

A predictive Score for Pulmonary Complications in Mechanically Ventilated Patients in a Surgical Intensive Care Unit

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Abstract

Background: Two-thirds of patients in a surgical intensive care unit (SICU) require mechanical ventilation. However, pulmonary complications and its associated risk factors are not adequately identified in these patients.

Objectives: To identify the risk factors and to develop a predictive score for pulmonary complications in mechanically ventilated patients in a SICU.

Methods: Mechanically ventilated patients admitted to a SICU were included in this prospective study. The onset of pulmonary complications within seven days after mechanical ventilation support was observed. A multivariate analysis with a logistic regression model was used to identify variables associated with the development of pulmonary complications and a predictive score was subsequently developed.

Results: There were 306 patients included in this

study and of these, 36.6% experienced pulmonary complications during the study period. An abnormal chest radiograph, hypoalbuminemia, and presence of respiratory, cardiovascular, and renal dysfunction upon SICU admission were the independent risk factors identified. The area under the receiver-operating characteristic curves for the predictive score was 0.768 (95% CI, 0.713-0.822). The best cut-off value was 8.5, which yielded 71.4% (95% CI, 62.1-79.6%) sensitivity and 71.7% (64.8-77.9%) specificity.

Conclusion: The incidence of pulmonary complications among mechanically ventilated patients in a SICU is high. Five independent risk factors were identified, and a new predictive score was developed which had a fair discriminative power. Further external validation is needed to verify its accuracy.

Keywords: mechanical ventilation, predictive score, pulmonary complication, surgical intensive care unit

Introduction

Pulmonary complications are one of the most devastating in patients receiving mechanical ventilation (MV). The complications range from mild and transient, such as atelectasis, to severe acute respiratory distress syndrome (ARDS).^{1,2} The consequences of pulmonary complications are numerous and include patient health, family burden, and economic issues.³⁻⁵ Accordingly, early recognition of high-risk patients and preventive measures such as lung-protective mechanical ventilation is beneficial.

For critically ill patients admitted to the intensive care unit (ICU), several predictive scoring systems have been developed to gauge the severity and mortality. Widely used scoring systems include the Acute Physiology and Chronic Health Evaluation II (APACHE II) score^{6,7} and the Sequential Organ Failure Assessment (SOFA) score⁸⁻¹⁰, which were developed between the late 1980s and early 1990s. Despite their widespread acceptance as valid predictors of mortality, neither is specific for pulmonary complications. In 2010, the Assess Respiratory Risk in Surgical Patients in Catalonia (ARISCAT) score was proposed to identify the risk of pulmonary complications among surgical patients following general or regional anesthesia.¹¹ In 2011, the lung injury prediction score (LIPS) was also developed to identify patients in emergency departments at high risk of ARDS.^{12,13} However, their reliability and accuracy is questionable when used to assess critically ill patients in ICU in order to predict pulmonary complications.

A recent survey of respiratory support in a ICU found that approximately two-thirds of patients admitted in a surgical ICU (SICU) required mechanical ventilation.¹⁴ Nevertheless, their clinical course and outcomes related to MV treatment are described inadequately. Therefore, we aimed to determine the incidence and develop a predictive score for pulmonary complications among patients admitted in a SICU treated with MV. In addition, we sought to compare the accuracy of our score to others in predicting pulmonary complications in patients.

Material and Methods

Study design and patient population

This prospective, single-center, observational cohort study was conducted in two SICUs at Siriraj Hospital (a university-based tertiary referral hospital in Bangkok, Thailand) between April 2018 and March 2019. The study was approved by the ethics committee of the Institutional Review Board, Faculty of Medicine Siriraj Hospital. All patients aged 18 and above who required MV support in the two SICUs for an anticipated duration of 12 hours or more were eligible for inclusion. Patients were excluded if they were 1) undergoing cardiothoracic surgery, neurological surgery, trauma surgery, and pediatric patients admitted to other respective ICUs; 2) patients requiring MV support for less than 12 hours in a SICU; 3) patients requiring MV support for more than 24 hours before SICU admission; 4) patients requiring MV support again after previous use; 5) patients re-admitted to a SICU; 6) patients requiring

non-invasive MV support; and 7) moribund or terminal cases. Written informed consent was obtained from all patients or their relatives before inclusion or as soon as possible.

Study procedure

Inclusion began on the start day of MV support, which was labeled as index day. All included patients received medical care, including resuscitation, medication, and MV support, based on the discretion of the primary care team. They were evaluated daily for seven consecutive days following index day or until they were discharged from SICU or died, whichever came first. SICU and hospital discharge status at day 28 and day 90 following index day was also observed.

