

Comparison of breathing patterns during exercise in patients with obstructive and restrictive ventilatory abnormalities

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Abstract—Patients with obstructive and restrictive ventilatory abnormalities suffer from exercise intolerance and dyspnea. Breathing pattern components (volume, flow, and timing) during incremental exercise may provide further insight in the role played by dynamic hyperinflation in the genesis of dyspnea. This study analyzed the breathing patterns of patients with obstructive and restrictive ventilatory abnormalities during incremental exercise. It also explored breathing pattern components with dyspnea at maximum oxygen uptake (VO_2 max). Twenty patients, thirteen obstructive patients (forced expiratory volume $38\% \pm 13\%$ predicted, forced expiratory volume in 1 s/forced vital capacity ratio $39 \pm 8\%$), and seven restrictive patients (forced vital capacity $55 \pm 16\%$ predicted, forced expiratory volume in 1 s/forced vital capacity ratio $84\% \pm 11\%$) performed symptom-limited incremental exercise tests on a cycle ergometer with breath-by-breath determination of ventilation and gas exchange parameters. Breathing patterns were analyzed at baseline, 20, 40, 60, 80, and 100 percent of VO_2 max. Dyspnea was measured at end-exercise with a 100 mm visual analogue scale. The timing ratio of inspiratory to expiratory time (T_I/T_E) and the flow ratio of inspiratory flow to expiratory flow ratio (\dot{V}_I/\dot{V}_E) were different ($p < 0.008$) between obstructive and restrictive patients at all exercise intensity levels. The timing components of expiratory time (T_E) and inspiratory time to total time (T_I/T_{TOT}) were significantly different ($p < 0.008$) at baseline and maximum exercise. Dyspnea scores were not significantly different. For obstructive patients, correlations were noted between T_I/T_E , \dot{V}_I/\dot{V}_E , T_I/T_{TOT} and dyspnea ($p < 0.05$). Breathing pattern-timing components, specifically T_I/T_E , in patients with obstructive and restrictive ventilatory abnormalities during exercise provided

further insight into the pathophysiology of the two conditions and the contribution of dynamic hyperinflation to dyspnea.

Key words: breathing pattern, dyspnea, exercise, obstructive ventilatory abnormality, restrictive ventilatory abnormality.

INTRODUCTION

Patients with obstructive and restrictive ventilatory abnormalities suffer from dyspnea and exercise limitation. Dyspnea, a complex symptom with multilayered pathophysiology [1], remains the most distressing symptom for those with progressive obstructive and restrictive lung disease. Furthermore, dyspnea is debilitating with

Abbreviations: ANOVA = analysis of variance, CI = confidence interval, COPD = chronic obstructive pulmonary disease, VAS = visual analogue scale, VO_2 max = maximum oxygen uptake.

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significant impact on health-related quality of life [2]. Dyspnea management has focused on pharmacologic therapies, with limited benefit. Nonpharmacologic approaches, such as breathing strategies and positioning, are recognized for their capability to provide dyspnea relief but are underused [3].

The breathing patterns of patients with obstructive and restrictive lung disease during exercise are likely to be important contributory factors in the genesis of dyspnea. Both groups are ventilatory-limited during exercise with high breathing frequency (f_R) and high minute ventilation (V_E). Obstructive patients are able to maintain or increase their tidal volume (V_T), while restrictive patients quickly become tachypneic with their V_T encroaching on their inspiratory capacity. Cardiac status does not usually limit exercise performance. This study analyzed the breathing patterns of patients with obstructive and restrictive ventilatory abnormalities during incremental exercise for a better understanding of the relationships among ventilatory abnormalities, breathing pattern changes with dynamic hyperinflation, and dyspnea. We reviewed our experience with these two groups of patients during exercise, with a focus on the timing and flow parameters of breathing patterns. We then explored relationships between these parameters and dyspnea.

