Ultrasonographic Evaluation of Liver/Spleen Movements and Extubation Outcome*

Jung-Rern Jiang, MD; Tzu-Hsiu Tsai, MD; Jih-Shuin Jerng, MD; Chong-Jen Yu, MD, PhD; Huey-Dong Wu, MD, FCCP; and Pan-Chyr Yang, MD, PhD, FCCP

Introduction: The diaphragm plays a pivotal role in weaning and successful extubation. We hypothesized that ultrasonographic evaluation of the movements of the diaphragm by measuring liver/spleen displacement during spontaneous breathing trials is a good predictor for extubation outcome.

Patients and methods: The studied subjects were intubated patients receiving mechanical ventilation who were scheduled to be extubated. The displacement of liver/spleen was measured by ultrasonography before extubation. The patients were classified into a success group (SG) or failure group according to the extubation outcome. The baseline data and organ displacements in these two groups were analyzed. The sensitivity and specificity for the mean organ displacements and weaning parameters to predict successful extubation were calculated.

Results: We included 55 patients, 32 of whom (58%) were in the SG. The baseline data are similar for these two groups, but the mean values of liver and spleen displacements were higher in the SG. Using a cutoff value of 1.1 cm, the sensitivity and specificity to predict successful extubation were 84.4% and 82.6%, respectively, better than traditional weaning parameters in this study.

Conclusion: The displacement of the liver/spleen, measured by ultrasonography, is a good predictor for extubation outcome. (CHEST 2004; 126:179–185)

Key words: diaphragmatic weakness; extubation; respiratory insufficiency; ultrasonography; weaning

Abbreviations: FG = failure group; MD = mean value of liver displacement and spleen displacement; NIPPV = noninvasive positive pressure ventilation; Pdi = transdiaphragmatic pressure; Pmax = maximum inspiratory pressure; RSBI = rapid shallow breathing index; SBT = spontaneous breathing trial; SG = success group; Vt spon = spontaneous tidal volume

Extubation failure is one of the most frequently encountered events in the management of patients receiving mechanical ventilation. As many as 20% of such patients require re-intubation within 72 h of extubation.1 A failed extubation attempt substantially prolongs the duration of mechanical ventilation and ICU stay, as well an increased risk of hospital mortality.1 Predicting extubation outcome and preventing extubation failure is, therefore, an important task. Various weaning parameters have been suggested to be useful, eg, rapid shallow breathing index (RSBI), maximum inspiratory pressure (Pmax), spontaneous tidal volume (Vt spon), and transdiaphragmatic pressure (Pdi). However, the prediction rate of these parameters may not be satisfactory.1,2

Evaluating the strength of the respiratory muscles becomes important, since the imbalance between respiratory demand and supply will lead to weaning failure through the development of respiratory muscle fatigue.3 There have been studies evaluating diaphragmatic function to predict weaning outcomes, including Pmax, pressure of the first 0.1 s of inspiration, and Pdi.2 The Pdi, lung volume, and inspiratory flow rate are used as surrogates for direct measures of diaphragm tension, length, and shortening velocity, respectively. However, these methods are limited by their invasive nature and dependency on maximal voluntary efforts of the patients.4

Ultrasonography has been shown to be a promis...
ing tool in the evaluation of diaphragm function. However, the methods described in the literature applied direct tracing of the movements of the hemidiaphragms, and were limited by the difficulty in localizing a reference point for the hemidiaphragm and the presence of uneven movements of different parts of the diaphragm. The extent of diaphragm movement influences neighboring organs, such as the liver and spleen. A study employing MRI showed that abdominal organs primarily undergo translational motion in cranio-caudal direction. The liver and spleen represent the whole movement of the right and left diaphragm during respiration, respectively.

