Print ISSN 1110-208X.

Online ISSN 2357-0016

Original article

Predictive Value of Airway Occlusion Pressure, Maximal Inspiratory Pressure and Their Ratio for Successful Extubation in Patients with Traumatic Brain Injury

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Received: 25 November 2024

Accepted: 19 December 2024

Abstract:

Background: The treatment of mechanical ventilation (MV) is essential for patients who have experienced traumatic brain injury (TBI); however, it is associated with a variety of complications. This study aimed to assess the predictive value of respiratory muscle factors, such as maximal inspiratory pressure (PIMax), and central drive indicators, such as airway occlusion pressure (P0.1) and their ratio, in predicting the success of MV withdrawal in patients with TBI. **Methods:** In this prospective observational study, 60 ventilated TBI patients who were eligible for weaning were examined for a period of two hours, spontaneous breathing trials were implemented for all patients, utilizing low-level pressure support ventilation. The ventilator supplied the P0.1 and PIMax values. **Results:** PIMax can significantly predict successful ventilator weaning with AUC of 0.786, P-value <0.001, and at cutoff value >-23 CmH2O with 78.95% sensitivity, 60.98% specificity. P0.1 was a significant predictor of successful ventilator weaning with AUC of 0.720, P-value of 0.010, and at cutoff value >2.6 CmH2O with 73.68% sensitivity, 51.22% specificity. P0.1/ PIMax ratio can significantly predict successful ventilator weaning with AUC of 0.776, P= 0.001, and at cutoff value >0.11 CmH2O with 84.21% sensitivity, 56.10% specificity. **Conclusion:** The weaning prognosis in TBI patients may be predicted by PIMax, P0.1, and the ratio of P0.1/PIMax, as evidenced by their moderate predictive accuracy. Patients with successful weaning showed lower ratio of P0.1/PIMax, PIMax, P0.1 higher PaO2/FiO2 ratio, lower RSBI, and lower number of days in the ICU.

Keywords: Airway Occlusion Pressure, Traumatic Brain Injury; Mechanical Ventilation, Maximal Inspiratory Pressure, Weaning.

Introduction

Traumatic brain injury (TBI) was the most prevalent cause of fatality and disability by 2020, according to the World Health Organization [(1)]. Although mechanical ventilation (MV) is essential for the patient with TBI, it does have complications. Therefore, once the cause or the reason for initiating MV is resolved and the patient recovers his or her ability to robustly ventilate and oxygenate spontaneously, the patient should be taken off MV[(2)]. The morbidity, mortality, and supply utilization of patients who effectively wean off mechanical ventilation are lower than those who require long-term support. Consequently, tapering planning should initiate upon the commencement of MV [(3)].

The diaphragmatic muscle's weakness is a significant factor contributing to weaning failure from MV [(4)].

In the intensive care unit, the maximal inspiratory pressure (PIMax) is frequently employed to assess the diaphragmatic muscle's capacity. During inspiration, it is the intense pressure that is exerted on an obstructed airway [(5)]. PIMax is a direct measurement of inspiratory muscle strength that requires the patient to exhale to residual volume and then maximally inhale against a closed airway [(6)]. PIMax can be determined at the bedside using a basic manometer or as part of pulmonary function assessment [(7)]. PIMax measurements are occasionally referred to as negative inspiratory force (NIF) when they are conducted on intubated patients in a clinical setting [(8)]. Although the utilization of PIMax as the sole predictor of successful extubation is somewhat restricted, it is still frequently taught, measured, and reported [(9)].

The airway occlusion pressure (P0.1) is the pressure at the airway orifice that is generated during the initial one hundred milliseconds of an inhalational effort against an obstructed airway. An adequate index of respiratory drive in the center is P0.1 [(10)]. Pressure time product, often known as work of breathing (WOB) [(11)], partial pressure of O2 (P0.1) strongly associated with inspiratory effort. P0.1 is a good marker for inspiratory effort, and adjusting it modulates the intensity of respiratory support. Support that is "too much" because the patient maintains high ventilation pressures. The "P0.1" value is a key indicator for excessive support. Lower P0.1 values show that there is "too much" assistance given to the patient. Conversely, higher P0.1 values suggest "too little" assistance in either assist-controlled or spontaneous support. A study is required to examine the precision of P0.1 in a variety of clinical settings, as evidenced by the use of flow or pressure triggers in modern ventilators [(12)].