MATERIALS AND METHODS

Study Subjects

The inclusion criteria for patients with an obstructive ventilatory abnormality were a forced expiratory volume in 1 s of less than 70 percent of the predicted value and forced expiratory volume in 1 s/forced vital capacity ratio less than 70 percent [4]. The inclusion criteria for patients with a restrictive ventilatory abnormality were a forced vital capacity of less than 70 percent of the predicted value and forced expiratory volume in 1 s/forced vital capacity ratio greater than 70 percent [4]. These values represent standard spirometric criteria for obstructive and restrictive ventilatory defects. The institutional review board approved the study as an analysis of existing data.

Study Design

This study involved a consecutive retrospective review of maximal exercise tests performed in the clinical exercise physiology laboratory at a large university-based hospital in southern California over a period of

3 years (1995–1998). Each of these studies provided an array of physiological variables with which to evaluate the subject in terms of aerobic capacity, cardiovascular response, ventilatory response, and gas exchange response to symptom-limited maximal exercise. Each exercise study was preceded by spirometry and measurement of maximal voluntary ventilation. Patients with only obstructive or restrictive ventilatory abnormalities were selected for breathing pattern analysis. Minimal duration of the exercise phase from the end of warm-up to the start of recovery was set at 4 min to allow sufficient data points for analysis.

Methods

The symptom-limited maximal incremental exercise tests were all performed with the use of a standard protocol administered by the same staff on an electromagnetically braked cycle ergometer (Ergoline, 800S). This protocol consisted of a period of equilibration at rest, breathing through the mouthpiece, followed by unloaded pedaling for 3 min, then a ramp increase in work rate to symptom-limited maximum. The rate of work rate increment was determined at the time of testing for each individual based on clinical evaluation of his or her level of impairment or physical fitness with the goal of obtaining 10 min of incremental exercise data. Ventilation and gas exchange were continuously measured with the use of a metabolic cart (SensorMedics 2900). The physiological indexes were displayed graphically and printed in tabular format for subsequent analysis. Immediately after cessation of exercise, breathlessness was measured with a horizontal 100 mm visual analogue scale (VAS). The line was anchored at one end (0 mm) with the words “not at all breathless” and at the other end (100 mm) with the words “extremely breathless.” All subjects were asked to mark the line at a point that best described their breathlessness at maximum exercise. The psychometric properties of the VAS for measuring breathlessness have been established in similar clinical populations [5,6].

Analysis

Breathing patterns were assessed in terms of V_E , V_T , f_R , inspiratory time, expiratory time, inspiratory time to expiratory time, total breath time, inspiratory time to total time, mean inspiratory flow, mean expiratory flow, and mean inspiratory flow to expiratory flow. These variables were determined during unloaded pedaling and at 20, 40,

60, 80, and 100 percent of VO_2 max by averaging three consecutive breaths at each level of exercise intensity.

Descriptive and inferential statistical analyses were performed with SPSS, (Statistical Package for the Social Sciences) version 10.0 [7]. The timing, volume, and flow components of the breathing pattern were compared between obstructive and restrictive patients at different exercise intensities with the use of analysis of variance (ANOVA). Bonferroni corrections were used to account for multiple comparisons at six exercise intensities. Pearson product-moment correlation was used to explore the relationships between indexes of breathing pattern and dyspnea. Breathing pattern components at maximal exercise that might explain the variance in dyspnea were explored with multiple linear regressions.