A real-time linear array ultrasound transducer has been used to measure cranio-caudal respiratory movement of the liver, pancreas, and kidneys. Davies et al used ultrasound to observe the displacement velocity and acceleration of the diaphragm, liver, and kidney movement during respiration. Ultrasound also has the advantage of searching for the cause of poor diaphragm movement such as lesions in the pleural or abdominal cavity.

The objective of this study was to use ultrasound to evaluate the movements of the liver and spleen that may represent the movements of the hemidiaphragms, with the purpose of analyzing their value in predicting successful extubation. We hypothesized that the measurement of liver and spleen displacement by ultrasound during spontaneous breathing is a good predictor for extubation outcome.

**Material and Methods**

This was a prospective observational study approved by the institutional ethics committee.

**Study Subjects**

We evaluated the intubated patients receiving and mechanical ventilation in our medical ICU from July 2002 to December 2002, for their eligibility to enter this study. Only patients who were prepared for extubation after spontaneous breathing trials (SBTs) were evaluated. The decision on extubation was made by the attending physicians, according to the clinical condition, weaning parameters, and results of the SBT of the patients. The attending physicians were blinded to the results of sonographic measurements. Patients who were prepared to be extubated were excluded.

Patients were included after informed consent was obtained, and if they fulfilled all of the following criteria: age ≥ 20 years, use of oxygen with a fraction of ≤ 0.4, use of positive end-expiratory pressure at ≤ 5 cm H₂O, pressure support at ≤ 8 cm H₂O, and a duration of continuous mechanical ventilation of ≤ 30 days. Patients were excluded from the study if they had at least one of the following conditions: intubation for elective surgery or due to upper airway obstruction, unstable hemodynamic status, mechanical ventilation via a tracheostomy tube, history of peritonitis, intraabdominal operation, empyema, or pleurodesis. Figure 1 shows the flowchart of inclusion of patients.

**Study Design**

We designed a prospective, observational study with intraobserver and interobserver variation control. Weaning parameters including RSBI, VT, Pmax, and Pmax were measured. The displacement of liver/spleen was measured by ultrasonography before extubation. The patients were classified into a success group (SG) or a failure group (FG) according to the extubation outcome. The baseline data and organ displacements in these two groups were analyzed. The sensitivity and specificity for the mean organ displacements and weaning parameters to predict successful extubation were calculated.

**Methods**

Weaning parameters including RSBI, VT, Pmax, and Pmax were measured and ultrasonography was performed within 6 h before extubation. All patients were in a supine position with discontinuing of ventilator and shifting to T-piece spontaneous breathing. Two well-trained experts measured liver and spleen displacement at the beginning of T-piece spontaneous breathing, respectively, twice with intervals of 5 min. An ultrasound scanner (Aloka Echo Camera SSD-1400; Aloka; Zug, Switzerland) equipped with a 3.5-MHz sonar probe was used. The probe was placed along the right anterior axillary line and the left posterior axillary line for measurement of liver and spleen displacement in cranio-caudal aspects, respectively (Fig 2). The displacements of liver and spleen were monitored in real-time. According to the functions provided by the manufacturer, a mark for measurement was placed on the image at the location of the most caudal margin of the liver or spleen at the end of expiration. With the probe fixed on the chest wall during respiration, the image of sonography was frozen at the end of inspiration, and a second mark was placed on the new location of the most caudal margin of the liver and spleen. The distances between the two marks were then measured and defined as the displacement of the liver or the spleen. All measurements were performed during quiet breathing, excluding deep breathing. The maximal liver and spleen displacements among 10 respiratory cycles were recorded. The final mean value of liver displacement and spleen displacement (MD) was calculated from results of the two measurements from each operator. Extubation was performed for all patients, who were classified into an SG or FG according to the extubation outcome. Patients who received reintubation or noninvasive positive pressure ventilation (NIPPV) within 72 h after extubation were included in the FG. The decision to re-institute ventilator support (including NIPPV) was made by the attending physicians based on clinical conditions by at least one of the following criteria: respiratory rate > 30 breaths/min, deoxygenation (arterial oxygen pressure < 70 mm Hg under oxygen fraction supplied > 0.5), respiratory acidosis (arterial CO₂ pressure > 55 mm Hg and pH < 7.25), paradoxical motion of abdomen with accessory respiratory muscles used, unstable hemodynamic status (arrhythmia or shock), and poor level of consciousness. Patients with delayed extubation, i.e., not extubated within 6 h after measurement of weaning parameters or ultrasonography, were excluded from further analysis.

