The Predictive Value of Diaphragm and Lung Ultrasound for Weaning Outcomes in Mechanically Ventilated Children

Abstract:

**Background:** To reduce the risks associated with a prolonged mechanical ventilation, in adults, the thickness of the right hemidiaphragm and the diaphragmatic thickening fraction (DTF) are used as predictors of successful extubation. In the pediatric population, no gold standard has been established.

**Aim:** To predict the value of diaphragmatic and lung ultrasound indices in anticipation of extubation success in the pediatric intensive care unit (PICU).

**Material & Methods:** This study was conducted in PICU in Benha university hospitals and children hospital, from October 2021 to April 2023. The study included any ventilated patient eligible for weaning. All patients were submitted to spontaneous breathing time (SBT). Diaphragmatic and lung ultrasound were done and scores calculated.

**Ethical approval:** The study was approved by the Ethical Committees of Faculty of Medicine, Benha University Hospital.

**Results:** This study included 80 children who were eligible for SBT. Fifty-eight patients (72.5%) were weaning success group and 22 patients were weaning failed group. The weaning success group had significantly higher diaphragm thickness and diaphragm excursion with mean total DTF of 29.6±2.8 % vs 20.9±6.8 % (<0.001) and mean total diaphragm excursion of 9.6±1.55 mm vs 5.7±1.9 mm (<0.001) compared to the failed group. However, the success group had lower lung US score 12.7±4.9 vs 24.6±7.1 compared to the failed group (<0.001).
Conclusion: Diaphragmatic and lung US is a quick and non-harmful technique for prediction of weaning success with highly accurate results. So, they can be added to the conventional parameters for accurate prediction of the weaning outcome.

Key words:
Diaphragm, Lung, Ultrasound, Weaning, extubation

Introduction:

In the low resource countries (LRIC), there is a high need for proper use of Mechanical Ventilation (MV), as the respiratory problems are the primary reason for admission to the pediatric intensive care unit (PICU) (1). However, most ICUs have no adequate mechanical ventilators in LRIC (2). No much data from African countries regarding the use of MV in PICUs is available with some reports estimating utilizing MV in children in Egypt was 32.8 % (3).

To reduce the risks associated with a prolonged MV, the clinicians should aim to constantly optimize the ventilation weaning (VWe) process, thus increasing the likelihood of a successful extubation. Traditionally, VWe was achieved by clinical judgement on a personal decision. Only in the last few years, protocol-based approaches have been implemented, with conflicting results. Extubation failure occurs in 3–22% of patients, independently from the
underlying illness severity, with evidence that its occurrence can directly worsen patient outcomes including an increased mortality rate (4).

Ultrasound can assess percentage change in diaphragmatic thickness from expiration to inspiration (diaphragmatic thickening fraction, DTF) and amplitude of diaphragmatic dome movements in respiratory cycle (diaphragmatic excursion, DE) which are indicators of strength of diaphragmatic contractions (5). Several recent studies have illustrated that diaphragm ultrasound is a feasible and precise method for evaluating the ventilator-induced diaphragmatic dysfunction (VIDD) (6). In addition, lung US can be used in the evaluation of the lung condition which is beneficial during making the decision of weaning as it gives us an idea about its aeration and so we can expect if respiratory distress will occur after weaning or not (7).

In adults, the thickness of the right hemidiaphragm and the diaphragmatic thickening fraction (DTF) are used to assess VIDD development. Furthermore, the DTF is applied as a predictor of successful extubation from MV (8). In the pediatric population, no gold standard has been established for weaning children from ventilators, and no optimal ventilator settings have been identified in PICU practice (9).

**Aim of the study:**

To predict the value of diaphragmatic and lung ultrasound indices in anticipation of the outcome of mechanical ventilation weaning of pediatric patients in the intensive care unit.

