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Difference Between Slow and Forced Vital Capacity and Its Relationship with Dynamic Hyperinflation in Patients with Chronic Obstructive Pulmonary Disease

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Abstract
The aim of the study was to investigate the relationship between slow and forced vital capacity (SVC–FVC) difference with dynamic lung hyperinflation (DH) during the 6-min walking test (6MWT) in subjects with chronic obstructive pulmonary disease (COPD). Twenty-four subjects with COPD (12 males; 67 ± 6 years; forced expiratory volume in first second [FEV_1] 56 ± 18% predicted) performed lung function tests by spirometry and plethysmography. DH was assessed by serial measurements of inspiratory capacity (IC) performed during the 6MWT and defined as $\Delta IC \geq 150$ mL or 10%. IC decrease significantly during the 6MWT (ΔCI: −0.48 ± −0.40 L; $P < 0.0001$), and 18 individuals (75%) presented DH. There was significant difference when comparing IC measured at rest with the other serial IC measurements ($P < 0.0001$). Correlation between the SVC–FVC difference and DH during the 6MWT was $r = -0.38$; $P = 0.06$. The SVC–FVC difference presented only weak correlation with the development of DH during the 6MWT in patients with COPD.

Keywords Pulmonary disease · Chronic obstructive · Respiratory function tests · Vital capacity · Inspiratory capacity · Total lung capacity · Exercise

Introduction

Vital capacity (VC) is an important outcome derived from lung function assessment which can be evaluated through slow vital capacity (SVC) or forced vital capacity (FVC) maneuvers [1]. A few studies described that SVC values are higher than FVC, and the difference between these two variables (SVC–FVC) is related to airflow limitation and air trapping in patients with chronic obstructive pulmonary disease (COPD) [2, 3].

A considerable proportion of individuals with COPD presents an increase in end-expiratory lung volume (EELV) as a consequence also of airflow limitation combined with reduction in elastic recoil, and this combination may lead to lung hyperinflation [4]. Lung hyperinflation may be increased when the respiratory system is stressed, for example, during activities in which there is an increase in ventilatory demand coupled with reduction in expiratory time. This phenomenon is called dynamic hyperinflation (DH) [4].

From a clinical perspective, it is possible to evaluate DH during progressive exercise by performing serial measurements of inspiratory capacity (IC), an accurate measure which reflects changes in EELV [5]. Also from a clinical perspective, an exercise test that can be used to detect DH is the 6-min walking test (6MWT) [6], a relatively simple test widely used to assess exercise (in)tolerance in COPD [7].

Both the SVC–FVC and DH evaluated by the reduction in IC during physical exertion in patients with COPD are related to reduction in the expiratory flow and air trapping; however, the relationship between the SVC–FVC difference assessed by simple spirometry and DH assessed during the 6MWT is unknown. If this correlation is confirmed, it could be assumed that patients with an increased SVC–FVC difference would also be those with DH, which would facilitate the investigation of DH in clinical practice. Thus, the objective of the present study was to investigate the relationship

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between the SVC–FVC difference and DH assessed during the 6MWT in subjects with COPD.

Methods

This cross-sectional and quantitative study recruited subjects from the registers of the Laboratory of Respiratory Physiotherapy Research (LFIP), State University of Londrina (UEL), Brazil, as patients previously involved or interested in being involved in a pulmonary rehabilitation program. As inclusion criteria they presented diagnosis of COPD according to international guidelines [8]; clinical stability (at least 3 months without exacerbation); no indication for long-term oxygen therapy; and absence of neuromuscular or skeletal disorders that could impair the performance of the tests. Subjects were excluded if they were required oxygen supplementation during the tests. The study was approved by the Ethics and Research Committee of the institution (151/2013), and all patients provided informed consent. Assessments were done in two moments: at the first visit, patients had their anthropometric data collected and underwent pulmonary function evaluation. At the second visit, patients performed the 6MWT with concomitant assessment of DH.