**Analysis**

The following clinical data were obtained from all patients: demographic data, underlying disease or comorbidity, admitting diagnosis, reason for mechanical ventilation, outcomes of extubation, and admission duration. Categorical variables were evaluated by the χ² test. MD and weaning parameters were presented as means ± SD. Intraobserver and interobserver variations were evaluated by paired-samples t test. Independent
A sample t test was used for evaluating weaning parameters and MD in the SG and the FG. The cutoff point for MD was determined by the receiver-operated characteristic curves. The sensitivity and specificity of MD and weaning parameters to predict successful extubation were calculated; \( p < 0.05 \) was considered statistically significant.

**Results**

During the study period, 196 patients were evaluated for inclusion in this study. Figure 1 shows the flowchart of inclusion of the patients, of whom 55 completed the study protocol. The reasons for incomplete study were as follows: informed consent unavailable (46 patients), poor cooperation from the patients \((n = 13)\), and poor imaging quality \((n = 4)\). None of the patients had distress during the study process. The poor image quality was due to masking of the lower edge of the liver by distended bowels. As a result, 18% of the patients failed the sonographic examination, although only 4% were due to poor imaging. Although all of the 196 patients were eventually extubated, a delay in extubation occurred in 24 patients, whose data were not included for further analysis.

Of the 55 patients eligible for further analysis, the mean age was 67 years (range, 33 to 84 years), and 27 were men (49%). Five patients (9%) had a history of respiratory failure requiring mechanical ventilation prior to this hospital admission. During the ICU course in this admission, 22 patients had recurrent respiratory failure with reintubation prior to the sonographic study, including 15 patients (27%) who had been extubated once, 5 patients (9%) extubated twice, and 2 patients (4%) extubated three times. Of all patients, the most common cause of acute respiratory failure was pneumonia (29 patients, 53%), followed by neurologic diseases (16 patients, 29%). The duration of mechanical ventilation before extubation was 11 ± 6 days (± SD) [range, 2 to 26 days].

Of the 55 patients with complete sonographic studies, the mean MD was 1.2 ± 0.54 cm (range, 0.4 to 2.2 cm), whereas the mean values of liver and spleen displacement were 1.1 ± 0.63 cm (range, 0.2 to 2.6 cm) and 1.3 ± 0.66 cm (range, 0.2 to 2.8 cm), respectively. Figure 3 shows that there was no significant difference between liver and spleen displacements, and the correlation between them was poor. During the ultrasonographic evaluation, none of the patients had paradoxical movements of the liver and spleen. The correlations of liver and spleen...
displacements between and within the observations were good ($r^2 = 0.988$ and $0.952$, respectively), and there was no significant variation ($p = 0.157$ and $p = 0.10$, respectively).

Of the 55 patients mentioned earlier, 32 patients (58%) were successfully extubated (the SG). Of the 23 patients in the FG, 11 patients underwent reintubation, whereas 12 patients were treated with NIPPV (BiPAP, Model S/T 30; Respironics; Murrysville, PA) for a mean duration of 26.5 h of NIPPV within the 72 h after extubation. Nine of these patients were free from NIPPV within 72 h, but three patients continued to receive intermittent NIPPV after the first 72 h. Conditions associated with reintubation within 72 h included the following: respiratory distress ($n = 6$), profuse airway secretion ($n = 4$), altered mental status ($n = 3$), and hemodynamic instability ($n = 4$). None of the patients showed evidence of upper airway obstruction. The baseline data and the etiologic findings of acute...
respiratory failure in the SG and the FG were similar and are summarized in Table 1. Table 2 summarizes the pertinent values of weaning parameters and MD, which were significantly different between the two groups. Notably, the MD was significantly higher in the SG than in the FG (p < 0.001).

