Abdominal muscle activity during breathing in different postures in COPD "Stage 0" and healthy subjects

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ABSTRACT

This study aims to evaluate the effect of different postures on the abdominal muscle activity during breathing in subjects "at risk" for the development of chronic obstructive pulmonary disease (COPD) and healthy. Twenty-nine volunteers, divided in "At Risk" for COPD (n = 16; 47.38 ± 5.08 years) and Healthy (n = 13; 47.54 ± 6.65 years) groups, breathed at the same rhythm in supine, standing, tripod and 4-point-kneeling positions. Surface electromyography was performed to assess the activation intensity of *rectus abdominis*, external oblique and *transversus abdominis*/internal oblique (TrA/IO) muscles, during inspi-ration and expiration. From supine to standing, an increased activation of all abdominal muscles was observed in "At Risk" for COPD group; however, in Healthy group, TrA/IO muscle showed an increased activation. In both groups, the TrA/IO muscle activation in tripod and 4-point kneeling positions was higher than in supine and lower than in standing. Subjects "at risk" for the development of COPD seemed to have a specific recruitment of the superficial layer of ventrolateral abdominal wall for the synchronization of postural function and mechanics of breathing.

Keywords: GOLD "Stage 0" Respiration Postural control Core abdominal Body position

1. Introduction

Chronic Obstructive Pulmonary Disease (COPD) is described as the presence of persistent airflow limitation that is usually progressive and associated with an enhanced chronic inflammatory response in the airways (Global Initiative for Chronic Obstructive Lung Disease, 2016; Vestbo et al., 2013). This obstructive ventilatory defect increases the volume of air in the lungs at the end of expiration, keeping the inspiratory muscles, especially diaphragm, in a mechanically disadvantaged position, which decreases their ability to generate inspiratory pressure (O'Donnell, 2001). This intrinsic mechanical loading of diaphragm muscle in COPD subjects (De Troyer et al., 1997; Gorini et al., 1990) presumably results in an increased activity of the accessory muscles of inspiration (Gandevia et al., 1996) and expiration (Ninane et al., 1992) and a changed thoraco-abdominal movement (Martinez et al., 1990). This increased activity of trunk muscles in COPD may imply a challenge for the synchronization of postural function and mechanics of breathing (Smith et al., 2010).

The central nervous system (CNS) modulates the motor activities of trunk muscles during both postural control and respiratory functions to regulate the intra-abdominal and intra-thoracic pressures (Hodges et al., 2001). This modulation occurs as a result of the coordination of the activity of abdominal, pelvic floor and diaphragm muscles (Hodges and Gandevia, 2000). Regarding trunk muscles' dual task, the change of body orientation in space alters their configuration and length and, consequently, the ability of respiratory muscles to act during breathing (De Troyer et al., 1983). Such modifications in mechanical efficiency may be due to the action of gravity and the changes in the base of support on the activity of trunk muscles required for the maintenance of posture (Meadows and Williams, 2009; Mihailoff and Haines, 2013). This affects the compliance of ribcage and abdomen (Estenne et al., 1985), changing the thoraco-abdominal configuration and movement (Lee et al., 2010; Romei et al., 2010), and, consequently, the functional residual capacity and the degree of limitation on expiratory tidal flow (Dean, 1985).

The body position is one of the controlled-breathing techniques to enhancement of COPD' debilitating effects on the ventilatory pump, improving the respiratory muscle function and decreasing the dyspnea (Gosselink, 2003). For that, COPD subjects often adopt the tripod position (sitting with forward-leaning trunk and arm support) during episodes of dyspnea (Booth et al., 2014). Literature has shown that this forward-leaning position improves the length-tension relationship of diaphragm muscle and its function, as well as decreases the recruitment of *sternocleidomastoideus* and *scalenus* muscles (Sharp et al., 1980), improving thoraco-abdominal movement (Delgado et al., 1982) and decreasing dyspnea (O'Neill and McCarthy, 1983). Also, the arm support, in tripod position, allows other accessory muscles (*pectoralis* major and minor) significantly contribute to the ribcage elevation (Banzett et al., 1988). Nevertheless, there is little evidence regarding the individual recruitment of abdominal muscles in this posture. As tripod position, the four-point kneeling position, which facilitates the recruitment of deep abdominal muscles (Hides et al., 2004), may be performed to improve the mechanics of breathing.

Although it is recognized that the primary underlying pathophysiology in COPD affects the respiratory muscle activity, the impact of different postures on abdominal muscle activity for the synchronization of postural function and mechanics of breathing is not yet clear in subjects "at risk" for the development of COPD (presence of chronic respiratory symptoms, in addiction to some evidence of impaired lung function) (Rodriguez-Roisin et al., 2016). When expanding symptomatic burden in COPD "Stage 0" to include other chronic respiratory symptoms, such as dyspnea, wheeze and limited physical activity, symptomatic smokers without airflow limitation experience significant morbidity and need health care resources, which represents a potential clinical entity (de Marco et al., 2007; de Oca et al., 2012; Mannino et al., 2006; Stavem et al., 2006). The scientific evidence in these subjects may be important to understand the natural history of COPD. The aim of the present study was to evaluate the effect of different postures on the abdominal muscle activity during breathing in subjects "at risk" for the development of COPD and healthy. Specifically, the activation intensity of *rectus abdominis* (RA), external oblique (EO) and *transversus abdominis*/internal oblique (TrA/IO) muscles, during inspiration and expiration, was analysed in supine, standing, tripod and 4-point-kneeling positions.

