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RESEARCH ARTICLE OPEN ACCESS

The Change of Central Vein Oxygen Saturation Level during Spontaneous Breathing Trial as a Predictor of Successful Extubation in Intensive Care Unit

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Abstract:

Background: Weaning from mechanical ventilation is an essential step in the care of critically ill patients. Central venous oxygen saturation ($ScvO_2$) could reflect tissue oxygenation.

Objective: The evaluation of the difference in $ScvO_2$ values at the beginning and end of the Spontaneous Breathing Trial (SBT) can be used as a predictor of successful extubation in critically ill patients.

Methods: This cross-sectional study was conducted in the ICU of Prof. Dr. I.G.N.G. Ngoerah Hospital from July to August 2024. This study involved 42 adult patients aged 18-65 who were using mechanical ventilation during their admission to the ICU. All patients had central venous access, were clinically ready for mechanical ventilation weaning, and could attempt SBT for 30-120 minutes with a rapid shallow breathing index (RSBI) of less than 105.

Results: All patients underwent 30-120 minutes of SBT. $ScvO_2$ levels were measured at the beginning of SBT (first minute) and at 30 minutes after SBT started, and the change in $ScvO_2$ level was recorded ($\Delta ScvO_2$). Patients with RSBI < 105 measured during SBT were extubated. Extubation failure was defined as the need for re-intubation, or patients died within 48 hours after extubation. Of 42 patients, 37 patients (89.1%) were successfully extubated. There was a significant difference in $\Delta ScvO_2$ between successfully extubated patients and those who failed (-2.89±1.63 *vs.* -8.2±4.27; p=0.049). The ROC curve analysis showed that a decrease in $ScvO_2$ ≤4.5% was the most optimal cut-off for a predictor of successful extubation with a sensitivity of 81.1%, specificity of 60%, positive predictive value of 93.8% and negative predictive value of 70%.

Conclusion: The difference in $ScvO_2$ between the beginning and after 30 minutes of SBT was a valuable early predictor for successful extubation from mechanical ventilation.

Keywords: Central venous oxygen saturation, Mechanical ventilation, Spontaneous breathing trial, Successful extubation, Weaning, Intensive Care Unit.

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1. INTRODUCTION

Mechanical ventilation is essential in managing critically ill patients in the intensive care unit (ICU). However, prolonged use increases the risk of complications such as ventilator- associated pneumonia, tracheal injury, stress ulcers, and sepsis, leading to higher morbidity and mortality [1]. Timely weaning is crucial, and predicting successful weaning poses a significant clinical challenge.

To determine readiness for weaning, a spontaneous breathing trial (SBT) is performed using a T-tube with minimal pressure support, assessing the patient's ability to breathe independently after the acute phase of illness resolves. Success in SBT is evaluated through hemodynamic stability, mental status, and oxygenation efficiency. However, a successful SBT does not guarantee successful extubation, with failure rates as high as 30% in the first 2-3 days. More accurate predictors of extubation success are needed [1, 2].

The Rapid Shallow Breathing Index (RSBI) is the most commonly used parameter for predicting extubation success due to its simplicity and high sensitivity. An RSBI below 105 breaths/min/L is a common threshold indicating likely extubation success. However, a recent meta-analysis revealed moderate sensitivity (83%) but low specificity (58%), highlighting the need for additional predictive tools [2, 3].

Global tissue oxygenation status during SBT is another potential predictor. Increased breathing effort raises oxygen demand, reducing tissue oxygenation. Mixed venous oxygen saturation (SvO_2) and central venous oxygen saturation (SvO_2) are key indicators. While SvO_2 is more representative, it is invasive. SvO_2, requiring only a central venous catheter, is less invasive and more practical. Studies suggest that greater decreases in SvO_2 during SBT may indicate extubation failure, while smaller decreases suggest success. Despite this, SvO_2 is not widely used due to limited data on its optimal cut-off values and prognostic accuracy [1, 2].

This study aims to evaluate whether changes in SvO_2 during SBT can predict successful extubation in ICU patients.

2. METHODS

2.1. Study Design and Setting

This analytical observational cross-sectional study involved medical and surgical patients who were admitted to the ICU of Prof. Dr I.G.N.G. Ngoerah Hospital from July to August 2024. This study was reviewed and approved by Ethics Committee at the Faculty of Medicine Universitas Udayana (Approval Number: 1878/UN14.2.2.VII.14 /LT/2024). Informed consent was obtained from each participant or their legal guardian regarding their involvement in this study.

