Role of lung ultrasound in weaning from mechanical ventilation in postoperative neurosurgical ICU patients

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Background: Prolonged postoperative mechanical ventilation after intracranial surgery is associated with significant morbidity and mortality. Many traditional tools could help in prediction of weaning success as blood gas analysis (ABG), chest radiography, ventilator parameters and rapid shallow breathing index (RSBI). These tools have a significantly higher failure rate. The aim of this study was to describe the role of transthoracic lung ultrasound (LUS) as a clinical tool in predicting weaning of postoperative mechanically ventilated patients after intracranial surgery.

Patients and method: 130 patients who were scheduled for weaning from mechanical ventilation (MV), were prospectively enrolled in the study, age 20-70 years, of either sex. They were randomly allocated into two groups- group C (n=65) were examined by traditional methods chest X-ray, ABG, ventilator parameters and RSBI, and group US (n=65) were examined by traditional methods plus LUS. Diaphragm thickness (DT) and fraction (DTF), lung aeration and extravascular lung water (EVLW) were assessed by LUS. A failure of weaning was considered when reintubation was needed within 48 hours.

Results: The success rate in group US (LUS+ traditional methods) was 84.6% compared to 66.2% in group C (traditional methods only). The value of diaphragm thickness and fraction were significantly more in the weaning success group than in failure group. B-lines detected by LUS in success and failure groups were ≤2, 3 respectively with no significant difference.

Conclusion: Lung ultrasound as an added tool could decrease failure rate of weaning in postoperative mechanically ventilated patients after intracranial surgery.

Keywords: Ultrasound; weaning; mechanically ventilated patients; intracranial surgery

Introduction
Postoperative mechanical ventilation (MV) after intracranial surgery is indicated in prolonged surgery >8hrs, haemodynamic instability, massive blood loss, brainstem handling, residual tumor, intraoperative acute brain bulge and preoperative lower cranial nerve palsy. 1

Simple indices as respiratory rate (RR), minute ventilation (VE), maximum inspiratory pressure (PImax), and integrative indices as RSBI, i.e., (RR/TV), airway occlusion pressure, CROP index [compliance × MIP ×PaO₂/PAO₂]/f, and simplified weaning index (SWI) have been used to assess patients for weaning.2,3 LUS helps urgent diagnoses with immediate therapeutic decisions.4,5 Diaphragmatic dysfunction is accompanied with weaning failure.6 LUS is used to assess diaphragmatic dysfunction.7 The aim of this study was to describe the role of LUS as a clinical tool in weaning of post-operative mechanically ventilated patients after intracranial surgery.

Patient and methods
This prospective, randomized controlled study was approved by the research ethical committee, Faculty of Medicine, Ain Shams University (FMASU R26/2019). It is registered in the clinical
trial.gov (NCT 03921112) and informed consent from patient’s guardians has been obtained. 130 patients who failed to be extubated in the operating room and needing post-operative MV after intracranial surgery, aged 20-70 years, of either sex and ready for weaning were enrolled in the study. Exclusion criteria were patients with traumatic cervical cord injury, neuromuscular disease, pneumothorax, pleural effusion, unconscious patients, high inotropic support, fever > 38°C and tracheostomized patients.

All patients met these criteria: FiO$_2$< 0.5, PEEP ≤5cmH$_2$O, pressure support ≤10cmH$_2$O, P/F ratio (PaO$_2$/FiO$_2$ > 200), RR<30 b/m, pH > 7.25, no fever, fully conscious, and cardiovascular stability with no need for vasopressors. Patients were removed from MV and a spontaneous breathing trial (SBT) was started up to 2hrs using humidified oxygen delivered through a T-piece.

SBT failure was considered in: patient exhaustion, anxiety, diaphoresis, RR>35 breaths/m, paradoxical breathing and use of accessory respiratory muscles, disturbed conscious level (central causes), unstable haemodynamics, and oxygen saturation <90%. Weaning failure was considered when patients were unable to maintain spontaneous breathing for at least 48hrs, without any ventilatory support.

Patients were randomly allocated to two groups: Group (c) (n=65): Patients were evaluated by:

1: Chest x-ray
   *No radiological signs of pleural effusion, pneumonia or lung collapse.
   *Radiological score for pulmonary oedema. Normal x-ray 0-1, lung congestion 2-4, pulmonary oedema (mild 5-6, moderate 7-8, severe 9-10).

2: Serial ABGs (before switching to SBT).

3: Ventilator parameters (before switching to SBT).

4: RSBI. (1min after switching to SBT).

Group (US) (n=65): (after switching to SBT). traditional parameters + LUS for assessment of diaphragm thickness (DT), diaphragm thickness fraction (DTF), lung aeration and extravascular lung water (EVLW).

Assessment of DT and DTF: Each hemi-diaphragm was examined by ultrasound subcostal views (B-mode) display with a 10-MHz linear transducer (TOSHIBA, Model USAP-770A, JAPAN).