**Material and methods**
This study was conducted in PICU in Benha university hospitals and Benha children hospital. Eighty mechanically ventilated children, during the period from October 2021 to April 2023 were included. The study was approved by the Ethical Committees of Faculty of Medicine, Benha University Hospital and consent was obtained from the parents prior to the children enrolment in the study. The study included any ventilated patient less than 18 years old who was eligible for weaning in accordance with the following weaning criteria & signs of reversal of the principal cause of mechanical ventilation:

- Accepted blood oxygenation i.e., partial pressure of arterial oxygen (PaO2) was equal to or more than 60 mmHg, partial pressure of arterial carbon dioxide (PaCO2) was equal to or less than 45 mmHg, fraction of inspired oxygen (FiO2) was equal or less than 0.40, positive end-expiratory pressure (PEEP) was equal to or less than 5 cmH2O and the ratio of partial pressure of arterial oxygen to the fraction of inspired oxygen was equal or more than 200; Potential of hydrogen (PH) ≥ 7.30; RR ≤45/m; Heart rate (HR) ≤ 140/min; Rapid shallow breathing index (RSBI) ≤8 breaths/min/ml/kg body weight
- Stable body hemodynamics with minimal use of inotropic or vasopressor drugs
- Adequate consciousness level and not receive sedatives or neuromuscular blocking drugs
- No fever
- Absence of hemorrhage or anemia which means that hemoglobin level was ≥7.5 g/dl
- No electrolyte disturbance and specially K level were above 4 mEq/dl

Patients with any of the following conditions were excluded:

- Chronic neuromuscular disorder, congenital lung or pleural malformation or with unilateral/bilateral absence of diaphragmatic mobility in US.
• Who had undergone diaphragmatic manipulation during thoracic or oesophageal Surgeries.
• Major cardiac or abdominal surgery

All children were subjected to detailed history and thorough bedside clinical examination. Routine blood samples were checked including blood gas. X ray chest for all cases and CT chest for some cases were done according to the clinical indications. Diaphragmatic and lung ultrasound were done as following:

**Diaphragmatic US**

Diaphragm US was done during the spontaneous breathing trial (SBT) and score was calculated. The intercostal approach was performed with a (10–15- MHz) linear array transducer positioned in a cranio-caudal direction and perpendicular to the skin in the zone of apposition between the mid-axillary and anteroaxillary line, in the 8th to 11th intercostal space.

We recommend measuring diaphragm thickness perpendicular to its fiber direction between the pleural and peritoneal membrane, but not including the membranes. The lower limit for normal diaphragm thickness is around 1.5 mm in healthy subjects. Diaphragm thickness was affected by body composition and gender.

Thickening fraction of the diaphragm (TFdi) was calculated in B-mode or M-mode as the percentage inspiratory increase in diaphragm thickness relative to end-expiratory thickness during tidal breathing (TFdi) or maximal inspiratory effort (TFdi (max)):

\[
\text{DTF} = \left( \frac{\text{Thickness at the end inspiration} - \text{thickness at the end expiration}}{\text{Thickness at the end expiration}} \times 100 \right) (10).
\]
Diaphragmatic excursion is measured with a low frequency phased curved-array ("abdominal") probe (2–5 MHz) positioned just below the costal arch at the midclavicular line, with the patient in semiseated position. Excursion is quantified in M mode, with the M-line placed perpendicular to the direction of motion the sweep speed is best adjusted to around 10 mm/s to obtain a minimum of three respiratory cycles within one image.

**Lung US**

Lung US was performed using a 2.5–5 MHz probe. The upper and lower regions of anterior, posterior and lateral walls of the right and left lungs were examined through the intercostal spaces i.e., 12 regions in total.

Four US aeration patterns were identified: (1) N, Normal aeration: The presence of lung sliding with A-lines or less than two isolated B lines; (2) B1, moderate loss of lung aeration: Multiple well-defined B lines; (3) B2, severe loss of lung aeration: Multiple abutting B lines; (4) C, lung consolidation: The presence of a tissue pattern characterized by dynamic air bronchogram.

