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Original Research

Measurement of expiratory muscle thickness during coughing using ultrasonic diagnostic equipment

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Abstract

Background : Coughing is one of the body's defense mechanisms, where the sputum expectoration function plays an important role. Expiratory muscle activity is required to increase the expiratory flow velocity between the third and fourth phases of a cough. However, few studies have reported the dynamics of abdominal muscle groups during coughing, such as those of the transverse abdominal muscle using ultrasonic image diagnostic equipment. Therefore, this study was aimed to examine the thickness of the external oblique, internal oblique, and transverse abdominal muscles during coughing.
Methods : Nine normal healthy males were included in this study. The measurement posture was the supine position. Ultrasound images of the external oblique, internal oblique, and transverse abdominal muscles were recorded during expiration at rest and coughing, in three rounds of 10 seconds each. The image analysis used OsiriX to view static images of the muscle thickness at maximum muscle hypertrophy during expiration at rest and on coughing, measured in units of 1 mm. The average thickness was calculated using the measurements obtained from three rounds.
Results : The thickness of the internal oblique and transverse abdominal muscles increased significantly during coughing compared with expiration at rest. However, there was no significant difference in the thickness of the external oblique muscle during coughing and expiration at rest.
Conclusion : The thickness of the internal oblique and transverse abdominal muscles increased significantly during coughing compared with expiration at rest, but there was no significant difference in the thickness of the external oblique muscle between these two phases.

Key words : Coughing, Expiratory muscle thickness, Ultrasonic diagnostic equipment

Introduction

Coughing is one of the body's defense mechanisms, where the sputum expectoration function plays an important role (Bach et al., 1996). Coughing plays an important role in the host defense function through airway clearance by sputum expectoration. Forceful and effective coughing successfully removes invading organisms with respiratory tract secretions. Therefore, a decreased coughing capacity increases the risk of developing pulmonary complications (Smith et al., 2001 ; Higuchi et al., 2007 ; Kimura et al., 2013).

The cough mechanism is divided into four phases : the first phase induces the cough ; the second phase closes the glottis after deep inspiration ; in the third phase, the intrathoracic pressure increases ; and in the fourth phase, rapid exhalation occurs, the so-called explosive expiratory flow velocity (Craig, 1998). In this way, an efficient cough increases the exhalation flow rate, and the airway secretions move towards the oral cavity. Between the third and fourth phases, expiratory muscle activity is required to increase the expiratory flow velocity. In a previous study investigating expiratory muscle activity (rectus abdominis and external oblique muscles) during coughing with surface electromyography (EMG), it was found that both muscles function during coughing, but the external oblique muscle was reported to function more easily than the rectus abdominis muscle (Yamashina et al., 2011). However, as described in the previous study above, as most muscle activity analyses during coughing are performed using EMG (Yamashina et al., 2011 ; Rhee MH et al., 2016), there are few studies that report the dynamics of abdominal muscle groups, including the transverse abdominal muscle using ultrasonic diagnostic imaging, which has been widely performed recently. Moreover, the muscle thickness of the abdominal muscle group during coughing has not been investigated. Therefore, we investigated the thickness of the external oblique, internal oblique, and transverse abdominal muscles during coughing.

Methods

1. Subjects

Nine normal healthy males were included in the study. Subjects who had a history of respiratory or cardiovascular disease, hypertension [resting systolic blood pressure (BP)≥140 and/or diastolic BP≥90], diabetes, obesity [body mass index (BMI) ≥30], or a habit of smoking were excluded. The eligible applicants who met the inclusion criteria participated in the study after familiarizing themselves with the experimental protocol, such as the measurement method using spirometry and the coughing method as described below. The characteristics of the subjects are summarized in Table 1. This study was approved by AINO University Research Ethics Committee (Aino, 2012–007), and also conformed to the standard set by the Declaration of Helsinki, and written informed consent was obtained from all subjects prior to the experiment.

Table 1 The physical characteristics of the subjects

Number	9
Age (years)	23.2±0.2
Height (m)	1.68±0.1
%VC	100.6±5.8
$FEV_{1.0}$ (%)	90.2±6.3

Values are means±SD.
Abbreviations : VC, vital capacity ; $FEV_{1.0}$, forced expiratory volume in one second.

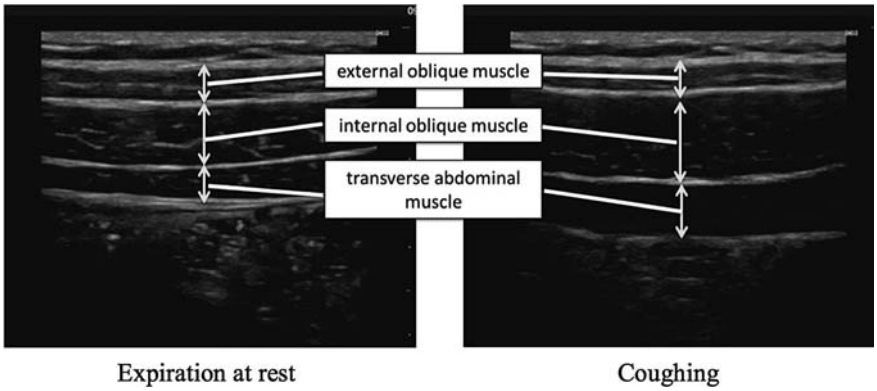

Figure 1 The measurement of expiratory muscle thickness by ultrasonic diagnostic equipment

2. Anthropometric measurements

The weight, height, and respiratory function were measured before the first experiment. The respiratory function was evaluated using a spirometer (AS-307, Minato, Osaka, Japan), and parameters such as the vital capacity (VC) and forced expiratory volume in one second ($FEV_{1.0}$).

