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Chest wall volumes during inspiratory loaded breathing in COPD patients

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ABSTRACT

Chest wall volumes and breathing patterns of 13 male COPD patients were evaluated at rest and during inspiratory loaded breathing (ILB). The sternocleidomastoid (SMM) and abdominal muscle activity was also evaluated. The main compartment responsible for the tidal volume at rest and during ILB was the abdomen. During ILB patients exhibited, in addition to increases in the ratio of inspiratory time to total time of the respiratory cycle and minute ventilation, increases ($p < 0.05$) in the chest wall tidal volume by an increase in abdomen tidal volume as a result of improvement of end chest wall inspiratory volume without changing on end chest wall expiratory volume. The SMM and abdominal muscle activity increased 63.84% and 1.94% during ILB. Overall, to overcome the load imposed by ILB, COPD patients improve the tidal volume by changing the inspiratory chest wall volume without modifying the predominant mobility of the abdomen at rest and without affecting the end chest wall expiratory volume.

1. Introduction

The breathing patterns of patients with chronic obstructive pulmonary disease (COPD) are abnormal, especially in patients with pulmonary hyperinflation (Aliverti et al., 2004; McKenzie et al., 2009). Airflow obstructions and mechanical disadvantages of the diaphragm contribute to the changes in the breathing pattern and thoracoabdominal motion observed in these patients (Sackner et al., 1984; Tobin et al., 1983). Most of these abnormalities suggest a malfunction of respiratory muscles, especially the diaphragm, with the use of sternocleidomastoid (SMM) and abdominal muscle (ABD) being enhanced (Decramer, 1997; McKenzie et al., 2009). These patients also exhibit other adaptations, such as modified chest wall and diaphragm shapes, which accommodate the increased volume and adaptations of muscles fibers to preserve strength and increase endurance (Loring et al., 2009; McKenzie et al., 2009). These abnormalities are associated with poor exercise tolerance, dyspnea and lower functional capacity (Loring et al., 2009).

To reduce these consequences, the Joint American College of Chest Physicians/American Association of Cardiovascular and Pulmonary Rehabilitation recommend inspiratory muscle training (IMT) with inspiratory loaded breathing at least 30% of the maximal inspiratory pressure (MIP) (Lotters et al., 2002) as part of rehabilitation programs for patients with COPD (American Association of Cardiovascular and Pulmonary Rehabilitation, 1997). The benefits of IMT have been described by many authors and include increased strength and endurance of the inspiratory muscles, reduced dyspnea and fatigue, increased exercise tolerance and distance walked during the six minute walk test, improved performance in daily activities and an improved quality of life (Geddes et al., 2008; Gosselink et al., 2011; Shoemaker et al., 2009).

Optoelectronic plethysmography (OEP) (Cala et al., 1996) can be used to elucidate which chest wall (CW) compartment contributes the most to the tidal volume and breathing pattern in different situations. Recent reviews summarized the use of OEP in COPD patients (Parreira et al., 2012; Romagnoli et al., 2008). Aliverti et al. (2004) found different behavior to increase the tidal volume during exercise: a decrease of end expiratory abdominal volume in euvolemics patients and an increase of end inspiratory abdominal and rib cage volume in hyperinflated patients. Bianchi et al. (2004) also identified during pursed-lip breathing an increased tidal volume associated with increasing end inspiratory rib cage volume and reducing end expiratory rib cage and abdominal volumes. Hostettler et al. (2011) assessed the effect of ILB and identified association between chest wall volume changes and respiratory muscle strength in 12 healthy subjects. To the best of our knowledge no

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previous studies evaluated the chest wall volumes and breathing pattern of COPD patients during inspiratory loaded breathing (ILB).

We hypothesized that COPD patients to overcome the load imposed by the ILB will present an increase of chest wall tidal volume as a result of an increase of chest wall end inspiratory volume by both compartments (rib cage and abdomen). We also hypothesized that these changes will occur associated with increase activation of inspiratory accessories muscles.

Therefore, the primary aim of this study was to evaluate the changes in the chest wall volumes and breathing patterns in COPD patients during ILB at 30% of MIP. As a secondary aim we also evaluate the activity of accessories respiratory muscles.

2. Methods

2.1. Participant characteristics

This cross-sectional study was approved by the institutional ethics committee, and all of the participants gave written informed consent.

The participants in the study met the following inclusion criteria: male, an age between 45 and 75 years, a body mass index between 18 and 30 kg/m^2, a clinical diagnosis of moderate to very severe COPD ($FEV_1/FVC < 0.70$; $FEV_1 < 0.80$) (GOLD, 2008), clinical stability with no exacerbations in the last four weeks, a history of smoking, the absence of any respiratory disease that could contribute to dyspnea, no cardiovascular, neurological or psychiatric disorders, and no participation in a pulmonary rehabilitation program. Participants were excluded if they were unable to understand and follow the procedures.