The purpose of the study was to assess the respiratory muscle determinants predictive ability, comprising the maximal inspiratory pressure, and the central drive determinant, comprising the airway occlusion pressure, in the weaning outcome of TBI patients who were weaning from invasive MV.

Patients and methods

This prospective observational study was conducted on 60 TBI patients who were admitted to ICU of Benha University hospitals, from Aug 2023 to May 2024. The research Ethics Committee of the Faculty of Medicine Benha University approved the study. The study has a special identifier number: MS 23-7-2023 and was registered online. In order to take part in this study, patients were required to provide informed consent.

Inclusion criteria were patients with closed-type TBI who were confined to the ICU and received invasive MV for a period exceeding twenty-four hours, age from 18 to 65 years (male or female) and fulfillment of criteria of readiness for weaning off MV [resolution of respiratory insufficiency cause and MV, stable hemodynamic profile, normal metabolic profile, adequate arterial blood gases, no or minimal tracheobronchial secretion, intact cough reflex and Richmond agitation score and scale of sedation (–1 to +1)].

Exclusion criteria were patients with open type TBI, age below 18 years or above 65 years, Glasgow coma scale (GCS) at extubation < 9, chest wall trauma, primary unilateral/bilateral absence of diaphragmatic mobility, chronic chest disease, pre-existing cardiovascular disease, severe ICU acquired neuromyopathy, and a previously failed spontaneous breathing trial (SBT).

All patients were subjected to complete history taking including demographic information (Age, gender, weight, and height), TBI details (causes of injury, GCS score at admission, presence of intracranial hemorrhage or edema, surgical intervention), medical history (including allergies and medications, pre-existing conditions, respiratory diseases, smoking history and previous intubation or MV), complete physical examination involved vital signs (blood pressure, heart rate, temperature, respiratory rate and oxygen saturation), general appearance, respiratory system (chest expansion, breath sounds, use of accessory muscles and tracheal deviation), neurological examination (cranial nerve assessment, motor and sensory function, and reflexes), and the laboratory investigations were performed on admission.

Weaning technique:

In order to facilitate spontaneous weaning, the patients were administered a two-hour SBT using a GE ventilator (Carescape R860, USA) that was equipped with low-level pressure support (8 cm H2O) and a PEEP level of ≤ 5 cm H_2O. SBT should be administered to patients who have successfully completed the daily "wean screen." Patients underwent tracheal measurements of PIMax and P 0.1 prior to undergoing 2-hour SBTs; the ratio of P 0.1/PIMax was subsequently computed. The parameters were automatically analyzed and measured using a pressure sensor in the ventilator that was affixed. Pressure support ventilation mode (12–20 cm H_2O) was applied to all subjects, who were not taking any sedatives. Successful weaning from MV was defined as maintaining spontaneous breathing for at least forty-eight hours following removal.

Study measurements:

While pressure support ventilation, tracheal P 0.1 with 5 cm H2O positive end expiratory pressure and 7 cm H_2O pressure support is measured. At least three measurements were made, and the measurements were made at separation of at least 15 seconds. For analysis, we used the mean value. Results below 4.2 cm H_2O for the tracheal P 0.1 suggest successful weaning.

The ventilator automatically measured PIMax; we then calculated the average of the three measurements. Values that were more negative than -25 cm H2O were indicative of successful weaning.

The ratio P 0.1/PIMax was determined by dividing tracheal P 0.1 by PIMax. As a consequence of both pressures' negative nature, the outcome was represented in positive values. Successful weaning was predicted by values less than 0.14. All patients who effectively completed SBT without experiencing any deterioration were extubated and received oxygen at a 40% concentration through a Venturi mask. However, it was presumed that failure of SBT would be with decreased consciousness, sweating, rate of breathing greater than thirty-five breaths a minute, unstable hemodynamics, an increased work on breathing.

