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Evaluation of Role of Ultrasound in Assessment of Successful Weaning from Mechanical Ventilation in Critically Ill Patients

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ABSTRACT

Background: Mechanical ventilation waning failure is a common problem, and bedside ultrasonography could be helpful in prediction of the weaning process and its results.

Aim of The Work: To ssess by means of ultrasound how diaphragmatic parameters are important in predicting weaning outcome by assessing diaphragmatic thickness, diaphragmatic mobility and variation.

Patients and Methods: This study included 62 mechanically ventilated patients who were subjected to transthoracic ultrasonography of the diaphragm throughout a spontaneous breathing experiment and had been divided into two groups: successful extubation and unsuccessful extubation.

Results: With a p-value of <0.001, a high DE after extubation was linked to extubation success. Extubation failure was linked to lower DTF before and after extubation, with a p-value of <0.001. DE before extubation > 15 had 100% sensitivity, 85.06% specificity, 70.5 PPV and 100% NPV with p-value <0.001 for detection of extubation failure. DTF before extubation > 20.4 had 93.55% sensitivity, 93.55% specificity, 93.5% PPV, and 93.5% NPV with p-value <0.001 or detection of extubation failure. MV duration was negatively correlated with DE before extubation in the success group and positively correlated with DE after extubation in the success group.

Conclusion: Diaphragm ultrasound evaluation of DTF and DE is a simple new weaning index which can be used as a bedside technique in clinical practice and has promising predictors of weaning success or failure before and after extubation.

Keywords: *mechanical ventilation; weaning; diaphragmatic parameters; ultrasonography.*

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Authorship: *All authors have a substantial contribution to the article.*

INTRODUCTION

About 40% of mechanically ventilated patients experience challenges throughout MV weaning[1]. Weaning is the process of gradually withdrawing mechanical ventilation while maintaining spontaneous breathing[2]. Early termination or an undue delay in weaning might result in a variety of negative outcomes. The presence of significant repercussions like ventilator-induced diaphragm atrophy, ventilator-associated pneumonia, and restart of mechanical ventilator treatment, among such findings, highlights the need to make the right weaning decisions[3].

Interactions between the heart and the lungs during weaning can cause pulmonary edema, which increases the heart's burden. Weaning-induced pulmonary edema (WIPO) is a type of weaning failure caused by this condition[4].

Aeration alterations in the lungs are scored during the examination (LUS score) [5,6]. While studies evaluating the diaphragm sonographically throughout weaning are adequate, the number of studies examining both the diaphragm as well as the lung sonographically at the same time is limited[7,8]

The aim of this research was to assess by means of US how diaphragmatic parameters are important in predicting weaning outcome by assessing diaphragmatic thickness, diaphragmatic mobility, and variation in diaphragmatic thickening and to what extent the ventilator affects the diaphragmatic power by measuring thickness and excursion.

PATIENTS AND METHODS

This was a prospective cohort study involving 62 mechanically ventilated patients admitted to Al-Azhar University hospitals during 2020.

The following parameters were fulfilled:

Demographic characteristics: age, anthropometric measurements including body mass index (BMI), clinical evaluation including; systolic blood pressure-heart rate-Glasgow coma score (GCS), cause of ICU admission, duration of ICU stay, duration of hospital stay, mechanical ventilation duration, outcome of the included patients, severity of illness evaluated by APACH II score, parameters of MV including; PaO2/FiO2- respiratory rate (RR), and laboratory results including; serum sodium (Na), potassium (K), bicarbonate (HCO3), magnesium (Mg), calcium (Ca), arterial pH, PCO2, PO2.

Criteria for readiness for extubation include : reversal of cause of respiratory failure, GCS >8, spontaneous breathing, PaO2/FiO2 >200, hemodynamically stable, able to cough, O2 saturation >90% on FiO2≤0.4, RR <35 bpm, PEEP≤ 8 cmH2O, RSBI <105 and successful 30 minutes spontaneous breathing.[9]

Ultrasonography parameters before and after extubation, including Diaphragmatic excursion (DE), and Diaphragmatic thickening fraction (DTF%).