Data collection

Demographic and baseline data recorded on index day included age, gender, weight, height, comorbidities, smoking status, intraoperative data, reasons for SICU admission and MV support, laboratory values, chest radiograph, requirement of vasopressor, presence of sepsis, ARDS, and acute kidney injury (AKI), APACHE II score, SOFA score, ARISCAT¹¹, and LIPS¹². Pulmonary complications including pneumonia, ARDS, atelectasis, cardiogenic pulmonary edema, pleural effusion, new pulmonary infiltrates, pneumothorax, need for mechanical ventilator support for more than four days, re-intubation, and conversion of an endotracheal tube to tracheostomy; and other complications including stroke, myocardial ischemia/infarction, arrhythmias, AKI, sepsis, new infection other than pneumonia, and re-admission to SICU were also documented for seven consecutive days following index day or until patients were discharged from SICU

or became deceased, whichever came first. The complications were identified according to European Perioperative Clinical Outcome (EPCO) definitions.¹⁵ Duration of MV support, LOS in SICU and the hospital, SICU and hospital discharge status, and status at 90 days either alive or death was also collected.

Study outcomes and sample size calculation

The primary aim of this study was to identify potential risk factors for pulmonary complications among mechanically ventilated patients admitted to a SICU. Based on our literature review, approximately eight variables were reported as risk factors for pulmonary complications in surgical patients.^{11,18,20} As a general rule, the number of patients having pulmonary complications should be 5-10 times the number of variables. The study, therefore, required 80 patients with pulmonary complications. With an estimated 30% incidence reported in literature¹⁹⁻²¹, a total of 267 patients were needed. We planned to include 300 patients to cover for possible missing data.

Statistical analysis

Continuous variables were expressed as mean with standard deviation or median with an interquartile range. Categorical variables were expressed as numbers with percentages. Student's t-test or Mann-Whitney U tests were used to compare continuous variables, and a chi-squared test or Fisher's exact test used for categorical variables as appropriate. We conducted a multivariate analysis using a logistic regression model with backward stepwise selection to identify potential risk factors independently associated with pulmonary

complications. Only statistically significant independent predictors ($P < 0.05$) in the univariate analysis were included in the model.

Based on multivariate logistic regression findings, a predictive score was developed. Each variable was assigned a score as a rounded integer based on beta coefficients. The total score for each patient was calculated by the sum of each component. Using a receiver operating characteristic (ROC) curve, we analyzed the predictive value of the new score and compared its performance against other scoring systems, including the APACHE II score, the SOFA score, the KIPS, and the ARISCAT score. For each scoring system, we defined the discrimination as excellent, good, fair, or poor according to the area under ROC curve as values 0.90-0.99, 0.80-0.89, 0.7-0.79, and 0.51-0.69, respectively.¹⁶ All statistical analyses were 2-tailed, and $P < 0.05$ was considered statistically significant. Data was prepared and analyzed using the PASW Statistics 18 (SPSS Inc., Chicago, IL, USA).

Results

Participants and data at SICU admission

Of the 587 patients enrolled, 306 were included in the analyses (Figure 1). One hundred and twelve patients requiring mechanical ventilation experienced at least one pulmonary complication (36.6%). Table 1 shows demographic data and SICU admission data of all patients, categorized either as with and without pulmonary complications. Overall, there was no difference in baseline characteristics between the groups. Approximately half of SICU admissions were planned, following elective

surgery. Eighty patients who developed pulmonary complications were admitted to SICU following emergency surgery due to medical conditions and unplanned admissions ($P < 0.001$). Patients with pulmonary complications had a significantly higher APACHE II score, SOFA score, and LIPS score but not the ARISCAT score. There was also a higher proportion of sepsis, AKI, and ARDS patients in SICU. In addition, they had significantly lower Hb concentrations, higher serum creatinine, lower serum albumin, lower serum bilirubin, and higher proportion of abnormal chest radiographs, including infiltration, pleural effusion, pulmonary edema, and atelectasis.

