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Case Report

Pulmonary rehabilitation in the intensive care unit using surface electromyography in a patient with diaphragmatic injury: A case report

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ABSTRACT

Diaphragmatic injury (DI) following blunt trauma can cause pulmonary complications and increased duration of ventilator-dependent intensive care unit stay. Herein, we present a 62-year-old female patient with severe trauma who was diagnosed with liver laceration and multiple rib fractures and underwent emergency laparotomy. Extubation was attempted; however, the patient had to be reintubated due to dyspnea. After reintubation, decreased right diaphragmatic excursion was confirmed by ultrasonography and the patient was diagnosed with DI. Surface electromyographic biofeedback was performed during diaphragmatic breathing training to increase the effect of pulmonary rehabilitation. Early diagnosis of DI may be possible using ultrasonography, and the use of surface electromyographic biofeedback is suggested for pulmonary rehabilitation in critically ill trauma patients.

Keywords: Electromyography, intensive care unit, multiple trauma, physical therapy modalities, rehabilitation, respiratory therapy.

Diaphragmatic injury (DI) after blunt trauma is difficult to diagnose,[1] and missed injuries have been associated with significant morbidity and mortality; therefore, prompt diagnosis is essential.[2,3] Pulmonary complications may occur, leading to increased mortality and durations of ventilator dependency and intensive care unit (ICU) stay.[4] Accordingly, early diagnosis and intervention, including pulmonary rehabilitation (PR), may be crucial for patients with suggested DI.

Although there have been reports of monitoring diaphragmatic changes at the ICU using ultrasonography (USG),[5] there were few reports of PR in trauma patients who were diagnosed with DI.[6] Albeit there are many barriers to the early mobilization of critically ill patients with trauma, PR is relatively easy to perform. Pulmonary rehabilitation includes deep breathing, which increases functional residual capacity and tidal volume and potentially helps clear secretions, and incentive spirometry, which prevents pulmonary complications and improves pulmonary function.[7] However, studies on physical therapy modalities and the effects of PR techniques in patients with trauma who can perform them in the ICU are insufficient. Thus, we report the case of a patient admitted to the ICU following blunt abdominal trauma, diagnosed early with DI by USG, and rehabilitated using surface electromyography (sEMG).

CASE REPORT

A 62-year-old woman was admitted to the emergency trauma department following a traffic accident. On admission, the chief complaint was pain

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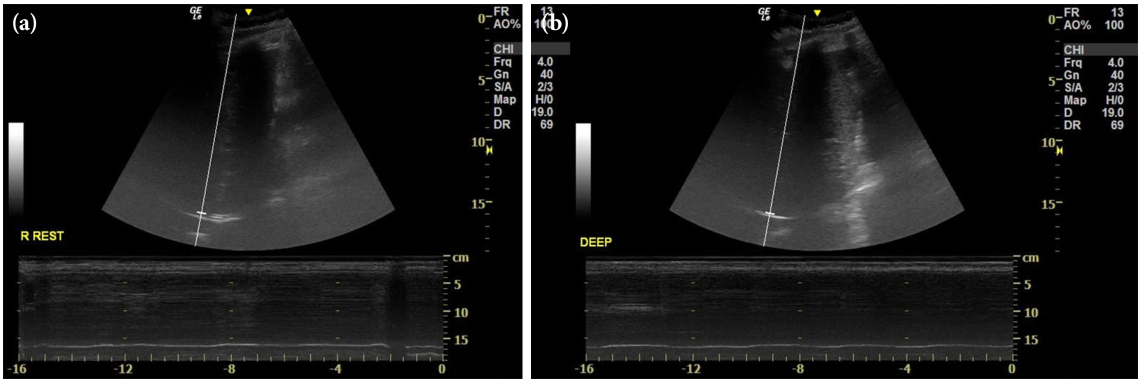

Figure 1. M-mode ultrasonography showing right hemidiaphragm paralysis during tidal volume **(a)** and deep **(b)** breathing after reintubation.

in the chest wall and abdomen, with an Injury Severity Score of 34, which indicates major trauma. Grade 4 liver laceration, a 2 cm right ventricular laceration, and multiple bilateral rib fractures were observed. Exploratory laparotomy was immediately performed owing to massive hemoperitoneum. Extubation was attempted in the ICU when the patient's condition stabilized (postoperative day four); however, reintubation was performed within 6 h owing to dyspnea and paradoxical breathing.

