Asynchronous Thoraco-abdominal Motion Contributes to Decreased 6-Minute Walk Test in Patients With COPD

Jung-Yien Chien MD, Sheng-Yuan Ruan MD, Yuh-Chin T Huang MD MHS, Chong-Jen Yu MD PhD, and Pan-Chyr Yang MD PhD

BACKGROUND: Abnormal thoraco-abdominal motion may contribute to exercise limitation in patients with COPD. The current study aimed to assess how the thoraco-abdominal asynchrony in COPD patients correlates with exercise performance during the 6-minute walk test (6MWT). METHODS: Eighty-eight COPD subjects (40 moderate and 48 severe) and 14 healthy controls were evaluated at rest and during the 6MWT for the magnitude of rib cage and abdominal motion and asynchrony between the two (phase angle) with respiratory inductive plethysmography. RESULTS: Compared to healthy control subjects, subjects with COPD had similar magnitude of rib cage and abdominal motion, but greater asynchrony at rest. During the 6MWT, subjects with COPD showed decreased rib cage motion and increased asynchrony. Rib cage excursion at 3 min after the beginning of the 6MWT was an independent predictor for the 6MWT distance (*P* < .001), in addition to age, percent of predicted FEV_1, and residual volume/total lung capacity. There was no correlation between rib cage excursion at 3 min and St George's Respiratory Questionnaire score. CONCLUSIONS: Thoraco-abdominal asynchrony worsens early during 6MWT in subjects with moderate and severe COPD, and rib cage excursion at 3 min predicts poor walking capability. A pulmonary rehabilitation strategy devised to improve rib cage excursion may help improve exercise tolerance.
Key words: COPD; 6-minute walk test; thoraco-abdominal motion; exercise; plethysmography. [Respir Care 2013;58(2):320–326. © 2013 Daedalus Enterprises]

Introduction

Exercise intolerance and exertional dyspnea are cardinal symptoms of patients with moderate to severe COPD.[1] The mechanisms for exercise intolerance are multifactorial, but the inability to increase ventilation to support exercise is a main contributor to exercise limitation.[2] Due to airway obstruction, predicted ventilation limitation (proportional to FEV_1) is frequently reached at a lower level of exercise. Exercise capacity can also be limited by desaturation or cardiac deconditioning. In addition, several studies have shown that patients with COPD had abnormal thoraco-abdominal motion during exercise and that this mechanical disadvantage increases the work of breathing and may further contribute to the exercise limitation.[3–5]

Previous studies have observed abnormal responses of thoraco-abdominal motion during exercise on cycle ergometer and treadmill. These studies showed that COPD patients increased the tidal volume by increasing abdominal movement, but had less abdomen-chest coordination during exercise.[3–6] The asynchronous thoraco-abdominal movement was observed more frequently in patients with more severe disease. Data obtained during exercise on cycle ergometer and treadmill, however, may not fully reflect the physiologic and metabolic events of routine daily activities in these patients.[6,7]

In this study we quantified asynchronous thoraco-abdominal movement with a respiratory inductive plethys-

The authors are affiliated with the Department of Internal Medicine, National Taiwan University Hospital, Taipei, Taiwan, with the exception of Dr Huang, who is affiliated with the Department of Medicine, Duke University Medical Center, Durham, North Carolina. Dr Chien is also affiliated with the Chest Hospital, Department of Health, Executive Yuan, Tainan, Taiwan.

The authors have disclosed no conflicts of interest.

Correspondence: Jung-Yien Chien MD, Chest Hospital, Department of Health, Executive Yuan, 864 Zhongshan Road, Rende District, Tainan 707 Taiwan. E-mail: jychien@ntu.edu.tw.

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mography (RIP) during a 6-min walk test (6MWT) in patients with moderate to severe COPD. We hypothesized that thoraco-abdominal asynchrony would independently predict the performance of 6MWT (ie, walking distance). We chose 6MWT because it is considered a form of submaximal levels of exertion that more closely represents daily activity for patients with COPD.[8] The test has been used widely for the evaluation of functional status and the response to therapeutic interventions in patients with cardiopulmonary diseases.[9]

QUICK LOOK

Current knowledge

Exercise intolerance and exertional dyspnea are symptoms of moderate to severe COPD. A main contributor is the inability to increase minute ventilation to support exercise. Exercise capacity can also be limited by desaturation or cardiac deconditioning. Abnormal thoraco-abdominal motion during exercise creates a mechanical disadvantage that increases the work of breathing and further contributes to the exercise limitation.