Management of mechanical ventilator

The most common reason for mechanical ventilation was postoperative ventilatory support (76.1%, Table 2). Forty-three patients who developed pulmonary complications received mechanical ventilation due to respiratory failure, hemodynamic instability, and post-cardiac arrest ($P < 0.001$). There was no demonstrable difference in mechanical ventilator parameters such as ventilator mode, tidal volume, peak airway pressure, level of PEEP, number of neuromuscular blocking agents used, and recruitment maneuvers between patients with and without pulmonary complications. The ratio of arterial oxygen pressure to fractional inspired oxygen ($\text{PaO}_2/\text{FiO}_2$ ratio) was significantly lower (327.0 ± 156.7 vs. 413.7 ± 172.6 , $P < 0.001$). Moreover, the proportion of patients with $\text{PaO}_2/\text{FiO}_2$ ratio below 200 was significantly higher (21.4% vs. 7.2%, $P < 0.001$) in patients with pulmonary complications.

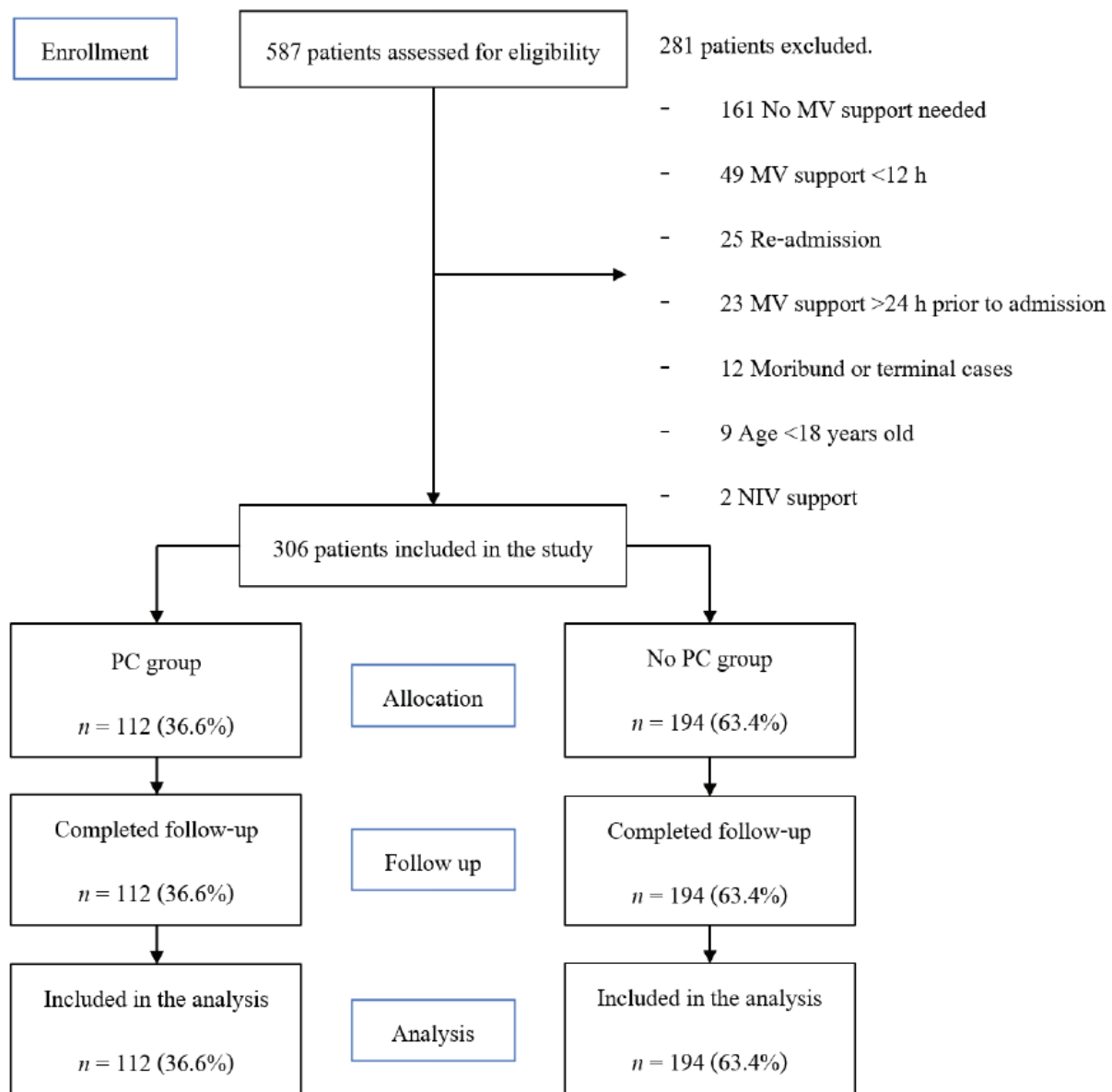


Figure 1 Flowchart of inclusion. MV, mechanical ventilation; NIV, non-invasive ventilation; PC, pulmonary complication

Clinical outcomes

In 112 patients with pulmonary complications, prolonged mechanical ventilation support for more than four days was the most common event (59.8%), followed by reintubation (33.9%), and cardiogenic pulmonary edema (17.9%, Table 3). The duration of mechanical ventilation

support in patients with pulmonary complications was significantly longer than those without. The SICU and hospital LOS, as well as the SICU, hospital, and 90-day mortality was significantly higher in patients with pulmonary complications (Table 3).

