Diaphragm dysfunction assessed by ultrasonography: Influence on weaning from mechanical ventilation

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Presented by R3 黃博彥
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Introduction

• Difficulties in discontinuing ventilatory support are encountered in 20% to 25% of all mechanically ventilated patients

• Approximately 40% of total ventilation time spent in weaning

• Ventilator induced diaphragmatic dysfunction:
  – Mechanical ventilation itself can induce diaphragmatic dysfunction (DD) by decreasing the force generating capacity of the diaphragm
Introduction

• Diagnostic tools of diaphragmatic dysfunction (DD):
  – **Fluoroscopy of the diaphragm**
    • Requires the transportation of ventilated patients
    • Impractical to impose fluoroscopic maneuvers such as sniffing
  – **Phrenic nerve conduction study**
    • Elicits an unpleasant sensation in the subject and can only detect abnormalities in neural conduction, which does not necessarily mean dysfunction of the diaphragm muscle
• Diagnostic tools of diaphragmatic dysfunction (DD):

  — Ultrasonography (US)
    • Devoid of radiation hazards
    • Available at the bedside, precluding the need of transportation
    • Gives functional information about the muscle itself
    • Can be repeated if follow-up is required
• Objective:
  – To determine the prevalence of diaphragmatic dysfunction diagnosed by M-mode ultrasonography (vertical excursion <10 mm or paradoxic movements) in MICU patients
  – To assess the influence of diaphragmatic dysfunction on weaning outcome.
• Design: Prospective, observational study
## MATERIALS AND METHODS

Medical ICU of Asan Medical Center, a university-affiliated, tertiary referral center in Seoul, Korea

88 consecutive patients who required mechanical ventilation for ≥ 48 hrs
2008-10 ~ 2009-03

### Inclusion Criteria

- Age ≥ 18 yrs
- FiO2 < 50%
- Positive end-expiratory pressure level ≤ 5 cm H2O
- Respiratory rate ≤ 30breaths/min
- PaO2/FiO2 ratio > 200 mm Hg
- Glasgow coma score ≥ 14
- Hemodynamic stability in the absence of vasopressors.
- Analgesic–sedative was allowed, if any, to a minimal dose such that patients were calm and easily arousable (Ramsay score 3)
- The use of any muscle-paralyzing agent was discontinued at least 2 days before the study
- Aminoglycosides were not used in any of the patients
**Exclusion criteria**

- History of diaphragmatic palsy, cervical spine injury, or neuromuscular disease (myasthenia gravis, Guillain-Barre’s syndrome, amyotrophic lateral sclerosis)
- Current thoracostomy; pneumothorax; or pneumomediastinum

**Spontaneous breathing trial (SBT)**

- Each hemidiaphragm was evaluated using US with the patient in the supine position. The patient’s rapid shallow breathing index (RSBI) was simultaneously calculated at the bedside by a respiratory nurse, classified according to US findings into a **DD group** and a **non-DD group**
- Probe placed over one of the lower intercostal spaces in the right anterior axillary line for the right diaphragm and the left midaxillary line for the left diaphragm
- A single well trained expert using an Esaote ultrasound machine
- With the probe fixed on the chest wall during respiration, the ultrasound beam was directed to the hemidiaphragmatic domes at an angle of not < 70°
Spontaneous breathing trial (SBT)
- The amplitude of excursion was measured on the vertical axis of the tracing from the baseline to the point of maximum height of inspiration on the graph.
- Six measurements were recorded and averaged for each side.
- All measurements were performed during tidal breathing at 6–12 mL/kg, excluding smaller or deeper breaths.
- The whole US examination was accomplished in 5 mins.
- Ultrasonographic DD was diagnosed if an excursion was < 10 mm or negative (paradoxical diaphragmatic movement).

Outcome parameters
- Primary and secondary weaning failure
- Weaning time
- Total ventilation time
- Underlying diseases (DM, thyroid dysfunction, COPD, and ARDS)
- Time to the SBT
- Relevant blood biochemistry findings
Definition of Terms

- **Successful weaning**
  - A state in which a patient was able to maintain his or her own breathing for 48 hrs without any level of ventilator support

- **Primary weaning failure**
  - Requirement for mechanical ventilation within 48 hrs of self-breathing

- **Secondary weaning failure**
  - Requirement for mechanical ventilation after a successful weaning, i.e., respiratory failure occurring past the 48 hrs of self-breathing

- **Total ventilation time**
  - The period between the start and end of mechanical ventilation