What this paper contributes to our knowledge

Compared to healthy controls, abnormal thoraco-abdominal coordination in patients with COPD was common. The abnormality worsened early during the 6-min walk test. The abnormal thoraco-abdominal coordination was characterized primarily by decreases in rib cage excursion. The degree of rib cage excursion is inversely correlated with the severity of lung hyperinflation.

Methods

Subjects

From March to July 2009, 88 subjects with COPD in a teaching hospital in Taiwan were enrolled. Subjects with post-bronchodilator $FEV_1 < 80\%$ of the predicted value and $FEV_1/FVC < 0.7$ were included. Patients were excluded if they had a history suggesting asthma, 12% or higher increase in FEV_1 after bronchodilator, active heart disease, musculoskeletal disorders, peripheral vascular diseases, or other disabling conditions that would interfere with the tests.

Subjects with $FEV_1 \geq 50\%$ and $< 80\%$ of the predicted value were classified as moderate COPD, and subjects with $FEV_1 < 50\%$ of the predicted value were classified as severe COPD. Fourteen volunteers between 18 to 80 years old with normal pulmonary function tests and without any respiratory problems, recruited from the regular health check-up clinic, acted as healthy controls. The institutional review board of the National Taiwan University Hospital approved the study (200811029R).

The 6-Min Walk Test

The 6MWT was conducted in a 30-m long corridor, according to the American Thoracic Society recommendations.[8] An experienced researcher supervised the test. Subjects were instructed to walk from one end of the corridor to the other end and to cover as much distance as possible in the allotted period of 6 min. They were encouraged every minute, using 2 phrases (ie, "You are doing well" and "Keep up the good work") and were allowed to stop and rest during the test, but were instructed to resume walking as soon as possible.

Measurements

Pulmonary function tests were performed before the 6MWT, according to the American Thoracic Society and European Respiratory Society recommendations.[10] Spirometry and lung volumes were measured using a pulmonary function system equipped with a whole-body plethysmograph (MasterScreen Body, Jaeger/CareFusion, San Diego, California). Health-related quality of life was determined using the St George's Respiratory Questionnaire, which was administered before the 6MWT.

During the 6MWT, oxygen saturation was monitored by pulse oximeter (Tidal Wave, Philips Respironics, Murrysville, Pennsylvania). Respiratory frequency, rib cage motion, abdominal motion, and phase angle were obtained by respiratory inductive plethysmography (Embletta, Embla Systems, Broomfield, Colorado) with a sampling frequency of 10 Hz. Teflon-coated inductance coils of appropriate size were placed around the rib cage (at the level of the axilla) and abdomen (at the level of the umbilicus), and an elastic mesh bandage was worn over the bands to minimize movement artifacts. RIP was calibrated using the qualitative diagnostic calibration procedure during a 5-min regular breathing period in a standing position, and validated against spirometry before the study.[11,12] Data were considered unacceptable if the validation procedure indicated that RIP measurement displayed a > 10% difference from spirometry. The coefficient of determination for tidal volume by spirometry and by inductive plethysmography was 0.95 (95% CI 0.89–1.00, $R^2 = 0.90$). Bland-Altman analysis[13] showed that the mean difference between those 2 methods was 3.85 mL (95%CI 1.58–6.12 mL) and the limits of agreement were −18.07 to 25.77 mL (Fig. 1). The phase angle was calculated by the principles employed by Agostoni and Mognoni.[14] When the rib cage and abdomen moved in perfect synchrony, phase angle was considered 0°. With increasing asynchronous thoraco-abdominal motion, the phase angle increased to 180°, the point at which the rib cage and abdomen were completely out of phase.