Subsequently, the patient was referred to the Department of Rehabilitation Medicine for pulmonary function evaluation and PR. The cause of extubation failure was determined by a physiatrist who used M-mode USG to evaluate the amplitude of diaphragmatic excursion during breathing (subcostal view).[8] Additionally, we measured the thickening fraction and contraction of the diaphragm in B-mode; however, it was difficult to obtain an accurate echo window due to pleural effusion. Right hemidiaphragmatic excursion was severely reduced (less than 0.5 cm) in a spontaneous breathing trial during tidal breathing and deep breathing (Figure 1a, b). Since diaphragmatic rupture was not identified during laparotomy, liver laceration likely caused a lower-grade DI such as diaphragmatic contusion, leading to respiratory failure. Breathing retraining and diaphragmatic breathing (DB) were performed to improve pulmonary function.

Visual biofeedback using sEMG was applied during DB to increase PR effectiveness (Figure 2a). A two-channel Bluetooth device (MOT10; PhysioLab Co., Ltd., Busan, Korea) and software (MoTive-Rs version 1.0, MOT10; PhysioLab Co., Ltd., Busan, Korea) were used (Figure 2b). Electrodes were placed bilaterally over the lower abdominal muscles 1 cm medial to the anterior superior iliac spines.[9] Electrodes were not attached to the diaphragm since it is difficult to record the signal when noise occurs due to ICU monitoring devices and equipment. Moreover, it was

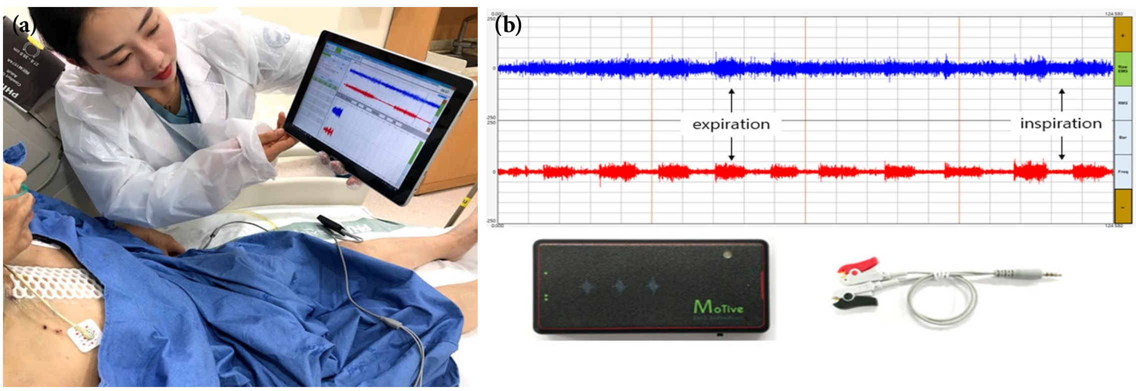

Figure 2. Diaphragmatic breathing training using surface electromyography (sEMG) in the ICU. **(a)** User interface of sEMG software (MoTive-Rs, version 1.0). **(b)** Bluetooth sEMG device (MOT10).

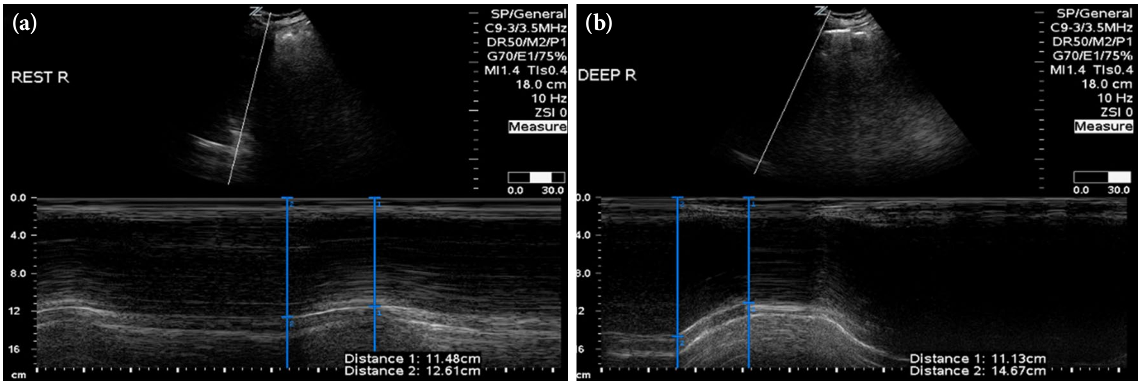

Figure 3. M-mode ultrasonography demonstrating improved right hemidiaphragm excursion during tidal volume **(a)** and deep **(b)** breathing six months post-trauma.

challenging to secure an electrode attachment site due to dressings after exploratory laparotomy for the abdomen. Therefore, the signal from the abdominal muscles was used as feedback to encourage abdominal muscle contraction during exhalation and relaxation during inhalation.