U/S was then carried out to assess the diaphragmatic thickness from the right hemidiaphragm using a 10–12MHz probe placed perpendicularly above the ninth–tenth intercostal space in the anterior axillary line, through the hepatic window, part of the diaphragm's apposition zone to the rib cage, and to assess diaphragm mobility, a 3.5–5MHz probe was placed beneath the rib cage, at the mid-clavicular line, with the ultrasonic beam directed perpendicularly towards the posterior third of the hemidiaphragm and done while inhaling.

The most frequently assessed parameters by ultrasound are diaphragm movement studies (as an indication of diaphragm activity), thickness of the diaphragm (as an indication of atrophy), and variation in thickness of the diaphragm.

Diaphragm mobility (Excursion)

To assess diaphragm mobility, a 3.5–5MHz probe should be placed beneath the rib cage at the mid-clavicular line, with the ultrasonic beam directed perpendicularly towards the posterior third of the hemidiaphragm. The normal diaphragm moves downward during inhalation, approaching the transducer.

Normal levels in healthy non-ventilated individuals differ between males and females (18±3 and 16±3 mm, respectively) [10], which is comparable to baseline levels in mechanical ventilation (MV) patients[11]. Dysfunction of the diaphragm is characterized by a negative excursion or an excursion of < 10 mm (or paradoxical motion). Such values are also good indicators of weaning failure[12].

Diaphragm Thickness

Ultrasonography could be performed to quantify diaphragm thickness, with the right hemidiaphragm becoming more accessible through the liver window than the left. A 10–12MHz probe, placed perpendicularly above the 9th–10th intercostal spaces in the anterior axillary line, has been employed to measure thickness by observing a portion of the zone of diaphragm apposition to the rib cage. The diaphragm is represented as three parallel layers of varying densities in this location (pleura, diaphragm, and peritoneum). During non-forced expiration, the thickness of the diaphragm is assessed using M-mode or 2D imaging. In ventilated patients, the normal thickness of the diaphragm is 2.4±0.8 mm, with atrophy described as values less than 2 mm. Thickness of 1.8 is regarded as normal, with a lower limit of 1.2 being accepted[13].

Variation in Diaphragm Thickness

The formula below could be used to calculate the variation in thickness of the diaphragm employing M-mode. The variation in diaphragm thickness could be employed to predict diaphragm capacity to create pressure[14]. A variance of <20% can be used to predict weaning failure.

The variation in the thickness of the diaphragm could be calculated by employing this formula. Thickness fraction= (Thickness at end of inspiration- Thickness at end of expiration)/ Thickness at end expiration x 100

Considering their reactions to weaning attempts, the patients have been divided into 2 categories:

Category A represented successful weaning.

Category B represented unsuccessful weaning followed by reintubation and mechanically ventilated.

Sample size

To estimate the sample size, we used the G-power program version 3.0.10 and according to:

The mean of Diaphragmatic displacement (DM) among the diaphragmatic dysfunction patients was 10.67 and standard deviation is 5.9 in comparison to non- diaphragmatic dysfunction patients (11.99+1.75) & effect size was 0.251.[15]

Precision of 2% - 95% confidence level- study power of 80%

Sample size should be at least 60, we already conducted the current study on 62 mechanically ventilated patients.

Statistical Analysis:

After data collection is completed, data entry, tabulation, and analysis are completed by employing the statistical package for the social sciences (SPSS, version 23; SPSS Inc., Chicago, Illinois, USA) (using an IBM personal computer). The results are provided in both tabular and diagrammatic formats. As for descriptive statistics, frequency, percentages, mean, and standard deviation were employed. Median and interquartile range (IQR) were used for describing non parametric data

For qualitative and quantitative variables, the chi-square or Fisher exact test, t tests, and Mann Whitney U test were employed to compare groups. The diagnostic effectiveness of ultrasonography diaphragmatic parameters determination for weaning failure prediction are determined using a Receiver Operating Characteristic Curve (ROC curve). P-value <0.05 was considered significant.