2. Methods

2.1. Sample

A cross-sectional study design was conducted with a sample composed by twenty-nine volunteers of an higher education institution: sixteen subjects "at risk" for the development of COPD – "At Risk" for COPD group; and thirteen healthy subjects – Healthy group. Sociodemographic, anthropometric and body composition data were similar between groups (Table 1). Participants had not participated in aerobic physical activities with a moderate intensity (a minimum of 30 min on five days a week) and/or aerobic physical activities with a vigorous intensity (a minimum of 20 min on 3 days a week), for a period exceeding one year (Thompson, 2014). As inclusion criteria for the "At Risk" for COPD group, participants had dyspnea, chronic cough and sputum production at least for three months in two consecutive years, as well as history of exposure to risk factors (e.g. smoking habits at least for fifteen years) (Rodriguez-Roisin et al., 2016). Moreover, these participants had to have Grade 1 or more in the Modified British Medical Research Council (mMRC) questionnaire and one point or more, out of five points, in the first four items of the COPD Assessment Test (CAT) (presence of cough, mucus, chest tightness and breathlessness) (Global Initiative for Chronic Obstructive Lung Disease, 2016). Exclusion criteria for both groups included chronic nonspecific lumbopelvic pain (recurrent episodes of lumbopelvic pain for a period longer than three months); scoliosis, length discrepancy of the lower limbs or other postural asymmetries; history of spinal, gynaecological or abdominal surgery in the previous year; neurological or inflammatory disorders; metabolic or chronic cardio-respiratory diseases; pregnancy or post-delivery in the previous six months; long-term corticosteroid therapy; and any conditions that may interfere with the data collection (American Thoracic Society/European Respiratory, 2002; Beith et al., 2001; Chanthapetch et al., 2009; Hermens et al., 2000; Mew, 2009; Miller et al., 2005; Reeve and Dilley, 2009). Each participant provided written informed consent, according to the Declaration of Helsinki. The anonymity of participants and the confidentiality of data were guaranteed. The Institutional Research Ethics Committee approved this study.

2.2. Instruments

Surface electromyography (sEMG) was performed to assess the muscle activity of RA, EO, TrA/IO and *erector spinae* (ES) of the dominant hand side. ES muscle activity was measured such as an indicator of the action of gravity and the changes in the base of support. The muscle activity was collected using the BioPlux research device (Plux wireless biosignals S.A., Arruda dos Vinhos, Portugal) with analogue channels of 12 bits and a sampling frequency of 1000 Hz, using double differential electrode leads. Disposable, self-adhesive Ag/AgCl dual snap electrodes (Noraxon Corporate, Scottsdale AZ, United States of America) were used for the sEMG. The electrode characteristics were 4 × 2.2 cm of adhesive area, 1 cm diameter of each circular conductive area and 2 cm of inter-electrode distance. These electrodes were connected to bipolar active sensors emgPLUX with a gain of 1000, an analogue filter at 25–500 Hz and a common-mode rejection ratio of 110 dB. The reference electrode used was a disposable self-adhesive Ag/AgCl snap electrode (Noraxon Corporate, Scottsdale AZ, United States of America) for the sEMG, with 3.8 cm diameter of circular adhesive area and 1 cm diameter of circular conductive area. The sensors were Bluetooth connected through the sEMG device to a laptop. MonitorPlux software, version 2.0, was used to display and acquire the sEMG signal. An electrode impedance checker was used to assess the impedance level of skin (Noraxon Corporate, Scottsdale AZ, United States of America).

A respiratory flow transducer TSD117 – Medium Flow Trans 300 L min^{-1} connected to an amplifier DA100C – General Purpose Transducer Amplifier Module, was used to detect both breathing phases. The respiratory flow was collected using the Biopac MP100WSW Data Acquisition System device (Biopac Systems Inc., Goleta CA, United States of America) with a sampling frequency of 100 Hz. A bacterial filter AFT1 – Disposable Bacterial Filter, 22 mm, a mouthpiece AFT2 – Disposable Mouthpiece, 22 mm and a nose clip AFT3 – Disposable Noseclip were also used. Acqknowledge software, version 4.1, (Biopac Systems Inc., Goleta CA, United States of America) was used to display and acquire the respiratory flow signal. A digital trigger signal coming from BioPlux research to Biopac MP100WSW Data Acquisition System was used to synchronize the respiratory flow signal and the sEMG signal.

A respiratory pressure meter MicroRPM (CareFusion Corporation, San Diego CA, United States of America) was used to assess the maximal expiratory pressure (MEP). This quasi-static maximal manoeuvre was used to normalize the sEMG signal of abdominal muscles (maximal muscle activity of each muscle during breath-

Table 1

"At Risk" for COPD and Healthy groups' characterization: sociodemographic, anthropometric and body composition data, with mean and standard deviation. *p* values for significant differences between groups are also presented.

	"At Risk" for COPD group(n = 16)	Healthy group(n = 13)	Between groups comparison (*p* value)
Demographic and anthropometric data			
Gender (n male)	5	6	0.466
Age (years)	47.4 ± 5.1	47.5 ± 6.7	0.941
Body mass (kg)	71.1 ± 14.8	79.6 ± 15.9	0.151
Height (m)	1.7 ± 0.1	1.7 ± 0.1	0.935
Body composition data			
Body fat (%)	29.3 ± 9.4	32.0 ± 8.9	0.446
Total body water (%)	48.9 ± 5.8	48.6 ± 4.7	0.890
Muscle mass (kg)	47.3 ± 10.5	52.9 ± 13.4	0.222
Bone mineral mass (kg)	2.5 ± 0.5	2.8 ± 0.6	0.209
Visceral fat	7.0 ± 3.2	9.2 ± 2.9	0.073

ing). A bacterial filter AFT1, mouthpiece AFT2 and nose clip AFT3 were also used.