Statistical Analysis

Demographic characteristics were compared by the Fisher exact test (categorical variable) or analysis of variance. Comparisons of the variables between rest and each time point, and between control and each group during the 6MWT were made by paired-*t* test and independent 2-sample *t* test adjusted for multiple comparisons with Bonferroni correction. A stepwise multiple linear regression analysis with backward elimination (exit $\alpha = 0.1$) was used to determine predictors for the 6MWT distance (6MWD). The independent variables were resting breathing frequency, resting rate, resting oxygen saturation, age, FEV_1 (% predicted), the ratio of residual volume (RV) to total lung capacity (TLC), resting phase angle, resting rib cage excursion, resting abdominal motion, phase angle at 3 min after the beginning of 6MWT, rib cage excursion at 3 min after the beginning of 6MWT, and abdominal motion at 3 min after the beginning of 6MWT.

Data are presented as mean ± SD unless otherwise noted. All statistical analyses were performed using statistics software (Stata 8, StataCorp, College Station, Texas). All *P* values were 2-sided, and a value < .05 was considered statistically significant.

Results

Baseline characteristics of the subjects and healthy controls are shown in Table 1. Compared to the healthy controls, the subjects with COPD had higher respiratory frequency at rest, and severe COPD subjects had the highest respiratory frequency during the 6MWT.

At rest, the subjects with COPD had rib cage excursion similar to that of the healthy controls. During the 6MWT, rib cage motion increased and plateaued after 3 min in all subjects. Subjects with COPD had less rib cage excursion than the control, and severe COPD subjects had the smallest rib cage excursion (Fig. 2A). The abdominal excursion at rest was similar in all 3 groups. It increased during the 6MWT and plateaued after 3 min for all subjects. Subjects with moderate COPD had greater abdominal excursion at the plateau than the control subjects (see Fig. 2B). At any time during the 6MWT, tidal volume was similar in the control subjects and the moderate COPD subjects, but smaller in the severe COPD subjects (see Fig. 2C). The rib cage excursion/abdominal excursion ratio increased in the control subjects but remained relatively unchanged in subjects with COPD (see Fig. 2D).

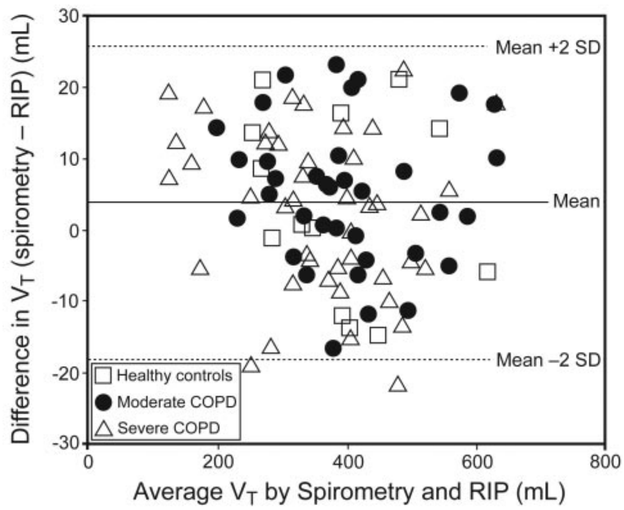

Fig. 1. Bland-Altman plot of the difference between tidal volume measured by spirometry and by respiratory inductive plethysmography (RIP) during the validation procedure.

The phase angle was significantly greater in the subjects with COPD than in the healthy controls at rest, especially in subjects with severe airway obstruction (see Fig. 2E). Although the phase angle increased significantly within the first minute of the 6MWT in all subjects, it quickly returned to the baseline in the control subjects, while in the COPD subjects the phase angle remained high during the entire 6MWT (see Fig. 2E). Oxygen saturation decreased most significantly in subjects with severe COPD during the 6MWT (Fig. 2F). A total of 12 (25%) subjects with severe COPD experienced desaturation to between 80–90% during the 6MWT, but the oxygen saturation recovered quickly by slowing down the walk or resting without oxygen supplement.

Of the RIP parameters, the magnitude of increase in rib cage excursion inversely correlated to RV/TLC in the control subjects and the subjects with moderate COPD, but not in the subjects with severe COPD. There was no correlation between abdominal motion or phase angle with RV/TLC. There were also no correlations between any of the RIP parameters and the St George's Respiratory Questionnaire scores in COPD subjects.