RESULTS

Data were obtained from 13 patients with obstructive ventilatory abnormalities and 7 patients with restrictive ventilatory abnormalities. The selected patients were considered “ventilatory limited” as defined by the conventional criterion of their maximum minute ventilation being within $15 \text{ L}\cdot\text{min}^{-1}$ of their previously measured maximal voluntary ventilation [8]. **Table 1** shows demographic and clinical information for these subjects. Smoking-related chronic obstructive pulmonary disease (COPD) was the clinical diagnosis for all patients with

obstructive ventilatory abnormalities. The clinical diagnoses for the restrictive ventilatory abnormalities were pulmonary fibrosis, either idiopathic or related to scleroderma or radiotherapy for lung cancer. The average duration of the exercise phase from the end of warm-up to the start of recovery was 5.8 min for the obstructive patients and 5.6 min for the restrictive patients. Breathlessness was the first stated reason for exercise termination for 11 of 13 obstructive patients and 4 of 7 restrictive patients. Other reasons for exercise termination were fatigue (generalized and leg fatigue), anxiety, and bigeminy.

The volume, flow, and timing components of the breathing pattern were compared during unloaded pedaling and at five levels of exercise intensity. The traditional parameters of breathing pattern, i.e., \dot{V}_E , \dot{V}_T , and f_R did not distinguish between the two patient groups (**Table 2**). During incremental exercise, while \dot{V}_T tended to remain smaller and f_R higher in the restrictive group, the differences were generally not statistically significant. Comparison of \dot{V}_E shows the similar ventilatory response between the two groups (**Figure 1**). **Table 3** shows the flow components of breathing pattern along with inspiratory flow/expiratory flow ratio (\dot{V}_I/\dot{V}_E). Neither the inspiratory nor the expiratory flows differed between the two groups, but \dot{V}_I/\dot{V}_E was distinctly different. The timing components of the breathing pattern are shown in **Table 4**. The clearest distinction between the obstructive and restrictive groups can be seen in terms of \dot{V}_I/\dot{V}_E and inspiratory to expiratory time (T_I/T_E). Both ratios were consistently different at unloaded pedaling and all levels of exercise intensity. In **Figure 2**, the differences in T_I/T_E were most pronounced at 80 percent (0.49, 95% CI [confidence interval] 0.14 to 0.72, $p = 0.002$) and 100 percent (0.53, 95% CI 0.30 to 0.83, $p < 0.000$) of VO_2 max. The differences in T_I/T_E ratios between the two groups largely are due to longer expiratory time in the obstructive group as seen in **Table 4**.

Dyspnea scores at maximum exercise were not significantly different ($p = 0.39$) between obstructive patients (mean \pm SEM [standard error of mean] 77 ± 5) and restrictive patients (68 ± 11). **Table 5** shows correlation coefficients for the various parameters of breathing pattern and dyspnea at maximum exercise. The timing components, T_I/T_E and T_I/T_{TOT} , showed a significant negative correlation with dyspnea in the obstructive patients ($r = 0.57$, $p = 0.04$), and a positive correlation with \dot{V}_I/\dot{V}_E . By multiple linear regression analysis, T_I/T_E and \dot{V}_T at maximal exercise accounted for 43 percent of

Table 1.

Demographic and physiological characteristics of subjects. Values indicate mean \pm standard deviation.

Characteristics	Obstructive	Restrictive
Number (male/female)	13 (6/7)	7 (2/5)
Age (yr)	68 ± 5	68 ± 19
MVV ($\text{L}\cdot\text{min}^{-1}$)	41 ± 20	57 ± 15
FEV ₁ ($\text{L}\cdot\text{min}^{-1}$)	0.97 ± 41	1.46 ± 40
FEV ₁ % Predicted	38 ± 13	66 ± 23
FEV ₁ /FVC %	39 ± 8	84 ± 11
FVC % Predicted	69 ± 18	55 ± 16
VO_2 max ($\text{L}\cdot\text{min}^{-1}$)	0.95 ± 0.40	0.80 ± 0.20
VO_2 max % Predicted	55 ± 22	56 ± 22

MVV = maximum voluntary ventilation

FEV₁ % predicted = forced expiratory volume in 1 s percent predicted

FEV₁/FVC % = forced expiratory volume in 1 s/forced vital capacity ratio

FVC % predicted = forced vital capacity percent predicted

VO_2 max = maximal oxygen uptake

Table 2.