Pulmonary Function

The assessment of lung function was performed by spirometry and plethysmography (Vmax, Carefusion, USA), according to the guidelines of the American Thoracic Society and the European Respiratory Society (ATS/ERS) [1, 9], and post-bronchodilator SVC–FVC difference was calculated in liters. Reference values were those proposed for the Brazilian population by Pereira et al. [10] and Neder et al. [11].

DH During the 6MWT

The 6MWT was performed according to the ATS/ERS guidelines [7], and reference values were those by Britto et al. [12]. The largest distance of two tests was used for analysis. DH was evaluated with serial IC measurements by the SVC maneuver following international protocols [1] after the use of a short-acting bronchodilator, since this allowed similar conditions for all patients during the test. At rest, reproducibility was defined as a difference of less than 5% between two maneuvers [1, 5], and the highest reproducible value was considered for analysis. The maneuvers were performed at rest, at the second (2′) and fourth (4′) minutes, 15 s before the end of the test (5′45″), and immediately at the end of the 6MWT. DH was defined as a decrease in IC at least 150 mL or 10% compared to rest [5, 13]. Assessments were done using the Spiropalm portable spirometer (Cosmed, Italy), with a facial mask coupled to the patient.

Statistical Analysis

Data distribution was analyzed by the Shapiro–Wilk test. According to normality in data distribution, data were described as mean and standard deviation or median and interquartile range. Correlation between SVC–FVC difference and DH was verified using the Spearman correlation coefficient. For the comparison of resting IC and lowest IC, the paired Student *t* test was used. One-way ANOVA with Tukey's post hoc was used to compare serial IC measurements during the 6MWT. Statistical significance was set at $P < 0.05$. The statistical analysis was performed using GraphPad Prism 6.0 (GraphPad Software Inc., La Jolla, CA, USA) and Statistical Package for the Social Sciences 22.0 (SPSS Inc., Chicago, USA).

In order to find a correlation of at least 0.60 between the SVC–FVC difference and DH, 20 subjects would be necessary to compose the study sample. This calculation was performed by the BioStat 3.0 software considering an $\alpha = 0.05$, $\beta = 0.80$, and 10% dropout rate.

Results

Out of 28 included patients, 4 did not conclude the assessments due to desaturation during 6MWT [7] and were therefore excluded. In total, 24 patients were analyzed, and characteristics of the sample are described in Table 1. The sample was composed of elderly subjects of both genders, with a BMI characterized as normal to overweight, with the majority of individuals presenting moderate to severe airflow limitation and preserved exercise capacity.

No subject had severe pulmonary hyperinflation verified by the IC/TLC ratio, whereas 9 subjects presented static pulmonary hyperinflation according to TLC values, and 13 subjects presented SVC–FVC difference above 0.20 L, likely indicating the presence of air trapping (Table 1) [14].

IC decreased significantly during the 6MWT (resting IC: 2.22 ± 0.54 L; lowest IC during the test: 1.74 ± 0.48 L; $P < 0.0001$; ΔIC: -0.48 ± -0.40 L), and 18 subjects (75%) presented DH according to the proposed criteria. There were significant differences between resting IC and measurements at 2′ (1.93 ± 0.51 L), 4′ (1.90 ± 0.48 L), 5′45″ (1.88 ± 0.51 L), and immediately at the end of the test (1.92 ± 0.53 L) (Fig. 1). Six patients had the lowest IC measurement at 2′, eight at 4′, six at 5′45″ and four immediately at the end of the 6MWT. A weak positive correlation was observed between the SVC–FVC difference and ΔIC measured during the 6MWT ($r = -0.38$; $P = 0.06$) (Fig. 2). Additionally,

