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The Role of Rapid Shallow Breathing Index in Predicting Successful Weaning of Pediatric Patients with Respiratory Failure

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Abstract

Background

About 40 to 60% of all patients admitted to pediatric intensive care units undergo mechanical ventilation and 10 to 20% will fail to be extubated. We aimed to determine the role of the rapid shallow breathing index (RSBI) in predicting successful weaning of pediatric patients with respiratory failure.

Materials and Methods: This cross-sectional study, was performed on 72 mechanically ventilated children (36 in the lung failure group and 36 in the pump failure group) who were admitted in Tabriz children's hospital in pediatric intensive care unit (PICU), Tabriz city, Iran. In order to spontaneous breathing trial (SBT) criteria, the patients who had FiO_2 less than 40%, PEEP less than or equal to 5 cmH_2O and PaO_2 higher than 60 $_{mmHg}$, was placed on spontaneous ventilation mode (PSV+CPAP) to maintain a PEEP of less than or equal to 5 cmH_2O, PS of less than or equal to 8 cmH_2O and FiO_2 of less than or equal to 40%. After 2 hours, measured tidal volume and respiratory rate to calculate the RSBI then the patient was extubated .

Results: From 72 patients were enrolled in this study, 26 patients failed in extubation. The total RSBI threshold was 6.7 breath/min/ml/kg (AUC = 0.739, 95%CI = 0.618 – 0.861; p = 0.001)) with a sensitivity of 73.1% and a specificity of 80.4% for success of extubation. Patients successfully extubated had significantly lower RSBI 4.65 ± 3.03 breath/min/ml/kg compared to extubation failure group.

Conclusion

Based on the result of this study, the rapid shallow breathing index with a threshold of 6.7 breath/min/ml/kg was considered to be an acceptable and practical criterion for predicting the outcome of weaning in children.

Key Words: Airway extubation, Intra tracheal intubation, Pediatric, Respiratory failure.

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1- INTRODUCTION

About 40 to 60% of patients admitted to the pediatric intensive care unit (PICU) are intubated and undergo mechanical ventilation. Among these patients, 10 to 20% fail in extubation (1, 2). Risk factors associated with extubation failure include: the age of less than 24 months, chronic pulmonary disease, chronic neuromuscular disease, and long-term hypoxia, such as shock, and cardiovascular arrest (3, 4). Early extubation increases the risk of reintubation and long-term mechanical ventilation, resulting in an increased risk of airway trauma, hospital infection and increasing costs, both of which are associated with increased mortality and morbidity. Therefore, determination of the best time for separation from the ventilator and extubation is essential, but is usually neglected among children (5).

Physical symptoms for extubation include spontaneous breathing, managing airway secretions, consciousness and good blood gas values; however, these are not sufficient to predict the success of extubation and prevent reintubation (6, 7). The rapid shallow breathing index (RSBI) is the criterion used to predict successful extubation in adults. This value is the result of dividing the number of respiratory rate (RR)/ per minute by the tidal volume (TV) (8). It was defined by Yang and Tobin in 1991 for adults with a threshold of 105 breath/min/liter, meaning that when the RSBI is less than this value, weaning will be successful (9, 10,11). RSBI is a tool to predict the successful weaning of mechanical ventilation used in intensive care unit (ICU). Patients attached to a ventilator develop tachypnea. A decrease in TV due to pulmonary disease, degree of illness and severity of the disease will increase the RSBI value (12, 13). Although RSBI has generally been defined and its threshold has been calculated for adults, different results have been obtained in various studies. Given the limited studies carried out in this regard among children and the importance of this issue, the authors of the present study undertook to evaluate the RSBI among children and determine its role in predicting successful extubation. We aimed to develop a measurable index and substitute it with clinical guesses as well as to prevent reintubation and long-term mechanical ventilation.

2- MATERIALS AND METHODS

2-1. Study design and population

This cross-sectional study was performed on 72 patients with respiratory failure (36 patients in the lung failure group, and 36 patients in the pump failure group) were evaluated that admitted to the pediatric intensive care unit (PICU) of Children's Hospital in Tabriz city, Iran, who underwent intubation or mechanical ventilation from 2017 to 2018. Using the studies of Young and Tobin (10) by calculating the sample size with a power of 90%, and an alpha coefficient of 0.05, the sample size was determined to be 36 subjects for each group or 72 patients in total. The study groups included 36 patients with lung failure and 36 patients with pump failure.

