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Application of Lung Ultrasound Combined with Multi-organ Evaluation in Assessing the Risk of Weaning from Mechanical Ventilation in Severe Patients

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Abstract: *Objective:* To explore the role of lung ultrasound combined with multi-organ evaluation in assessing the risk of weaning from mechanical ventilation (MV) in severe patients. *Methods:* A retrospective analysis was conducted on 60 severe patients admitted to the hospital from December 2022 to December 2024, all of whom underwent MV treatment. Based on weaning status, thirty-eight patients were successfully weaned (success group), and 22 patients failed weaning (failure group). All patients underwent lung ultrasound and multi-organ evaluation. The parameter differences between the two groups were compared, risk factors for weaning risk were evaluated, and a receiver operating characteristic curve (ROC) was drawn to assess the predictive value of lung ultrasound combined with multi-organ evaluation for weaning risk. *Results:* The lung ultrasound score (LUS) of the success group was lower than that of the failure group, the left ventricular ejection fraction (LVEF) was higher than that of the failure group, and the diaphragmatic excursion (DE) and diaphragmatic thickening fraction (DTF) were higher than those of the failure group ($P < 0.05$). Multifactor analysis showed that LUS was a risk factor for weaning risk, while LVEF, DE, and DTF were protective factors ($P < 0.05$). The ROC showed that the area under the curve (AUC) of a single parameter for weaning risk was smaller than that of the combined parameters ($P < 0.05$). *Conclusion:* Lung ultrasound combined with multi-organ evaluation can predict the weaning risk of severe patients undergoing MV treatment, and the diagnostic efficiency of multiple parameters combined evaluation is higher.

Keywords: Lung ultrasound; Multi-organ evaluation; Severe patients; Mechanical ventilation; Weaning risk

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1. Introduction

MV is a commonly used treatment technique for severe patients, which can maintain patients' lung ventilation function and stabilize their vital signs. MV treatment involves multiple complex processes, such as intubation and weaning, and weaning is the final step. When the patient's condition improves and vital signs stabilize, timely weaning is necessary to prevent complications such as ventilator-associated pneumonia [1]. The spontaneous breathing test (SBT) is a common weaning assessment method with high assessment accuracy, but it has a certain degree of subjectivity, which may lead to weaning failure. Currently, ultrasound technology has become a practical assessment method for severe patients. Among them, lung ultrasound can evaluate lung function status, and multi-organ ultrasound can visually evaluate diaphragmatic movement and thickness levels under noninvasive conditions, understand patients' cardiac function parameters, and thus comprehensively evaluate weaning risk and reasonably determine the weaning timing. However, previous studies have lacked systematic and mature ultrasound evaluation criteria, which have limited guiding significance for the weaning process [2]. Therefore, this study selected 60 severe MV-treated patients to explore the predictive effect of lung ultrasound combined with multi-organ evaluation on weaning risk.

2. Methods and materials

2.1. General information

A retrospective analysis is conducted on the clinical data of 60 patients with severe illness undergoing MV treatment who are admitted to the hospital between December 2022 and December 2024. The patients are grouped based on their weaning status. The successful group consisted of 38 patients, including 21 males and 17 females, aged between 26 and 78 years, with a mean age of (49.53 ± 4.15) years. The disease types included 11 cases of acute respiratory failure, 22 cases of severe pneumonia, and 5 other cases. The failure group consisted of 22 patients, including 13 males and 9 females, aged between 24 and 76 years, with a mean age of (49.61 ± 4.24) years. The disease types included 10 cases of acute respiratory failure, 9 cases of severe pneumonia, and 3 other cases. There was no significant difference between the two groups ($P > 0.05$).

The criteria for weaning failure are as follows: respiratory rate not less than 35 breaths per minute, or an increase of not less than 50%; blood oxygen saturation not less than 90%, or arterial oxygen partial pressure less than 60 mmHg; pH value less than 7.35; heart rate not less than 145 beats per minute or an increase of not less than 20%; severe arrhythmia; anxiety, profuse sweating; systolic blood pressure less than 90 mmHg, heart rate higher than 145 beats per minute, or an increase of not less than 20%. If none of the above situations occurred, the weaning is considered successful.

The inclusion criteria of the study are: admitted to the intensive care unit; meeting the indications for MV treatment; hemodynamically stable; complete clinical data; informed and consenting to participate in the study. Meanwhile, the exclusion criteria included: history of trauma; abnormal signs such as fever or hypothermia; comorbid pneumothorax; abnormal communication ability; intolerance to MV treatment; mental illness; comorbid malignant tumor; withdrawal from the study.

2.2. Methods

Color Doppler ultrasonography (portable) is used for all ultrasound examinations.