Stepwise multiple linear regression analysis showed that rib cage excursion at 3 min was an independent predictor for 6MWD, in addition to age, FEV_1 (% predicted), and RV/TLC (Table 2). Resting parameters of thoraco-abdominal movement were not. The model that included these 4 factors had an adjusted R^2 of 0.70. The regression equation is as follows:

$$6MWD\ (m) = -3.26 \times (\text{age, years}) + 0.795 \times (FEV_1,\ \%\ \text{predicted}) - 2.78 \times (RV/TLC,\ \%) + 0.247 \times (\text{rib cage excursion at 3 min, mL}) + 621.77$$

Table 1. Participant Characteristics

	Control (n = 14)	Moderate COPD (n = 40)	Severe COPD (n = 48)	P
Male, no. (%)	12 (86)	33 (83)	38 (81)	> .99
Age, y	62.9 ± 2.2	67.9 ± 1.45	69.4 ± 1.81	.06
BMI, kg/m^2	23 ± 1.01	24.3 ± 0.61	22.2 ± 0.65	.05
6-min walk distance, m	496 ± 27	405 ± 14	330 ± 15	< .001
FEV_1, L	2.80 ± 0.15	1.82 ± 0.07	0.89 ± 0.04	< .001
FEV_1, % predicted	92.25 ± 2.87	67.6 ± 1.84	35 ± 1.20	< .001
FVC, % predicted	84.60 ± 3.80	81.54 ± 2.68	60.78 ± 2.10	< .001
FEV_1/FVC, %	81.7 ± 1.4	63.3 ± 1.27	44.2 ± 1.57	< .001
RV/TLC, %	35 ± 5	49 ± 1	63 ± 2	< .001

Data are mean ± SD unless otherwise indicated.
RV = residual volume
TLC = total lung capacity

Discussion

In this study we used RIP to evaluate thoraco-abdominal movement in subjects with COPD during the 6MWT. RIP is a noninvasive method to measure breathing movement. It integrates signals from rib cage and abdominal sensors, and, with proper calibration, can measure rib cage and abdominal motion in out-patients at rest and during mild exercise. A previous study showed that, when compared to pneumotachograph, RIP accurately estimates ventilation parameters (respiratory cycle time, tidal volume, and minute ventilation) during treadmill exercise, with limits of agreement of ± 6–17%.[12] Another study also showed very high coefficients of determination for breathing frequency, tidal volume, and minute ventilation between RIP and pneumotachograph.[15]

We showed that, compared to healthy controls, there was abnormal thoraco-abdominal coordination in patients with COPD. The abnormality worsened early during the 6MWT. The abnormal thoraco-abdominal coordination was characterized foremost by decreases in rib cage excursion. The degree of rib cage excursion was inversely correlated with the severity of lung hyperinflation (RV/TLC). Thus, in these patients, the tidal breath occurs at the higher portion of the pressure-volume curve, closer to TLC,[16] that is less inflatable. Furthermore, patients with COPD have limitations on expiratory air flow. Therefore, during exercise, when ventilatory demand and breathing frequency increase, the time for expiration decreases, resulting in dynamic hyperinflation.[17] The dynamic hyperinflation shifts end-inspiratory lung volume toward TLC and further limits the excursion of the rib cage. Breathing at high lung volumes also puts inspiratory accessory muscles at an unfavorable length-tension relationship and reduced pressure generation efficiency.[18,19] This could explain why rib cage excursion at 3 min and RV/TLC were independent predictors for 6MWD in the regression analysis, in addition to age and FEV_1.

Several interventions, including bronchodilator therapy, rehabilitative exercise training, and inhalation of helium/oxygen mixture, could be beneficial to rib cage excursion by reducing dynamic hyperinflation. Bronchodilator therapy decreases the limitations on expiratory air flow and thus reduces hyperinflation during exercise.[20] Exercise training lowers ventilatory demand and perception of dyspnea at a given level of work, resulting in slower respiration, a longer expiratory time, and, therefore, less dynamic hyperinflation.[17] Pursed lips breathing also could improve rib cage excursion, by preventing airway collapse and decreased breathing frequency.[21] Inspiratory muscle training may help to optimize inspiratory muscle strength and/or endurance, which could also be beneficial to better rib cage excursion and, therefore, possibly a longer walking distance.[21] Stretch exercise involving neck and accessory muscles also helps improve rib cage excursion. Further clinical research will be needed to determine the evidence-based intervention for improvement of rib cage excursion.