2.2. Study Participant

Adult patients aged 18-65 who were using mechanical ventilation during their admission to the ICU were involved in this study. All patients with central venous catheter access in the superior cava vein, were clinically ready for weaning, and could perform SBT for 30-120 minutes with an RSBI <150. Patients were considered clinically ready for weaning if they met these criteria:

a) Resolution of the acute phase of the disease that becomes the main indication for intubation and mechanical ventilation.

b) Adequate cough reflex (peak cough expiratory flow >60 L/min) without excessive bronchial secretions (suction was not needed every 2-3 hours).

c) Hemodynamically stable (no signs and symptoms of myocardium ischemia, systolic blood pressure within 90-160 mmHg without or with the use of minimal vasoactive support, and a heart rate ≤140 beats/min)

d) Adequate oxygenation (partial pressure of oxygen (PaO_2) ≥60 mmHg at inspired oxygen fraction (FiO_2) ≤40%; or ratio of $PaO2/FiO_2$ >150 mmHg; positive end-expiratory pressure (PEEP) ≤8 cmH_2O; and $PaCO_2$ was within normal range or approaching patients' baseline level).

e) Adequate pulmonary function (maximum inspiratory pressure (MIP) ≤ -20 cmH_2O and respiratory rate ≤35 breaths/min).

f) No significant electrolyte imbalance (pH 7.35-7.45) with a hemoglobin level ≥10 g/dL.

g) Controlled pain with a behavioral pain scale (BPS) or numerical rating scale (NRS) less than 3.

h) Adequate consciousness (Glasgow Coma Scale (GCS) ≥13).

Table 1. Baseline characteristics.

Characteristics	All Patients (n=42)	Groups		P-value
		Successful Extubation (n=37)	Fail Extubation (n=5)	
Age (years), mean ± SD	42.2±15.34	40.7±15.52	53.2±8.64	0.15[b]
Sex, n (%)				
Male	24 (57.1)	23 (62.2)	1 (20.0)	0.146[c]
Female	18 (42.9)	14 (37.8)	4 (80.0)	
BMI (kg/m^2), mean ± SD	23.66±5.5	23.20±3.74	27.08±12.93	0.541[a]
Diagnosis groups				
Surgical	39 (92.9)	35 (94.6)	4 (80.0)	0.323[c]
Non-surgical	3 (7.1)	2 (5.4)	1 (20.0)	
Comorbidities, n (%)				
Neurologic disease	16 (38,1)	13 (35.1)	3 (60.0)	0.352[c]
Heart disease	23 (54.8)	21 (56.8)	2 (40.0)	0.644[c]

(Table 1) contd.....

Characteristics	All Patients (n=42)	Groups		P-value
		Successful Extubation (n=37)	Fail Extubation (n=5)	
Respiratory disease	3 (7.1)	2 (5.4)	1 (20.0)	0.323[c]
Renal disease	6 (14.3)	4 (10.8)	2 (40.0)	0.141[c]
Diabetes mellitus	4 (9.5)	4 (10.8)	0 (0)	1.000[c]
Mechanical ventilation duration (days), mean ± SD	1.98±1.55	1.89±1.47	2.6±2.07	0.346[b]
Length of stays (days), mean ± SD	4.05±1.99	3.92±1.96	5±2.34	0.252[b]
Outcome, n (%)				
Survive or improved	40 (95.2)	37 (100)	3 (60)	0.012[c]
Died	2 (4.8)	0 (0)	2 (40)	
Laboratories parameters, mean ± SD				
Leukocyte (x10^3/µL)	14.73±4.95	15.27±4.86	10.72±3.97	0.055[b]
Hemoglobin (g/dL)	11.1±2.01	11.01±1.97	11.76±2.46	0.44[a]
Creatinine	0.97±0.51	1.01±0.53	0.74±0.29	0.145[b]
Na	141.5±5.35	141.4±5.61	142.4±2.97	0.701[a]
K	3.85±0.74	3.92±0.74	3.33±0.56	0.098[a]
Arterial blood gas analysis, mean ± SD				
pH	7.377±0.072	7.375±0.072	7.394±0.079	0.594[a]
PO_2	133.5±36.86	136,6±36.8	110.6±31.5	0.107[b]
PCO_2	44.88±21.17	44.95±22.52	44.4±5.55	0.252[b]
BE	-0.12±4.66	-0.44±4.65	2.24±4.54	0.232[a]
HCO_3	24.93±3.9	24.64±3.9	27.12±3.52	0.185[a]
SO_2	98.48±1.45	98.65±1.36	97.2±1.64	0.072[b]

[a]Independent T-test; [b]Mann-Whitney-U test.