2-2. Methods

All patients were under mechanical ventilation in pressure-controlled SIMV mode (GRAPHNET ventilator). The patients were evaluated for their clinical status, spontaneous breathing, blood gas levels and ventilator settings as factors for weaning. The patient was required to be conscious with spontaneous breathing and able to handle airway secretions, with FiO_2 values of less than 40%, PEEP values of less than or equal to 5, and a PaO_2 value of higher than 60 (14). All the sedatives and narcotics were discontinued for at least 2 hours prior to evaluation. At this stage, the PIP, PEEP, RR, and TV of the ventilator were recorded. The patients were placed

on spontaneous ventilation mode (PSV+CPAP) with a PEEP value of less than or equal to 5, a PS of less than or equal to 8 and FiO_2 of less than or equal to 40% (15). After 2 hours, when the patient was calm or, preferably, asleep the spontaneous breathing rate was recorded and the tidal volume of spontaneous breathing was recorded through the ventilator before the patient was extubated. The patient was evaluated for reintubation within 72 hours of extubation. The RSBI was obtained by dividing the spontaneous respiratory rate per tidal volume (RR/TV) of the patient. This unit is calculated as breath/min/lit in adults and breath/min/ml/kg in children. The threshold, sensitivity and specificity of the RSBI were calculated based on successful extubation in all patients and in each group using statistical analysis.

2-3. Ethical consideration

This study was registered by the ethics committee of Tabriz University of Medical Sciences (IR.TBZMED.REC.1397.082). All of the measures taken were performed to treat the patients and no diagnostic or therapeutic action or additional costs were imposed upon them. A signed written consent form was received from the parents of the patients entering the study. The data and results of the study were used only for the purposes of the research and kept completely confidential in a secure place.

2-4. Inclusion and exclusion criteria

The study inclusion criteria were being below 14 years of age with respiratory failure that requires intubation and mechanical ventilation. The exclusion criteria were a diagnosis of heart failure, cyanotic congenital heart disease or congenital pulmonary anomalies.

2-5. Data Analyses

The data was analyzed using descriptive statistical methods for mean ± standard deviation (SD), rate percentage and independent t-test. The normal distribution of the data was investigated by the Kolmogorov-Smirnov test. The sensitivity and diagnostic values were evaluated using the receiver operating characteristic (ROC) curve. The data was analyzed in SPSS software (version 20; IBM; USA). A p-value < 0.05 was considered to be statistically significant.

3- RESULTS

In this cross-sectional study, 72 patients (36 patients in the lung failure group, and 36 patients in the pump failure group) were evaluated. The baseline characteristics of the patients studied are shown in **Table.1**. The data indicates that the lowest and highest ages were 70 days and 89 months in the lung failure group, respectively, and mean ± SD was 25.62 ± 2.87. In the pump failure group, these values were 2 months and 156 months, respectively, and mean ± SD was 40.66 ±4.49. The minimum and maximum weights were 3.7, and 19 kg, in the lung failure group, and 4.3, and 22 kg, in the pump failure group, respectively. There is no significant difference of demographic characteristics between the two groups.

In terms of gender distribution, 33 (45.8%) were males and 39 (54.2%) were females. In the lung failure group, 18 (50.0%) were males. In the pump failure group, there were 15 (41.7%) males, and 21 (58.3%) females. For the effect of gender as a confounding variable, the p-value was 0.38, indicating no significant relationship between groups and the lack of effect of gender on the results. A total of 27 (37.5%) patients lacked underlying diseases. The frequency of the history of underlying disease among patients is shown in **Table.2** in both groups. The highest frequency of underlying illness was related to myopathy with a frequency of 13 (18.1%) cases in the pump failure group. **Table.3** shows the frequency of the