Table 1 Demographic and admission data at a surgical intensive care unit

	No pulmonary complications (n=194)	Pulmonary complications (n=112)	All (n=306)	P-value
Age, yr	64.4±16.0	67.9±15.0	65.7±15.7	0.064
Male gender	114 (58.8)	58 (51.8)	172 (56.2)	0.236
Weight, kg	59.1±17.6	58.9±15.0	59.0±16.7	0.928
Height, cm	159.5±8.1	159.3±8.9	159.4±8.4	0.813
Body mass index, kg/m ²	23.1±6.1	23.1±5.3	23.1±5.8	0.947
Comorbidities				
Hypertension	105 (54.1)	66 (58.9)	171 (55.9)	0.415
Coronary artery diseases	19 (9.8)	17 (15.2)	36 (11.8)	0.159
Chronic obstructive pulmonary disease	5 (2.6)	3 (2.7)	8 (2.6)	>0.999
Recent respiratory infection	3 (1.5)	5 (4.5)	8 (2.6)	0.147
Chronic kidney disease	44 (22.7)	36 (32.1)	80 (26.1)	0.070
Diabetes	49 (25.3)	22 (19.6)	71 (23.2)	0.262
Cancers	93 (47.9)	51 (45.5)	144 (47.1)	0.685
Smoking	70 (36.1)	34 (30.4)	104 (34.0)	0.308
Reasons for SICU admission				
Planned elective surgery	106 (54.6)	32 (28.6)	138 (45.1)	<0.001
Emergency surgery	57 (29.4)	43 (38.4)	100 (32.7)	
Medical condition	16 (8.2)	27 (24.1)	43 (14.1)	
Unplanned admission	15 (7.7)	10 (8.9)	25 (8.2)	
Surgical sites*				
Upper and lower abdomen	69 (36.7)	46 (44.2)	115 (39.4)	0.194
Major and peripheral vascular	33 (17.6)	20 (19.2)	53 (18.2)	
Head and neck	31 (16.5)	7 (6.7)	38 (13.0)	
Urological	15 (8.0)	11 (10.6)	26 (8.9)	
Others	40 (21.3)	20 (19.2)	60 (20.5)	
APACHE II	10 (7, 14)	14 (9.5, 19)	11 (8, 16)	<0.001
SOFA	3 (1, 5)	6 (3, 9)	3 (1, 6)	<0.001
LIPS	4.5 (3, 6.5)	6 (4, 7.5)	5 (3, 7)	0.003
ARISCAT	34 (26, 43)	37 (26, 46)	34 (26, 45)	0.499
Hemoglobin, g/dL	11.0±2.2	10.3±2.4	10.8±2.3	0.015
Creatinine, mg/dL	0.82 (0.6, 1.2)	1.12 (0.73, 1.99)	0.93 (0.64, 1.46)	0.001
Albumin, g/dL	2.7 (2.3, 3.1)	2.5 (2.1, 2.9)	2.6 (2.3, 3.0)	0.047
Bilirubin, mg/dL	0.8 (0.49, 1.37)	0.98 (0.61, 2.16)	0.86 (0.52, 1.71)	0.047
Abnormal chest radiograph at admission	29 (14.9)	48 (42.9)	77 (25.2)	<0.001
Vasopressors used at admission	46 (23.7)	46 (41.1)	92 (30.1)	0.001
AKI at admission	29 (14.9)	36 (32.1)	65 (21.2)	<0.001
Sepsis on admission	42 (21.6)	49 (43.8)	91 (29.7)	<0.001
ARDS on admission	1 (0.5)	5 (4.5)	6 (2.0)	0.026

Data is presented as mean±standard deviation, number (%) or median (interquartile range).

