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Original Article

Added Utility of Diaphragm and lung Ultrasound Indices Along with Rapid Shallow Breathing Index in Predicting Extubation Success in Children

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Abstract

Introduction: Prolonged mechanical ventilation leads to diaphragm atrophy and impaired functions. An accurate assessment of its function by bedside ultrasonography during spontaneous breathing trial can add to predictive value of respiratory scores like RSBI. Lung and diaphragm ultrasound are bedside non-invasive techniques which can be used to assess the weaning readiness in children.

Methods: This study involved 50 children; newborn to 14 years of age, admitted to PICU and mechanically ventilated, during a period from November 2020 to November 2022. All patients were candidates for weaning and have been given a chance for spontaneous breathing trial (SBT), during which diaphragmatic and lung ultrasound indices were assessed. The diaphragm thickening fraction (DTF), diaphragmatic excursion (DE) and lung Ultrasound score (LUS) that included 4 US aeration forms, were assessed. Values satisfying any of the below variables were considered weaning failure; rapid shallow breathing index ≥ 8 breaths / min / ml / kg, Diaphragm thickness fraction ≤ 20%, Diaphragm excursion: ≤ 6 mm, Lung ultrasound score: ≥ 12. Sensitivity, specificity, PPV and NPV of each ultrasound parameters was calculated and compared.

Results: Statistically significant differences were found between patients with failed weaning and those with successful weaning regarding RSBI, DTF and LUSG. RSBI was found to be good predictor of weaning success. RSBI along with DTF and LUSG increased the specificity to predict weaning success rather than RSBI alone.

Conclusion: Rapid shallow breathing index of ≤ 8 is a sensitive predictor of weaning success. Lung and diaphragm ultrasound increase the specificity of RSBI to predict weaning success in critically ill children.

Introduction

Weaning from mechanical ventilation has always been a testing time for intensivists as no criteria can be said as "Fit for all". Premature weaning leads to aspiration and high probability of reintubation.[1] Delayed weaning leads to ventilator associated pneumonia, pneumothorax, diaphragmatic dysfunction, nosocomial infections, cardiovascular instability, and increased costs of PICU stay.[2] Extubation failure is associated with a fivefold increased risk of death in paediatric patients.[3]

The ability to maintain spontaneous breathing during weaning is dependent on

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the central respiratory control, the capacity of the inspiratory muscles and the load placed on them.[4] Diaphragm is the principal muscle involved in breathing as accessory respiratory muscles are not so well developed in infants and young children.[5] The respiratory parameters like RSBI, CROP index or Pimax used for extubation readiness overlook the power of diaphragm.[6] Diaphragmatic dysfunction (DD) has a high incidence in critically ill patients.[7]

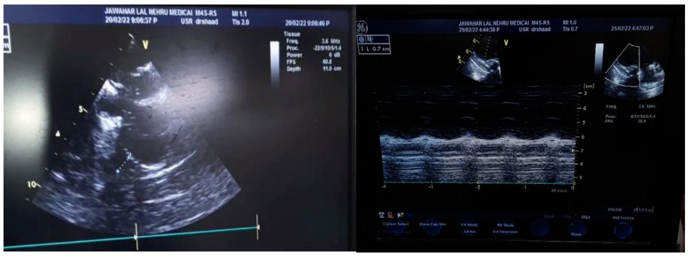
An accurate assessment of diaphragm and lung function during spontaneous breathing trial can thus add to predictive value of respiratory score. Lung and diaphragm ultrasound is a bedside and non-invasive technique to assess the same.[8] This study was conceptualized to see the added utility of diaphragm and lung ultrasound indices along with RSBI in predicting extubation success.