2.3. Procedures

2.3.1. Sample selection and characterization

An electronic questionnaire was delivered to all participants to verify the selection criteria and to collect sociodemographic information. Also, the mMRC and CAT were included in this questionnaire. Anthropometric and body mass composition measures were assessed in participants who met the participation criteria. Height (m) was measured using a seca 222 stadiometer with a precision of 1 mm. Body mass (kg) and body mass composition – body fat (%), total body water (%), muscle mass (kg), bone mineral mass (kg) and visceral fat – were assessed using a Tanita Ironman Inner Scan BC-549 body composition monitor with a precision of 1 kg and 1% (Tanita – Monitoring Your Health, Amsterdam, Netherlands). To assess postural asymmetries, the lower limb length (cm) was measured using a seca 201 tape with a precision of 1 mm (seca – Medical Scales and Measuring Systems, Hamburg, Germany) and the postural assessment was performed. These evaluations were performed to select the final sample. Women who were in luteal phase were contacted later for data collection.

A MasterScreen Body plethysmograph of volume-constant type (Jaeger – CareFusion Corporation, San Diego CA, United States of America) was used to record forced vital capacity and then to assess pulmonary function: forced expiratory volume in one second (FEV_1)/forced vital capacity (FVC); % predicted of FEV_1, FVC, peak expiratory flow, forced expiratory flow at 75% ($FEF_{75\%}$)/50% ($FEF_{50\%}$)/25% ($FEF_{25\%}$) of FVC and $FEF_{25-75\%}$. FVC manoeuvre (closed circuit method) was recorded with participants in sitting position, using a mouthpiece firmly held around the lips to prevent leakage and to support the cheeks, as well as a nasal clip to prevent nasal breathing. To assess this manoeuvre, a completely and rapidly inhalation was performed with a pause of one second at total lung capacity, followed by a maximally exhalation until no more air can be expelled while maintaining the upright posture. Each manoeuvre was encouraged verbally. A minimum of three manoeuvres was performed. To test result selection, three reproducible manoeuvres were recorded, according to Miller et al. (2005) standards. An expert cardiovascular, respiratory and sleep technician was responsible for this assessment.

2.3.2. Data collection protocol

The study procedures took place at a biomechanical laboratory and were performed in a controlled environment. To avoid interrater error, each researcher was responsible for only one task.

To perform the sEMG, the hair was shaved and an abrasive cream was used to remove the dead cells from the skin's surface. Skin was then cleaned with isopropyl alcohol (70%), removing its oiliness and holding the dead cells. An electrode impedance checker was used to make sure that the impedance levels were below 5 KΩ, thus ensuring a good acquisition of sEMG signal (Hermens et al., 2000). The self-adhesive electrodes were placed with participants in standing position, five minutes after the skin preparation. These electrodes were placed parallel to the muscle fibre orientation, according to the references described in Table 2 (Criswell, 2011; Marshall and Murphy, 2003). The electrode placements were confirmed by palpation and muscle contraction. The reference electrode was placed in the anterior superior iliac spine of the contralateral hand dominant side. All electrodes were tested to control the cross-muscular signal (cross-talk), electrical noise and other interferences of sEMG signal (Hermens et al., 2000).

Table 2

Recommendations for the electrode placements of *rectus abdominis* (RA), external oblique (OE), *transversus abdominis*/internal oblique (TrA/IO) and *erector spinae* (ES) muscles.

Muscle	Anatomical landmarks
RA	2 cm lateral to the umbilicus, over the muscle mass
EO	Lateral to the RA and directly above the anterior superior iliac, halfway between the crest and ribs at a slightly oblique angle
TrA/IO	2 cm medially and below to the anterior superior iliac spine In this local, TrA and inferior IO muscle fibres are mixed, so it is impossible to distinguish the surface electromyographic activity of both
ES	2 cm lateral to spine, at L3 vertebra, over the muscle mass

MEP was performed with the participant in standing, using a mouthpiece firmly held around the lips to prevent leakage and to support the cheeks, as well as a nasal clip to prevent the nasal breathing. To assess this manoeuvre, a forceful and maximal expiration was performed – the Valsalva manoeuvre – at total lung capacity. Each manoeuvre was encouraged verbally. These manoeuvres were performed during a six-second period, with a resting time of three minutes. To normalize the sEMG signal of abdominal muscles, three reproducible manoeuvres were selected, according to American Thoracic Society/European Respiratory (2002) standards.

In standing, the maximal isometric voluntary contraction (MIVC) of ES muscle was performed to normalize data. The participant performed a trunk extension against an inelastic band placed on the scapular region. Three MIVC were performed, each one for a six-second period, with a resting time of three minutes.