Breathing pattern analysis at baseline, 20, 40, 60, 80, and 100 percent VO_2 for patients with obstructive (O) or restrictive (R) ventilatory abnormalities. Traditional breathing pattern parameters are minute ventilation (V_E), breathing frequency (f_R), and tidal volume (V_T). Values are mean \pm standard error of the mean.

% VO_2 max	V_E ($\text{L}\cdot\text{min}^{-1}$)		f_R (min^{-1})		V_T (L)	
	O	R	O	R	O	R
Base	19.8 \pm 2.2	15.4 \pm 2.2	22 \pm 1	24 \pm 2	0.92 \pm 0.08	0.64 \pm 0.07
20	23.6 \pm 1.8	20.8 \pm 3.2	24 \pm 1	30 \pm 3	1.01 \pm 0.10	0.70 \pm 0.07
40	27.0 \pm 2.2	24.1 \pm 3.0	25 \pm 1	32 \pm 3	1.09 \pm 0.10	0.77 \pm 0.07
60	27.8 \pm 3.1	27.4 \pm 3.6	27 \pm 1	32 \pm 3	1.19 \pm 0.12	0.86 \pm 0.09
80	30.4 \pm 3.8	33.0 \pm 4.7	29 \pm 2	37 \pm 3	1.23 \pm 0.12	0.90 \pm 0.10
100	39.8 \pm 4.2	37.4 \pm 4.9	32 \pm 2*	41 \pm 2	1.23 \pm 0.11	0.91 \pm 0.10

Base = unloaded pedaling

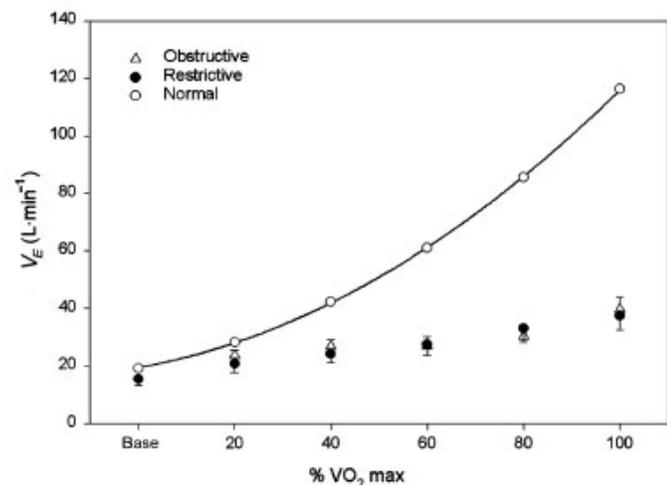
* $p < 0.05$ with Bonferroni corrections for six comparisons (critical value of $p = 0.008$)

VO_2 max = maximal oxygen uptake

the variance in dyspnea for obstructive patients ($R^2 = 0.43$, $p = 0.06$). The same model was not significant for the restrictive patients ($R^2 = 0.30$, $p = 0.48$).

DISCUSSION

This study highlights the differences in breathing patterns during incremental exercise between patients with obstructive and restrictive ventilatory abnormalities. The

**Figure 1.**

Relationship between minute ventilation (V_E) and exercise intensity relative to maximum oxygen (% VO_2 max) subjects with obstructive (Δ) and restrictive (\bullet) ventilatory abnormalities. Reference values of normal (\circ) subjects (based on unpublished laboratory data) are shown with their regression (---).

differences were most noticeable in examination of the timing components of breathing patterns. The inspiratory to expiratory ratio and flow ratio differences were significantly different at all levels of exercise, with the magnitude of difference most pronounced at maximal exercise. For patients with obstructive ventilatory abnormalities, T_I/T_E was consistently lower and \dot{V}_I/\dot{V}_E was consistently higher than for those with restrictive ventilatory abnormalities. The \dot{V}_I/\dot{V}_E is similar to T_I/T_E ; it incorporates both inspiratory and expiratory timing parameters. It highlights the contribution of volume as well and thus is a helpful indicant of the overall changes that occur with increasing exercise intensity. The T_I/T_{TOT} data show consistently lower proportion of inspiratory time in relation to total breath cycle time (below 0.5) for obstructive patients as compared to the restrictive patients who spend a greater proportion of the breath cycle in inspiration.