RESULTS

There was statistically significant negative correlation between (Age , BMI , Heart rate , Systolic Blood Pressure) in DE before and after extubation and also in DTF % before extubation while there was significant negative correlation values between Age , BMI , Heart rate , Systolic Blood Pressure and DTF % before and after extubation (Table 1).
Values of DE before and after extubation were significantly less in the extubation failure group compared to successful intubation group (P< 0.001 for each comparison). DE was significantly less before extubation compared to after extubation in the group of extubation failure (P< 0.001) while there was no significant difference between the two values in the group of successful extubation (Table 2).
Values of DTF% before and after extubation were significantly less in the extubation failure group compared to extubation success group (P< 0.001 for each comparison). The values of DTF% were significantly less before extubation compared to after extubation in the group of extubation failure (P< 0.001) while there was no statistically signidicant difference between the two times in the extubation success group (Table 3).
Table 4 shows that there was a statistically significant correlation between each of the values of DE and DTF% before and after extubation and each of the values of length of ICU stay (negative correlation), length of hospital stay (negative correlation), mechanical ventilation duration (negative correlation) and arterial PO2 (positive correlation).
There was a statistically significant negative correlation between the values of PaO2/FiO2 and each of the values of DE before and after extubation and also with DTF% after extubation (Table 4).
There was a statistically significant negative correlation between the respiratory rate and the values recorded before extubation for DE and DTF% (Table 4).
There was a statistically significant positive correlation between serum sodium and DE before extubation. Serum bicarbonate showed a statistically significant positive correlation with DE and DTF% before and after extubation (Table 4).
There was a statistically significant positive correlation between DE before extubation and each of the values of DE after extubation and DTF% before and after extubation. There was a statistically significant positive correlation between DE after extubation and each of the values of DTF% before and after extubation. There was a statistically significant positive correlation between DTF% before extubation and DTF% after extubation (Table 4).
Table 5 shows the values for DE before and after extubation regarding the cut-off values, sensitivity, specificity, positive and negative predictive values and area under the ROC curve.
Figures 2 and 3 show the validity of DE before and after extubation with area under the ROC curve as a predictor of extubation success.
Figure 4 shows the validity of DTF% before extubation with area under the ROC curve as a predictor of extubation success.

	DE/mm before		**DE/mm after**		**DTF% before**		**DTF% after**	
	R	P	r	P	R	P	R	P
Age	-0.143	0.268	-0.109	0.399	-0.119	0.357	-0.166	0.197
BMI	-0.149	0.246	-0.152	0.238	-0.383	0.002	-0.451	<0.001
Heart rate (HR)	-0.202	0.116	-0.089	0.493	-0.444	<0.001	-0.323	0.01
Systolic blood pressure (SBP)	-0.029	0.82	-0.104	0.419	-0.102	0.431	-0.098	0.449
GCS	0.132	0.308	0.118	0.36	0.164	0.203	0.156	0.226

Table1: Correlations between both DE and DTF%, before and after extubation as regards age BMI and vital signs in the whole group:

r = Correlation Coefficient

P ≤ 0.05= significant P <0.001 highly significant and P >0.05 non-significant

	Group (N=62)		**P value**
	Extubation failure N=31	Extubation success N=31	
	Median (Range)	Median (Range)	
DE/mm before	14 (8-19)	18 (16-20)	<0.001
DE/mm after	16 (12-20)	19 (16-22)	<0.001
P-value	<0.001	0.742	

Table 2: Comparison of DE in both groups before and after extubation

	Group		P value
	Extubation failure N=31	Extubation success N=31	
	Median (Range)	Median (Range)	
DTF% before	16.6 (9.8-32.1)	23.0 (9.3-44.0)	**<0.001**
DTF% after	18.0 (10.0-30.5)	24.0 (20.0-40.0)	**<0.001**
P-value	<0.001	0.199	