All patients were submitted to SBT by low level of pressure support (5 cm H2O). The patients were monitored closely for a period 30 to 120 min to assess the eligibility for weaning (7). Patients were considered not tolerating the SBT if: RR > 45/min or change in RR > 50% above baseline; Arterial oxygen saturation < 90%, arterial oxygen tension <50 mmHg, or increase in arterial carbon dioxide tension >10 mmHg; Increase or decrease in heart rate > 20% from the baseline; agitation and diaphoresis; developing manifestations of increased work of breathing (11). If the patient developed any of these manifestations, SBT was ended and the patients were returned to the former settings of MV.
Patients were classified into two groups in accordance with their outcome:

- Weaning success group; Patients were successfully extubated with no need for NIV (non-invasive ventilation) or reintubation.
- Weaning failed group; Weaning failure is stated when there is failure of extubation and need of the patient for re-intubation within 24–72 h.

**Statistical analysis:**

The data were coded, entered and processed on computer using SPSS (version 24). The results were represented in tabular and diagrammatic forms then interpreted. Mean, standard deviation, range, frequency, and percentage were use as descriptive statistics.

The accepted level of significance was 0.05.

**Results:**

This study included 80 mechanically ventilated children who were eligible for SBT. Fifty-eight patients (72.5%) were successfully weaned from MV (Weaning success group) and 22 patients (27.5%) failed to wean from MV (weaning failed group).

The mean age in weaning success group (6.0±3.9 years) was significantly higher that the weaning failed group (4.2±2.6 years), p=0.021. While there was no significant difference between groups regarding their sex or cause of PICU admission. As well, there was no significant difference between the two groups in terms of heart rate, respiratory rate, temperature, capillary refill time, or Glasgow coma scale (GCS) at time of SBT. Similarly, Haemoglobin level, infection markers, blood gas, and kidney and liver functions did not show significant difference between the two groups.
The mean duration of MV in weaning success group (8.2±4.4 days) was significantly lower than the weaning failed group (11.5±4.9 days), p<0.001.

The weaning success group had significantly higher diaphragm thickness and diaphragm excursion with mean total DTF of 29.6±2.8 % vs 20.9±6.8 % (<0.001) and mean total diaphragm excursion of 9.6±1.55 mm vs 5.7±1.9 mm (<0.001) in the success and failed groups respectively. However, the success group had lower lung US score 12.7±4.9 vs 24.6±7.1 compared to the failed group (<0.001).

ROC analysis was done to assess the performance of lung and diaphragmatic US parameters to predict weaning success; Regarding LUS; AUC was 0.887 (95% confidence interval: 0.806-0.972), p<0.001. At a cutoff point < 16, the sensitivity was 80.2% and specificity was 72.7%. Regarding DTF; AUC was 0.846 (95% confidence interval: 0.732-0.959), p<0.001. At a cutoff point > 24.3%, the sensitivity was 93.1% and specificity was 67.6%. Regarding diaphragmatic excursion; AUC was 0.933 (95% confidence interval: 0.882-0.985), p<0.001. At a cutoff point > 6.9 mm, the sensitivity was 82.8% and specificity was 81.5%.

**Discussion:**

The failure rate of children weaning can reach as high as 8–20%, and the failure in weaning is considered as an independent risk factor for a worse clinical outcome (12).

In the past 15 years of adult research, the functional indices, such as mobility, contraction speed, thickness, and thickening fraction of diaphragm ultrasound, in predicting weaning have been established (13). Similarly, diaphragm ultrasound can be used for monitoring the changes of the diaphragmatic muscle function of children (14). However, there is no relevant
adjusted value of diaphragmatic muscle index in healthy children at present. Also, lung US can be used in the evaluation of the lung condition which is beneficial during making the decision of weaning as it gives us an idea about its aeration and so we can expect if respiratory distress will occur after weaning or not. Few studies implement this tool in assessment of readiness of weaning in pediatrics (15). The current study aimed to predict the value of diaphragmatic and lung ultrasound indices (US) in anticipation of the outcome of mechanical ventilation of pediatric patients in the intensive care unit.

The study included 80 patients, 72.5% were successfully weaned from MV and 27.5% failed. In the same way, another study on the predictive value of diaphragm ultrasound for weaning outcomes in critically ill children, included 50 patients, the rate of weaning success was 78% (39/50), and the rate of weaning failure was 22% (11/50) (5), while, another study., who studied diaphragm and lung ultrasound indices in prediction of outcome of weaning from mechanical ventilation in PICU, included 106 children on invasive MV and eligible for SBT. Sixty-four patients (60.4%) were successfully weaned from MV, and rate of weaning failure was 39.6% (15). This variation might be due to differences in the definition of weaning failure, the types of underlying diseases, and the population studied. For this high rate of weaning failure, reliable tools are urgently needed to estimate the weaning outcome.