Table 1 General characteristics of the sample

Variables	$n=24$
Age (years)	67 ± 6
Gender (M/F)	12/12
BMI (kg/m^2)	29 ± 5
FEV_1 (l)	1.5 ± 0.4
FEV_1 (% predicted)	56 ± 18
FVC (l)	2.8 ± 0.5
FVC (% predicted)	84 ± 17
SVC (L)	3.2 ± 0.6
SVC (% predicted)	92 ± 22
FEV_1/FVC	52 ± 10
SVC–FVC (l)	0.21 [0.08–0.40]
TLC (l)	6.3 ± 1.4
TLC (% predicted)	113 ± 16
IC/TLC (%)	43 ± 9
RV (l)	2.7 [2.4–3.8]
RV (%)	135 [116–165]
6MWT (m)	459 ± 46
6MWT (% predicted)	88 ± 11
GOLD (I/II/III/IV)	1/12/10/1

Data presented in absolute frequency, mean ± standard deviation or median [interquartile range]

M male, *F* female, *BMI* body mass index, *FEV_1* forced expiratory volume in the first second, *FVC* forced vital capacity, *SVC* slow vital capacity, *TLC* total lung capacity, *IC* inspiratory capacity, *RV* residual volume, *6MWT* 6 min walking test, *GOLD* global initiative for chronic obstructive lung disease

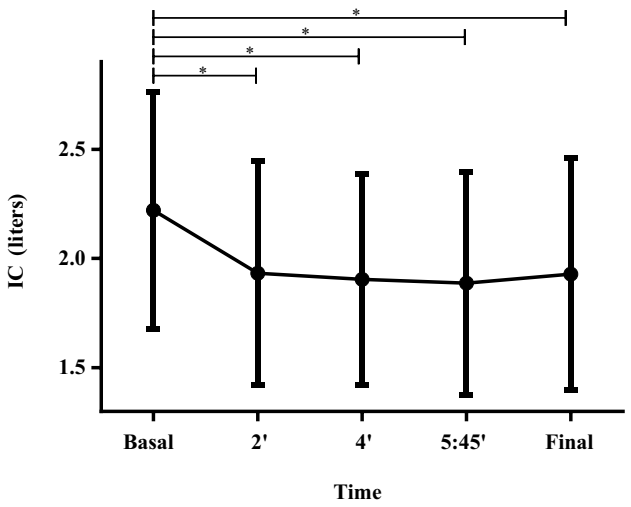

Fig. 1 Comparison between serial IC measurements during 6MWT. *IC* inspiratory capacity. *$P<0.0001$

when the 18 individuals who developed DH were analyzed separately, the exact same correlation was found ($r=-0.38$; $P=0.06$).

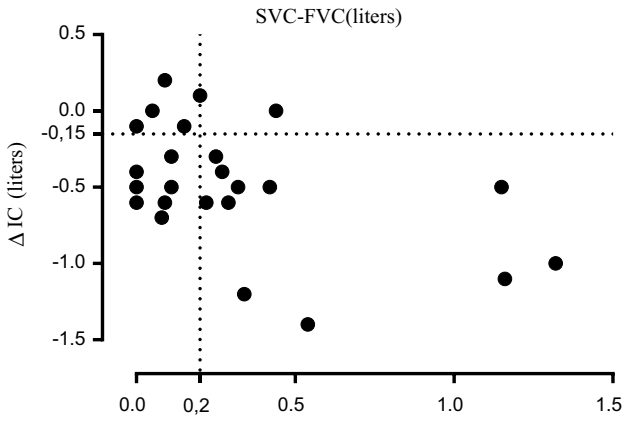

Fig. 2 Correlation between SVC–FVC difference and change in IC during the 6MWT. *SVC–FVC* difference between slow and forced vital capacity, *IC* inspiratory capacity, Δ*IC* difference between resting IC and the lowest IC value during the 6MWT ($r=-0.38$; $P=0.06$). Correlation analyzed by the Spearman coefficient. Dotted lines indicate cutoff values for DH (ΔIC > 150 mL) and air trapping (SVC–FVC > 0.2 L)