Each participant breathed in supine, standing, tripod and 4-point kneeling positions, in a single data collection moment. The order of postures was randomized. In supine and standing, the participant had the upper limbs along the body, with feet shoulder-width apart and knees in loose pack position. In 4-point kneeling position, the participant was in triple flexion of lower limbs (hip and knee at 90°), with hands shoulder-width apart and elbows in

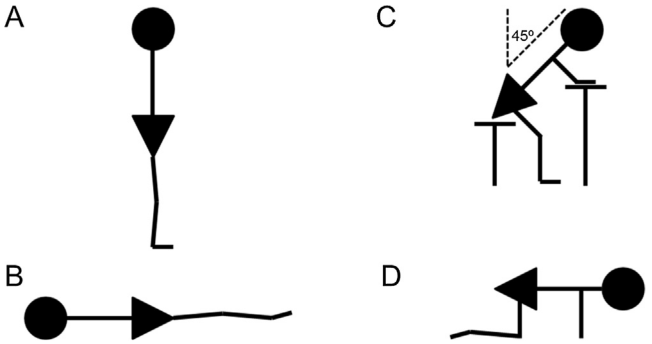

Fig. 1. Schematic representation of the four postures adopted by the participants. A: standing; B: supine; C: tripod position (45° of trunk flexion to vertical); D: 4-point kneeling position.

loose pack position. In tripod position, the participant was sitting, with 45° of trunk flexion to vertical, 90° of hip flexion and upper limbs supported on a table. All joint amplitudes were confirmed using the Bubble® Inclinometer (trunk amplitude) and Baseline® Plastic Goniometer 360° Head (hip and knee amplitudes), both with a precision of 1° (Fig. 1). The respiratory flow transducer was kept perpendicular to the participant during all tasks. A single repetition of each task was performed for ten consecutive respiratory cycles, with a resting time of three minutes. The respiratory rhythm (inspiratory time: two seconds; expiratory time: four seconds) was marked through a recorded voice. This respiratory rhythm was previously defined in a pilot study. The participant experienced and get used to this externally paced respiratory rhythm prior to data collection. The standardization of respiratory rhythm may have reduced the effect of different postures on minute ventilation.

After data collection, the electrodes were removed and a moisturizing cream was applied.

2.3.3. *Data processing*

A routine was developed in MatLab Student software (MathWorks, Pozuelo de Alarcon, Spain) to synchronize and process data. Firstly, the sEMG signal was converted into volts. It was applied to the sEMG signal a 2nd order digital filter Infinite Impulse Response – Butterworth, one of 20 Hz (high pass) and another of 500 Hz (low pass), to remove the electrical noise and/or cable movement; and, finally, a 2nd order digital filter Infinite Impulse Response – Butterworth of 30 Hz (high pass), to remove the cardiac signal. Root mean square (RMS) to 10 samples was then calculated.

Acknowledge software, version 4.1, was used to analyse data. The abdominal muscle activity was analysed during inspiration and expiration, independently. These both breathing phases were determined through the respiratory flow transducer signal. For the ten respiratory cycles collected, the mean RMS of four central respiratory cycles of each muscle was analysed in each task, with a posterior analysis of its average.

The muscle activity collected during the MEP manoeuvre was used to normalize data of the abdominal muscles. The mean RMS of three central seconds of the expiratory phase of each muscle was analysed, and then the average of the mean RMS of three reproducible manoeuvres was calculated. The percentage of the activation intensity of each muscle was determined according to the following equation:

$$\mathit{Muscle\ activation\ intensity}\ (\%) = \left(\frac{\mathit{mean\ RMS\ of\ each\ task}}{\mathit{RMS\ of\ the\ MEP}}\right) \times 100$$

ES muscle activity was analysed regardless the breathing phase. For the ten respiratory cycles collected, the mean RMS of four central respiratory cycles was analysed in each task, with a posterior analysis of its average. The muscle activity collected during the MIVC manoeuvre was determined to normalize data. The mean RMS of three central seconds was analysed, and then the average of the mean RMS of three repeated manoeuvres was calculated. The percentage of the activation intensity was determined according the following equation:

$$\mathit{Muscle\ activation\ intensity}\ (\%) = \left(\frac{\mathit{mean\ RMS\ of\ each\ task}}{\mathit{RMS\ of\ the\ MIVC}}\right) \times 100$$

2.4. *Statistical analysis*

IBM SPSS Statistics® software, version 20.0, (IBM Corporation, Armonk NY, United States of America) was used for the descriptive and inferential data analysis, with a significance level of 0.05. Shapiro-Wilk test was used to test the normality of the data. Central tendency (mean) and dispersion (standard deviation) measures were used for the descriptive statistics. Chi-square was used to compare gender between groups (“At Risk” for COPD and Healthy). Student *t*-test was used to compare the age, anthropometric, body composition and pulmonary function data, as well as the percentage of muscle activation intensity, between groups. In each group, Repeated Measures Analysis of Variance was used to compare the percentage of muscle activation intensity between the different evaluation tasks (four postures), during inspiration and expiration. Bonferroni correction was used for the post-hoc analysis (Marôco, 2014).

3. Results

3.1. *Pulmonary function*

The forced expiratory volume in one second, peak expiratory flow and forced expiratory flow at 75%/50%/25%/25–75% of FVC were significantly lower in “At Risk” for COPD group when compared to Healthy group ($p < 0.050$). No significant differences were found in the FVC between groups (Table 3).

3.2. *Abdominal muscle activity*

During both inspiration and expiration, no significant differences were found in the activation intensity of all abdominal muscles between groups (Figs. 2 and 3).

3.2.1. *“At Risk” for COPD group*

In “At Risk” for COPD group, during both inspiration and expiration, the activation intensity of all abdominal muscles was significantly greater in standing when compared to supine (RA: $p < 0.050$; EO: $p < 0.050$; TrA/IO: $p < 0.001$) and tripod positions (RA: $p \leq 0.010$; EO: $p < 0.010$; TrA/IO: $p = 0.001$). Also, TrA/IO muscle activation intensity was greater in standing when compared to 4-point kneeling, during both breathing phases ($p < 0.050$) (Figs. 2 and 3).