Table 3: Comparison of DTF% before and after extubation in both groups

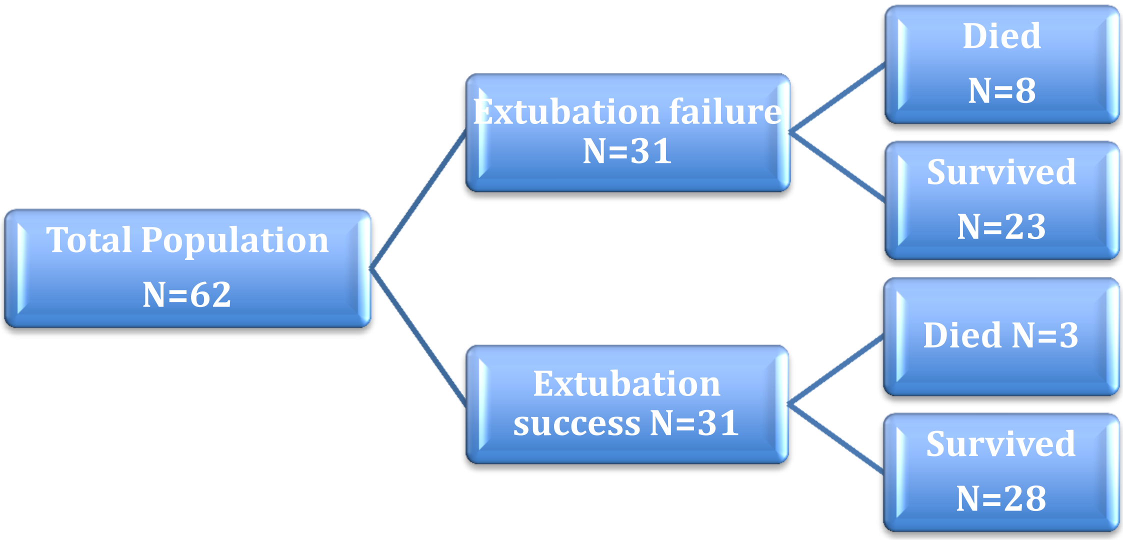

Fig. 1: Algorithmic flow chart of the population examined and their clinical outcome N=62

	DE before		*DE after*		*DTF% before*		*DTF% after*	
	R	P	r	P	r	P	r	P
Length of ICU stay, Days	-0.418	0.001	-0.474	<0.001	-0.455	<0.001	-0.577	<0.001
Hospital length of stay, Days	-0.381	0.002	-0.471	<0.001	-0.485	<0.001	-0.618	<0.001
MV duration, Days	-0.459	<0.001	-0.339	0.007	-0.502	<0.001	-0.478	<0.001
APACH II	-0.059	0.648	-0.030	0.82	-0.109	0.398	0.003	0.983
PaO2/FiO2	-0.254	0.047	-0.255	0.045	-0.143	0.266	-0.273	0.032
RR (breath/minutes)	-0.315	0.013	-0.201	0.118	-0.348	0.006	-0.142	0.271
Na (mmol/L)	0.266	0.037	0.247	0.053	0.078	0.547	0.101	0.435
K (mmol/L)	0.001	0.993	0.024	0.854	0.228	0.075	0.125	0.333
HCO3 (mEq/L)	0.337	0.007	0.289	0.023	0.414	0.001	0.361	0.004
Mg(mEq/L)	0.015	0.911	-0.041	0.751	0.120	0.353	0.069	0.596
Ca mg/dl	0.044	0.732	0.032	0.802	0.104	0.422	-0.015	0.911
Arterial pH	0.092	0.475	0.072	0.578	0.181	0.158	-0.010	0.939
Arterial PCO2	-0.149	0.248	-0.181	0.159	-0.017	0.896	-0.070	0.588
Arterial PO2	0.149	0.249	0.041	0.754	0.495	<0.001	0.307	0.015
DE before/mm			0.885	<0.001	0.288	0.023	0.370	0.003
DE after/mm	0.885	<0.001			0.262	0.04	0.398	0.001
DTF% before	0.288	0.023	0.262	0.04			0.683	<0.001
DTF% after	0.370	0.003	0.398	0.001	0.683	<0.001		

r = Correlation Coefficient
P ≤ 0.05= significant P <0.001 highly significant and P >0.05 non-significant
Table 4: Correlations between both DE and DTF%, before and after extubation and certain studied parameters in the whole group:

	Cut-off	Sensitivity % 95% CI	Specificity % 95% CI	PPV 95% CI	NPV 95% CI	AUC 95% CI	P
DE/mm before extubation	>15	100 88.8 - 100.0	58.06 39.1 - 75.5	70.5 61.2 - 78.3	100	0.823 0.705 - 0.908	<0.001
DE/mm after extubation	>17	96.77 83.3 - 99.9	64.52 45.4 - 80.8	73.2 62.8 - 81.5	95.2 74.1 - 99.3	0.822 0.703 - 0.907	<0.001

The 95%CI: 95% confidence interval, Positive predictive value (PPV) and negative predictive value (NPV), Area under the ROC curve (AUC)

Table 5: The validity of DE before and after extubation with area under the ROC curve (AUC) as a predictor for extubation success