Study outcome:

The primary outcome was the assessment of the weaning success prediction accuracy of PIMax, P 0.1, and the ratio of P 0.1/PIMax.

The secondary outcomes were assessment of the patients' demographics and baseline clinical criteria, causes of MV and length of ventilation, hemodynamics and laboratory investigations before SBT, ventilator settings (TV, PEEP, PS), weaning indices including (RSBI (breaths/L), P0.1, PIMax, P0.1/PIMax ratio, PaO2/FiO2 ratio), hospital stay and ICU stay length.

Approval code: MS 23-7-2023

Sample size

The null hypothesis AUC of the ROC curve is 0.5, and the expected AUC of the ROC curve for the prediction of the P 0.1 for weaning success is at least 0.76, as determined by a previous study. The sample size was determined using MedCalc Software Ltd v. 20 with a 5% confidence limit and 90% power [(13)]. The study should therefore include a minimum of 50 patients. ten patients were incorporated to solve the issue of dropout.

Statistical analysis

The statistical analysis was carried out using the Microsoft Statistical Package for the Social Sciences, Version 26 (IBM Inc., Chicago, IL, USA). The Shapiro-Wilk test was used to check whether the data was normal. Means with standard deviations (SD) or medians (IQR) were used to display quantitative data for the purpose of comparing ventilator cessation success against failure. The Mann-Whitney U test or the unpaired Student's t-test were used for the comparisons, depending on what was acceptable. The frequencies and percentages of the qualitative factors were shown. When appropriate, we used Fisher's exact test or the Chi-square test to examine the data. When the two-tailed P value was less than 0.05, the statistical analysis was considered significant. With the use of ROC curve analysis, diagnostic specificity, PPV, and NPV, we determined how well each test could diagnose a patient. The AUC is a trustworthy measure of a test's effectiveness in most cases

Results

After an initial screening for eligibility, eighty-two patients were chosen for the study. Subsequently, sixty patients participated in the final analysis. Hypoxemia and bradycardia during the test (n=5), laryngospasm (n=2), inability to acquire patient consent (n=6), and Glasgow coma score (n=9) were the reasons for exclusion. **Figure 1**

Demographics (age, gender, BMI, APACHE II, associated comorbidities, and GCS on admission), causes of MV (brain injury type and insult grade), MV length, and baseline vital signs (RR, HR, MAP) were insignificantly different among patients with successful and failed ventilator weaning. **Table 1**

Patients with successful ventilator weaning had significantly higher PaO2/FiO2 ratio compared to patients with failed ventilator weaning (P<0.001). PH, PaO2 and PaCO2 were insignificantly different between successful and failed ventilator weaning. Patients with successful ventilator weaning had significantly lower RSBI compared to patients with failed ventilator weaning (P=0.031). TV, PS, and PEEP were insignificantly different between successful and failed ventilator weaning. Patients with successful ventilator weaning had significantly lower ratio of PIMax P0.1 and P0.1/PIMax in comparison to patients with failed ventilator weaning (P<0.05). All patients had 2 trials. **Table 2**

Regarding success of ventilator weaning, 41 (68.33%) had successful weaning, while 19 (31.67%) patients had failed weaning. Length of MV was insignificantly different between successful and failed ventilator weaning. Patients with successful ventilator weaning had significantly lower number of days in the ICU compared to patients with failed ventilator weaning (P=0.038). The length of hospital stay did not differ significantly among successful and unsuccessful ventilator weaning. **Table 3**

PIMax can significantly predict successful ventilator weaning with AUC of 0.786, P value <0.001, and at cutoff value >-23 Cm H_2O with 78.95% sensitivity, 60.98% specificity, 48.4% PPV and 86.2% NPV. P0.1 was significant predictor of successful ventilator weaning with AUC of 0.720, P value of 0.010, and at cutoff value >2.6 Cm H_2O with 73.68% sensitivity, 51.22% specificity, 41.2% PPV and 80.8%