Similar to previous studies,[3,18] our study also found that the abdominal excursion increased during the 6MWT in patients with moderate COPD, but it was not a predictor for 6MWD. The increased abdominal excursion may be from the activation of diaphragmatic breathing, although it is still controversial whether or not activation of diaphragmatic breathing in these patients is actually beneficial.[22,23] One study found in moderate to severe COPD that the diaphragmatic breathing worsened the coordination of chest wall motion and mechanical efficacy of breathing.[19] Another study found that diaphragmatic breathing increased both inspiratory muscle effort and dyspnea.[20] Increased abdominal excursion could also be the result of recruit-

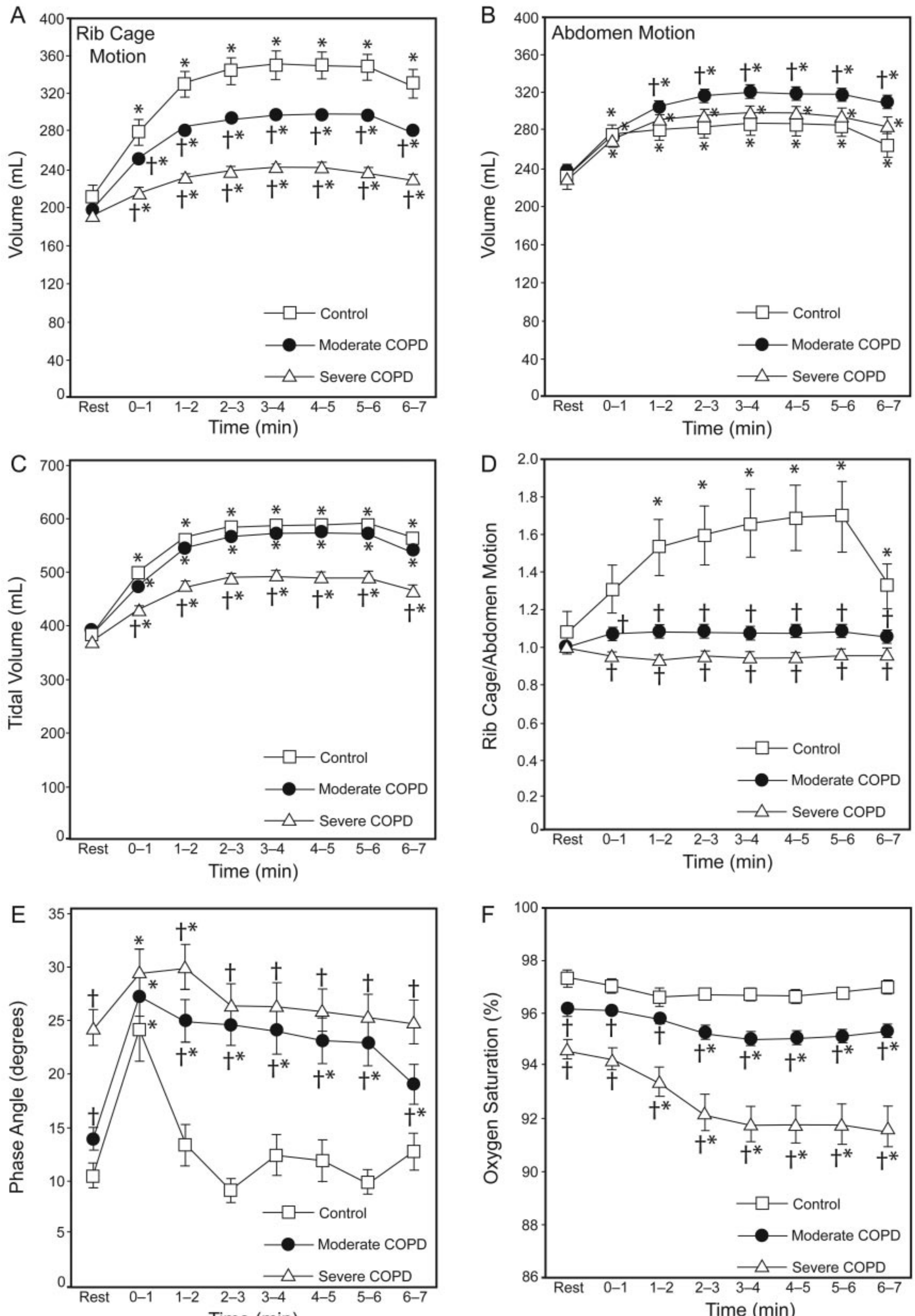

Fig. 2. The volume related to rib cage motion (A), abdominal motion (B), and tidal volume (C), and the ratio of rib cage to abdominal motion (D), phase angle between rib cage and abdominal excursions (E), and oxygen saturation (F) during a 6-min walk test in healthy controls, subjects with moderate COPD, and subjects with severe COPD subjects. * $P < .05$ compared to the rest. † $P < .05$ compared to control.

Table 2. Results of Stepwise Multiple Linear Regression Model for Predicting 6-Min Walk Distance

	Coefficient	95% CI	*P*
Age	–3.257	–4.546 to –1.967	< .001
Percent of predicted FEV_1	0.795	0.140 to 1.450	.02
Rib cage excursion at 3 min	0.247	0.115 to 0.379	< .001
RV/TLC	–2.777	–3.905 to –1.648	< .001

RV = residual volume
TLC = total lung capacity

ment of abdominal expiratory muscles. Recruitment of abdominal expiratory muscles helps attenuate the chest wall hyperinflation during exercise in normal young subjects; however, it may be ineffective and even energy wasting in COPD patients.[19,24,25] Aliverti et al[24] found that using abdominal muscles during expiration may decrease exercise tolerance, because blood flow to these muscles increases to meet the increased oxygen consumption and thereby reduces the blood flow and thus oxygen available to the leg muscles.[26] Another study[25] also found that greater activation of abdominal expiratory muscles in moderate COPD patients did not improve exercise tolerance.