Methods

This study was conducted in PICU of Jawaharlal Nehru Medical College, Aligarh Muslim University, Aligarh, UP, India during November 2020 to November 2022. The inclusion criteria include all the patients admitted in PICU < 14 years connected to mechanical ventilation and eligible for weaning in accordance with the following weaning criteria: signs of reversal of the principal cause of mechanical ventilation, blood pH ≥ 7.30; with accepted blood oxygenation i.e., partial pressure of arterial oxygen (PaO_2) equal to or more than 60 mmHg, partial pressure of arterial carbon dioxide ($PaCO_2$) equal to or less than 45 mmHg, fraction of inspired oxygen (FiO_2) equal or less than 0.40, Positive end-expiratory pressure (PEEP) equal to or less than 5 cm of water, Glasgow Coma Scale more than or equal to 6T, adequate cough reflex, no excessive secretions, stable hemodynamics with or without minimal use of inotropic or vasopressor drugs; not receiving sedatives or neuromuscular blocking drugs, haemoglobin level ≥ 7.5 g / dl and no electrolyte disturbance. The exclusion criteria were patient suffering from chronic neuromuscular disorder; congenital lung or pleural malformation or any patient undergoing surgery. This study was approved by the institutional ethical committee. All parents or guardians were apprised about the study, and they provided written informed consent. Once the patient maintained PaO_2 > 90 on SIMV mode on FiO_2 40% with adequate spontaneous breaths, the patient was subjected to spontaneous breathing trial (SBT), by low level of pressure support (5 cm H_2O) along with PEEP of 5 cm water. Patients were considered not tolerating SBT if: RR > 45 / min or change in RR > 50% above baseline; arterial oxygen saturation < 90%, increase or decrease in heart rate > 20% from the baseline; agitation, diaphoresis or increased work of breathing. If the patient developed any of these manifestations, SBT was aborted and reintubated. Weaning failure is considered when SBT had to be abated or need of the patient for re-intubation within 24 – 72 h. Weaning success is stated when patients do not require re intubation within 24 - 72 h. RSBI was measured when patient was on SBT with PS mode based on the formula:

$$RSBI = \frac{\text{Respiratory Rate (breaths / min)}}{\text{Tidal volume / weight (kg)}}$$

All patients with RSBI of less than 8 breaths / ml / kg / min were predicted as weaning success and rest were predicted to be weaning failure. Diaphragm and lung ultrasound were done using GE VIVID S6 machine. The 4 MHz convex probe and the 12 MHz phased array probes were used.



Thickness of the diaphragmatic muscle was measured from the central point of the pleural line to the central point of the peritoneal line during the termination of inspiration and the expiration. This was repeated to take the average and then the diaphragm thickening fraction (DTF) was calculated by the following equation:

DTF = (Thickness at the end inspiration – thickness at the end expiration / Thickness at the end expiration x 100 Or (TI – TE / TE × 100).

To measure the range of the diaphragmatic movement (diaphragmatic excursion, DE), the convex probe was placed in the subcostal region parallel to 8th intercostal space by using the M-mode with the cursor crossing the diaphragm and then highest and lowest peak points were assessed as a marker for the range of diaphragmatic movement. Four US aeration patterns were identified: a) N = 0, b) B1 = 1, c) B2 = 2, d) C = 3. This score ranged from 0 to 36 point. Values satisfying any of the below variables will be considered weaning failure; rapid shallow breathing index ≥ 8 breaths / min / ml / kg, Diaphragm thickness fraction ≤ 20%, Diaphragm excursion: ≤ 6 mm, Lung ultrasound score: ≥ 12. Each patient was followed up at 12 hourly intervals for 72 hours post SBT success and classified as weaning success or weaning failure. Sensitivity, specificity, NPV, PPV of each parameter was calculated. All statistical analysis was performed using version 26 of SPSS software. Categorical variables were analysed using chi square test. Continuous variables were analysed via t-test. ROC curves for prediction of weaning success was calculated for RSBI and each ultrasound parameter. A p value of < 0.05 was taken as significant. Figure 1 depctis the study flow chart.

Results

Out of 406 patients admitted during study period, 336 underwent mechanical ventilation. 224 patients could not be planned for extubation due to primary illness and associated complications. The study flow is represented in the Figure 1. Demographic and clinical characteristics of the study population is represented in Table 1. Tables 2 and 3 compare the patient parameters and observation with weaning outcome. Table 4 represents the specificity and sensitivity of lung ultrasound indices for weaning success. Table 5 depicts combined sensitivity and specificity of combined RSBI and ultrasound indices.

