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EXPERIMENTAL STUDY

Electromyographic activities of the abdominal muscles during 30% and 75% of maximum expiratory pressure

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ABSTRACT

The aim of this study was to quantify the activities of the rectus abdominis (RA), external oblique (EO), and internal oblique (IO) muscles during 30% and 75% of maximum expiratory pressure (PE max).

Fifteen healthy male university students participated in this study. Electromyographic (EMG) activities of the RA, EO, and IO muscles were measured during 30% and 75% of PE max and then normalized relative to maximum voluntary contractions (%MVC).

All muscles during 75% of PE max showed significantly higher %MVC compared to that during 30% of PE max ($P < 0.01$). The EO and IO muscles showed significantly higher %MVC compared to the RA muscle during 30% and 75% of PE max ($P < 0.05$).

Muscle endurance and strength induced by expiratory muscle strength training might be different in each abdominal muscle.

1. Introduction

Expiratory muscle endurance and strength can be impaired in a variety of populations including sedentary elderly and those with chronic obstructive pulmonary disease, multiple sclerosis, Parkinson's disease, and stroke (Ramírez-Sarmiento et al., 2002; Mangueira et al., 2009; Simões et al., 2010; Bosnak-Guclu et al., 2012; Wang et al., 2014; Messaggi-Sartor et al., 2015). With the potential to improve swallow, respiration, and physical performance, expiratory muscle strength training (EMST) programs are performed to increase maximum expiratory pressure (PE max) (Laciuga et al., 2014).

EMST uses a pressure threshold device with a calibrated pressure relief valve housed inside. To open the pressure relief valve, sufficient expiratory pressure is necessary. Previous literature shows that the threshold pressure used for EMST ranges from 30% to 75% of a trainee's PE max (Laciuga et al., 2014). As a mechanism of the device, the initial occlusion of the airway until the valve opens creates an isometric load to the muscle responsible for forced expiration. The valve opens afterward, and air begins to flow through the device.

In terms of electrical activity levels, electromyography (EMG) could be used to assess the activation of a muscle. It has been proposed that the minimum effort required to obtain a strengthening stimulus from the muscle is approximately at least 40%–60% of the maximal voluntary contraction (MVC) (Ekstrom et al., 2007). However, little is known about the activities of the expiratory muscles during EMST.

The abdominal muscles are responsible for forced expiration (Neumann, 2010). As such abdominal responses to expiratory resistance were investigated (Koehler and Bishop, 1979; Gothe and Cherniack, 1980; Ichiba et al., 2002; McGill et al., 1990). Koehler and Bishop, 1979 and Gothe and Cherniack, 1980 mentioned that high expiratory load increases the amplitude of the abdominal muscle as measured by EMG. A quantitative analysis, however, was not performed. To consider appropriate intensity of exercises, normalization of EMG data relative to MVC (%MVC) is required. Ichiba et al. (2002) reported the %MVC of the rectus abdominis (RA) and external oblique (EO) muscles during performance of five degrees of expiratory resistances. However, they used absolute five degrees of expiratory resistances. In addition, they did not set relative

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expiratory loads to the subject's PE max nor record the internal oblique (IO) muscle, which contributes to forced expiration (Neumann, 2010). Literature also presents limited evidence on EMG activities of abdominal muscles. Although Mesquita Montes et al. (2016) showed the activities of the RA, EO, and IO muscles during breathing, only 10% of PE max was used. Such value was lower than the standard threshold pressure used for EMST in the literature (Laciuga et al., 2014). Therefore, this study aims to quantify the activities of the abdominal (RA, EO, and IO) muscles during 30% and 75% of PE max.

2. Methods

2.1. Participants

Fifteen healthy male university students participated in this trial. The subjects were physiotherapy students attending the Kawasaki University of Medical Welfare. The protocol for the present study was approved by the Ethics Committee of the Kawasaki University of Medical Welfare. Written informed consent was obtained and the rights of the subjects were protected. Subjects were excluded if they presented with a history of chronic or acute cardiac, pulmonary, or neuromuscular disease, had a history of smoking, or had an acute upper respiratory infection. Pulmonary function measurement of percentage of the predicted vital capacity (%VC: vital capacity/predicted vital capacity) and the forced expiratory volume in 1 s (FEV_1%: forced expiratory volume in 1 s/forced vital capacity) was done to all the subjects using a multi-functional spirometer (HI-801; Chest Co. Ltd. Tokyo, Japan) with the subjects sitting and wearing nose clips during the measurements. The characteristics of the subjects are shown in Table 1.