BE, base excess; BMI, body mass index; HCO_3, bicarbonate; K, potassium; Na, sodium; PCO_2, partial pressure of carbon dioxide; PO_2, partial pressure of oxygen; SD, standard deviation; SO_2, oxygen saturation.

Patients who were using tracheostomy, had lung cancer or chronic obstructive pulmonary disorder (COPD), or died before weaning process, were excluded. Eligible patients were selected using consecutive sampling.

2.3. Study Protocol and Measurement

Each patient who was deemed ready for weaning underwent SBT for at least 30 minutes. SBT was performed using a T-piece tube with minimal pressure support (PS) ventilation mode (PS 6-8 cm H_2O and PEEP 4 cmH_2O), and FiO_2 was adjusted to be the same as when the patient was using mechanical ventilation. RSBI was calculated during SBT by dividing the respiratory rate by the tidal volumes (L). The patient was extubated if RSBI <105 breaths/min/L. If the RSBI >105 breaths/min/L, the patient was not extubated, and SBT was repeated the following day. A blood sample was obtained from the central venous catheter to determine the $ScvO_2$ level through blood gas analysis. $ScvO_2$ level measurement was performed at the beginning of SBT (first minute) and 30 minutes after SBT started. The change in $ScvO_2$ level was recorded as $\Delta ScvO_2$. Other hemodynamic parameters, including mean arterial pressure (MAP), heart rate (HR), respiratory rate (RR), and peripheral oxygen saturation (SaO_2), were also recorded before and after SBT. The signs of extubation failure were observed for the next 48 hours. Extubation failure was defined as the need for re-intubation, or patients died within 48 hours after extubation.

2.4. Statistical Analysis

A descriptive statistical analysis was carried out. Continuous data were expressed as means and standard deviations (SD), while categorical data were expressed as relative frequency (%). Baseline characteristics, $ScvO_2$ pre-SBT, $ScvO_2$ 30-min after SBT, and $\Delta ScvO_2$ were compared between successfully extubated patients and those who failed. A comparative test for continuous data was performed using an independent T-test or Mann-Whitney-U test, as appropriate. Meanwhile, comparative tests for categorical data were performed using the Chi-square or Fisher exact test, as appropriate. A Receiver Operating Curve (ROC) analysis was conducted to obtain the optimal cut-off of $\Delta ScvO_2$ for predicting successful extubation. Statistical significance was defined as $p < 0.05$. Diagnostic analysis was conducted to determine the diagnostic accuracy of $\Delta ScvO_2$ in predicting successful extubation based on the optimal cut-off obtained from ROC analysis. All statistical analyses in this study were performed using Statistical Package for Social Science (SPSS) version 25.0 software.

3. RESULTS

Forty-two eligible patients were involved in this study, with a mean age of 42.2±15.34 years. The majority of patients (37/42; 89.1%) were successfully extubated. Detailed demographic and clinical baseline characteristics are shown in Table **1**. There was no significant difference in baseline characteristics between successfully extubated patients and those who failed, except for higher survival status in successfully extubated patients (100% *vs.* 60%, p=0.012).

There was a significant difference in RR, SaO_2, and MAP between successfully extubated patients and those who failed at the first minute and after 30 minutes of SBT (Table **2**). The baseline PaO_2 and $ScvO_2$ were also not significantly different between successfully extubated patients and those who failed. However, when the change of PO_2 level (ΔPaO_2) and change of $ScvO_2$ level ($\Delta ScvO_2$) after 30 minutes of SBT were compared between groups, patients who were success- fully extubated significan- tly had a lower decrease of PaO_2 (ΔPaO_2 -2.54±1.88 vs -8.6±9,42; p=0.016) and $ScvO_2$ ($\Delta ScvO_2$ -2.89±1.63 vs -8.20±4.27; p=0.049) (Table **3**). Thus, a decrease in $ScvO_2$ could be used to discriminate successfully extubated patients from patients more likely to fail.

Table 2. Hemodynamic parameters at beginning and at 30-minute of SBT.

