Inspiratory Capacity and Decrease in Lung Hyperinflation With Albuterol in COPD*

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Study objectives: **Inspiratory capacity (IC) has been proposed as a simple method to assess acute changes in functional residual capacity (FRC) with bronchodilation, assuming that total lung capacity (TLC) is unchanged. This assumption is based on studies using body plethysmography, which may not accurately measure TLC in severely obstructed subjects. The aim of this study is to validate the use of IC measured by optoelectronic plethysmography (OEP) [ICOEP], a noninvasive technique capable of computing changes in absolute lung volumes with great accuracy.**

Methods and measurements: **We studied 13 subjects with COPD in clinically stable condition at baseline and after 200 μg of inhaled albuterol. Changes in lung volumes were obtained from changes in chest wall volume (Vcw) measured by OEP and were compared with those measured by standard techniques.**

Results: **Albuterol treatment caused a small but significant increase in FEV_1 and FVC, a significant decrease of Vcw at FRC (VcwFRC), but no changes of Vcw at TLC (VcwTLC) and breathing pattern variables. The reduction of VcwFRC was not correlated with either spirometric or breathing-pattern variables. IC measured with a pneumotachograph was highly correlated with and not significantly different from ICOEP ($p < 0.001$).**

Conclusions: **A single dose of inhaled albuterol does not significantly modify VcwTLC in subjects with COPD, thus validating the use of IC to measure changes of FRC in the assessment of reversibility of airway obstruction.** ***(CHEST 2002; 122:2009–2014)***

Key words: bronchodilation; functional residual capacity; optoelectronic plethysmography; total lung capacity

Abbreviations: ATS = American Thoracic Society; BF = breathing frequency; FRC = functional residual capacity; IC = inspiratory capacity; ICOEP = inspiratory capacity measured by optoelectronic plethysmography; ICPN = inspiratory capacity measured by a pneumotachograph; OEP = optoelectronic plethysmography; PFT = pulmonary function testing; RV = residual volume; TLC = total lung capacity; Vcw = chest wall volume; VcwFRC = chest wall volume at functional residual capacity; VcwTLC = chest wall volume at total lung capacity; $\dot{V}E$ = minute ventilation; $\dot{V}p30$ = forced expiratory flow at 30% of FVC from a partial flow-volume curve; VT = tidal volume

The American Thoracic Society (ATS) and the European Respiratory Society suggest that the effects of the β_2-agonists on lung function in patients with COPD be assessed by measuring the FEV_1 and FVC.[1,2] Studies in the last decade have, however, stressed the importance of measurement of the operational lung volumes, with special reference to functional residual capacity (FRC) in addition to forced expiratory flows in evaluating the acute bronchodilator response.[3] The decrease of the degree of lung hyperinflation, which is defined in the present article as a decrease in FRC, has been demonstrated to be critically associated with decrease of elastic work of breathing[4] and breathlessness.[5]

Direct measurement of FRC needs sophisticated techniques that are not always available in every pulmonary function testing (PFT) laboratory. In contrast, inspiratory capacity (IC), *ie*, the difference between total lung capacity (TLC) and FRC, can be easily measured even with a simple spirometer, and

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may accurately track the changes in FRC after bronchodilatation if TLC remains constant. Thus, IC has been proposed for inclusion in the criteria for reversibility of airway obstruction.[3,6–8] Nevertheless, accurate physiologic validation of IC for this use has never been done, probably due to the technical difficulties to prove that TLC is stable with the bronchodilator agents. Indeed, even with the best available techniques, such as body plethysmography, TLC cannot be accurately estimated especially when airflow obstruction is severe.[9]

Optoelectronic plethysmography (OEP) is a new noninvasive technique capable of computing with great accuracy and precision changes in absolute lung volumes of the entire chest wall by monitoring the three-dimensional movements of markers placed on the chest and abdominal walls.[10] Its versatility to measure lung volumes under a variety of functional conditions prompted us to turn to this technique with the specific purpose to validate IC for the bronchodilator tests in clinical practice in subjects affected by chronic airflow obstruction.