(1) Lung ultrasonography: Patients are positioned in a supine position, and a 12-zone method is adopted. The ultrasound probe is placed on areas such as the patient's anterior axillary line and paravertebral line, which served as the longitudinal axis, while the transverse axis is the nipple level area. The unilateral chest wall is divided into six zones: upper and lower zones of the lateral chest wall, anterior chest wall, and posterior chest wall. A convex array probe with a frequency of 1–5 MHz or a linear array probe with a frequency of

4–12 MHz is used for scanning. Various regions are observed for A/B lines and pleural lines to evaluate pathological manifestations such as lung consolidation or fluid accumulation, and the LUS score was assessed.

(2) Multi-organ ultrasonography: Echocardiography is performed on the patient's chest. The patient is positioned in a supine position, and a phased array probe with a frequency of 1–5 MHz is used. The probe is placed in areas such as the subxiphoid region, suprasternal notch, and apical region for multi-slice scanning, including parasternal short-axis view, five-chamber view, and apical four-chamber view. Cardiac function parameters are recorded. A convex or linear array probe is placed in the ZOA area, which is the circular lateral area of the diaphragm connected to the lower chest wall. The probe is positioned perpendicular to the chest wall to measure indicators such as diaphragmatic thickness at the end of exhalation and inhalation.

Two senior imaging physicians are responsible for analyzing the ultrasound images using a double-blind method. If there are disagreements, a consensus is reached through discussion to provide the final results. All ultrasound parameters are continuously evaluated three times, and the average value is taken.

2.3. Observation indicators

2.3.1. Ultrasonic parameters

(1) LUS score: Zero points indicate fewer than 3 A/B lines; 1 point indicates at least 3 well-spaced B lines; 2 points indicate diffuse fusion of B lines; 3 points indicate concomitant lung consolidation. The total score is the sum of the scores in 12 regions, with a maximum of 36 points. Lung lesions are positively correlated with the score.

(2) Cardiac function parameters: Record values such as LVEF, right/left ventricular end-diastolic diameter ratio (RV/LV), cardiac output [CO, calculated as blood flow velocity-time integral (VTI) in the left ventricular outflow tract * πr2 * heart rate], and tricuspid annular plane systolic excursion (TAPSE).

(3) Diaphragmatic function parameters: diaphragmatic thickness, DE, and DTF (the difference in diaphragmatic thickness between end-inspiration and end-exhalation divided by diaphragmatic thickness at end-exhalation).

2.3.2. Risk factors for weaning

Use multifactor analysis to evaluate protective and risk factors for weaning.

2.3.3. Predictive value of ultrasonic parameters for weaning risk

Use ROC curves to evaluate various parameters' AUC values, cut-off values, sensitivity, and specificity for weaning risk.

2.4. Statistical analysis

Data processing is performed using SPSS 28.0 software. Measurement data are expressed as $\bar{x}\pm s$ and compared using the t-test. Count data are expressed as [n/%] and compared using the x^2 test. Logistic multifactor regression analysis is used to identify independent influencing factors, ROC analysis is used to assess predictive value, and the AUC is compared using the Z-test. Statistical significance is set at $P < 0.05$.

3. Results

3.1. Comparison of ultrasonic parameters between the two groups

The successful group had a lower LUS score, higher LVEF, and higher DE and DTF than the failure group (*P* < 0.05). There were no differences in other ultrasonic parameters between the two groups (*P* > 0.05). The results are shown in **Table 1**.

Table 1. Comparison of ultrasonic parameters between the two groups [$\bar{x}$±s]

Group	Number of cases	LUS score (points)	Cardiac function parameters				Diaphragmatic function parameters		
			LVEF (%)	RV/LV	CO (L/min)	TAPSE (cm)	Diaphragm thickness (cm)	DE(cm)	DTF(%)
Success group	38	15.14 ± 2.08	56.04 ± 4.38	0.92 ± 0.24	5.91 ± 0.44	2.11 ± 0.22	0.18 ± 0.27	1.79 ± 0.43	32.48 ± 4.12
Success group	22	21.48 ± 2.91	44.05 ± 4.31	0.88 ± 0.27	5.87 ± 0.49	2.08 ± 0.25	0.17 ± 0.25	1.42 ± 0.40	26.15 ± 4.03
t	-	9.805	10.277	0.594	0.325	0.484	0.142	3.293	5.780
P	-	＜ 0.001	＜ 0.001	0.555	0.746	0.630	0.888	0.002	＜ 0.001

3.2. Multifactor analysis of weaning risk

Using weaning status as the dependent variable, with a value of 1 assigned to successful weaning and 0 assigned to failed weaning, and using the ultrasonic parameters from **Table 1** with *P* < 0.05 as independent variables. Logistic analysis showed that LUS was a risk factor for weaning, while LVEF, DE, and DTF were protective factors (*P* < 0.05). The results are shown in **Table 2**.