The cutoff value of MD for predicting successful extubation was determined to be 1.1 cm by receiver operated characteristic curve analysis. Using this cutoff value, the sensitivity and specificity of MD to predict successful extubation were 84.4% and 82.6%, respectively. The positive and negative predictive values were 81.8% and 86.4%, respectively. The accuracy was 83.6%. By applying traditional cutoff values, including RSBI ≤ 105/L, Pmax ≤ −20 cm H2O, and Vrspon ≥ 5 mL/kg of body weight, the sensitivities and specificities to these weaning parameters for predicting successful extubation were calculated and summarized in Table 3. Table 3 shows that the sensitivity and specificity of MD for predicting successful extubation were better than RSBI, Vrspon, and Pmax.

**DISCUSSION**

We found that the MD was significantly larger in the SG than that in the FG. Compared to other commonly used parameters, the MD had a better prediction rate for extubation success.

In this study, the measurement of the movements of the liver and spleen served as surrogates for diaphragmatic movements. The Pdi, a similar tool previously used to represent the strength of the diaphragm, lacks the information concerning volume contribution of the diaphragm. Although in our study the contribution of the diaphragm to tidal breathing remains to be explained, its application appears promising because the diaphragm plays a pivotal role of respiratory muscle endurance. If fatigue of the diaphragm occurs, the velocity of movement is slowed, and amplitude of movement is decreased. Diaphragmatic movement is a final result of diaphragmatic strength, intrathoracic and intraabdominal pressure. Among the various causes of extubation failure, poor endurance is probably the most difficult to predict. Evaluation of the diaphragmatic movements by ultrasonography therefore may be an important tool to evaluate the endurance of the patient.

In this study, the liver and spleen displacements measured by ultrasound in the cranio-caudal aspect are reproducible because the reference points are easier to find compared to direct sonographic visualization of the diaphragm. Mild rotations of the spleen and the liver during the respiratory cycle were occasionally detected, but they were considered of little contribution to the lung volume change, and therefore may be neglected. However, it should be noted that the sonographic evaluation in this study does not measure the absolute distance of displacement of the liver or spleen with reference to fixed structures such as the spine. It measures the relative displacement between the probe and the liver or spleen, and the displacements may be contributed by

**Table 1—Baseline Data**

<table>
<thead>
<tr>
<th>Variables</th>
<th>SG (n = 32)</th>
<th>FG (n = 23)</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean age (range), yr</td>
<td>65 (33–57)</td>
<td>70 (43–83)</td>
<td>0.171</td>
</tr>
<tr>
<td>Male/female gender, No.</td>
<td>16/16</td>
<td>11/12</td>
<td>0.277</td>
</tr>
<tr>
<td>Causes of acute respiratory failure, No.</td>
<td>6</td>
<td>7</td>
<td>0.351</td>
</tr>
<tr>
<td>COAD*</td>
<td>6</td>
<td>7</td>
<td>0.351</td>
</tr>
<tr>
<td>Neurologic diseases†</td>
<td>8</td>
<td>8</td>
<td>0.550</td>
</tr>
<tr>
<td>Pneumonia/ARDS</td>
<td>15</td>
<td>14</td>
<td>0.413</td>
</tr>
<tr>
<td>Congestive heart failure</td>
<td>8</td>
<td>3</td>
<td>0.326</td>
</tr>
<tr>
<td>Others</td>
<td>2</td>
<td>1</td>
<td>0.624</td>
</tr>
</tbody>
</table>

*COAD = chronic obstructive airway diseases, including COPD, asthma, and bronchiectasis.
†Including cerebrovascular accident, consciousness disturbance, and CNS or peripheral neuromuscular disorder.