diagnosis of the reason for hospitalization. The most frequent disease was pneumonia with 36 (50.0%) cases with 19 (52.8%) in the lung failure groups, and 17 (47.2%) in the pump failure group. The mean ± SD of the duration of intubation was 10.09 ± 7.79 days for all patients. The minimum and maximum values were one and 32 days, respectively. The mean ± SD of the duration of intubation was 8.47 ± 6.55 and 11.27 ± 8.64 days, respectively, for the lung failure and pump failure groups. The mean duration of intubation in the pump failure group was higher than that of the lung failure group and the difference was statistically significant (p = 0.047). The mean ± SD of the respiratory rate (RR) among patients was 36.90 ± 15.37 breath/min with the lowest and highest RR values being 16 and 79 breath /min, respectively. The mean RR was 35.97 ± 14.84 and 37.83 ± 16.04 breath/min in the lung failure and pump failure groups, respectively. The mean RR was higher in the pump failure group than in the lung failure group, but the difference was not statistically significant (p = 0.886).

The mean ± SD of TV among all patients was 73.91 ± 42.41 ml, with the lowest and highest values being 11 and 170 ml, respectively. The mean ± SD for TV was 77.58 ± 41.85 and 70.25 ± 43.26 ml in the lung failure and pump failure groups, respectively. The TV in the lung failure group was higher than in the pump failure group, but the difference was not statistically significant (p = 0.886). The mean ± SD of RSBI was 5.56 ± 3.28 breath/min/ml/kg among all subjects. The lowest and highest values were 1.1 and 13.0 breath/min/ml/kg, respectively. The mean ± SD for RSBI in the lung failure and pump failure groups were 5.26 ± 2.76 and 5.86 ± 3.47 breath/min/ml/kg, respectively. The rate of RSBI in the pump failure group was higher than in the lung failure group. This was a significant difference for the difference in variance between groups (p = 0.035); however, the difference was not significant for mean RSBI between groups (p = 0.441). In terms of frequency of the need for reintubation among patients, 26 (36.1%) were reintubated and 46 (63.9%) patients did not require reintubation after 72 hours. The highest number of reintubations was for patients in the pump failure group and there was a significant difference between groups (p = 0.042). The mean ± SD of RSBI in patients with successful and unsuccessful extubation was 4.65 ± 3.03 and 7.17 ± 3.13 breath/min/ml/kg, respectively. This marked a significant difference between groups (p = 0.002).

Table.4 shows the thresholds, sensitivities and specificity are demonstrated in of RSBI among all patients and in both groups. The total RSBI threshold was 6.7 (Area under the curve [AUC] = 0.739, 95% confidence interval [CI] = 0.618 – 0.861; p = 0.001) with a sensitivity of 73.1% and a specificity of 80.4%; this value for the lung failure group was 6.7 (AUC = 0.844; 95%CI = 0.716 - 0.971; p = 0.002) with a sensitivity of 88.9% and a specificity of 81.5%. For the pump failure group, it was 6.3 (AUC= 0.697; 95% CI = 0.521 – 0.872; p = 0.044) with a sensitivity of 64.7% and a specificity of 68.4%.

The Receiver Operating Characteristic (ROC) curve analysis of RSBI in the present study showed cut-0ff value 6.7 had sensitivity of 73.1%, and a specificity of 80.4% in total patients **(Figure.1)**; and cut-0ff value 6.7 with a sensitivity of 88.9%, and a specificity of 81.5% for the lung failure group **(Figure.2)**; and cut –off value 6.3 with a sensitivity of 64.7%, and a specificity of 68.4%. For the pump failure group **(Figure.3**). There was no statistical difference in RSBI cut-off between lung and pump failure groups (p= 0.441).

Table-1: Statistical comparison 0f demographic data between in two groups

Variables	Mean ±SD OR Frequency (%)		P-value
	Lung Failure Group (n=36)	Pump Failure Group (n=36)	
Age (month)	25.62 ± 2.87	40.66 ± 4.49	0.341
Gender	Boy= 18 (50 %) Girl= 18 (50 %)	Boy= 15 (41.7 %) Girl= 21 (58.3 %)	0.091
Weight (Kg)	9.38 ± 4.95	9.89 ± 4.92	0.218

SD: Standard Deviation.