NPV. (P=0.010) P0.1/ PIMax ratio can significantly predict successful ventilator weaning with AUC of 0.776, P value of 0.001, and at cutoff value >0.11 Cm H2O with 84.21%sensitivity, 56.10%specificity, 47.1% PPV and 88.5% NPV. RSBI was insignificant predictor for successful ventilator weaning, PaO_2/FiO_2 was significant predictor for successful ventilator weaning with AUC of 0.755, P value of 0.001, and at cutoff value ≤290 Cm H_2O with 47.37%sensitivity, 70.73%specificity, 42.9%PPV and 74.4% NPV. **Table 4, Figure 2**

Table 1: Demographic data and causes and length of MV of the studied patients

		Total (n=60)	Success (N=41)	Failure (N=19)	P value
Age (years)		39.7 ± 8.89	39.5 ± 8.81	40.3 ± 9.28	0.733
Gender	**Male**	34 (56.67%)	23 (56.1%)	11 (57.89%)	0.891
	Female	26 (43.33%)	18 (43.9%)	8 (42.11%)	
BMI (kg/m^2)		28.6 ± 3.19	29 ± 3.24	27.9 ± 3.03	0.225
APACHE II		17.2 ± 4.24	16.6 ± 3.76	18.5 ± 4.98	0.105
Associated comorbidity	**No**	51 (85%)	35 (85.37%)	16 (84.21%)	0.76
	DM	4 (6.67%)	3 (7.32%)	1 (5.26%)	
	HTN	4 (6.67%)	2 (4.88%)	2 (10.53%)	
	DM, HTN	1 (1.67%)	1 (2.44%)	0 (0%)	
GCS on admission		9.53 ± 1.60	9.3 ± 1.56	10.2 ± 1.86	0.073
Type of brain injury	**Extradural**	33 (55%)	20 (48.78%)	13 (68.42%)	0.363
	Intraventricular	9 (15%)	7 (17.07%)	2 (10.53%)	
	Subdural	18 (30%)	14 (34.15%)	4 (21.05%)	
Grade of insult	**Mild**	36 (60%)	26 (63.41%)	10 (52.63%)	0.072
	Moderate	15 (25%)	7 (17.07%)	8 (42.11%)	
	Severe	9 (15%)	8 (19.51%)	1 (5.26%)	
Length of MV (Days)		4.3 ± 1.46	4.1 ± 1.39	4.8 ± 1.51	0.087
RR (breaths/min)		13.3 ± 1.38	13.2 ± 1.24	13.6 ± 1.64	0.233
HR (Beats/min)		85.7 ± 9.68	85.4 ± 9.09	86.2 ± 11.07	0.777
MAP (mmHg)		89.6 ± 6.99	89.3 ± 6.82	90.2 ± 7.5	0.640

Data presented as mean ± SD or frequency (%), BMI: Body mass index, DM: Diabetes mellitus, HTN: Hypertension, APACHE II: Acute Physiology and Chronic Health Evaluation II, GCS: Glasgow coma score, MV: mechanical ventilation, MAP: mean arterial pressure, HR: heart rate, RR: respiratory rate.