**Table 2—Comparisons of the Traditional Weaning Parameters and MD Between Groups**

<table>
<thead>
<tr>
<th>Variables</th>
<th>SG</th>
<th>FG</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pmax, cm H2O†</td>
<td>−46.3 ± 10.6</td>
<td>−35.0 ± 15.3</td>
<td>0.002</td>
</tr>
<tr>
<td>Vrspon, mL†</td>
<td>382 ± 119</td>
<td>296 ± 111</td>
<td>0.004</td>
</tr>
<tr>
<td>RSBI, L/min × L†</td>
<td>73 ± 30</td>
<td>136 ± 43</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>MD, cm†</td>
<td>1.45 ± 0.48</td>
<td>0.84 ± 0.39</td>
<td>&lt; 0.001</td>
</tr>
</tbody>
</table>

Data are presented as mean ± 1 SD.
†p < 0.05.

**Table 3—Sensitivity and Specificity of Traditional Weaning Parameters and MD for Predicting Successful Extubation**

<table>
<thead>
<tr>
<th>Tests</th>
<th>Sensitivity, %</th>
<th>Specificity, %</th>
<th>Area*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pmax ≤ −20 cm</td>
<td>93.1</td>
<td>50.1</td>
<td>0.74</td>
</tr>
<tr>
<td>H2O</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vrspon ≥ 5 mL/kg body weight</td>
<td>71.9</td>
<td>65.2</td>
<td>0.73</td>
</tr>
<tr>
<td>RSBI ≤ 105</td>
<td>81.3</td>
<td>56.5</td>
<td>0.51</td>
</tr>
<tr>
<td>MD ≤ 1.1 cm</td>
<td>84.4</td>
<td>82.6</td>
<td>0.84</td>
</tr>
</tbody>
</table>

*Area under the receiver operated characteristic curve.
two components: movement caused by diaphragmatic contraction and movement of the chest wall as well as the probe. It is interesting that the former component is considered to be contributed by the diaphragm and the latter by respiratory muscles other than diaphragm. Therefore, the liver and spleen displacements measured in this study may actually reflect the “global” functions of the respiratory muscles rather than the diaphragm alone, and may probably explain that this method may be a good parameter of respiratory muscle endurance and predictor of extubation success.

The rate of successful extubation in this study was 58%, a value less than previously reported in the literature.15 Explanations of this finding include advanced age, multiple comorbidity of patients, and defining NIPPV use as extubation failure. Since patients supported by NIPPV still have a high probability of reintubation, their stay in the ICU may be longer because of the need for close observation. Ultrasonographic evaluation therefore may provide information concerning the transfer of patients out of the ICU with a low risk of reintubation.

All parameters before extubation—including P\textsubscript{max}, V\textsubscript{spon}, RSBI, and MD—were significantly better in the SG than in the FG. We identified a cutoff point for MD of 1.1 cm according to receiver operating characteristic curve. The sensitivity and specificity for successful extubation by MD ≥ 1.1 cm are better than by traditional weaning parameters, including the P\textsubscript{max}, V\textsubscript{spon}, and RSBI. The sensitivity and specificity of these traditional weaning parameters are similar to that described in previous reports. In the FG, 15 of the 23 patients with extubation failure needed NIPPV or reintubation with a ventilator with time intervals > 6 h after extubation. Most of these patients (n = 13) had poor MD (< 1.1 cm) and fair V\textsubscript{spon} (> 5 mL/kg body weight) before extubation. Shallow breathing (small V\textsubscript{spon}) was noticed before failure. This means that V\textsubscript{spon} in those patients with poor MD seems more likely to become small and to lead to respiratory failure than those with better MD and similar V\textsubscript{spon}, as in the SG, before extubation. Diaphragm movement and other respiratory muscles contribute to V\textsubscript{spon} together. Although diaphragm movement is only one component for V\textsubscript{spon}, it seems that the measurement of MD is a more sensitive and specific parameter than the initial V\textsubscript{spon} before extubation in predicting deterioration of V\textsubscript{spon}, which leads to extubation failure, especially in patients with poor endurance. Patients who maintain tidal volumes by recruiting accessory respiratory muscles before extubation usually fatigue and fail extubation. This is why MD is better than V\textsubscript{spon} or RSBI for predicting successful extubation.