In the current study, there was no significant difference between the two groups regarding blood gas which is similar to the findings in other studies (5, 12). In the same way, another group reported that monitored parameters during weaning process like PO2, FiO2, P/F ratio, SpO2, RR, RSBI, PEEP, and pressure had no significant difference between the succeed and failed weaning groups (16).
In our study, the mean duration of MV in weaning success group (8.2±4.4 days) was statistically lower than the weaning failed group (11.5±4.9 days), p<0.001. This matched with another study which reported that ventilatory treatment time in the weaning failure group (median 15, range 7-22 days) was significantly longer than the success group (median 5, range 5-7 days), (P = 0.002) (5). Similarly, one more study reported that there were statistically significant differences between patients with failed weaning and those with successful weaning regarding days of MV (p < 0.001), patients with prolonged mechanical ventilation showed more liability for weaning failure (15). Also, another report found that duration of MV before weaning was significantly longer in weaning failure group as compared to the successful group (7.7±2.5 vs. 5.1±2.0, P=0.033) (16).

In the current study, the weaning success group had statistically higher diaphragm thickness (Tdi) at end of inspiration and expiration and DTF on both sides and higher total DTF, compared to weaning failed group (P<0.001 for all parameters) (Table1). Our results were in agreement with others (12), who reported that the end-inspiratory and end-expiratory thicknesses of the diaphragm and also the DTF were significantly higher in the weaning success group than that in the weaning failure group under various conditions, each parameter had p < 0.05. Another group (15), which did similar work on different age groups reported similar results in infants group. While in children group; DTF is the only parameter which showed significant difference regarding the outcome between the two groups, being higher in successful weaning group. In addition, in adolescent group; there was no significant difference between groups regarding any of US’S data. Nevertheless, this can be explained as in children and adolescent groups, only one patient in every group had weaning failure; so statistical analysis may be not accurate.
As well, another research (5) reported that the DTF was significantly higher in the weaning success group than the failure group, P < 0.001. However, they noted that there were no differences in Tdi at end of inspiration and expiration between the weaning success and failure groups (p= 0.97 and p=0.59, respectively). From different studies, The DTF seems to be a more consistent valid parameter rather than the end-inspiratory or expiratory thickness.

In the present study, the weaning success group had statistically higher diaphragm excursion on both sides and higher total diaphragm excursion, compared to weaning failed group. Our results were matched with others (12), who reported that the DE in the weaning success group was higher than that in the weaning failure group p < 0.05. However, some researches (5), noted that there were no differences in diaphragm excursion between the weaning success and failure groups, p= 0.23. All the previous studies on adults confirmed that diaphragmatic excursion and DTF are helpful indicators for weaning outcome prediction. However, The DTF has a higher sensitivity and better AUC score than excursion (17,18).

In the current study, the weaning success group had statistically lower lung US score compared to weaning failed group. This was in the same line with (15), who reported that the mean values of this score were significantly higher in the failed (p < 0.001). In the same way, another study (16), who studied role of lung ultrasound patterns in monitoring coronavirus disease 2019 pneumonia and acute respiratory distress syndrome in children, reported that weaning failure group had higher median LUS, compared to weaning success group, P<0.001.

However, our results were not in agreement with another group (19), who studied role of ultrasound in predicting weaning failure in children undergoing cardiac surgery, who reported
that LUS scores cannot predict weaning failure and there was no significant difference between the LUS scores between the two groups at the three time points. This can be attributed to the fact that the post cardiac surgery lung edema is of multifactorial origin with the impaired post-surgical cardiac function.

In the current study, there was a significant positive correlation between DTF and diaphragmatic excursion and there was a significant negative correlation between LUS and (DTF and diaphragmatic excursion). Similarly, (5), showed that there was significant correlation between DTF and DE ($r = 0.380$, $P = 0.006$).