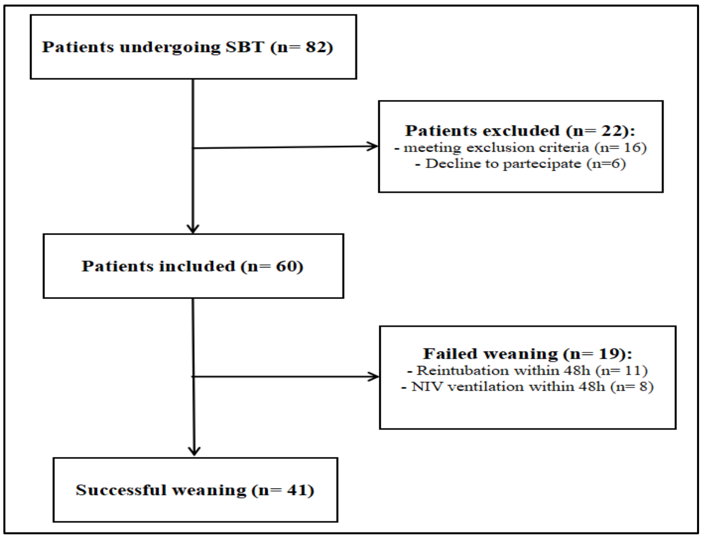


Figure 1: Chart showed the distribution of the studied patients.

Table 2: Comparison of blood gas, MV parameters and measured parameters at weaning of the studied patients based on the success of ventilator weaning

	Total (n=60)	Success (N=41)	Failure (N=19)	P value
		Blood gas before SBT		
PH	7.4 ± 0.03	7.39 ± 0.03	7.38 ± 0.03	0.987
PaO_2 (mmHg)	90.7 ± 4.5	91.3 ± 4.07	89.5 ± 5.22	0.159
$PaCO_2$ (mmHg)	38.4 ± 3.33	38 ± 3.42	39.3 ± 3.05	0.191
PaO_2/FiO_2	329 ± 61.27	348.9 ± 63.17	285.9 ± 24.01	**<0.001***
		MV parameters before SBT		
TV (ml)	456.2 ± 37.85	453.7 ± 37.23	461.6 ± 39.62	0.456
PS (H_2O)	10.9 ± 0.82	11 ± 0.8	11 ± 0.88	0.833
PEEP (cmH_2O)	5.5 ± 0.5	5.4 ± 0.5	5.6 ± 0.51	0.321
RSBI (breaths/L)	40.8 ± 17.82	37.4 ± 12.44	48 ± 24.8	**0.031***
		Measured parameters at weaning		
PIMax (cm H_2O)	-22.6 ± 4.91	-24.1 ± 4.11	-19.2 ± 4.87	**<0.001***
P0.1 (cm H_2O)	3.2 ± 1.12	3.1±0.99	3.9±1.66	**0.013***
P0.1/PIMax ratio	0.14± 0.08	0.1±0.05	0.2±0.11	**<0.001***
Number of trials **2**	60 (100%)	41 (100%)	19 (100%)	--

Data presented as mean ± SD, PaO2: Partial pressure of oxygen, PaCO2: Partial pressure of arterial carbon dioxide, TV: Tidal volume, PS: Pressure support, PEEP: Positive End-Expiratory Pressure, RSBI: Rapid shallow breathing index, PIMax: Maximal inspiratory pressure, P0.1: Airway occlusion pressure. * Significant as P-value ≤ 0.05.

Table 3: Comparison of the ICU length of stay and Hospital length of stay of the studied patients based on the success of ventilator weaning

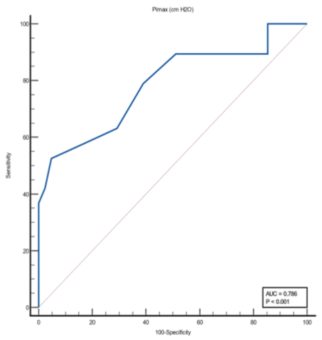
	Total (n=60)	Success (N=41)	Failure (N=19)	P value
ICU length of stay (Days)	10.1 ± 1.53	9.8 ± 1.58	10.7 ± 1.25	**0.038***
Hospital length of stay (Days)	13.1 ± 1.46	12.9 ± 1.59	13.6 ± 1.02	0.096

Data presented as mean ± SD, ICU: Intensive care unit; MV: mechanical ventilation, * significant as P-value ≤ 0.05

Table 4: Diagnostic accuracy of PIMax, P0.1, P0.1/ PIMax ratio, RSBI and PaO2/FiO2 for prediction of successful ventilator weaning