Accurate quantification of respiratory muscle strength is important in assessing patients with respiratory muscle dysfunction and respiratory failure. The simplest method is measuring the P\textsubscript{max}, but wide range of normal values have been reported; these are closely related to voluntary effort (which is difficult to evaluate in uncooperative patients).8 The P\textsubscript{max} relates more to diaphragm contractile strength in deep respiration than in quiet respiration. We evaluated diaphragm movement in quiet respiration by liver and spleen displacement, which is a better predictor than traditional weaning parameters for predicting successful extubation, especially in patients with poor endurance.

Rapid respiratory rate will increase the loading of the respiratory muscles, and therefore may lead to fatigue of the diaphragm, resulting in impaired endurance. Correcting liver and spleen displacements with respiratory rate during spontaneous breathing may, therefore, enhance the sensitivity and specificity for predicting successful extubation. Body weight, rather than height and body surface area, was reported to offer a significant positive correlation to diaphragm movement.16 MD corrected by body weight may provide a more accurate prediction of successful extubation.

There are limitations for this study. This was an observational study, in which the primary care physicians made the extubation and reintubation decisions. This may reduce the prediction value of all parameters used in the study. Only the diaphragm was assessed among the respiratory muscles, and we did not evaluate the correlation between liver and spleen displacements and Pdi or pressure in the esophagus.

One problem in measuring the liver and spleen displacement is the possibility of interference of the respiratory movements by the measurement maneuver. Applying a sonographic probe onto the abdominal wall of a patient might change the breathing pattern of that patient; therefore, the measured liver and spleen displacement might not be the distance of liver and spleen movements during spontaneous breathing.

Late expiratory strain of the abdominal muscles, as would be seen in patients with expiratory flow obstruction or increased ventilatory demand, may result in caudal displacement of the liver and spleen when the abdominal muscles relax. Therefore, the “neutral” positions of the abdominal organs needs to be judged by the ultrasound operator; meanwhile, some patients are not suitable for this position.

The test method may not be applicable to patients who are weaned only by pressure support, which has been shown to be as good as an SBT for extubation in several studies. It might be difficult to evaluate...
patients with an irregular respiratory pattern with high breath-by-breath variability of liver and spleen displacement. Because we measure the displacement of the liver and spleen directly on the ultrasound monitor, higher breath-to-breath variation of the liver and spleen displacement is determined by the ultrasound operator. As we have encountered in evaluating traditional weaning parameters, the test is unable to detect upper airway obstruction. Ultrasonography of the abdomen requires adequate techniques, but it also has the advantage of being non-invasive in nature.

Other factors, including consciousness level, cough function, secretion amount, and other clinical or hemodynamic conditions, should also be taken into consideration before successful extubation. In conclusion, ultrasonographic measurement of liver and spleen displacement during an SBT before extubation is a good method for predicting extubation outcome.

REFERENCES
1 Epstein SK. Extubation. Respir Care 2002; 47:483–492
2 MacIntyre NR. Evidence-based guidelines for weaning and discontinuing ventilatory support. Chest 2001; 120:375S–396S
4 Gottesman E, McCool FD. Ultrasound evaluation of the paralyzed diaphragm. Am J Respir Crit Care Med 1997; 155:1370–1374
16 Harris RS, Giovannetti M, Kim BK. Normal ventilatory movement of the right hemidiaphragm studies by ultrasonography and pneumotachography. Radiology 1983; 146:141–144