Table-2: Frequency of underlying disease in two groups and all patients

Underlying disease	Frequency (Percentage)		
	Lung Failure Group (n=36)	Pump Failure Group (n=36)	Total
Myopathy	0	13 (36.1%)	13 (18.1%)
CF	1 (2.8%)	0	1 (1.4%)
CRF	2 (5.6%)	0	2 (2.8%)
ALL	2 (5.6%)	0	2 (2.8%)
Encephalopathy	1 (2.8%)	2 (5.6%)	3 (4.1%)
Asphyxia	0	2 (5.6%)	2 (2.8%)
Metachromatic leukodystrophy	0	2 (5.6%)	2 (2.8%)
Scoliosis	0	2 (5.6%)	2 (2.8%)
Axonal neuropathy	0	3 (8.3%)	3 (4.1%)
Hypotonia	0	4 (11.1%)	4 (5.5%)
HRAD	2 (5.6%)	0	2 (2.8%)
BPD	4 (11.1%)	0	4 (5.5 %)
CP	0	1 (2.8%)	1 (1.4%)
SMA	0	2 (5.6%)	2 (2.8%)
Arthrogryposis	0	2 (5.6%)	2 (2.8%)
Total	12 (26.7%)	33 (73.3%)	45 (63.5%)

SMA: Spinal Muscular Atrophy; CF: Cystic Fibrosis; CRF: Chronic Renal Failure; ALL: Acute lymphoblastic leukemia; HRAD: Hyper Reactive Airway Disease; BPD: Bronchopulmonary Dysplasia; PAP: Pulmonary Alveolar Proteinosis; CP: Cerebral Palsy.

Table-3: Frequency of patient's current diagnosis in two groups and total

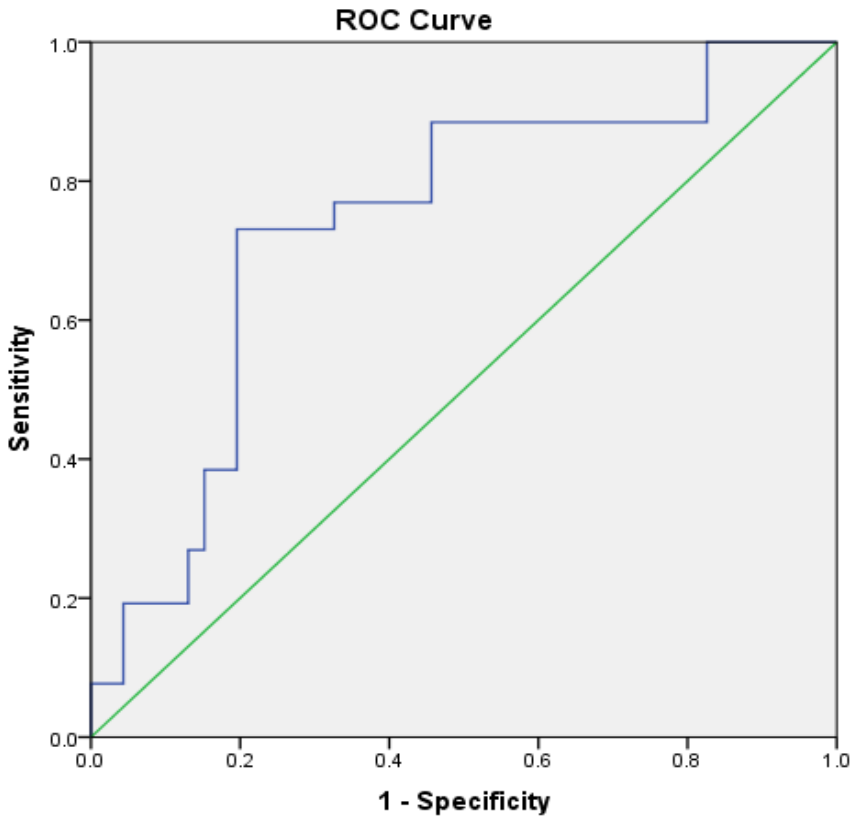
Current Diagnosis	Frequency (%)		
	Lung Failure Group (n=36)	Pump Failure Group (n=36)	Total
ARDS	4 (1.11%)	0	4 (5.6%)
Plural Effusion	3 (8.3%)	2 (5.6%)	5 (6.9%)
Bronchiolitis	1 (2.8%)	3 (8.3%)	4 (5.6%)
Bronchiectasis	1 (2.8%)	0	1 (1.4%)
Pneumonia	17 (47.2%)	19 (52.8%)	36 (50%)
Pneumothorax	4 (11.1%)	0	4 (5.6%)
Meningitis	0	2 (5.6%)	2 (2.8%)
Aspiration pneumonia	4 (11.1%)	6 (16.7%)	10 (13.9%)
Botulism	0	4 (11.1%)	4 (5.6%)
PAP	2 (5.6%)	0	2 (2.8%)
Total	36 (50%)	36 (50%)	72 (100%)