The phase angles, which measure thoraco-abdominal asynchrony, measured at rest in normal individuals (10.5 ± 1.1°) and subjects with moderate COPD (14 ± 1.1°) in our study were comparable to that reported by Alves et al[3] (11.95°). The phase angle was greater in subjects with severe COPD (24.4 ± 1.7°). The phase angle increased within the first minute of the 6MWT in all 3 groups, to 25–30°. The phase angle quickly returned to baseline in normal individuals as the 6MWT continued, but it remained large in subjects with COPD during the entire 6MWT. In the study of Alves et al,[3] which included moderate-severe COPD subjects (FEV_1 = 42.6%), the magnitude of the phase angle was independent of the exercise levels (~22°). These data indicate that subjects with moderate to severe COPD were not able to compensate thoraco-abdominal asynchrony to support exercise. The mechanisms for this, however, remain unclear. Gosselink et al[22] demonstrated that diaphragmatic breathing was associated with more asynchronous breathing in patients with COPD. Sharp and co-workers[4,27] speculated that the reason for the asynchronous motion is related to dynamic hyperinflation and consequent diaphragm flattening and dysfunction. On the other hand, Jubran et al[28] showed that the primary factor contributing to asynchronous motion in patients with COPD is airway resistance, not hyperinflation. Our study could not differentiate the relative contribution of airway resistance and hyperinflation, but we did note that there was no correlation between the phase angle and RV/TLC ratio.

There were some limitations in our study. First, there could be interference of the abdominal RIP signals from leg motion. The artifacts may be reduced by a garment embedded portable RIP device. Rotation or flexion/extension of the spine or changes in sterno-umbilical distance also could alter breathing volume during exercise but not be detected by the present method. Second, we did not measure dynamic hyperinflation during walking test. Third, without electromyography we do not know the relative contribution of recruitment of diaphragmatic breathing and abdominal expiratory muscle activities to increased abdominal excursion. Future investigations will be needed to clarify their impact on thoraco-abdominal asynchrony and exercise tolerance.

Conclusions

With RIP we were able to quantify thoraco-abdominal asynchrony in a large group of patients with moderate and severe COPD during the 6MWT, and show that thoraco-abdominal asynchrony, primarily due to limited rib cage excursion, occurred early during the test. Strategies during pulmonary rehabilitation that aim at improving rib cage excursion could further enhance exercise tolerance in these patients.

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