	AUC	Cut off	Sensitivity	Specificity	PPV	NPV	P-value
PI Max (cm H_2O)	0.786	>-23	78.95%	60.98%	48.4%	86.2%	**<0.001***
P0.1 (cm H_2O)	0.720	>2.6	73.68	51.22	41.2	80.8	**0.010***
P0.1/ PIMax ratio	0.776	>0.11	84.21%	56.10%	47.1	88.5	**0.001***
RSBI	**0**.596	32.87	52.63	51.22	33.3	70	0.27
PaO_2/FiO_2	0.755	≤290	47.37	70.73	42.9	27.7 - 59.5	74.4

RSBI: Rapid shallow breathing index, PIMax: Maximal inspiratory pressure, P0.1: Airway occlusion pressure. AUC: Area under the curve, CI: Confidence interval, PPV: Positive predictive value, NPV: Negative predictive value, PIMax: Maximal inspiratory pressure, * significant as P-value ≤ 0.05; RSBI: Rapid shallow breathing index; PaO2: Partial pressure of oxygen.



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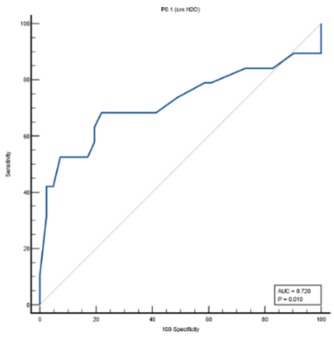

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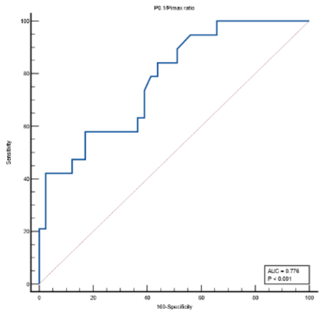

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Figure 2: A: ROC curve analysis of PIMax for prediction of successful ventilator weaning, B: ROC curve analysis of P0.1 for prediction of successful ventilator weaning, C: ROC curve analysis of P0.1/ PIMax ratio for prediction of successful ventilator weaning

Discussion

Weaning failure may result from a variety of factors, including poor gas exchange, neuromuscular diseases, and an impairment of the respiratory center's activity [14, 15]. The predictive indexes maintain their complete predictive power when they are integrated into weaning protocols, as clinicians typically do not employ them to identify a subgroup of patients who are considered suitable for weaning [16].

In the current study, patients with successful ventilator weaning had significantly lower ratio of PIMax, P0.1, and P0.1/PIMax in comparison to patients with failed ventilator weaning (P<0.001).

The P0.1 was significant predictor of successful ventilator weaning with AUC of 0.720, P value of 0.010, and at cutoff value > 2.6 cmH_2O with 73.68% sensitivity, 51.22% specificity, 41.2% PPV and 80.8% NPV.

This was confirmed by Telias et al., [17] who object to ascertain the validity of the "ventilator" P0.1 (P0.1vent) exhibited on the screen as a measure of drive and the capacity of P0.1 to identify potentially detrimental levels of exertion. P0.1 is a dependable bedside instrument for evaluating respiratory drive and identifying potentially harmful inspiratory exertion, as per their findings.

Conversely, de Souza et al [18]. conducted an investigation into the maximal inspiratory pressure predictive value in relation to weaning outcome and proposed that a value of P0.1 greater than 2.33 cmH2O was correlated with failure of weaning.

PIMax can significantly predict successful ventilator weaning with AUC of 0.786, P value <0.001, and at cutoff value >-23 cmH_2O with 78.95% sensitivity, 60.98% specificity, 48.4% PPV and 86.2% NPV.

In partial agreement with us, Fahmy et al [19]. the examined indices predictive values regarding weaning success were analyzed, and it was determined that PIMax can significantly predict successful ventilator weaning with an AUC of 0.93 and a cutoff value of ≤ -22 cmH2O. The sensitivity was 91.67%, the specificity was 80.95%, the PPV was 87.3%, and the NPV was 87.2%.