Patients were in supine position and elevated (45°). The diaphragm could be seen by placing the probe vertical to the chest wall, in the 8th to 10th intercostal space, between the anterior and mid-axillary lines. The diaphragm was visualized as three layers, two outer parallel echoic lines (pleura, peritoneal membranes) and in between a hypoechoic structure (the muscle proper). The patient was asked to take deep inspiration to measure the (DT) at total lung capacity (TLC) and then to do full expiration to measure (DT) at residual volume (RV).

DT was obtained as a vertical line from the middle of the pleural line to the middle of the peritoneal

| Parameter                          | Value |
|------------------------------------|-------|
| Redistribution of lung vessels     |       |
| No                                 | 0     |
| Yes                                | 1     |
| Width of the cardiac silhouette > 60% |       |
| No                                 | 0     |
| Yes                                | 1     |
| Peri bronchial cuffing             |       |
| No                                 | 0     |
| Yes                                | 1     |
| New pleural effusion               |       |
|                                   |       |
DT was calculated: (DT) at TLC –(DT) at RV/ (DT) at RV ×100. Establishment of MV was done in patients with severe diaphragmatic dysfunction (DTF<26%) or paradoxical diaphragmatic movement visualized by US.

Figure 1: DT at TLC (1), DT at RV (2)

Assessment of EVLW:LUS was performed with patient in the supine position using 3.5 MHz convex transducer. Sonographic evaluation of EVLW was based on detecting hyperechoic vertical lines which arise from the pleura to the bottom of the image and move with respiration(B-lines). The visualization of ≥ 3 B-lines in a longitudinal plane between two ribs indicated pulmonary oedema.

Sample size calculation
The sample size was calculated using STATA program, setting α error at 5% and power at 80%. Result from a pilot study showed that the success rate of weaning in group A (traditional methods) was 83% compared to 98% in group B (US group). Based on this the needed sample size was 65 cases per group, taking in to account a 10% dropout rate.

Statistical methods
The collected data were coded, tabulated, and statistically analyzed using IBM SPSS statistics (Statistical Package for Social Sciences) software version 18.0, IBM Corp., Chicago, USA, 2009.

Descriptive statistics were done for quantitative data as minimum and maximum of the range as well as mean ± SD (standard deviation) for quantitative normally distributed data, while it was done for qualitative data as numbers and percentages.

Inferential analyses were done for quantitative variables using Shapiro-Wilk test for normality testing and independent t-test in cases of two independent groups with normally distributed data. In qualitative data, inferential analyses for independent variables were done using Chi square test for differences between proportions and Fisher’s Exact test for variables with small expected numbers. The level of significance was taken at P value < 0.050 as significant, otherwise as non-significant.

Results
A total of 200 patients were chosen to record success of weaning from MV. Seventy patients were excluded because they did not meet the inclusion criteria. 130 patients matched the study criteria and were randomly allocated into two groups (n =65 per each). (Figure 2).

The demographic data including age, sex, type and duration of surgery showed no significant difference between the two groups. As regards PO2, FiO2, P/F ratio, SpO2, respiratory rate, (RSBI), radiological score≤ 2 in both groups (no pulmonary oedema), PEEP and pressure support there was no significant difference between the two groups. (P < 0.05). (Table 1)
Figure 2. CONSORT patient flow chart.

Table 1: Demographic data and basic respiratory conditions

| Parameters | US group | Control group | P value |
|------------|----------|---------------|---------|
| Age (years) | 41.3±7.4 | 42.5±7.9 | ##0.378 |
| Sex | Male | 44 (67.7%) | 41 (63.1%) | #0.580 |
| | Female | 21 (32.3%) | 24 (36.9%) | |
| Surgery type | | | |
| Tumor removal | 29 (44.6%) | 27 (41.5%) | #0.755 |
| Aneurysm clipping | 24 (36.9%) | 28 (43.1%) | |
| Haematoma evacuation | 12 (18.5%) | 10 (15.4%) | |
| Duration of surgery (h) | 6.7±2.5 | 6.1±2.0 | ##0.146 |
| Fio2 (partial pressure of oxygen) | 145.6±22.4 | 143.7±22.3 | ##0.627 |
| FiO2 (fraction of inspired oxygen) | 0.4±0.0 | 0.4±0.0 | #0.415 |
| P/F ratio | 292.6±44.3 | 287.9±39.2 | ##0.518 |
| SpO2 (peripheral oxygen saturation) | 98±1.7 | 98±1.9 | #0.507 |
| Respiratory rate (Breaths/min) | 22.5±1.8 | 22.3±2.0 | ##0.616 |
| Rapid shallow breathing index | 44.1±5.1 | 44.8±4.6 | #0.400 |
| Radiological score | 0 | 17 (26.2%) | 16 (24.6%) | |
| | 1 | 21 (32.3%) | 26 (40.0%) | #0.643 |
| | 2 | 27 (41.5%) | 23 (35.4%) | |
| Positive End Expiratory Pressure ≤5 mmHg | 65 (100%) | 65 (100%) | -- |
| Pressure Support ≥10 mmHg | 65 (100%) | 65 (100%) | -- |

Data are expressed as mean ± SD or number of patients. ##Independent t-test. #Chi square test.

