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Computed tomography confirms a reduction in diaphragm thickness in mechanically ventilated patients

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ABSTRACT

Purpose: Patients who require mechanical ventilation (MV) may experience diaphragm atrophy, which may delay the discontinuation of MV. Here, we used computed tomographic (CT) scans to confirm this phenomenon.
Method and Materials: Patients who underwent two chest CT scans while on MV were retrospectively evaluated. Diaphragm thickness was measured using a three-dimensional CT image processing program.
Results: Thirteen patients, including 8 men, who underwent 26 CT scans were assessed. The mean age was 67.8 ± 7.5 years. The interval between CT scans was 18.4 ± 14.9 days. The first CT scans revealed that the mean thicknesses of the left and right sides of the diaphragm were 3.8 ± 0.6 and 3.9 ± 0.8 mm, respectively (total: 7.7 ± 1.4 mm). These values were significantly reduced to 3.4 ± 0.6 and 3.5 ± 0.9 mm, respectively, (total: 6.9 ± 1.5 mm) after the second scan ($P < .01$). No significant change in body weight (57.3 ± 12.6 vs. 56.7 ± 11.6 kg) or body mass index (21.8 ± 5.1 vs. 21.6 ± 4.8 kg/m^2) was observed.
Conclusion: Computed tomography confirmed that diaphragm thickness was reduced in critically ill patients who underwent MV.

1. Introduction

Although mechanical ventilation (MV) is a life-saving therapy in intensive care units (ICUs), it is also associated with various complications [1]. Difficulties in weaning patients from MV are encountered in 20–25% of cases [2], and 40% of the time spent in the ICU is to wean the patient from MV [3]. Preservation of the function of the respiratory muscles may be associated with weaning outcomes, and diaphragm weakness may cause difficulties in weaning patients from MV [4].

Some studies have established that prolonged, controlled MV resulted in decreased diaphragm muscle fiber size and decreased contractile force in animals [5,6]. In humans, several studies evaluating functional and histological changes showed that MV resulted in decreased muscle fiber cross-sectional area and increased protein degradation, providing evidence for diaphragm atrophy and dysfunction in critically ill patients undergoing MV [7–10]. However, few studies have shown gross changes in diaphragm thickness in patients on MV as assessed by radiologic examinations [11].

The aim of the present study was to evaluate diaphragm thinning in mechanically ventilated patients using computed tomographic (CT) scans to provide further evidence of MV-induced diaphragm atrophy.

2. Materials and methods

2.1. Subjects

All patients admitted to the medical ICU at Gyeongsang National University Hospital (Jinju, Korea) between December 2011 and August 2013 were screened for eligibility, and patients who (1) were aged 18 years and older, (2) had been admitted to the ICU for 3 days or longer, and (3) were mechanically ventilated were enrolled in this retrospective study. Among the eligible patients, only those who underwent two chest CT scans for clinical reasons during MV were retrospectively assessed. We excluded patients who underwent chest CT without MV. Demographic information and clinical data were reviewed from medical records.

2.2. Measurement of diaphragm thickness on chest CT

The thickness of the diaphragm was measured on CT scans using three-dimensional (3D) imaging software (Rapidia 2.8; Infinitt, Seoul, Korea). The celiac axis was selected as the reference level on axial

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images, and a line was drawn through the anterior border of the spinal canal. The 3D imaging software automatically displayed corresponding points on the right and left sides of the diaphragm on coronal and axial images when dot cursors were placed on the points where the lines from the left and right sides of the diaphragm intersected. Diaphragm thickness was then measured at the same points on axial and coronal images using the cursor (Fig. 1). The measurements were performed three times on each side of the diaphragm by a radiologist. The mean value was obtained from each set of measurements. The radiologist was blinded to the order of the chest CT scans.

2.3. Statistical analysis

Descriptive data are presented as numbers and percentages, and continuous data as the mean ± SD. Continuous variables were compared with a parametric *t* test or the Mann–Whitney *U* test. Values that reached $P < .05$ were considered significant. All analyses were performed using SPSS version 18.0 for Windows (SPSS Inc, Chicago, IL).