During both breathing phases, TrA/IO muscle activation was greater in 4-point-kneeling ($p < 0.010$) and tripod ($p < 0.050$) positions when compared to supine. Also, EO muscle activation intensity was greater in 4-point kneeling position when compared to supine, during both inspiration and expiration ($p < 0.050$) (Figs. 2 and 3).

During both inspiration and expiration, only RA muscle activation intensity was greater in 4-point kneeling position when compared to tripod position ($p < 0.050$) (Figs. 2 and 3).

3.2.2. *Healthy group*

In Healthy group, during both inspiration and expiration, no significant differences were found in activation intensity of RA and OE muscles between tasks (Figs. 2 and 3).

Table 3
Pulmonary function data in “At Risk” for COPD and Healthy groups, with mean and standard deviation. *p* values for significant differences between groups are also presented.

Pulmonary function	“At Risk” for COPD group(n = 16)	Healthy group(n = 13)	Between groups comparison(*p* value)
FEV_1/FVC	74.3 ± 6.5	82.8 ± 1.5	<0.001
FEV_1 (% pred)	94.9 ± 15.3	116.8 ± 13.6	0.001
FVC (% pred)	107.4 ± 15.8	117.5 ± 14.9	0.098
PEF (% pred)	103.2 ± 17.3	120.6 ± 14.5	0.009
FEF_{75} (% pred)	92.8 ± 27.2	126.9 ± 17.2	0.001
FEF_{50} (% pred)	64.00 ± 17.2	112.4 ± 17.6	<0.001
FEF_{25} (% pred)	50.2 ± 13.5	85.2 ± 15.2	<0.001
FEF_{25-75} (% pred)	60.9 ± 15.1	104.7 ± 16.1	<0.001

FEV_1 forced expiratory volume in one second; FVC forced vital capacity; PEF peak expiratory flow; FEF_{75}/FEF_{50}/FEF_{25}/FEF_{25-75} forced expiratory flow at 75%/50%/25%/25-75% of FVC, respectively; % pred% predicted.

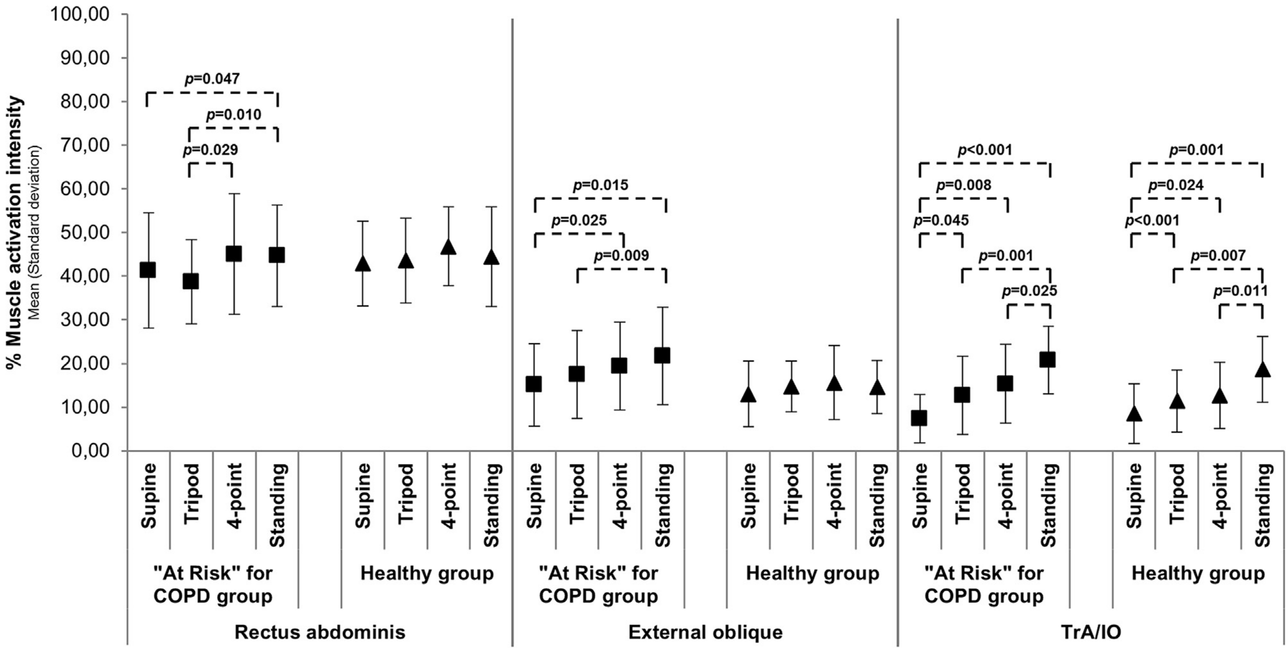

Fig. 2. Activation intensity of *rectus abdominis*, external oblique and transversus abdominis/internal oblique (TrA/IO) muscles (expressed as%) during inspiration in supine, tripod position, 4-point kneeling (4-point) and standing in “At Risk” for COPD and Healthy groups, with mean and standard deviation. *p* values for comparison within subjects is also presented.

During both breathing phases, TrA/IO muscle activation intensity was significantly greater in standing when compared to supine ($p \leq 0.001$), tripod ($p < 0.010$) and 4-point kneeling ($p < 0.050$) positions (Figs. 2 and 3).

During both inspiration and expiration, TrA/IO muscle activation intensity was significantly greater in 4-point kneeling ($p < 0.050$) and tripod ($p < 0.001$) positions when compared to supine (Figs. 2 and 3).