*Intraoperative data is available for 292 patients (188 without pulmonary complications and 104 with pulmonary complications)

AKI=acute kidney injury, APACHE II= Acute Physiology and Chronic Health Evaluation II score, ARDS=acute respiratory distress syndrome, ARISCAT=Assess Respiratory Risk in Surgical Patients in Catalonia score, LIPS=lung injury prediction score, SICU=surgical intensive care unit, SOFA=Sequential Organ Failure Assessment score

Table 2 Management of mechanical ventilator

	No pulmonary complications (n=194)	Pulmonary complications (n=112)	All (n=306)	P-value
Reasons for mechanical ventilation				
After general anesthesia	164 (84.5)	69 (61.6)	233 (76.1)	<0.001
Respiratory failure	16 (8.2)	29 (25.9)	45 (14.7)	
Hemodynamic instability	7 (3.6)	10 (8.9)	17 (5.6)	
Depressed level of consciousness	6 (3.1)	0	6 (2.0)	
Post-cardiac arrest	1 (0.5)	4 (3.6)	5 (1.6)	
Ventilator modes				
PCV	122 (62.9)	77 (68.8)	199 (65.0)	0.032
VCV	48 (24.7)	22 (19.6)	70 (22.9)	
PSV	11 (5.7)	12 (10.7)	23 (7.5)	
SIMV	13 (6.7)	1 (0.9)	14 (4.6)	
Tidal volume, ml	458.5 (400, 510)	461 (400, 528.5)	460 (400, 521)	0.962
Tidal volume/kg PBW, ml/kg	8.4 (7.5, 9.9)	8.7 (7.4, 10.0)	8.5 (7.5, 9.9)	0.666
Peak airway pressure, cmH₂O	14 (12, 16)	15 (12, 18)	14 (12, 17)	0.295
PEEP, cmH₂O	5 (5, 5)	5 (5, 5)	5 (5, 5)	0.895
FiO₂	0.4 (0.4, 0.5)	0.4 (0.4, 0.55)	0.4 (0.4, 0.5)	0.022
Minute ventilation, L/min	7.1 (5.9, 9.0)	8.0 (6.5, 10.0)	7.3 (6.0, 9.5)	0.054
Respiratory rate, /min	15 (14, 19)	17.5 (14, 21)	16 (14, 20)	0.001
Arterial blood gas				
pH, mmHg	7.37±0.08	7.34±0.10	7.36±0.09	0.005
PaO ₂ , mmHg	178.5±70.6	155.4±80.0	170.0±74.8	0.010
PaCO ₂ , mmHg	36.3±6.9	35.2±7.0	35.9±7.0	0.171
PF ratio	413.7±172.6	327.0±156.7	382.0±171.8	<0.001
PF ratio less than 200	14 (7.2)	24 (21.4)	38 (12.4)	<0.001
NMBA used	20 (10.3)	9 (8.0)	29 (9.5)	0.513
Recruitment maneuver	1 (0.5)	2 (1.8)	3 (1.0)	0.557

Data is presented as mean±standard deviation, median (interquartile range), or number (%).

FiO₂=fraction of inspired oxygen, MV=mechanical ventilation, NMBA=neuromuscular blocking agent, PaO₂=partial pressure of oxygen, PaCO₂=partial pressure of carbon dioxide, PBW=predicted body weight, PCV=pressure control ventilation, PEEP=positive end-expiratory pressure, PSV=pressure support ventilation, PF ratio= ratio of arterial oxygen pressure to fractional inspired oxygen, SIMV=synchronized intermittent mandatory ventilation, VCV=volume control ventilation

Table 3 Clinical outcomes

	No pulmonary complications (n=194)	Pulmonary complications (n=112)	All (n=306)	P-value
Pulmonary complications				
MV >4 days	0	67 (59.8)	67 (21.9)	NA
Reintubation	0	38 (33.9)	38 (12.4)	NA
New cardiogenic edema	0	20 (17.9)	20 (6.5)	NA
Tracheostomy	0	16 (14.3)	16 (5.2)	NA
New pleural effusion	0	15 (13.4)	15 (4.9)	NA
New pneumonia	0	12 (10.7)	12 (3.9)	NA
New infiltration	0	6 (5.4)	6 (2.0)	NA
New ARDS	0	5 (4.5)	5 (1.6)	NA
New atelectasis	0	4 (3.6)	4 (1.3)	NA
New pneumothorax	0	3 (2.7)	3 (1.0)	NA
Duration of MV, hour	30 (17, 50)	114.5 (55.5, 234.5)	42.5 (20, 90)	<0.001
Non-pulmonary complications	28 (14.4)	54 (48.2)	82 (26.8)	<0.001
New AKI	22 (11.3)	23 (20.5)	45 (14.7)	0.029
New arrhythmias	3 (1.5)	19 (17.0)	22 (7.2)	<0.001
New all infections	5 (2.6)	15 (13.4)	20 (6.5)	<0.001
New MI/ischemia	1 (0.5)	4 (3.6)	5 (1.6)	0.062
New stroke	1 (0.5)	1 (0.9)	2 (0.7)	>0.999
SICU LOS, day	3 (3, 4)	10 (6, 18)	4 (3, 8)	<0.001
Hospital LOS, day	16 (10, 27)	27 (15.5, 51)	19 (12, 32)	<0.001
SICU mortality	2 (1.0)	19 (17.0)	21 (6.9)	<0.001
Hospital mortality	11 (5.7)	36 (32.1)	47 (15.4)	<0.001
90-day mortality	19 (9.8)	40 (35.7)	59 (19.3)	<0.001