- **Weaning time**
  - The time spent in partial support mode such as pressure support or continuous positive airway pressure
  - = total ventilation time - the full support period (the time spent in either volume-controlled or pressure-controlled mode)
• A: A patient with normal right diaphragmatic excursion showing an inspiratory peak (arrow) above the baseline.
• B: A patient with dysfunction of the right hemidiaphragm with a negative inspiratory peak below the baseline, indicating paradoxic movement of the diaphragm.
RESULTS

88 – 6 = 82

50: male (61%)

Mean age: 66 yrs

Overall incidence of primary weaning failure: 66%

The prevalence of ultrasonographic DD: 29%
(24 patients, 11 right DD, 9 left DD, 4 bilateral)

US diaphragmatic excursion was positively correlated with the magnitude of tidal volume (right: r = .40, p < .01, left: r = .43, p < .01), but not with age, weight, total ventilation time, or weaning time
Table 1. Clinical characteristics of the patients with ultrasonography-diagnosed DD and patients without DD

<table>
<thead>
<tr>
<th>Variables</th>
<th>DD Group (n = 24)</th>
<th>Non-DD Group (n = 58)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demographic factors</td>
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<tr>
<td>Age, yrs</td>
<td>70.1 ± 11.1</td>
<td>64.5 ± 12.4</td>
<td>.06</td>
</tr>
<tr>
<td>Male</td>
<td>16 (67)</td>
<td>34 (59)</td>
<td>.50</td>
</tr>
<tr>
<td>Body mass index, kg/m²</td>
<td>21.1 ± 4.6</td>
<td>22.9 ± 4.8</td>
<td>.11</td>
</tr>
<tr>
<td>Comorbidity:</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Diabetes</td>
<td>10 (42)</td>
<td>33 (57)</td>
<td>.23</td>
</tr>
<tr>
<td>Hypertension</td>
<td>11 (46)</td>
<td>35 (60)</td>
<td>.33</td>
</tr>
<tr>
<td>Chronic obstructive pulmonary disease</td>
<td>9 (38)</td>
<td>19 (33)</td>
<td>.80</td>
</tr>
<tr>
<td>Hypothyroidism</td>
<td>2 (8)</td>
<td>1 (2)</td>
<td>.20</td>
</tr>
<tr>
<td>Coronary artery bypass grafting</td>
<td>2 (8)</td>
<td>1 (2)</td>
<td>.20</td>
</tr>
<tr>
<td>Acute respiratory distress syndrome</td>
<td>4 (167)</td>
<td>12 (21)</td>
<td>.77</td>
</tr>
<tr>
<td>Laboratory findings</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>(\text{PaCO}_2)</td>
<td>42.6 ± 8.3</td>
<td>37.3 ± 8.0</td>
<td>.01</td>
</tr>
<tr>
<td>(\text{PaO}_2)</td>
<td>93.9 ± 24.1</td>
<td>101.3 ± 24.0</td>
<td>.20</td>
</tr>
<tr>
<td>(\text{FiO}_2)</td>
<td>35.8 ± 6.5</td>
<td>35.9 ± 5.8</td>
<td>.93</td>
</tr>
<tr>
<td>Creatinine</td>
<td>1.1 ± 0.9</td>
<td>1.2 ± 0.9</td>
<td>.42</td>
</tr>
<tr>
<td>Sodium</td>
<td>139.0 ± 6.7</td>
<td>138.4 ± 5.4</td>
<td>.63</td>
</tr>
<tr>
<td>Potassium</td>
<td>3.7 ± 0.3</td>
<td>3.8 ± 0.6</td>
<td>.70</td>
</tr>
<tr>
<td>Calcium</td>
<td>8.1 ± 0.9</td>
<td>8.2 ± 0.9</td>
<td>.49</td>
</tr>
<tr>
<td>Magnesium</td>
<td>2.1 ± 0.2</td>
<td>2.1 ± 0.4</td>
<td>.51</td>
</tr>
<tr>
<td>Ultrasonographic findings</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>DE, right, mm (IQR)</td>
<td>7.0 (1.8–13.5)</td>
<td>17.9 (14.5–22.7)</td>
<td>&lt;.01</td>
</tr>
<tr>
<td>DE, right, mm (n = 11)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3.0 (0.0–7.0)</td>
<td>18.8 (12.2–22.4)</td>
<td></td>
</tr>
<tr>
<td>DE, left, mm (IQR)</td>
<td>7.9 (2.1–18.9)</td>
<td>18.0 (15.6–23.2)</td>
<td>&lt;.01</td>
</tr>
<tr>
<td>DE, left, mm (n = 9)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.6 (0.0–6.2)</td>
<td>18.3 (12.4–23.1)</td>
<td></td>
</tr>
<tr>
<td>Pleural effusion</td>
<td>14 (58.3)</td>
<td>27 (46.6)</td>
<td>.47</td>
</tr>
<tr>
<td>Rapid shallow breathing index</td>
<td>73.5 ± 23.5</td>
<td>55.6 ± 26.9</td>
<td>.01</td>
</tr>
<tr>
<td>Hospital length of stay, days (IQR)</td>
<td>66.0 (52.0–99.0)</td>
<td>42.0 (30.0–72.0)</td>
<td>&lt;.01</td>
</tr>
<tr>
<td>Intensive care unit length of stay, days (IQR)</td>
<td>31.0 (18.5–58.5)</td>
<td>14.0 (10.0–33.0)</td>
<td>&lt;.01</td>
</tr>
<tr>
<td>Inhospital mortality</td>
<td>6 (25)</td>
<td>17 (29)</td>
<td>.79</td>
</tr>
</tbody>
</table>