The breathing patterns that we observed for the obstructive group generally confirm findings previously noted at rest and with increased workloads for those with COPD [9–12]. The changes in breathing pattern with incremental exercise include increased f_R , modest changes in V_T , shorter expiratory times, and doubling of flow rates. Interestingly, the conventionally studied breathing pattern components of V_E , f_R , and V_T during incremental exercise did not demonstrate differences between conditions as well as the timing components. As seen in **Figure 1**, V_E was comparable at each exercise intensity. Only f_R at maximal exercise was significantly different (**Table 2**).

Table 3.

Ventilatory flow analysis at baseline, 20, 40, 60, 80, and 100 percent VO_2 for patients with obstructive (O) or restrictive (R) ventilatory abnormalities. Values are mean \pm standard error of the mean.

% VO_2 max	V_T/T_I ($\text{L}\cdot\text{s}^{-1}$)		V_T/T_E ($\text{L}\cdot\text{s}^{-1}$)		V_I/V_E	
	O	R	O	R	O	R
Base	0.80 \pm 0.10	0.47 \pm 0.09	0.58 \pm 0.05	0.65 \pm 0.09	1.36 \pm 0.13*	0.76 \pm 0.15
20	0.90 \pm 0.10	0.65 \pm 0.15	0.67 \pm 0.05	0.81 \pm 0.08	1.39 \pm 0.12*	0.79 \pm 0.16
40	1.05 \pm 0.11	0.82 \pm 0.14	0.77 \pm 0.07	0.82 \pm 0.06	1.47 \pm 0.11*	0.97 \pm 0.11
60	1.27 \pm 0.13	0.93 \pm 0.14	0.86 \pm 0.10	0.92 \pm 0.10	1.66 \pm 0.15*	1.00 \pm 0.08
80	1.37 \pm 0.16	1.10 \pm 0.19	0.96 \pm 0.12	1.15 \pm 0.15	1.55 \pm 0.12*	0.95 \pm 0.10
100	1.69 \pm 0.19	1.16 \pm 0.16	1.12 \pm 0.13	1.36 \pm 0.18	1.55 \pm 0.09 [†]	0.87 \pm 0.06

Base = unloaded pedaling
 * $p < 0.05$ with Bonferroni corrections for six comparisons (critical value of $p = 0.008$)
[†] $p < 0.01$ with Bonferroni corrections for six comparisons (critical value of $p = 0.002$)
 V_T/T_I = inspiratory flow
 V_T/V_E = expiratory flow
 V_I/V_E = inspiratory flow/expiratory flow
 VO_2 max = maximal oxygen uptake

Table 4.

Ventilatory timing analysis at baseline, 20, 40, 60, 80, and 100 percent VO_2 for patients with obstructive (O) or restrictive (R) ventilatory abnormalities. Values are mean \pm standard error of the mean.