PAP: Pulmonary alveolar proteinosis; ARDS: Acute Respiratory Distress Syndrome.

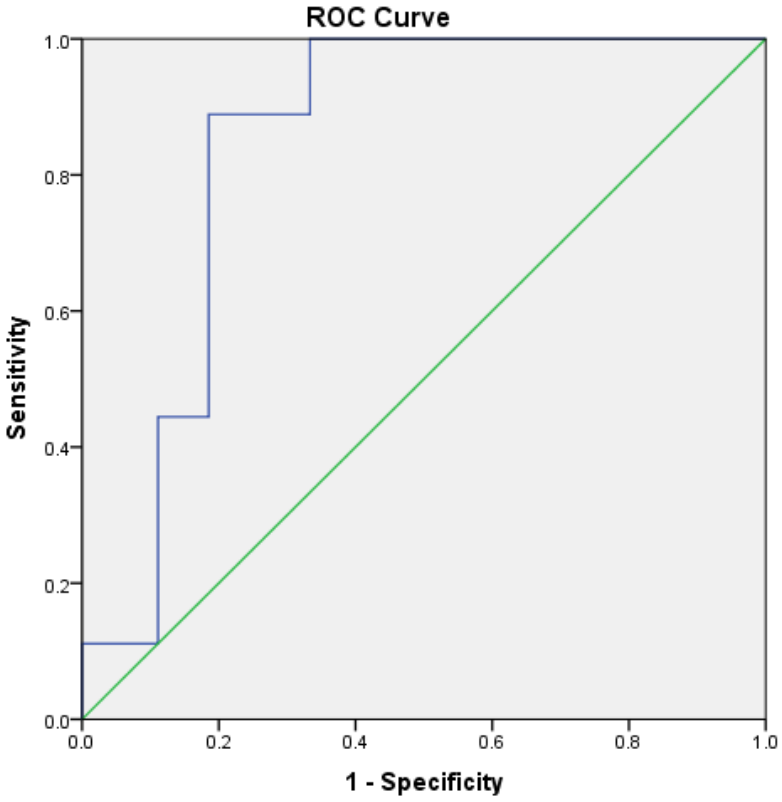
Table-4: Statistical comparison of RSBI threshold and sensitivity and specificity in two groups and total

Group	AUC	STE	Threshold	Sensitivity	Specificity	95% CI		P-value
Total	0.739	0.062	6.7	73.1%	80.4%	0.618	0.861	0.001
Lung Failure	0.844	0.065	6.7	88.9%	81.5%	0.716	0.971	0.002
Pump Failure	0.697	0.090	6.3	64.7%	68.4%	0.521	0.872	0.044

AUC: Area Under the Curve; STE: Standard Error; CI: Confidence Interval.