DD, diaphragmatic dysfunction; DE, diaphragmatic excursion; IQR, interquartile range.

<sup>a</sup>Data of only diaphragms with DD. Values are expressed as mean ± sd, median, and IQR or no. (%).
<table>
<thead>
<tr>
<th>Variables</th>
<th>DD Group</th>
<th>Non-DD Group</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total ventilation time, hrs (IQR)</td>
<td>576 (374–850)</td>
<td>203 (109–408)</td>
<td>&lt;.01</td>
</tr>
<tr>
<td>Weaning time, hrs (IQR)</td>
<td>401 (226–612)</td>
<td>90 (24–309)</td>
<td>&lt;.01</td>
</tr>
<tr>
<td>Time to the spontaneous breathing trial, day (IQR)</td>
<td>4 (2.5–7.5)</td>
<td>4 (3.0–6.0)</td>
<td>.55</td>
</tr>
<tr>
<td>Primary weaning failure, no. (%)</td>
<td>20/24 (83)</td>
<td>34/58 (59)</td>
<td>&lt;.01</td>
</tr>
<tr>
<td>Secondary weaning failure, no. (%)</td>
<td>10/20 (50)</td>
<td>10/46 (22)</td>
<td>.01</td>
</tr>
<tr>
<td>Died before weaning, no. (%)</td>
<td>4/24 (17)</td>
<td>12/58 (21)</td>
<td>.79</td>
</tr>
</tbody>
</table>

DD, diaphragmatic dysfunction; IQR, interquartile range.
<table>
<thead>
<tr>
<th>Variable</th>
<th>Sensitivity</th>
<th>Specificity</th>
<th>Positive Predictive Value</th>
<th>Negative Predictive Value</th>
<th>Area Under the Curve</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diaphragmatic excursion (right 10, left 10)</td>
<td>83</td>
<td>41</td>
<td>37</td>
<td>86</td>
<td>0.61</td>
</tr>
<tr>
<td>Diaphragmatic excursion (right 14, left 12)</td>
<td>60</td>
<td>76</td>
<td>82</td>
<td>51</td>
<td>0.68</td>
</tr>
<tr>
<td>Rapid shallow breathing index ≥80/L</td>
<td>26</td>
<td>90</td>
<td>82</td>
<td>40</td>
<td>0.58</td>
</tr>
</tbody>
</table>

Values are expressed as percentages.
• DD has probably been underestimated in patients in medical ICUs
• **Unilateral** dysfunction was more common than bilateral
• **RSBI:** short of reflecting the functional state of this principal respiratory muscle
  • The area under the ROC curve of this index was low (0.58)
  • The **low sensitivity** of this index in predicting weaning failure (26%)
    -> unnecessary prolongation of mechanical ventilation in some patients
Discussion

• The high failure rate in our subjects (66%) might also be associated with the stricter criteria of successful weaning, defined as the state of self-breathing for $\geq 48$ hrs without the need of any level of ventilatory support

• Lack of data on interobserver variability was a main limitation of the present study

• Other parameters of diaphragmatic function were not measured
  • To correlate morphometric parameters of the diaphragm assessed by US with force/pressure parameters of the diaphragm such as maximum inspiratory pressure or transdiaphragmatic pressure

• The cutoff of diaphragm excursion for predicting weaning failure we found in our patients (right diaphragm 14 mm, left diaphragm 12 mm) warrants validation in a new cohort of patients
Conclusion

• Using M-mode ultrasonography, diaphragmatic dysfunction was found in a substantial number of medical intensive care unit patients without histories of diaphragmatic disease
• Patients with such diaphragmatic dysfunction showed frequent early and delayed weaning failures
• Ultrasonography of the diaphragm may be useful in identifying patients at high risk of difficulty weaning
THANKS