% VO_2 max	T_I (s)		T_E (s)		T_I/T_E		T_{TOT} (s)		T_I/T_{TOT}	
	O	R	O	R	O	R	O	R	O	R
Base	1.29 \pm 0.12	1.55 \pm 0.18	1.62 \pm 0.11*	1.06 \pm 0.15	0.82 \pm 0.08*	1.65 \pm 0.28	2.91 \pm 0.18	2.61 \pm 0.20	0.44 \pm 0.02*	0.59 \pm 0.04
20	1.21 \pm 0.13	1.32 \pm 0.22	1.49 \pm 0.11	0.90 \pm 0.10	0.77 \pm 0.06*	1.54 \pm 0.26	2.58 \pm 0.17	2.21 \pm 0.27	0.47 \pm 0.04	0.58 \pm 0.04
40	1.14 \pm 0.15	1.04 \pm 0.13	1.44 \pm 0.11	0.96 \pm 0.10	0.72 \pm 0.06*	1.14 \pm 0.15	2.47 \pm 0.14	2.00 \pm 0.21	0.46 \pm 0.04	0.52 \pm 0.03
60	1.01 \pm 0.12	0.99 \pm 0.10	1.44 \pm 0.12	0.96 \pm 0.09	0.67 \pm 0.07*	1.05 \pm 0.10	2.34 \pm 0.13	1.95 \pm 0.18	0.44 \pm 0.05	0.51 \pm 0.02
80	0.98 \pm 0.11	0.88 \pm 0.09	1.38 \pm 0.16	0.81 \pm 0.07	0.69 \pm 0.05 [†]	1.13 \pm 0.12	2.25 \pm 0.22	1.69 \pm 0.15	0.45 \pm 0.04	0.52 \pm 0.02
100	0.75 \pm 0.03	0.80 \pm 0.03	1.17 \pm 0.09*	0.69 \pm 0.06	0.68 \pm 0.05 [†]	1.21 \pm 0.12	1.92 \pm 0.12	1.49 \pm 0.08	0.40 \pm 0.01 [†]	0.54 \pm 0.02

Base = unloaded pedaling
 * $p < 0.05$ with Bonferroni corrections for six comparisons (critical value of $p = 0.008$)
[†] $p < 0.01$ with Bonferroni corrections for six comparisons (critical value of $p = 0.002$)
 T_I = inspiratory time
 T_E = expiratory time
 T_I/T_E = inspiratory time/expiratory time
 T_{TOT} = total breath time (s)
 T_I/T_{TOT} = duty cycle
 VO_2 max = maximal oxygen uptake

A preferential increase in f_R rather than V_T in patients with restrictive ventilatory abnormalities has been previously noted [13,14]. Our restrictive patients with restrictive ventilatory abnormalities had smaller V_T at baseline and tended to have higher f_R during exercise as compared to those with obstructive ventilatory abnormalities. Presumably, adopting a more rapid, shallower breathing pattern optimizes work of breathing and helps avoid diaphragmatic muscle fatigue. As a consequence of the higher f_R , the total breath time tended to be shorter compared to the patients with obstructive ventilatory abnormalities. Both inspiratory and expiratory times from 40 percent to maximal exercise were shorter in the restrictive group compared with the obstructive group. The timing difference was more pronounced for expiratory time. Shorter expiratory times com-

pared to inspiratory times in the restrictive group have been previously noted [14]. This difference may not be appreciated if only the duty cycle, T_I/T_{TOT} , is considered.

When normal subjects exercise, V_T increases both as a result of increased end-inspiratory lung volume and decreased end-expiratory lung volume. The fall in end-expiratory lung volume, which is a minor but important contribution to the increased V_T , is thought to be facilitated by expiratory muscle recruitment. O'Donnell and Webb demonstrated normal breathing patterns and showed important differences in patients with COPD [15]. Increased airway resistance slows expiratory flow, prolonging lung emptying. Furthermore, airway collapse, especially in patients with emphysema, causes air trapping and prevents complete lung emptying. During exercise, as breath time shortens, insufficient time for expiration