3. Experimental protocol

The measurements were recorded in B-mode using the Fujifilm ultrasound system (Fazone CB ; Fujifilm, USA). Using components measured in the previous research as a reference, the posture was set to a supine position, in which the anterior iliac spine passes at a one-third distance between the anterior and posterior iliac spines on a straight line parallel to the floor. This was taken as the midpoint between the ribcage's lower edge and iliac crest (Fuse et al., 2010). For supine measurements, the subjects lay on a bed, keeping their knees extended, and placed both arms at their sides. The measurements were recorded by a physical therapist. The ultrasound images of the external oblique, internal oblique, and transverse abdominal muscles were recorded during expiration at rest and coughing, in three rounds of 10 seconds each. The image analysis used OsiriX to view a static image of the muscle thickness at maximum muscle hypertrophy during expiration at rest and coughing, measured in units of 1 mm. The average thickness was calculated using measurements obtained in three rounds. Additionally, we asked subjects to maximize their efforts during maximum deep inspiration and coughing. Every subject practiced coughing prior to the day of the experiment.

4. Statistical analysis

Statistical analysis was performed using statistical software (Stat View ; SAS, Cary, NC, USA). Data are expressed as the mean±standard deviation (SD). We compared the maximum muscle thickness during coughing and expiration at rest by paired t-tests, and the significance level was set to less than 5 %.

Table 2 The thickness of abdominal muscles during resting and coughing

	external oblique muscle	internal oblique muscle	transverse abdominal muscle
expiration at rest	5.48±0.29	8.03±0.41	3.85±0.27
coughing	5.32±0.25	9.98±0.42#	5.95±0.39#

Values are means±SD. #p <0.05 vs. expiration at rest.

5. Results

The thickness of the internal oblique and transverse abdominal muscles increased significantly during coughing compared with expiration at rest. However, there was no significant difference in the thickness of the external oblique muscle during coughing and expiration at rest.

6. Discussion

In this study, we observed that the thickness of the internal oblique and transverse abdominal muscles increased significantly during coughing compared with expiration at rest ; however, no such change was observed in the thickness of the external oblique muscle. This shows that although the external oblique, internal oblique, and transverse abdominal muscles are classified as muscles of exhalation, they function differently during coughing. As the expiratory muscle contracts during the third and fourth phases of coughing, the abdominal wall is drawn inside, the abdominal pressure rises, and subsequently, the intrathoracic pressure increases due to the compression of the diaphragm from below. Abe et al. reported that when ventilation was increased by carbon dioxide (CO_2) stimulation, the transverse abdominal muscle showed the maximum activity, followed by the internal and external oblique muscles, and the abdominal rectus showed nearly no activity (Abe et al., 1996). Ichiba et al. reported that while breathing with a respiratory muscle-training device, the activity of the rectus abdominis muscle was about one-fourth of that of the external oblique muscle (Ichiba et al., 2002). Furthermore, when resistance was applied, the abdominal transverse muscles were reported to be selectively active during exhalation, inside the abdominal muscles forming the outer front abdominal wall using intramuscular electrodes (Wakai et al., 1992). Thus, the exercised muscle activity at a resistive load suggests that deeper muscles are more likely to be selectively activated. Similar to this report, our study indicated that the activity of deeper muscles was greater in the abdominal muscle group during coughing.

As described earlier, using the ultrasonic image diagnostic equipment, we could determine the state of muscle contraction in real time. Thus, effective utilization of this technique can be expected in the field of respiratory physiotherapy. Although this research was conducted involving healthy adults, it could be useful for patients with neuromuscular disease, respiratory disease, spinal cord injury, progressive muscular dystrophy, and

an impaired coughing ability, such as central deformity disease, in the future.

This study has several limitations. The results of the present study in a small number of subjects suggested that the activity of the deeper muscles was greater in the abdominal muscle group during coughing. However, in this study, we could not clarify the reason why deeper muscles are more likely to be selectively activated during coughing. The respiratory function such as VC has been reported to be affected by the posture. Although it has been reported that the respiratory function in a supine position is lower than that in a sitting position, in this study, the measurement posture was set to a supine position in consideration of the influence of trunk movement. The muscle activity may be different in other postures. Moreover, it is not possible to specify whether the thickness of each muscle while coughing is maximal during the exhalation phase. Although it has been reported that the abdominal flexion strength is related to the thicknesses of the abdominal muscles (Noguchi et al., 2016), the relationship between the coughing ability and muscle thickness could not be elucidated in this study because we did not measure the coughing ability of subjects. Thus, in the future, there will be a need to measure the synchronization among the flow sensor, muscle activity, and coughing ability. Furthermore, confirmation of the reliability of measurement by ultrasonic diagnostic equipment might a problem. Isaka et al. reported that the inter-examiner reliability (intraclass correlation coefficient [ICC]) during the resting expiratory phase and the time of maximal muscle thickness upon coughing on measuring the abdominal lateral muscle thickness was 0.8 or higher (Isaka et al., 2016).

Conclusion

Using ultrasonic diagnostic equipment, we examined the thickness of the external oblique, internal oblique, and transverse abdominal muscles during coughing. In the internal oblique and transverse abdominal muscles, the thickness increased significantly during coughing compared with expiration at rest ; however, there was no such difference observed in the thickness of the external oblique muscle. Also, the activity of deeper muscles appeared to be greater in the abdominal muscle group during coughing.

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Conflicts of interest statement

The authors declare no conflicts of interest.

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