ROC analysis was done to assess the performance of lung and diaphragmatic US parameters to predict weaning success. Regarding DTF, a cutoff point $> 24.3\%$, had sensitivity of 93.1\% and specificity of 67.6\%. Similarly, (15), reported that the best cut-off value of DTF for predicting weaning success was $\geq 23.175$ with a sensitivity of 100\% and a specificity of 76.2\% and, (5), reported that cut-off value of DTF $\geq 21\%$ was associated with weaning success with a sensitivity of 82\% and a specificity of 81\%.

Regarding diaphragmatic excursion, a cutoff point $> 6.9$ mm, the sensitivity was 82.8\% and specificity was 81.5\%. In line with our study, (15) reported that the best cut-off value of excursion for predicting weaning success was $\geq 6.2$ with a sensitivity of 87.5\% and a specificity of 66.7\%. similarly, (12) reported that the DE had moderate value of prediction for weaning outcome. In contrast to our results, another group (5), reported that DE has limited value in predicting weaning success ($P = 0.20$). The area under the ROC curve for DE was 0.63 (95\% confidence interval [0.43 to 0.83]).
Lung US had a cutoff point < 16, with sensitivity of 80.2% and specificity of 72.7%. Similarly, another research, (15) reported that the sensitivity and specificity of this score for predicting weaning failure at a cut-off point of 12 were 85.7% and 81.2%, respectively. However, (16) had a lower cutoff value of 5 or less with a sensitivity of 79% and specificity of 100%.

**Conclusion:**

Diaphragmatic and lung US is a quick and non-harmful technique for prediction of weaning success with highly accurate results. So, they can be added to the conventional parameters for accurate prediction of the weaning outcome.

**Limitations:**

This study was limited by the relatively small sample size. Larger or multicenter studies are recommended for more reliable accurate data to detect the exact range of cut-offs of the ultrasonographic measurements to include them with the validated weaning parameters in PICU protocols.

Because no reference values of diaphragm US parameters have been established in children, it is difficult to determine whether the initial diaphragmatic function of our enrolled children is abnormal or not. Therefore, studies with larger sample size should be conducted to establish the reference values and determine the difference in diaphragmatic function between children with different ventilation support.

**Conflict of interest:**

No conflict of interest.
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References


**Tables**

**Table 1:** Bilateral Diaphragm Thickness and Diaphragm thickening Fraction in the studied groups.
<table>
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<tr>
<th></th>
<th>Weaning success</th>
<th>Weaning failed</th>
<th>Test</th>
<th>P value</th>
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<tbody>
<tr>
<td></td>
<td>N=58 %</td>
<td>N=22 %</td>
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<tr>
<td>Tdi at end inspiration Rt. (mm)</td>
<td>Mean ±SD 1.99±0.28</td>
<td>1.43±0.33</td>
<td>t=7.5</td>
<td>&lt;0.001*</td>
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<td>Range 1.56-2.43</td>
<td>1.10-2.30</td>
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<td>Tdi at end expiration Rt. (mm)</td>
<td>Mean ±SD 1.76±0.26</td>
<td>1.22±0.36</td>
<td>t=7.3</td>
<td>&lt;0.001*</td>
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<td>Range 1.43-2.13</td>
<td>0.80-2.10</td>
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<tr>
<td>DTF Rt. (%)</td>
<td>Mean ±SD 30.2±2.9</td>
<td>22.1±6.4</td>
<td>t=7.6</td>
<td>&lt;0.001*</td>
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<td>Range 24.4-36.2</td>
<td>14.1-34.7</td>
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<tr>
<td>Tdi at end inspiration Lt. (mm)</td>
<td>Mean ±SD 1.80±0.28</td>
<td>1.29±0.35</td>
<td>t=6.8</td>
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<td>Tdi at end expiration Lt. (mm)</td>
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<td>t=6.1</td>
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<td>DTF Lt. (%)</td>
<td>Mean ±SD 29.1±2.76</td>
<td>20.4±6.5</td>
<td>t=8.3</td>
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<td>DTF (%)</td>
<td>Mean ±SD 29.6±2.8</td>
<td>20.9±6.8</td>
<td>t=8.5</td>
<td>&lt;0.001*</td>
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