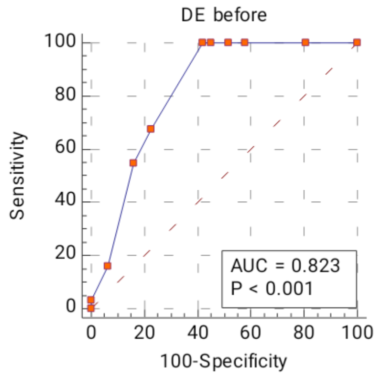

Fig. 2: The validity of DE before extubation with area under the ROC curve (AUC) as a predictor for extubation success

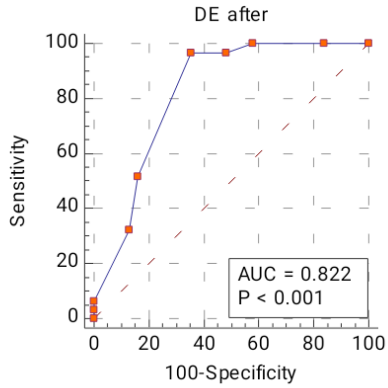

Fig. 3 : The validity of DE after extubation with area under the ROC curve (AUC) as a predictor for extubation success

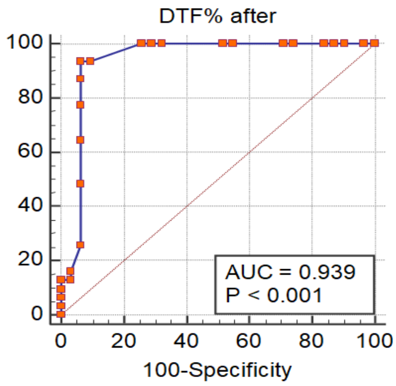

Fig. 4: The validity of DTF% following extubation with area under the ROC curve (AUC) as a predictor for extubation success

DISCUSSION

For physicians caring for severely ill intubated sick people undergoing mechanical ventilation, liberation from invasive mechanical ventilation represents a major problem[16].

This study was performed on 62 mechanically ventilated patients to assess extubation failure and related factors.

The current study showed no statistically significant relationship among extubation failure, patient age. Similarly, Varon-Vega et al.’s study showed no statistically significant relationship among age and extubation failure[17]. Keyal et al. study reported no statistically significant association between age and extubation failure[18]. In contrast to Jaber et al. study, which included 1541 patients undergoing extubation between December 2013 and May 2015 in 26 ICUs and found statistically significant increased extubation failure with female gender [19]. Yonaty et al. reported that older age was significantly related to extubation failures[20].

The Current study revealed no statistically significant association between lower GCS and extubation failure. This goes in line with Baptistella et al. study which also revealed no statistically significant association between extubation failure and GCS of mechanically ventilated patients[21]. Similarly, Miu et al. also found that GCS did not affect extubation failure[22].

In the current study, the cause of admission to the ICU did not significantly affect extubation success. In contrast, the Frutos-Vivar et al. study previously evaluated risk variables for extubation failure and revealed that the reason for starting MV was pneumonia, which was an independent risk variable for extubation failure[23]. Also, another study by Jaber et al. found that cause of ICU admission significantly affected extubation failure especially post-operative patients, and neurological causes [19].

The current study found that higher BMI was significantly related to extubation failures. This goes in line with Kaur et al. study, which included 216 mechanically ventilated patients planned for extubation to compare the integrated pulmonary index's prognostic ability in determining extubation failures and revealed that higher BMI was significantly related to extubation failures [24]. This finding was in contrast to Huang et al.'s study, which was conducted on 40 patients scheduled for extubation to evaluate the utility of M mode ultrasound for ventilator weaning in older patients and found no statistically significant differences between extubation failure and extubation success regarding BMI[15].

The current study revealed, that a prolonged duration of ICU stay was significantly related to extubation failures. According to Baptistella et al.'s study, which was conducted on 110 patients who were scheduled for extubation to determine the respiratory and non-respiratory factors influencing the outcome of extubation, patients with extubation failure had a statistically significant increased duration of ICU stay (13 days in extubation failure vs 7 days in extubation success) [21]. Similarly, another study by Thille et al. which included 168 mechanically ventilated patients planned for extubation and revealed that longer ICU duration had statistically significant higher rate of extubation failure[25]. On the same line, the study by Wang et al. also revealed that the length of MV had been statistically significant to cause extubation failure[26]. This finding was in contrast to Yu et al.'s study, which discovered no statistically significant differences in the duration of ICU stay among extubation failure and extubation success [27].