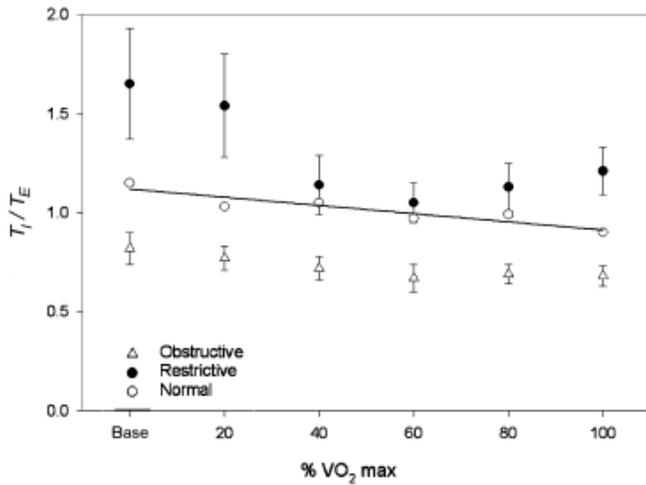


Figure 2.

Relationships between the ratio of inspiratory to expiratory time (T_I/T_E) and exercise intensity relative to maximum oxygen uptake (% VO_2 max) in subjects with obstructive (Δ) and restrictive (\bullet) ventilatory abnormalities. Reference values of normal (\circ) subjects (based on unpublished laboratory data) are shown with their regression line (--).

compounds these problems, resulting in dynamic hyperinflation as manifested by an increase in end-expiratory lung volume with increased end-inspiratory lung volume. This phenomenon is thought to contribute to exercise limitation by constraining the increase in V_T and forcing operational lung volumes toward an unfavorable portion of the compliance curve for the respiratory system. The resulting increase in elastic work contributes to a vicious cycle of worsening breathing efficiency.

By contrast, in subjects with restrictive ventilatory abnormalities either because of reduced lung or chest wall compliance or because of respiratory muscle weakness, there may be insufficient time for adequate inspiration as f_R increases and T_{TOT} decreases. The decreased inspiratory flow (V_T/T_I) as compared to obstructive patients' V_T/T_I reflects restricted lung expansion (**Table 3**). Marciniuk and colleagues found that end-expiratory lung volume did not fall significantly during exercise in interstitial lung disease [16]. Markovitz and Cooper drew attention to the changes in end-inspiratory and end-expiratory lung volumes with respect to the level of V_E in patients with interstitial lung disease [17]. They identified a fall in end-inspiratory lung volume and end-expiratory lung volume toward maximal exercise and referred to this phenomenon as "dynamic hypoinflation." Dynamic hypoinflation, caused by inadequate time for lung inflation at a time of increased ventilatory demand, may limit exercise capacity and contribute to the sensation of dyspnea in those with restrictive ventilatory abnormalities.

The timing components, T_I/T_E , \dot{V}_I/\dot{V}_E , and T_I/T_{TOT} , further underscore our current understanding of these exercise-associated changes in respiratory mechanics. Increases in dynamic hyperinflation for the obstructive patient are associated with proportionately slower expiratory flow rates as compared to inspiratory flow rates and would be manifested as increasing \dot{V}_I/\dot{V}_E . In restrictive patients, exercise is associated with increases in inspiratory flow, resulting in \dot{V}_I/\dot{V}_E ratios that approach unity and a T_I/T_{TOT} closer to 0.5. The assessment of the changes in end-inspiratory and end-expiratory lung volume observed in dynamic hyperinflation requires additional equipment and measurement, which is not usually performed in most

Table 5.

Relationship of breathing pattern components with dyspnea at maximal exercise.