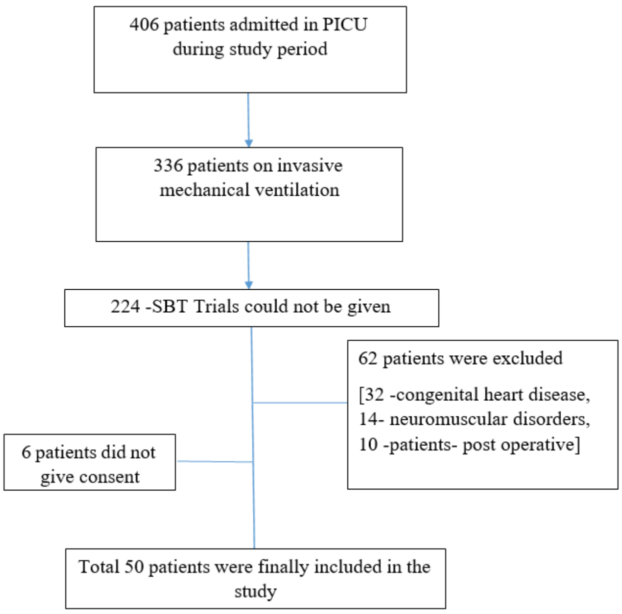


Figure 1: Flowchart of the study

Table1: Demographic details

Demographic Parameter	Frequency	Percent(%)
Total no. of patients	50	100
Gender		
Male	32	64
Female	18	36
Age		
Neonates	33	66
> 2.5 kg	17	34
LBW 1.5 - 2.5	9	18
Very LBW < 1.5	7	14
Chief complaints		
Difficulty in breathing	32	64
Altered sensorium	14	28
Abdominal symptoms	3	6
Decreased urine output	1	2
Cause of intubation		
Acute respiratory failure	32	64
Shock	1	2
Shock + respiratory failure	3	6
Encephalopathy	7	14
Shock + respiratory failure+ encephalopathy	7	14

Table2: Comparison of patient parameter with weaning outcome

Age			0.488
< 1year	20	24	
> 1 year	6	0	
Gender			0.832
Male	17	15	
Female	09	09	
Complaint			0.673
Altered sensorium	8	6	
Breathing difficulty	16	6	
Abdominal pain	1	2	
Decreased urine output	1	0	
Indication for Endotracheal Intubation			0.527

Table 2 continue...

Acute respiratory failure	14	18	
Shock	1	0	
Shock and respiratory failure	2	1	
Encephalopathy	4	3	
Acute respiratory failure + shock + encephalopathy	5	2	
Total days intubated (mean ± 1 SD)	4.63 ± 3.13	6.13 ± 2.93	0.156
Total days in PICU (mean ± 1 SD)	10.5 ± 2.14	7.6 ± 4.4	0.009

Table 3: Comparison of observation with weaning outcome

Weaning Predictor	Weaning Success	Weaning Failure	t value	p value
RSBI mean±SD	6.2 ± 2.06	10.4 ± 2.94	5.8	0.000
LUS ± SD	11.9 ± 4.85	15 ± 4.85	-1.54	0.028
LDE (cm)	0.86 ± 0.49	0.71 ± 0.19	-1.42	0.147
RDE (cm)	0.84 ± 0.49	0.68 ± 0.19	-1.151	0.130
MDE (cm)	0.85 ± 0.47	0.70 ± 0.25	-1.48	0.143
RDTF%	52.8 ± 37.42	32.6 ± 22.6	-2.2	0.027
LDTF %	53.6 ± 29.8	32.8 ± 17.31	-2.9	0.005
M DTF (in %)	53.18 ± 29.6	32.8 ± 16.88	-3.0	0.004

Table 4: Table depicting sensitivity specificity of various ultrasound parameters

Indices	Sensitivity	Specificity	PPV	NPV	Accuracy	AUC
RSBI	76%	84%	90%	91.6%	88%	0.888
LDE	80%	25%	53%	54%	54%	0.613
RDE	84%	33%	57%	66%	56%	0.608
MDE	58%	62.5%	76%	41%	60%	0.617
LDTF	96%	20%	73%	83%	88%	0.703
RDTF	80%	41%	60%	66%	62%	0.667
MDTF	92%	29.1%	77%	77.7%	62%	0.716
LUSG	61%	62%	64%	60%	62%	0.688

Table 5: Sensitivity and specificity of combined RSBI and ultrasound indices

Parameters	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)
RSBI alone	76	84	90	91.6
RSBI + LDE	60.8	88	84.6	67.5
RSBI+RDE	64	89	86.8	69.5
RSBI+MDE	44	94	89.2	60.8
RSBI+LDTF	73	87	85.9	74.8
RSBI+RDTF	61	91	88	68.3
RSBI+MDTF	70	89	87.3	73.3
RSBI+LUSG	46	94	89.3	61.6

Discussion

It has been evident that ventilator induced diaphragm dysfunction starts within 18 - 24 hours on fully controlled ventilation and reaches its peak within 72 hours.[9,10] An attempt has been made to evaluate contractility of diaphragm muscle fibres by measuring diaphragm excursion and diaphragm thickening fraction along the zone of apposition.