Table 2: Comparison between the two groups in terms of success or failure of weaning:

| Outcomes | Group (US) | Group (C) | P value |
|----------|------------|-----------|---------|
| Weaning | | | |
| Success | 55 (84.6%) | 43 (66.2%) | #0.015* |
| Failure | 10 (15.4%) | 22 (33.8%) | |
| Duration of MV (hours) | 77.7±22.9 | 88.4±25.6 | ##0.013* |
| Length of ICU stay (days) | 6.8±2.0 | 7.8±2.3 | ##0.010* |

Data are expressed as mean ± SD or number of patients. ##Independent t-test. #Chi square test. * P value <0.05 is considered significant.

Right and left DT, DTF were significantly higher in cases with successful weaning. B-lines ≤2 in 89.1% in weaning successful group and in 30% in weaning failure group, B lines = 3 in 10.9% of successful group and 7 (70%) with no significance. No evidence of B- pattern (multiple B lines) was determined in both groups. (Table 3)

Table 3: Comparison of the ultrasound findings between the success and failure group

| Parameters | Weaning success (n = 55) | Weaning Failure (n = 10) | P value |
|------------|--------------------------|--------------------------|---------|
| Right DT at TLC (mm) | 4.4±1.5 | 2.6±0.7 | #<0.001* |
| Right DT at RV (mm) | 2.5±0.6 | 1.9±0.5 | #0.004* |
| Left DT at TLC (mm) | 4.5±1.6 | 2.6±0.6 | #<0.001* |
| Left DT at RV (mm) | 2.6±0.6 | 2.0±0.4 | #<0.001* |
| Right DTF (%) | 70.7±20.1 | 33.3±3.2 | #0.008* |
| Left DTF (%) | 72.3±25.1 | 32.9±4.7 | #<0.001* |
| B-lines | | | |
| ≤2 | 49 (89.1%) | 3 (30.0%) | |
| 3 | 6 (10.9%) | 7 (70.0%) | #0.135 |

Data are expressed as mean ± SD or number of patients. ##Independent t-test. #Fisher's Exact test.

Discussion

Prolonged MV is associated with many complications as ventilator associated pneumonia (VAP), ventilator induced lung injury (VILI) and ventilator induced diaphragmatic dysfunction. Recently, ultrasound has been used to assess
This study was designed to evaluate the possibility of using ultrasound as an added tool in the weaning of postoperative mechanically ventilated patients in decreasing failure rate of weaning. LUS plus traditional tools in predicting weaning success aim to reach a very minimal rate of failure of weaning in post-operative mechanically ventilated patients. This study showed that using LUS plus traditional tools provided better success rate of weaning from MV (84.6%), this is due to the ability of US to assess the diaphragmatic dysfunction with further therapeutic interventions before completing the process of weaning.

Assessment of diaphragmatic movement in the form of diaphragmatic thickness by ultrasound proved feasible and useful in evaluating diaphragmatic dysfunction. It had advantage over traditional fluoroscopy, was noninvasive, with no exposure to ionizing radiation, with bedside availability.

Gerscovich et al showed in their study that diaphragm ultrasonography could be a useful tool in assessing diaphragmatic motion. In agreement with our results Ferrari et al found that diaphragmatic movement by measuring DTF by US as a new index of weaning from MV in comparison to RSBLA significant difference between DTF in patients who succeeded SBT in comparison to patients who failed was shown. This study showed that the detection of DTF by lung ultrasound was a good index in predicting weaning from mechanical ventilation. In the current study a DTF≥ 40% was associated with weaning success. These finding agree with the results of studies from Ferrari et al, Dube et al and DiNino et al which showed that DTF of more than 36%, 29% and 30% respectively were associated with weaning success.

Another study done by Pirompanich and Romsaivut concluded that DTF ≥ 26% combined with RSBI ≤ 105 increased the rate of successful weaning compared to RSBI alone. Our study found that DTF of more than 40% was associated with successful weaning. Establishment of MV and further therapeutic interventions were done in patients with DTFs ≤ 25%.

In another study Theerawit et al found that there was a relation between lower DTFs and reintubation after weaning failure. LUS has the ability to show the absence of lung expansion, alveolar consolidation and abolished lung sliding. Lung aeration loss during SBT in non-dependent lung zones was demonstrated in subjects who failed to wean. There were no studies on these ultrasound parameters collectively as a weaning predictor in comparison to traditional parameters. Previous studies were either focusing on every ultrasound parameter alone or using it as a diagnostic tool compared to other traditional or standard tool.

**Conclusion**

LUS as an added tool in weaning success prediction could decrease failure rate of weaning from mechanical ventilation in postoperative mechanically ventilated patients.

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