During both breathing phases, no significant differences were found in activation intensity of all abdominal muscles between tripod and 4-point kneeling positions (Figs. 2 and 3).

3.3. ES *muscle activity*

During breathing, no significant differences were found between groups in ES muscle activation intensity (Fig. 4).

In both “At Risk” for COPD and Healthy groups, ES muscle activation intensity was significantly greater in standing when compared to supine ($p = 0.001$ and $p = 0.018$, respectively), tripod ($p = 0.005$ and $p = 0.027$, respectively) and 4-point-kneeling ($p = 0.004$ and $p = 0.032$, respectively) (Fig. 4).

4. Discussion

The present study showed that the different postures promoted a different impact on the abdominal muscle activity in each group. From supine to standing, an increased activation of all abdominal muscles (superficial and deep layers of ventrolateral abdominal wall) was observed in “At Risk” for COPD group However, in Healthy group, TrA/IO muscle showed an increased activation intensity. These data suggested that subjects “at risk” for the development of COPD had a different recruitment pattern of abdominal muscles for the synchronization of postural function and mechanics of breathing.

The outcomes of the present study indicated that there were no significant differences between “At Risk” for COPD and Healthy groups in the activation intensity of all abdominal muscles in supine, during both inspiration and expiration. Neural drive to the diaphragm muscle (De Troyer et al., 1997; Gorini et al., 1990) and activity of parasternal intercostal and scalene muscles (Gandevia et al., 1996) are increased in COPD, during breathing at rest or when ventilation increases. Also, evidence has been described that the recruitment of abdominal muscles is frequent in subjects with COPD (Ninane et al., 1992; Ninane et al., 1993). Ninane et al. (1992) reported that, when breathing at rest in supine, this activation mainly concerns the *transversus abdominis* (TrA) muscle

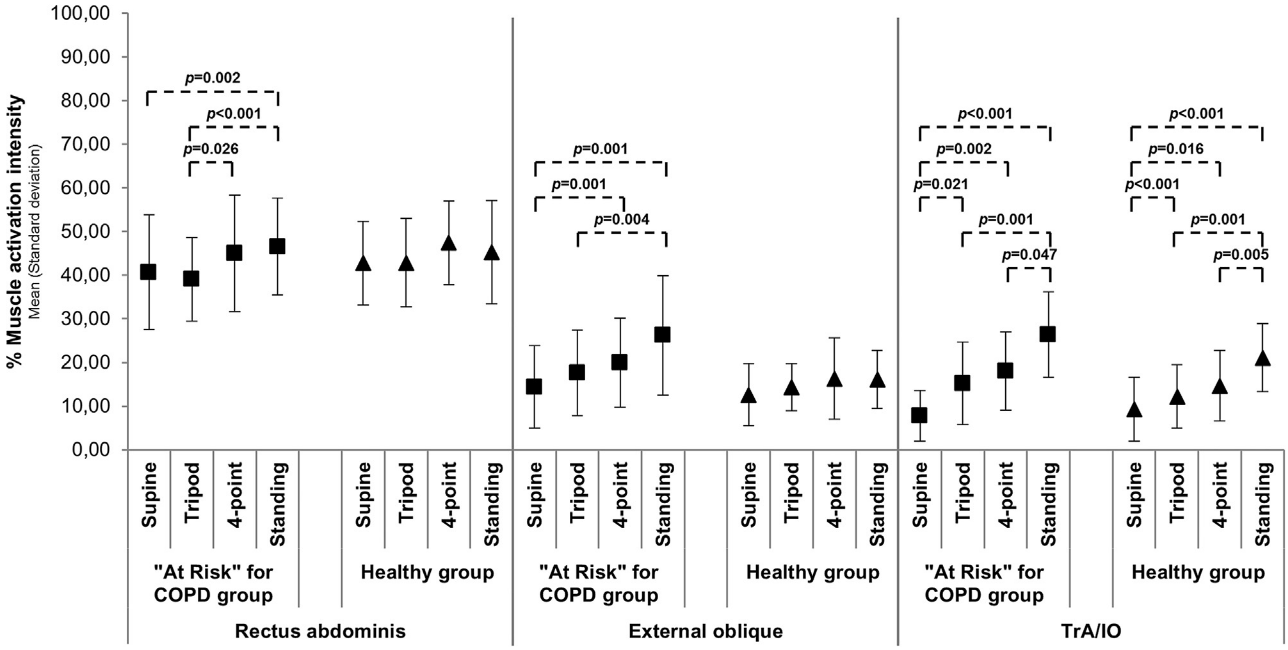

Fig. 3. Activation intensity of *rectus abdominis*, external oblique and transversus abdominis/internal oblique (TrA/IO) muscles (expressed as%) during expiration in supine, tripod position, 4-point kneeling (4-point) and standing in "At Risk" for COPD and Healthy groups, with mean and standard deviation. *p* values for comparison within subjects is also presented.