The current study revealed that prolonged length of hospital stay was significantly related to extubation failures with p-value. This goes in line with the Yonaty et al. study, which revealed that patients who failed extubation would have a lengthier hospital stay than patients who succeeded in extubation, with a p-value <0.01[20]. Similarly, Spadaro et al. found a statistically significant rise in hospital duration of stay in the extubation failure group in a study of 51 ventilated patients to assess the role of diaphragmatic US to assess weaning[28].

Duration of MV was another parameter for extubation failure, as the present research revealed that long MV duration was significantly related to extubation failures. Jaber et al. found that length of mechanical ventilation was one of the related factors for extubation failure using multivariant regression analysis[19]. Similarly, another study by Baptistella and colleagues reported that the duration of MV was one of the predictor factors for extubation failure in a univariate logistic regression analysis [21]. This finding was in line with the findings of Vidotto et al., which were conducted on 317 individuals who underwent elective intracranial surgery for tumors to assess failure of extubation and the related factors, which revealed that prolonged MV of more than 48 hours was significantly related to extubation failures [29]. This can be explained by the fact that combining full diaphragmatic inactivity with MV causes diaphragm myofiber atrophy, which was observed even following only 18 hrs of mechanical ventilation [30]. In contrast, another Egyptian study performed on 30 ventilated patients to evaluate the degree of diaphragm thickness and/or diaphragm displacement as determined by ultrasonography throughout weaning found no statistically significant difference in MV duration in extubation failures and extubation successes [31].

The current study revealed statistically significant lower HCO_3 with extubation failure compared to extubation success with p-value=0.035. This is consistent with the findings of Boniatti et al., which was conducted on 153 MV patients for an analysis of the modified integrative weaning index’s performance to predict the extubation process and revealed that lower bicarbonate was significantly linked to failure of extubation and reintubation [32].

The current study revealed a statistically significant lower PaO2 with extubation failure compared to extubation success. This is consistent with the findings of Dodgen et al., which was conducted on 164 MV patients and found a statistically significant low PaO2 was significantly linked to failure of extubation [33]. In contrast to Rizzo et al., which has been done on 851 ventilated patients in a burn unit to examine the rate of extubation failure and revealed no statistically significant association between PaO2 and failure of extubation [35].

The current study revealed that high DE after extubation was significantly linked to extubation success with a p-value <0.001. Similarly, Mohamed et al. studied 80 ventilated patients to assess diaphragm thickening using real-time ultrasonography to predict extubation outcomes and revealed a statistically significant higher DTF in the extubation success group compared with the extubation failure group [35]. While this finding was in contrast to Youssef et al.'s study, which discovered no statistically significant differences between the extubation success and failure groups as regards DE after extubation [36], the difference can be explained by the different pressure support used during spontaneous breathing trials, which obviously affected the diaphragmatic movement. It may also be different in population studies as regards age and sex[37].

The current study revealed that lower DTF before and after extubation was significantly linked to failure of extubation. This goes in line with the findings of Ferrari et al., who did a study on 46 mechanically ventilated patients who had been scheduled for weaning to evaluate a novel weaning index comprised of the diaphragm thickening fraction (DTF) as evaluated by ultrasonography and found a statistically significant lower DTF in the extubation failure group compared with extubation success [38]. Similarly, Youssef et al. performed research on fifty mechanically ventilated patients to evaluate the value of echocardiography, lung, and diaphragm ultrasounds as indicators of weaning outcomes compared to clinical weaning criteria and found that DTF before extubation had highly significant values in the successfully weaned group than in the failed group [36]. This is consistent with Samanta et al., who discovered a statistically significant lower DTF after extubation in the extubation failure group [39].

The current study found no statistically significant association between extubation failure and mortality, which goes in line with the findings of Yonaty et al. that was conducted on 158 MV patients planned for extubation and revealed no statistically significant association between extubation failure and mortality [20]. Our finding was in contrast to what was reported by Aloma Ft et al. study, which discovered a 10-fold increase in mortality with extubation failure versus extubation success [40].

CONCLUSION

mechanical ventilation, weaning, diaphragmatic parameters, ultrasonography.

Conflict of interest : none

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