Materials and Methods

Subjects

We studied 13 subjects affected by COPD, as defined by the criteria of the ATS.[11] Their anthropometric and functional respiratory characteristics are presented in Table 1. All subjects were very well familiar with pulmonary function techniques. To enter the study, the subjects had to be in clinically stable condition for at least 4 weeks before the study, to abstain from bronchodilators for at least 8 h before the study, and to show an arbitrary increase of FEV_1 with albuterol treatment of at least 50 mL. None of the subjects were receiving long-acting bronchodilators. The protocol was approved by our ethics committee, and informed consent was approved prior to the study.

Measurements

Standard spirometry prior to the study was obtained by a water-sealed spirometer (Pulmonet III; SensorMedics; Yorba Linda, CA). FRC was measured by helium-dilution rebreathing technique. Residual volume (RV) was computed by subtracting expiratory reserve volume from FRC, and TLC was computed by adding vital capacity to RV. All the tests were done according to the standards recommended by the ATS.[1] The reference values for spirometry and lung volumes are from Quanjer et al.[2]

Table 1—*Anthropometric Data and Baseline Lung Function*

Variables	Mean ± SD
Age, yr	66 ± 7
Height, cm	173 ± 6
Body mass index	28.6 ± 3.4
FEV_1, % of predicted	45 ± 21
FVC, % of predicted	71 ± 22
FRC, % of predicted	142 ± 32
RV, % of predicted	172 ± 48
TLC, % of predicted	113 ± 10

Chest wall volume (Vcw) was computed by using the OEP system. Details of the technique are reported elsewhere.[10] In brief, four cameras (two cameras placed 4 m in front of the subject, and two cameras placed 4 m behind the subject) tracked the three-dimensional movements of 89 small surface markers attached to the skin of the trunk with double-sided adhesive tape and lit by infrared light-emitting diodes coaxial with the lenses of the cameras. The markers, 5-mm hemispheres coated with reflective paper, were positioned along seven horizontal and vertical lines both anteriorly and posteriorly to the chest wall and abdomen. The OEP data were recorded at a sampling frequency of 25 Hz. The coefficient of variation of the difference between changes in lung volumes measured with OEP method and with spirometry is $< 3.5\%$.[10]

Flow at the mouth was measured by a Fleisch No. 3 pneumotachograph connected to a pressure transducer (± 2 cm H_2O; Validyne Engineering; Northridge, CA). Volume was electrically integrated from the flow signal. Flow and volume signals were synchronized to the kinematic signals of the OEP and sent to a personal computer through an RTI 800 analog-to-digital card for subsequent analysis (Analog Devices; Norwood, MA).

Protocol

Standard spirometry and absolute lung volume measurements were obtained prior to the study. On the study day, the subjects attended the PFT laboratory in the midmorning after avoiding short-acting bronchodilators for at least 8 h and long-acting bronchodilators for 24 h. The preparatory procedures consisted of explanation of the technical aspects of the study to the subjects and positioning of the 89 reflective markers on the surface of the trunk. Then, the subjects seated on a stool in the center of the designated area with the cameras in front and in the back and were requested to breathe regularly. Approximately 10 min later, tidal breathing pattern was recorded for a duration of 4 min on two random occasions. On the first occasion, the subjects wore a nose clip and were connected to a pneumotachograph through a mouthpiece. The measurements were made when the subjects felt comfortable and well adapted to the mouthpiece and nose clip. Breathing signals were simultaneously collected by the pneumotachograph and the OEP system. Then, after four to six regular tidal breaths, the subjects were asked to take a deep breath to TLC in order to have IC measured by the pneumotachograph (ICpn) and IC measured by OEP (ICoep). On the second occasion, the measurements were performed by OEP without nose clip, mouthpiece, and pneumotachograph. All the IC maneuvers were always performed in triplicate.

Forced expiratory flows were measured at least in triplicate during a forced expiration initiated from end-tidal inspiration and terminated to RV (partial forced expiratory maneuver) and from TLC to RV (maximum forced expiratory maneuver) soon after taking a maximum and fast inspiration. The reason for measuring partial flow is that it is more sensitive than maximal flows to detect changes in airway caliber after bronchodilatation than maximal flows.[6,7,12,13] The same measurements were repeated 20 min after inhalation of albuterol, 200 μg, by a metered-dose inhaler with spacer device during a full inspiratory maneuver from RV.

Data Analysis and Statistics

Only regular breaths were used for analysis of breathing pattern. Tidal volume (Vt), inspiratory time, and expiratory time