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

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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

Introduction

- 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

MATERIALS AND METHODS

Exclusion criteria

•History of diaphragmatic palsy, cervical spine injury, or neuromuscular disease (myasthenia gravis, Guillain-Barre´ 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°

MATERIALS AND METHODS

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 (paradoxic diaphragmatic movement)

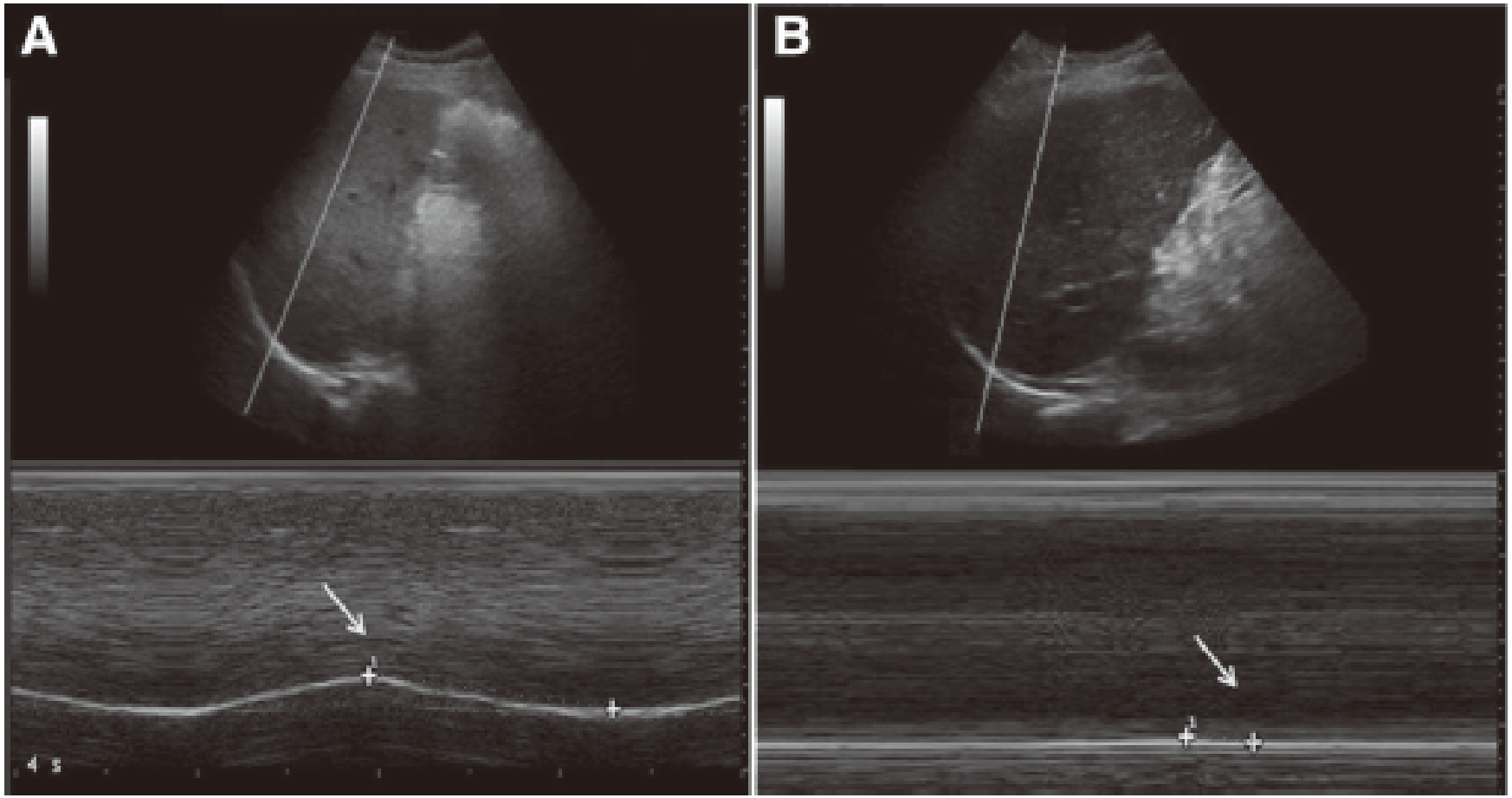
Outcome parameters

- 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

MATERIALS AND METHODS

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

Variables	DD Group (n = 24)	Non-DD Group (n = 58)	*p*
Demographic factors			
Age, yrs	70.1 ± 11.1	64.5 ± 12.4	.06
Male	16 (67)	34 (59)	.50
Body mass index, kg/m^2	21.1 ± 4.6	22.9 ± 4.8	.11
Comorbidity:			
Diabetes	10 (42)	33 (57)	.23
Hypertension	11 (46)	35 (60)	.33
Chronic obstructive pulmonary disease	9 (38)	19 (33)	.80
Hypothyroidism	2 (8)	1 (2)	.20
Coronary artery bypass grafting	2 (8)	1 (2)	.20
Acute respiratory distress syndrome	4 (167)	12 (21)	.77
Laboratory findings			
$PaCO_2$	42.6 ± 8.3	37.3 ± 8.0	.01
PaO_2	93.9 ± 24.1	101.3 ± 24.0	.20
FiO_2	35.8 ± 6.5	35.9 ± 5.8	.93
Creatinine	1.1 ± 0.9	1.2 ± 1.0	.42
Sodium	139.0 ± 6.7	138.4 ± 5.4	.63
Potassium	3.7 ± 0.3	3.8 ± 0.6	.70
Calcium	8.1 ± 0.9	8.2 ± 0.9	.49
Magnesium	2.1 ± 0.2	2.1 ± 0.4	.51
Ultrasonographic findings			
DE, right, mm (IQR)	7.0 (1.8–13.5)	17.9 (14.5–22.7)	<.01
DE, right, mm (n = 11)[a]	3.0 (0.0–7.0)	18.8 (12.2–22.4)	