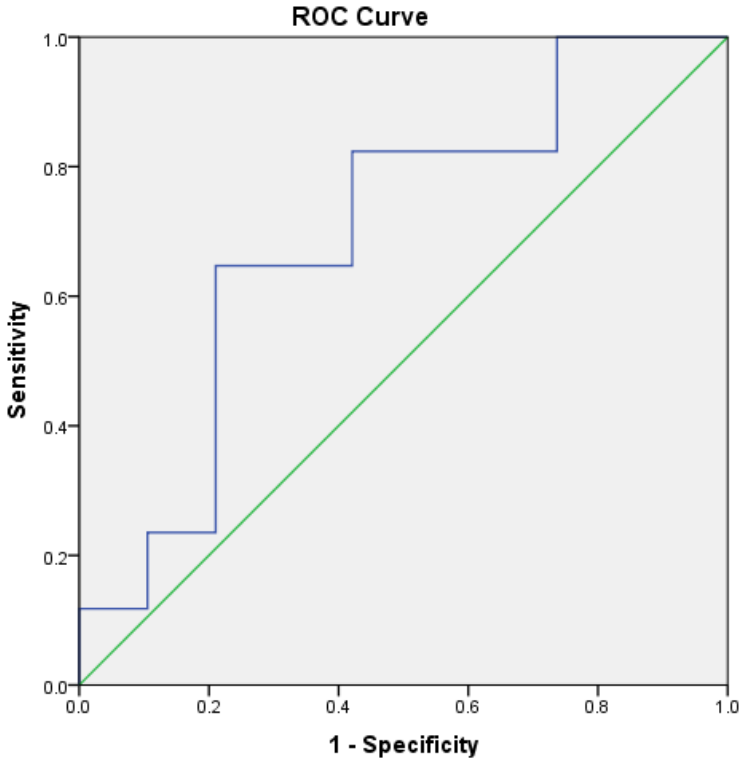


RSBI: Rapid Shallow Breathing Index.
Fig.1: ROC Curve for RSBI threshold in all patients.



RSBI: Rapid Shallow Breathing Index.

Fig.2: ROC Curve for RSBI threshold in Lung Failure Group.



RSBI: Rapid Shallow Breathing Index.

Fig.3: ROC Curve for RSBI threshold in Pump Failure Group.

4- DISCUSSION

In this study we aimed to calculate RSBI and its sensitivity and specificity on 72 patients with respiratory failure (36 patients in the lung failure, and 36 patients in pump failure groups). There was no history of previous illness for 30 (41.7%) patients. The highest incidence of previous disease was related to myopathy, with 13 (18.1%) cases, all in the pump failure group. The mean ± SD of duration of intubation was 10.09 ± 7.79 days for all patients, with the minimum and maximum values being one day and 32 days, respectively. The mean ± SD for duration of intubation was 8.47 ± 6.55 and 11.27 ± 8.64 days in the lung failure and pump failure groups, respectively. The mean duration of intubation in the pump failure group was higher than that of the lung failure group, which was statistically significant (p = 0.047). The mean ± SD of the duration of intubation in patients with successful and unsuccessful extubation was 7.34 ± 4.86 and 14.80 ± 9.67, respectively; which showed a significant difference between groups (p = 0.001).

Thiagarajan et al. evaluated the predictive factors of successful extubation in children and reported that the mean ± SD of duration of intubation in patients with successful and unsuccessful extubation was 4.9 ± 9.3 and 18.4 ± 19.9, respectively (p = 0.001) (16). As seen, in both, our study and recent study, the duration of intubation was significantly higher among patients with unsuccessful extubatation. In terms of the diagnosis of the cause of hospitalization, the most frequent was pneumonia at 36 (50.0%) patients. This rate was 19 (52.8%), and 17 (47.2%) patients for the lung failure and pump failure groups, respectively. A total of 26 (36.1%) patients required reintubation and 46 (63.9%) did not require reintubation. The highest rate for reintubation was observed in patients with pump failure at 17 (23.6%) patients, which shows a significant difference between groups (p = 0.042). Thiagarajan et al. evaluated the predictive factors of successful extubation in 254 children. In their study, 28 (11%) cases had unsuccessful extubation, of whom 23 (82%) were due to increased respiratory function due to cardiovascular causes, four (14%) were from increased respiratory function due to obstruction of the upper airway, and one (4%) was from acute pulmonary hemorrhage (16). In the present study, the most frequent cause of unsuccessful extubation was pneumonia at 9 (34.6%) patients. The highest rate of unsuccessful extubation was for patients with pump failure; highest values were 1.1 and 13.0 breath/min/ml/kg, respectively.

