Kouatchet A, Bruneel F, Vincent F, Hamidfar R, Moreau D, Mohammedi I, *et al*: Diagnostic bronchoscopy in hematology and oncology patients with acute respiratory failure: Prospective multicenter data. *Crit Care Med* 36: 100-107, 2008.
17. Grasselli G, Zangrillo A, Zanella A, Antonelli M, Cabrini L, Castelli A, Cereda D, Coluccello A, Foti G, Fumagalli R, *et al*: Baseline characteristics and outcomes of 1591 patients infected with SARS-CoV-2 Admitted to ICUs of the Lombardy Region, Italy. *JAMA* 323: 1574-1581, 2020.
18. Melsen WG, Rovers MM, Groenwold RH, Bergmans DC, Camus C, Bauer TT, Hanisch EW, Klarin B, Koeman M, Krueger WA, *et al*: Attributable mortality of ventilator-associated pneumonia: A meta-analysis of individual patient data from randomised prevention studies. *Lancet Infect Dis* 13: 665-671, 2013.

19. Mahmoodpoor A, Sanaie S, Saghaleini SH, Ostadi Z, Hosseini MS, Sheshgelani N, Vahedian-Azimi A, Samim A and Rahimi-Bashar F: Prognostic value of National Early Warning Score and Modified Early Warning Score on intensive care unit readmission and mortality: A prospective observational study. *Front Med (Lausanne)* 9: 938005, 2022.
20. Yang J, Lim HG, Park W, Kim D, Yoon JS, Lee SM and Kim K: Development of a machine learning model for the prediction of the short-term mortality in patients in the intensive care unit. *J Crit Care* 71: 154106, 2022.
21. Fronczek J, Flaatten H, Guidet B, Polok K, Andersen FH, Andrew BY, Artigas A, Beil M, Cecconi M, Christensen S, *et al*: Short-term mortality of patients ≥ 80 years old admitted to European intensive care units: An international observational study. *Br J Anaesth* 129: 58-66, 2022.
22. Costa e Silva VT, de Castro I, Liano F, Muriel A, Rodriguez-Palomares JR and Yu L: Performance of the third-generation models of severity scoring systems (APACHE IV, SAPS 3 and MPM-III) in acute kidney injury critically ill patients. *Nephrol Dial Transplant* 26: 3894-3901, 2011.
23. Soares M, Silva UV, Teles JM, Silva E, Caruso P, Lobo SM, Dal Pizzol F, Azevedo LP, de Carvalho FB and Salluh JJ: Validation of four prognostic scores in patients with cancer admitted to Brazilian intensive care units: Results from a prospective multicenter study. *Intensive Care Med* 36: 1188-1195, 2010.
24. Patrizio E, Zambon A, Mazzola P, Massariello F, Galeazzi M, Cavalieri d'Oro L, Bonfanti P and Bellelli G: Assessing the mortality risk in older patients hospitalized with a diagnosis of sepsis: The role of frailty and acute organ dysfunction. *Aging Clin Exp Res* 34: 2335-2343, 2022.
25. Akavipat P, Thinkhamrop J, Thinkhamrop B, and Sriraj W: Acute physiology and chronic health evaluation (Apache) II score - the clinical predictor in neurosurgical intensive care unit. *Acta Clin Croat* 58: 50-56, 2019.
26. Zhang AT, Tan SX, Pillay PS and Stewart D: A critical decision point: Short- and long-term outcomes of older surgical patients admitted to a Queensland intensive care unit. *Australas J Ageing* 41: e32-e40, 2022.
27. Chan MC, Pai KC, Su SA, Wang MS, Wu CL and Chao WC: Explainable machine learning to predict long-term mortality in critically ill ventilated patients: A retrospective study in central Taiwan. *BMC Med Inform Decis Mak* 22: 75, 2022.
28. Wang M, Wang W, Jia X, He Q, Zhu S, Kang Y, Zhang R, Ren Y, Li L, Zou K, *et al*: Associations between antithrombosis and ventilator-associated events, ICU stays, and mortality among mechanically ventilated patients: A registry-based cohort study. *Front Pharmacol* 13: 891178, 2022.
29. Esteban A, Frutos-Vivar F, Muriel A, Ferguson ND, Penuelas O, Abaira V, Raymonds K, Rios F, Nin N, Apezteguía C, *et al*: Evolution of mortality over time in patients receiving mechanical ventilation. *Am J Respir Crit Care Med* 188: 220-230, 2013.



Copyright © 2024 Zhong et al. This work is licensed under a Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International (CC BY-NC-ND 4.0) License.