Data is presented as median (interquartile range) or number (%).

AKI=acute kidney injury, ARDS=acute respiratory distress syndrome, LOS=length of stay, MI=myocardial ischemia, MV=mechanical ventilation, SICU=surgical intensive care unit

Table 4 Independent variables associated with increased pulmonary complications

	B	Odds ratio	95% confidence interval	P-value
Abnormal chest radiograph	0.923	2.52	1.32–4.80	0.005
Hypoalbuminemia (serum albumin < 3 g/dL)	0.750	2.12	1.11–4.05	0.024
SOFA renal subcomponent	0.439	1.55	1.15–2.09	0.004
SOFA respiratory subcomponent	0.407	1.50	1.15–1.96	0.003
SOFA cardiovascular subcomponent	0.188	1.21	1.02–1.43	0.030

SOFA=sequential organ failure assessment score

Model development, discrimination, and performance

Table 4 shows the five independent variables of postoperative pulmonary complications among mechanically ventilated patients identified in a logistic regression analysis, including abnormal chest radiographs, hypoalbuminemia (serum albumin <3.0 g/dL), and SOFA subcomponent score of the renal, respiratory, and cardiovascular system. The predictive score for pulmonary complications was developed based on the following five independent risk factors: predictive score = (five x abnormal chest radiographs) + (four x hypoalbuminemia) +

(two x renal SOFA) + (two x respiratory SOFA) + cardiovascular SOFA. The receiver-operating characteristic (ROC) curve for the developed predictive score compared to other scores is presented in Figure 2. The area under the ROC curve (AUROC) for the developed score, the APACHE II score, the SOFA score, the LIPS, and the ARISCAT score was 0.768 (95% CI, 0.713-0.822), 0.672 (0.608-0.736), 0.715 (0.653-0.776), 0.618 (0.552-0.683), and 0.535 (0.467-0.604), respectively. The developed predictive score ranged between 0 and 29 and the most relevant cut-off value was 8.5, which yielded 71.4% (95% CI, 62.1-79.6%) sensitivity, 71.7% (64.8-77.9%)