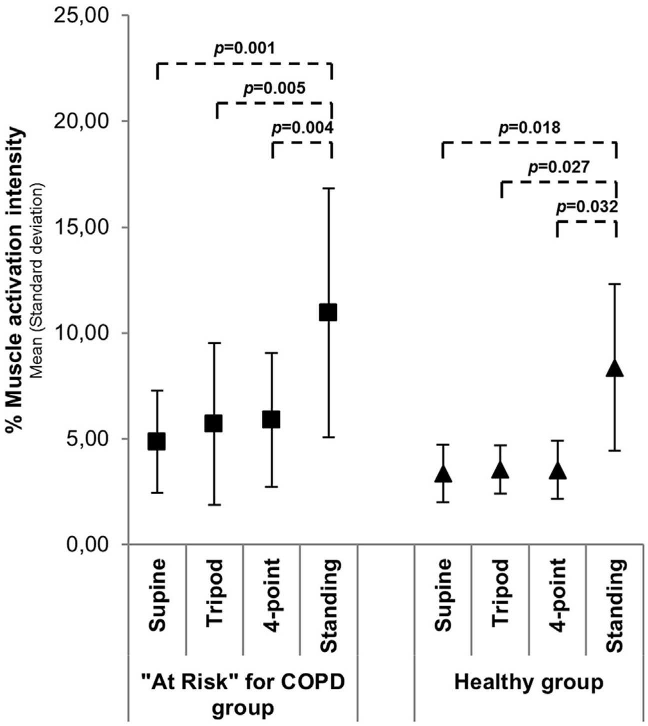

Fig. 4. Activation intensity of *erector spinae* muscle (expressed as%) during breathing in supine, tripod position, 4-point kneeling (4-point) and standing in "At Risk" for COPD and Healthy groups, with mean and standard deviation. *p* values for comparison within subjects is also presented.

and its recruitment is related to the degree of airflow obstruction. In spite of existing a significant decrease in pulmonary function data, associated with airflow obstruction, it was not enough to reflect an obstructive ventilatory defect in "At Risk" for COPD group when compared to Healthy group (Global Initiative for Chronic Obstructive Lung Disease, 2016; Rodriguez-Roisin et al., 2016). The Tiffeneau index, FEV_1 and $FEF_{25-75\%}$ values, in the study' sample, were above the cut-off points that define the limit of normality (Global Initiative for Chronic Obstructive Lung Disease, 2016; Rodriguez-Roisin et al., 2016). Thus, in supine, there was a decreased postural load that may not have been sufficiently challenging for the postural-respiratory synergy to change the recruitment pattern of abdominal muscles in these specific subjects.

From supine to standing, the recruitment pattern of abdominal muscles seemed to be different within each group. During both breathing phases, the activation intensity of all abdominal muscles was greater in standing when compared to supine, in "At Risk" for COPD group; however, in Healthy group, TrA/IO muscle activation intensity in standing was greater than in supine. Different postures and functional goals (such as respiration) require that the CNS appropriately adjusts the co-activation of trunk extensor and abdominal muscles to the action of gravity and the changes in the base of support (Meadows and Williams, 2009; Mihailoff and Haines, 2013). The human skeletal motor system, due to the high position of the centre of mass regarding the small size of the base of support, is poorly adapted to the preservation of a vertical position (standing) (Hodges et al., 2002). Unlike supine, the gravitational pull would be increased in standing, resulting in greater feedback from the stretch receptors of antigravity muscles (as ES muscle), thus raising motor-neuron pool excitability and increasing its muscle recruitment (Meadows and Williams, 2009; Mihailoff and Haines, 2013). Thus, in both groups, the activation intensity of abdominal muscles in standing was greater than in supine, which supports the primary postural function of abdominal muscles, increasing a postural tone when the challenge to stability is increased (Cholewicki et al., 1999). Nevertheless, the mechanics of ribcage and abdomen is affected due to the action of gravity. As opposed to supine, the abdominal content is being pulled away from the diaphragm muscle in standing, increasing the overall outward recoil of the chest wall, and so the functional residual capacity (Dean, 1985). Thus, from supine to standing, an increased activation intensity of abdominal muscles reduces the abdominal compliance. These changes allow the resistance provided by the abdominal content to the diaphragm muscle descent is more effective in expanding the lower rib cage (Strohl et al., 1984). The results of this study were consistent with earlier studies of Abe et al. (1996), Barrett et al. (1994) and De Troyer (1983). The specific recruitment of abdominal muscles observed in each group may provide information relative to an impaired synchronization of postural function and mechanics of breathing in subjects who have dyspnea, chronic cough or sputum production, and a history of exposure to risk factors for the chronic obstructive pulmonary disease (as tobacco smoke), but did not exhibited an obstructive ventilatory defect (Rodriguez-Roisin et al., 2016). In Healthy group, the TrA/IO muscle activity may increase the transverse diameter of the lower rib cage (Key, 2013). Otherwise, the recruitment in concert of the superficial (RA and EO) muscles of ventrolateral abdominal wall, observed in “At Risk” for COPD group, helps to anchor the thorax caudally and their excessive activity may constrict the inferior thorax, interfering with diaphragm descent (Key, 2013). Further studies are needed to evaluate the effect of different postures on the thoraco-abominal movement in these subjects.

As supine, the lean-forward position in sitting with the passive fixing shoulder girdle, which characterizes the tripod position, reduces the postural load Therefore, in both “At Risk” for COPD and Healthy groups, lower ES muscle activation intensity was observed in tripod position when compared to standing, resulting in lower recruitment of abdominal muscles, as previously discussed. Furthermore, in both groups, TrA/IO muscle activation intensity was greater in tripod position when compared to supine. Some degree of lean forward displaces downward and outward the abdominal content, lengthening the fibres of abdominal muscles (Dean, 1985), and may place them in an improved position for contraction. TrA muscle, due to its circumferential arrangement, has the most appropriate mechanical efficiency, which makes it easier to recruit into this posture (De Troyer et al., 1990). This TrA/IO muscle recruitment, similar in both groups, may help to place the diaphragm muscle in a more favorable position on its length-tension curve, decreasing accessory muscle of inspiration’ recruitment and improving the thoraco-abdominal movement (Barach, 1974). Thus, it is reasonable to hypothesize that, in tripod position, the TrA/IO muscle recruitment for the synchronization of postural function and mechanics of breathing is beneficial to relief the dyspnea in subjects “at risk” for the development of COPD patients.