Hemodynamic Parameters	All patients (n=42)	Groups		P-value
		Successful Extubation (n=37)	Fail Extubation (n=5)	
At first minute of SBT, mean ± SD				
Respiratory rate (breaths/min)	16.76±3.43	16.30±3.09	20.20±4.27	0.015[a]
Peripheral oxygen saturation (SaO_2; %)	99.52±1.02	99.7±0.62	98.20±2.17	0.034[b]
MAP (mm Hg)	85.60±12.42	84.14±11.86	96.40±12.22	0.037[a]
Heart rate (beats/min)	88.20±16.40	86.86±16.57	98.40±11.84	0.142[a]
At 30 minutes of SBT, mean ± SD				
Respiratory rate (breaths/min)	18.48±3.70	17.97±3.35	22.20±4.71	0.015[a]
Peripheral oxygen saturation (SaO_2; %)	99.55±1.04	99.76±0.49	97.80±2.34	0.034[b]
MAP (mm Hg)	88.29±11.90	86.86±11.39	98.80±12.13	0.037[a]
Heart rate (beats/min)	91.21±15.90	89.38±15.92	104.80±7.16	0.142[a]

Note: [a]Independent T-test; [b]Mann-Whitney-U test
MAP, mean arterial pressure; SBT, spontaneous breathing trials.

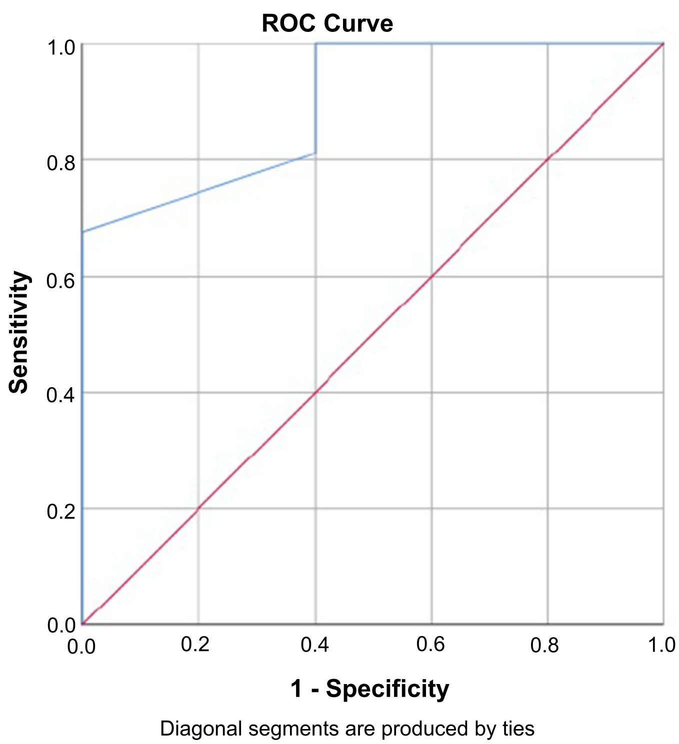

Fig. (1). Receiver operating curve (ROC) analysis of $\Delta ScvO_2$ for predicting successful extubation.

Table 3. Blood gas analysis and $ScvO_2$ level at beginning and at 30-minute of SBT.

Blood Gas Analysis Parameters	All Patients (n=42)	Groups		P-value
		Successful Extubation (n=37)	Fail Extubation (n=5)	
At first minute of SBT, mean ± SD				
pH	7.342±0.106	7.345±0.083	7.318±0.228	0.802[a]
pO_2	41.07±7.61	40.27±5.91	47.00±15.13	0.379[a]
pCO_2	43.84±6.81	44.62±6.61	38.08±5.88	0.042[a]
BE	-1.33±6.63	-1.03±5.32	-3.60±13.72	0.984[b]
HCO_3	24.37±4.96	24.66±4.03	22.22±9.97	0.712[b]
$ScvO_2$	70.74±8.22	70.00±7.76	76.20±10.40	0.167[b]
At 30 minutes of SBT, mean ± SD				
pH	7.344±0.082	7.345±0,072	7.335±0.152	0.811[a]
pO_2	37.81±5.91	37.73±5.52	38.40±9.13	0.830[b]
pCO_2	44.34±7.46	45.06±7.33	39.08±6.92	0.087[b]
BE	-1.19±5.88	-0.95±4.99	-3.00±11.20	0.470[a]
HCO_3	24.34±4.89	24.64±4.28	22.12±8.57	0.037[a]
$ScvO_2$	67.21±8.05	67.11±7.75	68.00±11.07	0.142[a]
Change during SBT, mean difference ± SD				
ΔpH	0.002±0.051	-0.0003 ±0.042	0.018±0.100	0.460[b]
ΔPO_2	-3.26±3.96	-2.54±1.88	-8.6±9.42	0.016[a]
ΔPCO_2	0.50±3.32	0.44±3.46	1.00±2.22	0.727[a]
ΔBE	0.14±2.01	0.08±1.86	0.60±3.13	1.000[b]
ΔHCO_3	-0.03±1.73	-0.02±1.71	-0.10±2.06	0.928[a]
$\Delta ScvO_2$	-3.52±2.67	-2.89±1.63	-8.20±4.27	0.049[a]