Ventilatory Abnormality	V_E	V_T	f_R	T_I	T_E	T_I/T_E	T_{TOT}	T_I/T_{TOT}	V_T/T_I	V_T/T_E	\dot{V}_I/\dot{V}_E
Obstructive											
r	-0.33	-0.13	-0.46	-0.02	0.42	-0.57*	0.33	-0.58*	-0.11	-0.48	0.59*
p	0.26	0.67	0.12	0.96	0.15	0.04*	0.27	0.04*	0.73	0.10	0.03*
Restrictive											
r	0.21	0.04	0.22	-0.26	-0.56	0.48	-0.54	0.49	0.12	0.31	-0.50
p	0.65	0.94	0.65	0.57	0.19	0.27	0.21	0.27	0.49	0.50	0.25
V_E = minute ventilation	T_E = expiratory time					\dot{V}_I/\dot{V}_E = inspiratory flow/expiratory flow					
V_T = tidal volume	T_I/T_E = inspiratory/expiratory time					r = correlation coefficient					
f_R = breathing frequency	T_{TOT} = total breath time					p values = significance					
T_I = inspiratory time	\dot{V}_I/\dot{V}_E = inspiratory flow/expiratory flow					* $p < 0.05$					

exercise laboratories. These timing components could provide another avenue to assess these changes and is attractive given its derivation from current measures or derived parameters.

We also compared breathing pattern parameters with dyspnea as quantified by VAS at maximum exercise. Significant correlations were found between dyspnea and the timing components of T_I/T_E and T_I/T_{TOT} as well as \dot{V}_I/\dot{V}_E for subjects with obstructive ventilatory abnormalities ($p = 0.04$). We did not find a significant relationship between mean expiratory flow and dyspnea as reported by Eltayara and colleagues in those with COPD [18]. These contradictory findings could be explained by the use of different methods for measuring expiratory flow and dyspnea. Eltayara and colleagues used an application of negative expiratory pressure to study expiratory flow at rest and measured dyspnea using a modified Medical Research Council dyspnea scale [18,19]. Our study derived mean expiratory and inspiratory flows from measured tidal volumes and the time components of the breath. We also found that while inspiratory flow rates were not associated with dyspnea, \dot{V}_I/\dot{V}_E was associated with dyspnea. To our knowledge, other investigators have not explored the relationship between T_I/T_E , \dot{V}_I/\dot{V}_E , and dyspnea.

Studies of breathing pattern and dyspnea have implications for the teaching of breathing strategies. Since T_I/T_E and V_T at maximal exercise explained 43 percent of the dyspnea variation for obstructive and not restrictive patients, the ventilatory disorder should direct the choice of breathing strategy. Prolonged expiratory times in relation to inspiratory times would likely decrease air trapping and reduce dynamic hyperinflation for those with obstructive ventilatory disorders and provide dyspnea relief. The focus on expiratory time may be more effective compared with the usual teaching instructions to increase V_T or slow f_R , since there would be direct emphasis on the breathing parameter more likely to bring dyspnea relief. Our findings suggest the need for further investigation of manipulation of the timing components of the breathing pattern during low-level exercise. Since dynamic hyperinflation is difficult to measure directly, use of noninvasive measures, such as the timing components of T_I/T_E and T_I/T_{TOT} , would be useful.

The retrospective study design and the small number of subjects in each group limit the conclusions that can be drawn from this study. While the patients with ventilatory abnormalities were selected by pulmonary function crite-

ria, the groups were not matched based on gender or body mass index. Dyspnea was measured at maximum exercise only. The small number of subjects in each group may be responsible for Type II errors where there is insufficient power to detect a difference between groups, when such a difference might be present. For example, the expected differences in f_R at baseline were not detected. However, despite the small number of subjects, differences were clearly present for T_I/T_E at all levels of exercise intensity studied.

CONCLUSIONS

Patients with obstructive and restrictive ventilatory abnormalities have similar changes in V_E , f_R , and V_T with incremental exercise. By contrast, analyses of the timing components of breathing pattern were consistently different between subjects with obstructive and restrictive ventilatory abnormalities. Diametrically opposite changes in T_I/T_E and \dot{V}_I/\dot{V}_E provide insight into their different pathophysiological mechanisms and highlight the contribution of dynamic hyperinflation in the genesis of dyspnea. Finally, we demonstrated a relationship between timing components and dyspnea at maximum exercise in subjects with obstructive ventilatory abnormalities.

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