P0.1/ PIMax ratio can significantly predict successful ventilator weaning with AUC of 0.776, P value of 0.001, and at cutoff value >0.11 cmH_2O with 84.21% sensitivity, 56.10% specificity, 47.1 PPV, and 88.5% NPV.

In agreement with our findings, Nemer et al [20]. assessed the predictive performance of PIMax, P 0.1, and its ratio (P 0.1/PIMax) in the context of weaning outcomes and determined that a P0.1/PIMax ratio of less than 0.14 was significantly correlated with weaning success.

The blood gas was significantly more alkaline in patients who successfully weaned from their ventilators than in those who failed to wean. Patients with successful ventilator weaning had significantly higher PaO_2/FiO_2 ratio compared to patients with failed ventilator weaning. PH, PaO_2 and $PaCO_2$ were insignificantly different between successful and failed ventilator weaning.

Similar to our results, Yu et al [21]. stated that, the PaO2/FiO2 ratio and PaCO2 were not significantly difference among the groups of Extubation success and Extubation failure among the arterial blood gas in the study. Nevertheless, the p-value was 0.039, indicating that the PH was not significantly different among the groups.

Patients with successful ventilator weaning had significantly lower RSBI compared to patients with failed ventilator weaning. TV, PS, and PEEP were insignificantly different between successful and failed ventilator weaning.

In agreement with us, Shamil et al [22]. study stated that patients with successful ventilator weaning had significantly lower RSBI (52.11 ± 15.8) compared to patients with failed ventilator weaning (70.03 ± 25.4) with p value= 0.008.

PaO_2/FiO_2 was significant predictor for successful ventilator weaning with AUC of 0.755, P value of 0.001, and at cutoff value ≤ 290 cmH_2O with 47.37% sensitivity, 70.73% specificity, 42.9 %PPV, and 74.4% NPV. However, El Khoury et al [23]. demonstrated that the AUC using the ratio of PaO_2:FiO_2 was 0.62 and concluded that Successful extubation in patients with hypoxemic respiratory failure is not effectively predicted by the PaO2:FiO2 ratio.

In comparison to patients who failed ventilator weaning, those who successfully weaned from their ventilators spent a significantly fewer number of days in the ICU.

In agreement with our results, Asehnoune et al [24]. conducted a prospective observational cohort study to establish a measure that could anticipate the efficacy of extubation in patients with brain injury. The results suggested that a reduced duration of stay in the intensive care unit was significantly correlated with extubation efficacy [24].

The hospital stay length did not differ significantly among successful and unsuccessful ventilator weaning. However, Muzette et al [25]. study found that hospitalization time was significantly lower in success in extubation group (9.0 ± 3.0) compared to failure in extubation (9.0 ± 3.0) with p value= 0.002.

Limitations: This observational study had a relatively small sample size comparing to previous studies, also it was conducted in single center which may contribute to insignificant results and Lack of some variable and multivariate analysis. Therefore, conducting same study aim and methodology on larger sample size and conducting a multivariate analysis and measuring more new scores as in previous literature is recommended

Conclusion

The weaning prognosis of traumatic brain injury patients undergoing invasive mechanical ventilation can be predicted by

PIMax, P0.1, and the P0.1/PIMax ratio. PIMax and P0.1/PIMax ratio have moderate predictive ability (AUC > 75%), while P0.1 has limited predictive ability (AUC= 72. %). Patients with successful ventilator weaning had lower PIMax, P0.1, P0.1/PIMax ratio, higher PaO2/FiO2 ratio, lower RSBI, and lower number of days in the ICU. We suggest that the weaning prognosis of mechanically ventilated traumatic brain injury patients be predicted by the P0.1/PIMax ratio, PIMax, and P0.1.

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To cite this article: Ali R. Abd El Bary, Ehab A. Abdelrahman, Eman S. Badr, Samar R. Amin. Predictive Value of Airway Occlusion Pressure, Maximal Inspiratory Pressure and Their Ratio for Successful Extubation in Patients with Traumatic Brain Injury. BMFJ 2025;42(7):788-797.