2.2. Respiratory muscle strength measurements

Using the same multi-functional spirometer with an optional respiratory pressure unit, PE max also measured. For the measurement of PE max, the subjects were instructed to inspire fully to total lung capacity, and then to forcefully exhale against an occluded mouthpiece for 3 s. The PE max was then measured during the exhalation period. One-minute rests were taken between the measurements. Three trials were done and the highest value among them was used to calculate 30% and 75% of PE max.

2.3. EMG measurements

In measuring the EMG activities of the abdominal muscles, disposable silver/silver chloride surface electrodes with a recording diameter of 1 cm (Blue Sensor P-00S; Mets Co. Ltd., Tokyo, Japan) were used. The EMG signals were recorded using a data acquisition system (Myosystem 1200; Noraxon Inc., AZ, USA). Electrode placement was based on previous works (McGill et al., 1990; Richardson et al., 1999) that noted the following positions of these muscles on the right side: RA, 2.5 cm lateral to the umbilicus; EO, the anterior end of the eighth rib; and IO, midpoint between the anterior-superior iliac spine and the pubic symphysis. Skin preparation gel (Skin Pure; Nihon Kohden Co. Ltd., Tokyo, Japan) was applied to the skin before electrode placement; subsequently, the skin was cleaned with alcohol to reduce skin surface impedance. Electrode pairs were placed longitudinally over the muscle at 2.5-cm intervals. A grounded electrode was placed over the anterior superior iliac spine.

Table 1
Characteristics of the subjects (n = 15).

	Characteristics
Age (years)	20.9 ± 0.5
Height (cm)	169.6 ± 3.8
Weight (kg)	60.6 ± 9.0
%VC	102.9 ± 13.8
FEV_1%	90.4 ± 4.3
PE max (cmH_2O)	82.4 ± 22.8

%VC: Vital capacity/predicted vital capacity.
FEV_1%: Forced expiratory volume in 1 s/forced vital capacity.
PE max: Maximal expiratory pressure.

2.4. Procedure

The EMG signals were recorded for 3 s during 30% and 75% of PE max. Expiratory pressures were monitored using the same multi-functional spirometer with an optional respiratory pressure unit during the tasks. The subjects were asked to inspire fully to total lung capacity, and then to exhale against an occluded mouthpiece to maintain 30% and 75% of PE max, respectively. One investigator was responsible for confirming visually the expiratory pressure, which was displayed on the screen of the spirometer during the tasks. If the expiratory pressure was more and less than the levels of 5%, the data was excluded. Subjects were allowed to practice until they could perform the tasks consistently. The subjects could see the screen of the spirometer as well as the investigator during the practice and the tasks. Data were collected two times for each task. The EMG signals were amplified, band-pass filtered (10–500 Hz), digitized, and stored with a sample frequency of 1000 Hz. The average EMG values were calculated during the tasks and then normalized relative to a MVC (%MVC). For each abdominal muscle, different isometric maximal exertion task was performed to measure the MVC. Each task was held for 3 s with a 30-s rest period between each trial (Ekstrom et al., 2007). During the measurement, wide straps secured the thorax, pelvis, and thighs. For the RA muscle, MVC was recorded when the subject performed partial curl-up. On the other hand, the MVC of the EO muscle was measured when partial oblique curl-up was performed while attempting to move the right shoulder toward the opposite knee. Lastly, the MVC of the IO muscle was recorded when the subject performed partial oblique curl-up while attempting to move the left shoulder toward the opposite knee.

2.5. Data analysis

Normalized EMG data were used in the statistical analysis of this study, specifically the SPSS Statistics 23.0. After using the Shapiro-Wilk test to confirm the data normality, the Wilcoxon signed-rank test was used to examine the significance of differences between pressures. For the comparison of muscles, the Friedman test and post-hoc analysis were performed with the Wilcoxon signed-rank test with a Holm's correction. The level of significance was then chosen as $P < 0.05$.

3. Results

All muscles during 75% of PE max present significantly higher muscle activity compared to that during 30% of PE max ($P < 0.01$) (see Table 2). In addition, for each pressure, the results of the Friedman test indicated that there were median differences among the muscles ($P < 0.01$). The EO and IO muscles showed significantly higher %MVC compared to the RA muscle during 30% and 75% of PE max ($P < 0.05$).