The mean ± SD of RSBI in the lung failure and pump failure groups was 5.26 ± 2.76, and 5.85 ± 3.47 breath/min/ml/kg, respectively. The rate of RSBI in the pump failure group was higher than in the lung failure group, which was significant difference between groups for the difference of variance (p = 0.035). No statistically significant difference was observed for mean RSBI between groups (p = 0.441). Also, the mean ± SD of RSBI in patients in the successful and unsuccessful extubation groups were 4.65 ± 3.03 and 7.17 ± 3.13 breath/min/ml/kg, respectively; which marked a significant difference between groups (p = 0.002).

Thiagarajan et al. found that the mean ± SD of RSBI in patients with successful and unsuccessful extubation was 5.8 ± 3.8, and 12.6 ± 8.5 breath/min/ml/kg, respectively; which was a significant difference between groups (p = 0.001) (16). Considering the duration of intubation and RSBI, in line with their study, the duration of intubation and the RSBI showed a dependent relationship with the outcome of extubation. It appears that the degree of success in extubation decreases with an increase in the duration of attachment to the ventilator and increase in the RSBI (13- 16). In the present study, the threshold

of RSBI in patients in the lung failure and pump failure groups, the RSBI threshold 6.7 (AUC = 0.739; 95%CI = 0.618-0.861; p = 0.001) with a sensitivity of 73.1%, and a specificity of 80.4%. In the lung failure group, the RSBI threshold was 6.7 (AUC = 0.844; 95%CI = 0.716-0.971; p = 0.002) with a sensitivity of 88.9%, and a specificity of 81.5%. In the pump failure group, the RSBI threshold was 6.3% (AUC = 0.697; 95%CI = 0.521-0.872; p = 0.044) with sensitivities of 64.7%, and 68.4%, respectively. Khan et al. examined the predictive factors of successful extubation in children, including RSBI index and SVT, FiO_2, PaO_2, Paw and other clinical parameters of the patients. In their study, of 208 patients under study, 34 (16.3%) had unsuccessful extubation.

The threshold values for all variables were calculated in this study. It was concluded that the use of all clinical factors should be taken into account in order to predict the outcome of successful extubation of children and the use of the RSBI alone cannot successfully be used to predict successful extubation (17). Baumeister et al. evaluated the value of RSBI and CROP criteria to determine successful extubation in children and reported 47 (19%) cases of unsuccessful extubation (18). Khan et al., in contrast to the aforementioned study and in line with the present study, reported RSBI, and CROP indices as criteria with high sensitivity, specificity and reliability for predicting successful extubation of children. In the current study, CROP showed a diagnostic value higher than RSBI (17). A wide RSBI values with high sensitivity and specificity have been used to predict successful weaning from the ventilator (11, 16, 19). It appears that the variety of values reported in different studies may be due to the presence of factors other than the respiratory load, capacity and tolerance. These factors include gender, size of the endotracheal tube, degree of agitation, anxiety level, mental stress of the patient, the time and techniques of clinical measurement and the duration on the mechanical ventilation prior to extubation; which can influence the RSBI measurement (20-21-22).

4-1. Limitations of the study

In this study we have some limitations. At first, low age and low weight of patients may affect the results. In addition, measurement of spontaneous tidal volume and respiratory rate in awake and intubated patients was very difficult.

5- CONCLUSION

It appears an increase time of mechanical ventilation and decrease in the RSBI, the success rate of extubation increases. Based on the result of this study, RSBI values with a threshold of 6.7 breath/min/ml, a sensitivity of 73.1% and a specificity of 80.4% is an acceptable and practical criterion for predicting the outcome of extubation of children.

6- ABBREVIATIONS

FiO_2: Fraction of Inspired Oxygen,
PaO_2: Partial Pressure of Oxygen,
PIP: Peak Inspiratory Pressure,
PEEP: Positive End Expiratory Pressure,
PAW: Airway pressure,
RR: Respiratory Rate,
TV: Tidal Volume,
PS: Pressure Support,
RSBI: Rapid Shallow Breathing Index,
SVT: Spontaneous Tidal Volume,
PAW: Pressure Air Way,
CROP: Compliance, Rate, Oxygenation, Pressure.

7- CONFLICT OF INTEREST: None.

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