DE, left, mm (IQR)	7.9 (2.1–18.9)	18.0 (15.6–23.2)	<.01
DE, left, mm (n = 9)[a]	2.6 (0.0–6.2)	18.3 (12.4–23.1)	
Pleural effusion	14 (58.3)	27 (46.6)	.47
Rapid shallow breathing index	73.5 ± 23.5	55.6 ± 26.9	.01
Hospital length of stay, days (IQR)	66.0 (52.0–99.0)	42.0 (30.0–72.0)	<.01
Intensive care unit length of stay, days (IQR)	31.0 (18.5–58.5)	14.0 (10.0–33.0)	<.01
Inhospital mortality	6 (25)	17 (29)	.79

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

[a]Data of only diaphragms with DD. Values are expressed as mean ± SD, median, and IQR or no. (%).

Table 2. Weaning variables of the study patients with and without DD

Variables	DD Group	Non-DD Group	*p*
Total ventilation time, hrs (IQR)	576 (374–850)	203 (109–408)	<.01
Weaning time, hrs (IQR)	401 (226–612)	90 (24–309)	<.01
Time to the spontaneous breathing trial, day (IQR)	4 (2.5–7.5)	4 (3.0–6.0)	.55
Primary weaning failure, no. (%)	20/24 (83)	34/58 (59)	<.01
Secondary weaning failure, no. (%)	10/20 (50)	10/46 (22)	.01
Died before weaning, no. (%)	4/24 (17)	12/58 (21)	.79

DD, diaphragmatic dysfunction; IQR, interquartile range.

Table 3. Sensitivity, specificity, and negative and positive predictive values of ultrasonography-diagnosed diaphragmatic excursion and rapid shallow breathing index for predicting primary weaning failure

Variable	Sensitivity	Specificity	Positive Predictive Value	Negative Predictive Value	Area Under the Curve
Diaphragmatic excursion (right 10, left 10)	83	41	37	86	0.61
Diaphragmatic excursion (right 14, left 12)	60	76	82	51	0.68
Rapid shallow breathing index ≥80/L	26	90	82	40	0.58

Values are expressed as percentages.

Discussion

- 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