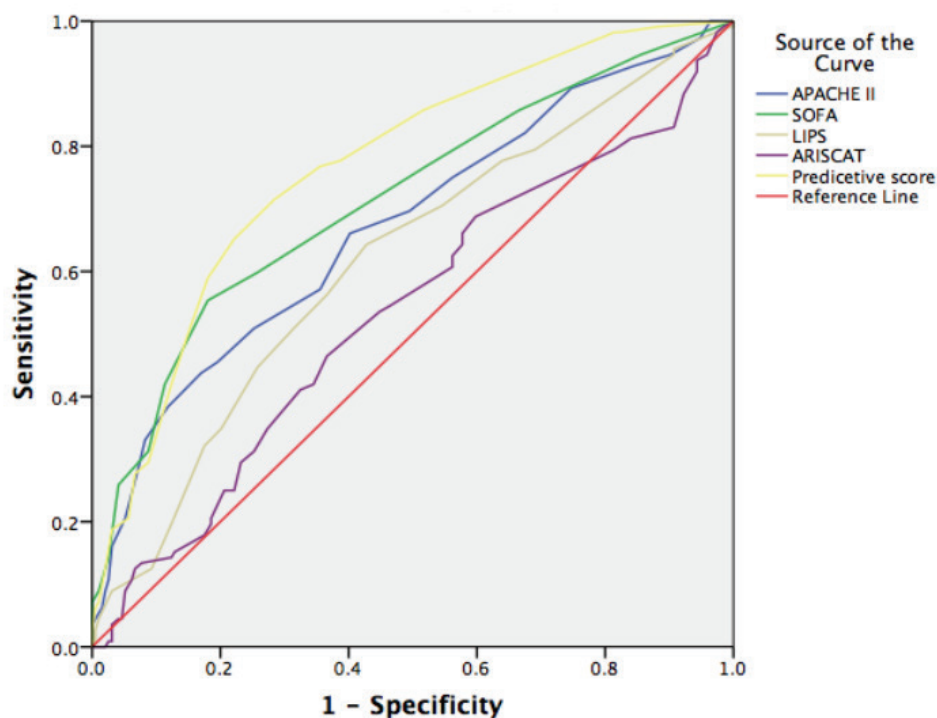


Figure 2 The receiver-operating characteristic (ROC) curves for the developed predictive score compared to the APACHE II score, SOFA score, LIPS and ARISCAT score in predicting pulmonary complications in mechanically ventilated patients in a SICU

APACHE II, Acute Physiology and Chronic Health Evaluation II score; ARISCAT, Assess Respiratory Risk in Surgical Patients in Catalonia score, LIPS, lung injury prediction score; SOFA, Sequential Organ Failure Assessment score, SICU, surgical intensive care unit

specificity, 59.3% (53.1-65.2%) positive predictive value, 81.3% (76.2-85.5%) negative predictive value, and 71.6% (66.2-76.6%) accuracy.

Discussion

The main finding of this prospective observational study was that approximately one-third of patients who were treated with mechanical ventilation in a SICU developed pulmonary complications. Patients with pulmonary complications did not only have increased length of SICU and hospital stay but also mortality. Furthermore, we identified the relevant risk factors of pulmonary complications and developed a score, which had an acceptable discriminative power, to predict pulmonary complications among patients in a SICU receiving mechanical ventilation treatment.

In our study, the incidence of pulmonary complications following mechanical ventilation support in patients admitted to a SICU was 36.6%, which was within the range reported in previous literature.^{11,17-20} The slight differences can be attributed to the variety of definitions used in each study. Pulmonary complications in our study were based on EPCO definitions¹⁵, which are considered as the standard. However, we also included prolonged mechanical ventilation (>96 hours), which is not part of the EPCO-recommended definitions, as a pulmonary complication in our study as this has been reported to increase ICU utility and hospital LOS.²¹ It should be noted that prolonged mechanical ventilation was identified as the most common cause of pulmonary complications in our study, possibly contributing to the higher reported

incidence.

Our results emphasize how pulmonary complications increase morbidity and mortality.^{3,18,19} The mortality rate of patients with pulmonary complications is around 2-8 times higher than those without.^{18,19} It is estimated that around one out of four mechanical ventilated patients who develop pulmonary complications die during hospitalization.¹⁷ Our hospital mortality rate of 32.1% was comparable with the rate observed in a recent study investigating patients who underwent abdominal surgery.⁵ However, this rate was higher than some other studies^{11,17} which investigated general surgery patients admitted in a SICU. Differences in patient populations and baseline characteristics may have caused a variation in mortality rates reported in the studies.

Previous studies also explored potential risk factors for postoperative pulmonary complications. Fernandes et al. reported that the risk of pulmonary complications after abdominal surgery was related to the use of a neuromuscular blocking drug, preoperative abnormal arterial blood gases, median abdominal surgical incision, long operation times, and high body mass index.⁵ Foster et al. investigated the risk factors of pulmonary complications after pancreatectomy, hepatectomy, esophagectomy, abdominal aortic aneurysm repair, aortoiliac open operation, and lung resection.²² They found that factors such as being male, age, high American Society of Anesthesiology (ASA) physical status, preoperative hypoalbuminemia (<3.5 g/dL), preoperative creatinine >1.2 mg/dL were linked to pulmonary complications in such operations. Our study demonstrated that abnormal clinical data of SICU admission, i.e., chest radiograph,