Note: [a]Independent T-test; [b]Mann-Whitney-U test
BE, base excess; HCO_3, bicarbonate; PCO_2, partial pressure of carbon dioxide; PO_2, partial pressure of oxygen; SD, standard deviation; $ScvO_2$, central venous oxygen saturation.

Table 4. Cross-tabulation between $\Delta ScvO_2$ cut-off and extubation outcome.

$\Delta ScvO_2$	Extubation Outcome		Total
	Successful Extubation	Fail Extubation	
≤4.5%	30 (81,1%)	2 (40%)	32 (76,2%)
>4.5%	7 (18,9%)	3 (60%)	10 (23,8%)
Total	37 (59.1%)	18 (40.9%)	42 (100.0%)

Note: $\Delta ScvO_2$, mean difference between first minute and after 30 minutes of SBT.

Table 5. Diagnostic analysis of $\Delta ScvO_2$ cut-off.

Variable	AUC	Sensitivity	Specificity	Cut-off Point	CI95%
$\Delta ScvO_2$	89.7%	81.1%	60%	-4.5	0.769 – 1.000

Note: AUC, area under the curve; CI95%, confidence interval 95%; $\Delta ScvO_2$, mean difference between first minute and after 30 minutes of SBT.

Further analysis using the ROC curve (Fig. **1**) showed that the most optimal $\Delta ScvO_2$ cut-off to predict successful extubation in critically ill patients was 4.5%. Thus, a decrease of $ScvO_2$ less than 4.5% is associated with a higher probability of successful extubation (Table **4**). This cut-off had an area under curve (AUC) of 0.897, sensitivity of 81.1%, specificity of 60%, positive predictive value (PPV) of 93.8%, and negative predictive value (NPV) of 70% (Table **5**).

4. DISCUSSION

A decreased $ScvO_2$ level by less than 4.5% during SBT could predict successful extubation with high sensitivity (81.1%) and moderate specificity (60.0%). Both groups also had comparable comorbidities, mechanical ventilation duration, and even similar blood gas analysis and other laboratory parameters at baseline. This indicated that the change in $ScvO_2$ level during SBT could discriminate successfully extubated patients from patients more likely to fail even if they had similar clinical characteristics. Thus, our study suggests that a decrease in $ScvO_2$ level of less than 4.5% during SBT could be utilized in clinical practice as a guide for the mechanical ventilation weaning process in critically ill patients.

Previous studies also proved that $\Delta ScvO_2$ during SBT could predict successful extubation in difficult-to-wean patients [4]. Ashmawi et al. also reported that a decrease of $ScvO_2$ of more than 3.8% is significantly associated with extubation failure. Even though their cut-off was slightly different, this study showed that a decrease in $ScvO_2$ level had a high sensitivity (89.74%), specificity (90.91%), and PPV (97.22%) but with moderate NPV (71.43%) [5]. Mallat et al. also found that $\Delta ScvO_2$ was an independent predictor of extubation success in patients with good SBT tolerance. A decrease of $ScvO_2$ ≥5.4% had an excellent NPV and a moderate PPV in predicting extubation failure [6]. Teixeira et al. also found that a greater decrease in $ScvO_2$ level during a T-tube trial could predict extubation failure in 86% of cases. Meanwhile, patients who were successfully extubated had minimal change in $ScvO_2$ level [7]. They found that the extubation failure and re-intubation requirement rate significantly increased when $ScvO_2$ decreased to more than 4.5% (sensitivity 88%, specificity 95%, PPV 0.93, and NPV 0.90) [8]. Shalaby et al. also stated that the risk of re-intubation was significantly higher when the decrease in $ScvO_2$ level >5% (sensitivity 87%, specificity 90%, PPV 0.78, and NPV 0.93) [7].