Table 2. Multifactor analysis of weaning risk

Variables	Standard error	Regression coefficient	Wald x^2 value	OR value	95%CI	*P* value
LUS	0.214	0.699	10.715	2.010	1.320–3.051	0.001
LVEF	0.105	-0.271	6.968	0.768	0.621–0.936	0.009
DE	0.095	-0.211	8.710	0.764	0.630–0.915	0.004
DTF	0.084	-0.210	6.692	0.814	0.690–0.955	0.008

3.3. Predictive value of ultrasonic parameters for weaning risk

ROC analysis showed that the AUC values of single parameters for predicting weaning risk were all lower than that of combined detection (*P* < 0.05), as shown in **Table 3**.

Table 3. Predictive value of ultrasonic parameters for weaning risk

Parameters	AUC	Cut-off value	Sensitivity	Specificity	*P*-value
LUS	0.818	19.55	72.65%	85.01%	＜ 0.001
LVEF	0.770	49.75%	71.25%	70.90%	＜ 0.001
DE	0.779	1.71cm	86.60%	63.05%	＜ 0.001
DTF	0.815	28.20%	71.25%	75.64%	＜ 0.001
Combined parameters	0.904	-	69.90%	95.31%	＜ 0.001

4. Discussion

Critically ill patients require respiratory support and other means to maintain normal physiological functions due to their severe condition. Mechanical ventilation (MV) is the primary treatment modality for these patients, providing noninvasive respiratory support based on their respiratory function and allowing for the rational selection of treatment plans [3]. However, these patients often experience prolonged coma, complex illnesses, and extended treatment cycles, leading to elevated risks of weaning failure during MV, which can result in complications such as hypostatic pneumonia or respiratory failure, ultimately affecting treatment outcomes. To prevent weaning failure, clinical practice commonly employs spontaneous breathing trials (SBT) to assess weaning risk and determine appropriate weaning opportunities. Nevertheless, critically ill patients may exhibit significant ventilator dependency, decreased physiological function, and considerable difficulty in weaning [4]. While SBT can predict weaning opportunities, it still has a failure rate of over 10%, limiting its applicability in severe cases.

Tissue damage is often severe in critically ill patients, and even if lung function indicators suggest readiness for weaning, conditions such as inadequate cardiac function may exist, increasing the likelihood of weaning failure [5, 6]. Therefore, actively incorporating indicators such as cardiac and diaphragmatic function into weaning risk assessment projects, adopting lung ultrasound combined with multi-organ evaluation techniques, can help clinicians grasp patients' respiratory status and cardiac health, enabling timely weaning and improving weaning success rates.

Results indicate that the Lung Ultrasound Score (LUS) was lower in the successful weaning group compared to the failure group, while Left Ventricular Ejection Fraction (LVEF), Diaphragmatic Excursion (DE), and Diaphragmatic Thickening Fraction (DTF) were higher in the successful group ($P < 0.05$). Logistic analysis revealed that LUS is a risk factor for weaning, whereas LVEF, DE, and DTF serve as protective factors ($P < 0.05$). Evidently, patients who successfully wean exhibit less severe lung pathology, better gas exchange function in lung tissue, and good lung compliance, reducing the likelihood of abnormalities such as hypoxemia or shortness of breath after weaning and lowering the difficulty of the weaning process [7]. If a patient's LUS score is high, they may require continued MV treatment with dynamic assessment of LUC score changes to adjust treatment plans and determine appropriate weaning opportunities[8].

Echocardiography, with its noninvasive advantages and good repeatability, can adequately assess the positional relationship between cardiac tissue and surrounding large blood vessels, comprehensively capture cardiac function information, understand patients' cardiac structural characteristics, and grasp their cardiac preload and afterload, as well as systolic and diastolic functions. This allows for accurate assessment of patients' hemodynamic characteristics and determination of weaning opportunities. A high LVEF parameter in successfully weaned patients indicates good cardiac function and a high tolerance for weaning procedures, reducing adverse events such as weaning failure [9]. Diaphragmatic ultrasound assesses diaphragmatic thickness and activity, predicting diaphragmatic excursion. High DE and DTF parameters in the successful weaning group suggest strong diaphragmatic contractility and endurance, enhancing patients' tolerance to the weaning process. Their respiratory and diaphragmatic functions are better, and they are less likely to experience symptoms such as dyspnea after weaning [10].

Under the ROC curve, the AUC values of single parameters for weaning risk are all less than those of combined detection ($P < 0.05$). This suggests that combined parameters can scientifically guide weaning decisions, providing comprehensive and accurate assessments of critically ill patients' physical conditions. This approach enables clinicians to control weaning opportunities, prevent weaning failures, and achieve better disease prognosis.

5. Conclusion

In summary, implementing lung ultrasound combined with multi-organ evaluation for critically ill patients undergoing MV treatment can predict their weaning risk, screen for protective and risk factors during the weaning process, and obtain better diagnostic performance using a combined parameter evaluation method. This approach offers high predictive value.

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Disclosure statement

The authors declare no conflict of interest.

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