2.2. Protocol

Data were collected on two occasions within a one-week period. On the first day, lung function and muscle strength were evaluated. On the second day, the chest wall volumes, breathing pattern and respiratory muscle activity were simultaneously recorded at two situations: (1) quiet breathing (resting), divided into three sets of two minutes with a one-minute interval between sets, totaling six minutes; (2) ILB at 30% of MIP for five minutes, without any specific requirements regarding the breathing pattern to be adopted.

2.2.1. Lung function and respiratory muscle strength

A calibrated spirometer (*Vitalograph 2120*, Buckingham, England) was used to evaluate lung function according to the Brazilian recommendations (Sociedade Brasileira de Pneumolologia e Tisiologia, 2004) and predicted values proposed for Brazilian subjects (Pereira, 2007). Inspiratory muscle strength was evaluated using a calibrated manometer (GERAR® Classe B – SP/Brazil) connected to corrugated plastic tube and a mouthpiece with a 2-mm air leak orifice (Neder et al., 1999). Each patient performed at least five maneuvers (considering a variation of up to 10%) to achieve MIP from residual volume to total lung capacity. The highest value observed was recorded, as long as this value was not the last to be obtained.

2.2.2. Inspiratory loaded breathing (ILB)

ILB was performed using a threshold device (Threshold Inspiratory Muscle Trainer, New Jersey, USA), which imposes a workload on the inspiratory muscles, maintains a constant load during inspiration, and is flow-independent, with no resistance during expiration. The patients breathed through the mouthpiece with their nose occluded by a noseclip for five minutes with a workload of 30% of the MIP, the load frequently used in most studies (Lotters et al., 2002). The patients were instructed to breathe deeply to overcome the load. There were no requirements for the breathing pattern or the breathing frequency to be adopted during the ILB.

2.2.3. Chest wall volumes and breathing pattern

The chest wall volumes and breathing pattern were measured by optoelectronic plethysmography (OEP-BTS, Milan, Italy) with a sampling frequency of 60 Hz. This non-invasive technique measures breath-by-breath changes in the volume of chest wall and its compartments (Aliverti and Pedotti, 2003; Aliverti et al., 2009). Eighty-nine reflecting markers were placed over the front and back of the trunk along pre-defined horizontal and vertical lines. The landmark coordinates were measured with a system consisting of six infrared cameras, three of which were positioned in front of the participants and three of which were positioned behind the participants (Aliverti and Pedotti, 2003; Aliverti et al., 2009). The recorded images were transmitted to a computer, where a 3-D geometric model was formed (Cala et al., 1996). The chest wall was modeled from the compartments: pulmonary rib cage (RCP), abdominal rib cage (RCA) and abdomen (AB). For this study, we considered the rib cage (RC) as the sum of the RCP and the RCA.

The participants remained seated on a backless bench with their feet flat on the floor and their upper limps abducted, externally rotated and flexed (for the visualization of the lateral markers) and comfortably supported to minimize the activity of the accessory respiratory muscles both at rest and during ILB. The participants were instructed to look forward. To allow the cameras to capture the lateral chest wall markers, the examiner held the inspiratory threshold device at the participant's right side.

The chest wall volumes were determined by analyzing the tidal volumes based on the difference (VT) between the end-inspiratory volume (Vei) and end-expiratory volume (Vee) of each compartment. The chest wall tidal volume (VT_{cw}) was the sum of rib cage tidal volume (VT_{rc}) and abdomen tidal volume (VT_{ab}). The breathing pattern was analyzed by the contribution of each compartment to the chest wall volume. The ratio of the inspiratory time to the total time of the respiratory cycle, the respiratory frequency and the minute ventilation were also assessed. These ventilator parameters were obtained from chest wall volume variations measurements.

2.2.4. Respiratory muscle activity

Surface electromyography (EMG System do Brazil Ltd, São Paulo, Brazil) was used to record the muscle respiratory activity. Because a wireless device was not available, to avoid covering the OEP markers by EMG electrodes and cables we evaluated only the sternocleidomastoid (SMM) and abdominal (ABD) muscles. An EMG system with a biological signal acquisition module consisting of eight channels, an amplifier gain of 1000× and a common mode rejection ratio >120 db was used for data acquisition. The data were processed using specific acquisition and analysis software (WinDaq® Acquisition Software, Akron, OH, USA) and an A/D 12 bit signal converting plate, which was used to convert analog signals to digital signals with an anti-aliasing sampling frequency of 2000 Hz for each channel and an input range of 5 mV. Active bipolar superficial electrodes consisting of two parallel rectangular Ag/AgCl bars (1 cm in length, 0.78 cm^2 of contact area) were used with an internal amplifier to reduce the effects of electromagnetic interference and other noise. For SMM, the electrodes were fastened to the lower third of the muscle belly, which was identified by palpation during manually resisted flexion of the neck (Falla et al., 2002). For ABD, the electrodes were placed 2 cm away from the umbilicus on the rectus abdominal muscle (Duiverman et al., 2004). The ground electrode was fixed on the ulnar styloid process. All of the electrodes were fixed on the right side. The EMG signal collection and analysis were carried out as recommend by the International Society for Electrophysiology and Kinesiology (Merletti, 1999). The