Oxygen consumption (VO_2) depends on the delivery of oxygen (DO_2) and oxygen extraction ratio (O_2ER). Therefore, increased DO_2 will increase VO_2 levels. During the transition from mechanical ventilation to spontaneous breathing, the respiratory muscle will work harder, increasing VO_2 [9, 10]. Thus, CO and DO_2 will also increase as compensation to offset the increased demand for respiratory muscle VO_2. Increased VO_2 demand during this transition process will cause decreased O_2 supply to cells, resulting in decreased global tissue oxygenation muscle [11-13]. In addition to the effects of increased VO_2, other factors, such as laryngeal oedema and low muscle endurance, are some of the potential causes for extubation failure, which are not directly related to oxygen consumption and use, so these results may be, to some extent, difficult to explain [4]. These confounding factors (mental status alteration and inadequate cough) were excluded from our study.

The respiratory rate, MAP and SaO_2, in the successful and unsuccessful group during the first minute and after 30 minutes show a significant difference statistically, but clinically it's difficult to precisely predict the failure of extubation using only a small difference in respiratory rate (16.30±3.09 *vs.* 20.20±4.27), SaO_2 (99.7±0.62 *vs.* 98.20±2.17) and MAP (84.14±11.86 *vs.* Line 187-19196.40±12.22). An Intensivist should use not one but several parameters, from patient's vital signs, clinical conditions, and laboratory parameters that show tissue perfusion to predict the failure of extubation.

$ScvO_2$ is used as a surrogate of SvO_2, which is more invasive, high-risk, and expensive because it requires pulmonary catheter insertion. Now, $ScvO_2$ has become part of standard care for critically ill patients. The previous study showed a significant correlation between $ScvO_2$ and SvO_2 [14, 15]. Therefore, $ScvO_2$ measurement is also a reliable indicator for global tissue oxygenation status, but it is easier, safer, and affordable in clinical practice.

The outcomes of successfully extubated patients and patients who failed significantly differed. A higher survival rate was found in groups of successfully extubated patients (100% *vs.* 60%, p=0.012). This emphasizes that proper timing of extubation in patients ready for weaning is critical, and failure of extubation significantly affects the morbidity and mortality of critically ill patients. Therefore, we highly suggest using the change in $ScvO_2$ level as a guide to predict successful extubation in critically ill patients because successful SBT does not always mean successful extubation.

This study also had limitations. It was a non-randomized study with a limited number of participants, which may limit the generalization of its results. However, it involved both surgical and medical critically ill patients. Another limitation is the absence of hemodynamic measurements to assess CO and also no SvO_2 measurement as a gold standart test, due to the limited use of right heart catheterization. Nevertheless, the results of this study still add important points regarding the role of $ScvO_2$ measurements during SBT to guide clinicians in selecting patients who are likely to be successful or unsuccessfully extubated.

CONCLUSION

The change of $ScvO_2$ during SBT was a good predictor of successful intubation in critically ill patients in the ICU. A decrease of $ScvO_2$ less than 4.5% after 30 minutes of SBT is associated with a higher probability of successful extubation, with a sensitivity of 81.1%, specificity of 60%, positive PPV of 93.8%, and NPV of 70%. An Intensivist should use not one, but several parameters, from patient's vital signs, clinical condition, laboratory parameters that show tissue perfusion to predict the failure of extubation. We suggest using this new parameter as an additional judgment in selecting patients in the ICU who are likely to be successfully extubated.

AUTHORS' CONTRIBUTION

The authors confirm their contribution to the paper as follows: study conception and design: I.W.S.; analysis and interpretation of results: P.A.S.P., T.G.A.S.; draft manuscript: B.J., M.W.W. All authors reviewed the results and approved the final version of the manuscript.

LIST OF ABBREVIATIONS

PS	=	Pressure Support
COPD	=	Chronic Obstructive Pulmonary Disorder
ICU	=	Intensive Care Unit
RSBI	=	Rapid Shallow Breathing Index
SBT	=	Spontaneous Breathing Trial

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

This study was reviewed and approved by the Ethics Committee at the Faculty of Medicine Universitas Udayana Indonesia (Approval Number: 1878/ UN14.2.2.VII.14 /LT/2024).

HUMAN AND ANIMAL RIGHTS

All procedures performed in studies involving human participants were in accordance with the ethical standards of institutional and/or research committee and with the 1975 Declaration of Helsinki, as revised in 2013.

CONSENT FOR PUBLICATION

Informed consent was obtained from each participant or their legal guardian regarding their involvement in this study.

STANDARD OF REPORTING

STROBE guidelines were followed.

AVAILABILITY OF DATA AND MATERIALS

The data and supportive information are available within the article.

FUNDING

None.

CONFLICT OF INTEREST

The authors declare no conflict of interest, financial or otherwise.

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Declared none.

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