The findings of the present study indicated that, during both breathing phases, the TrA/IO muscle activation intensity was lower in 4-point kneeling position when compared to standing, as well the activation intensity of EO and TrA/IO muscles was greater in this position when compared to supine, in “At Risk” for COPD group; however, in Healthy group, TrA/IO muscle activation intensity in 4-point kneeling was lower than in standing and greater than in supine. In 4-point kneeling position, the large base of support reduces the postural load, resulting in lower ES muscle activation intensity in this position when compared to standing, in “At Risk” for COPD and Healthy groups. In fact, as explained above, the gravitational pull would be reduced in 4-point kneeling position, decreasing recruitment of abdominal muscles. Moreover, this position, as well as the tripod position, allows the abdominal muscles to sag, facilitating their stretch (Norris, 1999). As observed in Healthy group, this posture is likely to increase the feedback from the muscle stretch receptors, thus raising the motor-neuron pool excitability of the TrA/IO muscle (Beith et al., 2001). However, in subjects “at risk” for the development COPD, breathing in 4-point kneeling position was more challenging for the synchronization of postural function and mechanics of breathing. An additional demanding recruitment of the superficial layer of ventrolateral abdominal wall, namely EO muscle, was required in these subjects (Mesquita Montes et al. 2016).

In both groups, there were no significant differences in TrA/IO muscle activation intensity between 4-point kneeling and tripod positions. The postural load and gravitational stretch on the abdominal content and wall seemed to be similar in both postures. In 4-point kneeling and tripod positions, the TrA/IO muscle recruitment may be important to the improvement of the mechanics of breathing. However, in “At Risk” for COPD group, the RA muscle activation intensity was greater in 4-point kneeling position when compared to tripod position. As stated above, the challenge for postural-respiratory synergy may be increased during breathing in 4-point kneeling position. The RA muscle recruitment, observed in “At Risk” for COPD group, may be definitively harmful in an advanced pathological context. This specific recruitment of abdominal muscles in subjects with expiratory flow limitation may place the diaphragm under a mechanical disadvantage, impairing mechanics of breathing (Aliverti and Macklem, 2008; O’Donnell, 2001). Further studies conducted among several degrees of COPD are needed to evaluate the impact of tripod and 4-point kneeling position or other recruitment strategies of abdominal muscles on the breathing kinematics

4.1. *Implications for future practice*

These data suggested that subjects “at risk” for the development of COPD represent a new clinical entity. The recruitment pattern of the superficial layer of ventrolateral abdominal wall during breathing may have a negative impact on its mechanics. Thus, strategies are needed to improve this recruitment pattern of abdominal muscles in these subjects. The specific recruitment of TrA/IO muscle in tripod position, observed in this study, may be of particular interest to the mechanics of breathing in subjects “at risk” for the development of COPD, as well as with expiratory flow limitation.

Furthermore, 4-point kneeling position is usually performed to dissociate muscle activity in the internal oblique (IO) and TrA from that of RA and EO (Hides et al., 2004). This dissociation, observed in Healthy group, may contribute to improve the mechanics of breathing. In subjects “at risk” for the development of COPD, the isolated recruitment of TrA/IO muscle becomes more difficult in 4-point kneeling position. Although the potential positive impact of TrA/IO muscle activity on the chest wall kinematics, the increased challenge for postural-respiratory synergy, in this posture, should be carefully controlled.

4.2. *Methodological considerations*

The results of the present study should be considered in light of a few limitations. First, the muscle activity of the deep layer of ventrolateral abdominal wall (namely TrA) was collected by the sEMG. For TrA/IO muscle, the bipolar electrodes were placed in parallel with the TrA muscle fibres. Nevertheless, the sEMG signal probably represents the muscle activity from both muscles. Similar to TrA muscle, the lower fibres of IO muscle have been proven to function as local muscle, contributing both muscles to the modulation of intra-abdominal pressure and to the support of abdominal content (Hodges, 2004; Marshall and Murphy, 2003). Furthermore, a crosstalk into the superficial and deep layers of ventrolateral abdominal wall might have occurred. A clinical test was performed for each abdominal muscle to test whether the bipolar electrodes have been placed properly (Hermens et al., 2000). Previous studies reported that the crosstalk between EO and TrA/IO muscles (at the electrode placement of EO muscle), as well as the crosstalk between RA and other abdominal muscles is minimal (Marshall and Murphy, 2003).

Second, the breathing pattern was not evaluated. Among the factors that may influence the respiratory system, sociodemographic, anthropometric and body composition variables can be highlighted

(Kaneko and Horie, 2012; Romei et al., 2010). Although the variability between subjects may have been present, "At Risk" for COPD and Healthy groups were considered similar in those variables. So, the effect of natural variability between subjects upon the results was reduced.

5. Conclusion

The change of body orientation promoted different impact on the abdominal muscle activity during breathing within each group. Subjects "at risk" for development of COPD seemed to have a specific recruitment of the superficial muscle layer of ventrolateral abdominal wall (RA and OE muscles) during breathing in situations wherein the postural load increases. Further studies are needed to evaluate the impact of this recruitment pattern on the mechanics, as well as the work and cost of breathing. Furthermore, TrA/IO muscle recruitment in tripod and 4-point kneeling positions should be taken into consideration for the improvement of the mechanics of breathing.

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