Discussion

The main finding of this study is that, in subjects with COPD, SVC–FVC difference (evaluated by simple spirometry) and DH (assessed by serial IC measurements during the 6MWT) are weakly related. A study by Wibmer et al. [15] aimed to compare the correlation between 6MWT and lung volumes before and after the 6MWT in patients with COPD. Lung volumes measured immediately after test were more closely related to walking distance than baseline lung volumes in this population. Similarly, only moderate correlation between SVC–FVC difference and maximal oxygen uptake during a cycle-ergometry test ($r=-0.40$) was described in patients with COPD [16]. These findings suggest that lung volumes assessed by baseline pulmonary function testing at rest provide insufficient information about the ventilatory constrains during exertion. This can be a possible explanation for the weak correlation between SVC–FVC difference and DH during 6MWT.

The fact that 75% of the individuals developed DH during the 6MWT corroborated with previous findings in the literature [6, 15]. There was no difference between the magnitude of the DH assessed by the measurement of serial IC or at the end of the test. During cycle exercise, IC decreases rapidly in the first 2 min and continues to decrease although less abruptly until symptom limitation [17]. The same behavior was observed in IC change during the 6MWT in the present study, and maybe this can be explained by the physiological responses to the 6MWT, in which an increase in cardiac, ventilatory and metabolic variables is observed until the third minute of the test followed by a plateau [18]. However, these results

are not sufficient to support the premises that serial IC assessment during 6MWT is not necessary. It has already been described by O'Donnell et al. [19] that the ΔIC isotime during constant-load symptom-limited cycle exercise correlated better with dyspnea than any other resting or exercise parameter. Thus, future studies that investigate the relationship between DH during the 6MWT with the physiological responses to this test should be encouraged.

Although SVC and FVC are routinely measured in lung function assessment, the SVC–FVC difference has been given little consideration in clinical practice. To our knowledge, there have been no previous studies describing the relationship between SVC–FVC and DH during exercise in patients with COPD. Also, no similar studies involving any other population were found in the literature. Therefore, the present study is the first to investigate this relationship. If these variables were well correlated (which was not the case), we could assume that patients with increased SVC–FVC difference would also be those who present DH and possibly more symptoms during exercise.

Limitations of this study include the fact that few individuals in GOLD stages I and IV were included. However, patients with mild airway obstruction are still unusually referred for pulmonary rehabilitation, which was the target population of this study. Furthermore, patients with very severe disease likely present desaturation during exercise tests [20]. Serial IC measurements during the 6MWT were evaluated with a facial mask, which hindered oxygen supplementation and therefore the inclusion of very severe patients. Perhaps a more heterogeneous sample regarding the degree of disease severity would yield a stronger correlation, since individuals with COPD who have SVC > FVC have worse airflow obstruction than those with SVC ≤ FVC [16]. Another limitation is the fact that our sample was composed by subjects with preserved functional exercise capacity (6MWT: 88 ± 11% predicted) and a BMI characterized as overweight (BMI: 29 ± 5 kg/m^2). Patients with preserved exercise capacity tend to have less respiratory constraints and therefore are less subject to develop DH. Additionally, the combination of obesity and COPD could theoretically provide an advantage through reducing the deleterious effects of DH, since obese patients with COPD have reduced TLC and FRC compared with normal weight patients [21]. Finally, unfortunately no measure of ventilatory variables was available for use, which could be helpful in explaining and discussing the findings. Future studies with a larger number and a wider spectrum of patients are welcome (i.e., including patients with mild and very severe disease).

In conclusion, despite the previously described relationship with airflow limitation and air trapping, the SVC–FVC difference measured by a simple spirometry at rest presented only weak correlation with DH during 6MWT in patients with COPD.

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Compliance with Ethical Standards

Conflict of interest The authors declare that they have no conflict of interest.

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