This study found a significant correlation between RSBI values and days on ventilator per patient ($p = 0.004$ $r = 0.402$), implying RSBI is an excellent predictor of weaning success with accuracy of 88%, sensitivity of 76%, specificity of 84%, PPV of 90% and NPV of 91.6% (p value = 000). Mean Lung Ultrasound Score (LUS) was observed to be significantly higher in weaning failure with a p value of 0.028. Sensitivity, specificity, PPV and NPV of LUS was found to be 61%, 62%, 64% and 60% respectively. LDTF was found have high sensitivity (96%) and low specificity (20%). Accuracy of LDTF was 62% which was comparable to LUS. Area under the curve for LDTF, RDTF and Mean DTF was found to be 0.703, 0.667 and 0.716 respectively which is suggestive of acceptable discrimination.

Various studies have been conducted to find the role of lung and diaphragm indices in predicting weaning with some evaluating diaphragmatic indices only,[11-16] some lung only,[17-19] while one assessing both lung and diaphragm.[8] We had utilised cut off values of lung and diaphragm indices to from previous studies.[8,14,20]

Acute respiratory failure was found to be the most common reason of intubation (64%) followed by encephalopathy (14%), and RDS was the commonest diagnosis for admission in this study in congruence with findings of the past.[21]

It was observed that rate of weaning failure significantly increased as days of intubation increased in our study (P value- 0.014). A significant correlation was found between weaning outcome and total number of days in PICU ($P = 0.009$). This was probably due to the survival and longer duration of treatment required in the unit. Additionally, those patients who could not be weaned were sick and suffered from multiorgan failure resulting in mortality. Failure to pass SBT was associated with increased rate of weaning failure as similarly concluded by multiple studies ($P = 0.000$).[21-25]

A modified RSBI score of 8 breaths / ml / kg / min was taken as a cut off to predict weaning outcome with reference to study done by Thiagrajan et al.[26] Mean RSBI was observed to be significantly more in weaning failure group (10.4 ± 2.94 vs 6.2 ± 2.06) (P value = 0.000), with all above RSBI 11 going into failure. This cut off value was the same as given by Venkatraman et al.[27] Some researchers concluded RSBI good whereas others considered it to be a poor predictor of weaning outcome.[21,22,27,28]

Yang et al found RSBI to be 97% sensitive and 64% specific to predict weaning success.[30] AUC for RSBI was found to be 0.890 which was similar to what we observed (0.888). Baumeister et al found the sensitivity of modified RSBI to be 79%, similar to ours of 76%.[28] Thus, RSBI was found to have high specificity and high negative predictive value in this study compared to previous studies.[26,29]

Eltomey et al observed that LUS score cut-off value of < 14 had 85% sensitivity and 100% specificity to predict weaning outcome with (AUC of 0.986) which was more than what we observed.[19] Similarly in our study mean LUS was observed to be significantly higher in weaning failure (15 ± 4.85) than in success group (11.9 ± 4.85) (P value = 0.028). Hence, specificity, PPV and NPV of LUS was found to be 61%, 62%, 64% and 60% respectively which was less than predicted by Abdel Rahman et al (sensitivity of 85.7% and a specificity of 81.2%).[8] Overall the predictive value of LUS was observed to be lower than what was observed by previous studies.[17,19] DTF and DE both are considered to have good specificity and sensitivity to predict weaning outcome as observed in other studies.[8,13,16]

In our study, on comparing the mean diaphragm excursion in weaning success and weaning failure patients, no significant difference was appreciated. (0.85 ± 0.47 vs 0.70 ± 0.25 P value = 0.143) similar to the observations reported by Xue et al in 2019.[11] Similarly in our study DE alone had limited value in predicting weaning outcome. This is probably an impression of the fact that during diaphragm assessment children cannot take deep breaths voluntarily, as adults can. LDTF was observed to be more sensitive than RDTF. In our study use of RSBI with MDE and RSBI with LUS have been found to be highly specific (94%) in predicting weaning outcome than RSBI alone. Combined specificity of RSBI with RDTF was 91%, RSBI with LDTF was 87%. From this study we observed that combination of diaphragm and lung ultrasound index with RSBI had more specificity to predict weaning success than RSBI alone.

Conclusion

The combination of diaphragm thickening fraction or LUS with RSBI increase the specificity of RSBI to predict weaning success. This combined model of weaning can be used to decrease rate of weaning failure in children.

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Conflict of Interest None

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