serum albumin, SOFA renal, respiratory, and cardiovascular subcomponents, were linked to pulmonary complications in mechanically ventilated patients in a SICU. An abnormal chest radiograph and low $\text{PaO}_2/\text{FiO}_2$ ratio (SOFA respiratory subcomponent) obviously indicates poor baseline pulmonary function, which tends to develop into a pulmonary complication. Serum albumin levels lower than 3.5 mg/dL is also associated with a higher risk for acute respiratory failure and pulmonary complications^{2,12,23,24} due to rapid breakdown or shredding of the endothelial glycocalyx of pulmonary capillaries.²⁵ The presence of circulatory compromise (SOFA cardiovascular subcomponent) is a well-known predisposing factor associated with acute lung injury (ALI) and ARDS.^{2,12,13} The persistence of low pulmonary circulatory volume and long exposure of norepinephrine may result in pulmonary capillaries malfunctioning and increased microvascular permeability.^{26,27} Furthermore, a high serum creatinine level or acute kidney injury (SOFA renal subcomponent) leads to increased inflammatory mediator, reduced fluid excretion, and cytokine elimination. These phenomena lead to the accumulation of fluid and inflammatory mediators, which can damage respiratory tissues.^{28,29} Our study focused on the information upon SICU admission rather than during admission, with a goal to provide early detection and prompt prevention to improve patient outcomes.

When compared to the APACHE II score, SOFA score, LIPS, and the ARISCAT score, our predictive score had the best ability to discriminate between mechanically ventilated patients who developed pulmonary complica-

tions. The APACHE II score was initially developed to measure illness severity and predict the hospital mortality rate in either medical or surgical patients in an ICU.^{6,7} Although its prognostication is well-proven in several patient populations, its effectiveness in predicting pulmonary complications in mechanically ventilated patients is not documented. The SOFA score was initially developed in patients with sepsis to determine the extent of organ dysfunction, including neurological, cardiovascular, respiratory, hepatic, renal, and coagulation systems.⁸ Both absolute scores and changes in the score show good prognostication in critically ill patients.^{9,10} However, our study demonstrated that its values in predicting pulmonary complications were modest. Nevertheless, the newly developed score yielded better results in predicting pulmonary complications in mechanically ventilated patients by gathering SOFA subcomponent scores, i.e., cardiovascular, respiratory, and renal; plus chest radiography and serum albumin. For LIPS, Bauman et al. demonstrated that it can reliably predict the development of ARDS in mechanically ventilated patients in a SICU.³⁰ However, we showed that LIPS has a fair predictive value for pulmonary complications. This may be explained by the fact that LIPS has better predictive value for ARDS but no other pulmonary complications. Unfortunately, we did not determine the predictive value of LIPS for ARDS in our study. Lastly, the ARISCAT score accurately predicted postoperative pulmonary complications in patients undergoing surgery under general or regional anesthesia.¹¹ However, we were able to demonstrate that it had limited value in predicting pulmonary complications in

mechanically ventilated patients in a SICU.

The strength of our study was the creation of the simplified predictive score for pulmonary complications in mechanically ventilated patients in a SICU. The score consists of only five variables, routinely available in patients admitted to a SICU. The simplicity of the score may aid clinicians in early identification of patients receiving mechanical ventilation treatment who are at risk of pulmonary complications and promptly intervene to prevent or attenuate complications such as adapting the lung-protective mechanical ventilation strategy, restrictive fluid strategy, or implementation of a protocol to discontinue mechanical ventilation. In addition, our results show that pulmonary complications in mechanically ventilated patients are not uncommon and that its burden on patient outcomes should be a major concern.

There were some limitations in our study that deserve a mention. First, although the developed predictive score was simplified, it had modest sensitivity, which might lead to some patients at risk being overlooked. Also, it lacks calibration and external validation, which are essential before general application. Second, we only explored patients who required mechanical ventilation support in a SICU. Its use in the general surgical population may not be valid. Last, we evaluated only clinical data in SICU admissions, however, data during SICU stays was not taken into account. The clinical course of patients and intervention during a SICU stay could potentially impact the development of pulmonary complications. Nonetheless, we aimed to incorporate clinical data at SICU admission. We believed that if patients at risk

for pulmonary complications could be identified early such as during admission, we could apply some preventive measures, leading to better clinical outcomes associated with pulmonary complications.

Conclusion

The incidence of pulmonary complications among mechanically ventilated patients in a SICU was high. Patients who developed pulmonary complications seemed to have worse clinical outcomes, including extended hospitalizations and higher mortality rates. Abnormal chest radiographs, hypoalbuminemia, and the presence of organ dysfunction of the respiratory, cardiovascular, and renal system at SICU admission were independent risk factors for developing pulmonary complications. A predictive score consisting of five regularly assessed variables was developed to predict pulmonary complications among patients receiving mechanical ventilation treatment in a SICU. This score provided better insights compared to other commonly used scores and had an acceptable discriminative ability. Despite its performance, external validation is necessary to verify the accuracy of the score.

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