Diaphragmatic breathing was performed in the semi-Fowler position with a slow and deep inhalation through the nose, relaxed shoulder muscles, and no upper chest movement. A set consisted of four to five DB exercises in 1 min, each followed by a 30-sec rest. A session consisted of five sets followed by a 1-min rest, and a total of four sessions were performed.

We evaluated pulmonary function to monitor recovery and predict the success of weaning and extubation. Negative inspiratory pressure (NIP), using the mechanical ventilator, and peak expiratory flow (PEF) were repeatedly measured to assess inspiratory muscle strength and ability to expectorate and exhale, respectively. A NIP of less than -30 cmH_2O[10] and a PEF of at least 60 L/min[11] are successful predictors of weaning and extubation.

At the start of PR, the NIP was -23 cmH_2O, and the PEF was 40 L/min (postoperative day eight). On the eighth day after reintubation, the patient was stable during a spontaneous breathing trial, and the NIP was -40 cmH_2O, PEF was 103 L/min (over the extubation cut-off value), and the patient was successfully extubated without tracheostomy (postoperative day 12). Two days later, the patient was discharged from the ICU. The patient underwent PR during their stay in the ICU and general ward and was discharged without pulmonary complications on the postoperative 33rd day. The home exercise program included DB and aerobic exercises. Ultrasonography, pulmonary function tests, and 6-min walk tests (6MWT) were performed at the six-month follow-up. Right hemidiaphragmatic excursion during tidal volume and deep breathing had improved to 1.5 cm and 4.5 cm, respectively (Figure 3a, b). The elevated diaphragm improved close to the normal position on chest radiography three months postoperatively. Pulmonary function tests showed improvement in all values. Furthermore, the 6MWT distance improved from 349 m (56.23% predicted, pre-discharge) to 577 m (97.57% predicted, six months postoperatively).

DISCUSSION

Diaphragmatic injury is demanding to diagnose and often missed on chest radiography or computed tomography due to low sensitivity.[12] Ultrasonography has various advantages over radiography: it is easily accessible in the ICU, can detect diaphragmatic dysfunction in patients with trauma, and can evaluate diaphragmatic contraction.[13] Ali and Mohamad[5] evaluated diaphragm movement using USG in critically ill mechanically ventilated patients. As in our case, early ultrasonographic evaluation of patients with suggested DI aids the diagnosis and defining PR treatment goals to prevent pulmonary complications and improve pulmonary function. Furthermore, sEMG is useful for PR in patients with chest and blunt abdominal trauma with limited mobility. In conventional DB training, clinicians obtain feedback on abdominal movements by placing their hand on the abdomen; however, objectively confirming abdominal muscle relaxation is challenging. Most of the previous studies in which sEMG electrodes were placed to confirm the muscle activity of the diaphragm were placed one pair on the front and back at the level of the diaphragm.[14-16]

However, substantial heart activity and unwanted external factors interfere with the diaphragm sEMG signal.[14] Our aim was not to record the muscle activity of the diaphragm but to provide visual biofeedback to the patient by confirming the muscle contraction and relaxation of the abdomen in real time instead of the contraction and relaxation of the diaphragm that occurs during the DB. According to Peper et al.,[9] DB can be effectively performed using visual sEMG biofeedback. The patient was unaware of shoulder and chest lifting with inhalation during conventional DB training, and control was difficult. Nevertheless, visual biofeedback using sEMG was comfortable and efficient for the patient since ideal breathing was possible. Using sEMG may improve patients' participation and cooperation as they better understand the role of the diaphragm and abdominal muscles during breathing. Since the patient's mental status and cooperation level affect the effectiveness of PR, it is beneficial to prevent delirium in the ICU.

In conclusion, PR using sEMG can be applied in an early stage to patients in the ICU who need respiratory retraining as a result of diaphragmatic dysfunction secondary to ICU-acquired weakness, prolonged mechanical ventilation, open-heart surgery, transplantation, or trauma. Additionally, sEMG can be used alongside conventional rehabilitation techniques. This case highlights not only the use of USG in the early diagnosis of DI but also its contribution to rapid patient recovery by determining the starting point and efficient performance of PR. Based on our experience, we suggest that PR using sEMG and early diagnosis using USG may be beneficial in helping patients with traumatic DI recover quickly in the ICU.

Patient Consent for Publication: A written informed consent was obtained from the patient.

Data Sharing Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

Author Contributions: Concept, data collection, writing manuscript: H.J.S.; Analysis, concept, critical review, design, supervision: M.H.J.; Concept, materials, resources, writing manuscript: M.J.S.; Analysis, literature search, writing manuscript: J.W.L.

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