3. Results

Thirteen patients, including 8 men, were enrolled. The mean age was 67.8 ± 7.5 years. Two patients underwent 3 CT scans; thus, we assessed 26 chest CT scans from 13 patients. The mean duration between chest CT scans was 18.4 ± 14.9 days. Acute Physiology and Chronic Health Evaluation II and Sequential Organ Failure Assessment scores were 18 ± 10.5 and 8.8 ± 3.9, respectively, and pneumonia was the most common cause of ICU admission, occurring in 7 patients Table 1. The thicknesses of the left and right sides of the diaphragm were 3.8 ± 0.6 and 3.9 ± 0.8 mm, respectively, on the first CT scan (total: 7.7 ± 1.4 mm); on the second scan, diaphragm thicknesses were 3.4 ± 0.6 and 3.5 ± 0.9 mm, respectively (total: 6.9 ± 1.5 mm). The thickness of the diaphragm was significantly decreased on both the left and right sides ($P < .01$), and the reduction in total thickness was also significant ($P < .01$) (Table 2). The changes in diaphragm thickness in each patient are shown in Fig. 2. There was no difference in diaphragm thickness reduction in 5 patients receiving corticosteroid therapy versus 8 patients not receiving corticosteroid therapy (8.3% ± 6.2%. vs 12.0% ± 12.3%, $P = .488$).

Mean body weight (57.3 ± 12.6 vs 56.7 ± 11.6 kg) and body mass index values (21.8 ± 5.1 vs 21.6 ± 4.8 kg/m^2) were not significantly different between the first and second CT scans. In addition, there was no significant difference in tidal volume or positive end-expiratory pressure (PEEP) (398.8 ± 52.5 mL and 6.8 ± 1.3 cm H_2O at the first CT scan vs 385.6 ± 70.6 mL and 5.7 ± 1.9 cm H_2O at the second CT scan, respectively) (Table 3).

Table 1
Baseline clinical characteristics of the enrolled patients

Characteristics	Mean ± SD or No. (%)
No of patients	13
Age, (y)	67.8 ± 7.5
M:F	8:5
Time interval between 1st and 2nd chest CT scan (d)	18.4 ± 14.9
APACHE II score	18 ± 10.5
SOFA score	8.8 ± 3.9
BMI at ICU admission	22.3 ± 1.2
Underlying disease	
HT	3 (23)
DM	2 (15.3)
CVA	2 (15.3)
Parkinson's disease	1 (7.6)
Pneumoconiosis	1 (7.6)
MI	1 (7.6)
Cause of ICU admission	
Pneumonia	7 (53.8)
Sepsis with ARDS	1 (7.6)
Interstitial lung disease with exacerbation	1 (7.6)
Hemothorax	1 (7.6)
Pulmonary tuberculosis	2 (15.3)
Duration of MV (d)	25.5 ± 12.7
Duration of ICU stay (d)	39.7 ± 41.3
Survived, (%)	13 (100)
Receiving corticosteroid, %	5 (38.5)

Data are presented as number (%) or mean ± SD unless otherwise indicated.
APACHE, Acute Physiology and Chronic Health Evaluation; SOFA, Sequential Organ Failure Assessment; BMI, body mass index; DM, diabetes; HT, hypertension; CVA, cerebrovascular accident; MI, myocardial infarction; ARDS, acute respiratory distress syndrome.

4. Discussion

This study provided further evidence that critically ill patients may experience diaphragm atrophy during MV. A previous study using sonographic assessments also showed that diaphragm thickness significantly decreased over time with MV, at a mean rate of 6% per day [11]. This was the first study to assess the diaphragm thicknesses of mechanically ventilated patients using CT.

The human diaphragm consists of a muscled sheath approximately 5.5 mm in thickness, with an average length of 15.2 to 30.5 cm [12]. Although studies using radiologic assessments to measure diaphragm

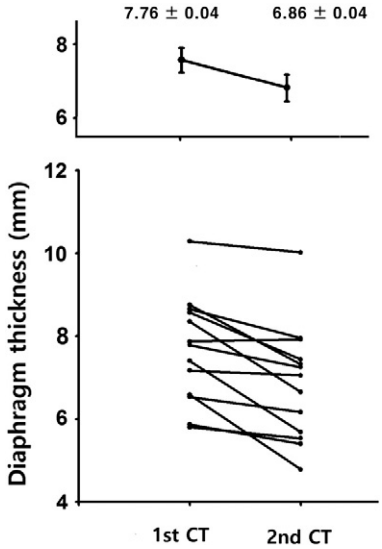

Fig. 1. Changes in diaphragm thickness among the enrolled patients. Most patients experienced a reduction in diaphragm thickness during mechanical ventilation. The mean reduction was approximately 10% among the enrolled patients.