Performing the Apnea of the Single-Breath Carbon Monoxide Diffusing Capacity*

Relaxation on the Shutter or Full Inspiration With Near Atmospheric Intrapulmonary Pressure?

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Study objectives: **The aim of the study was to measure the single-breath diffusing capacity of the lung for carbon monoxide (DLCOsb) in healthy subjects in the following two conditions originally proposed by the American Thoracic Society (ATS) guidelines: relaxation against the shutter; and full inspiration without straining.**

Setting: **DLCOsb was measured in 76 young adults in duplicate, in the two conditions. Mouth pressure was recorded during all of the trials.**

Results: **The mean (± SD) value of the duplicate DLCOsb measurements was higher when measured with the patient in the nonrelaxed condition than in the relaxed condition (32.65 ± 7.65 vs 31.54 ± 7.11 mL/min/mm Hg, respectively; $p < 0.001$). The mean effective alveolar volume measured during the single-breath maneuver (VAeff) was also higher in the nonrelaxed condition (VAeff: nonrelaxed condition, 5,779 ± 1,093 mL; relaxed condition, 5,596 ± 1,097 mL; $p < 0.001$), at least as a consequence of a higher inspiratory volume (Vin) in the nonrelaxed condition (nonrelaxed condition, 4,378 ± 900 mL; relaxed condition, 4,232 ± 902 mL; $p < 0.001$). Asking the subject performing a DLCOsb maneuver to relax on the shutter during apnea lowers the DLCOsb value by approximately 3.4% in comparison to full inspiration without straining, at least in part because it results in a reduced Vin.**

Conclusion: **These data lend further support to the new European Respiratory Society/ATS Task Force recommendations (full inspiration maintained with near atmospheric intrapulmonary pressure).** ***(CHEST 2006; 130:207–213)***

Key words: carbon monoxide; practice guidelines; pressure; pulmonary diffusing capacity; pulmonary gas exchange; respiratory system

Abbreviations: ATS = American Thoracic Society; COHb = carboxyhemoglobin; DLCOsb = single-breath diffusing capacity of the lung for carbon monoxide; ERS = European Respiratory Society; Hb = hemoglobin; KCOsb = single-breath carbon monoxide diffusing capacity of the lung per unit of alveolar volume; TLC = total lung capacity; VAeff = effective alveolar volume measured during the single-breath maneuver; VC = vital capacity; Vin = inspiratory volume during a single breath

Several factors relating to the equipment used, how the operation is performed, the methods of calculation, and a subject's characteristics can influence the measurement of single-breath diffusing capacity of the lung for carbon monoxide (DLCOsb). Using DLCOsb as an index of pulmonary function requires that the technique be fully standardized. The European Respiratory Society (ERS)/American

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Thoracic Society (ATS) Task Force[1] very recently proposed a standardized methodology for DLCOsb measurement based on earlier statements from the ERS and the ATS.[2,3] Discrepancies between the two previous sets of recommendations included those for measuring alveolar pressure during apnea. During the maneuver, the patient is invited to produce a full inspiration to total pulmonary capacity before the shutter is closed. During the following 10 s of apnea, the patient may be instructed to release the inspiratory effort against the shutter or to maintain a full inspiratory position with a persistent inspiratory muscle contraction. In the first case, the muscle relaxation produces an increase in the alveolar pressure, depending on the pulmonary volume, the total respiratory compliance, and the effectiveness of the muscle relaxation. If the maneuver is performed with an open glottis, the mouth pressure represents the alveolar pressure; if not, the glottis forms an internal shutter, and so mouth pressure is not dependent on respiratory system compliance. In the second case, the alveolar pressure remains close to the atmospheric pressure. Using the data from the study by Smith and Rankin,[4] it is possible to calculate a 17.4% decrease in DLCOsb during a Valsalva maneuver with an 86 cm H_2O increase in mouth pressure. Suzuki et al[5] have also demonstrated an 8% decrease in DLCOsb during a 30-cm H_2O increase in mouth pressure. Even in healthy subjects, it is difficult to predict alveolar pressure during inspiratory muscle relaxation against the shutter, because at high pulmonary volume the respiratory system pressure-volume curve is flat, and a small deviation from the full inspiratory position may produce a large decrease in alveolar pressure even if the total respiratory compliance is normal. Furthermore, relaxation is difficult to achieve, and the residual effect of respiratory muscle activity (inspiratory or expiratory) on alveolar pressure may largely overcome the effects of the passive mechanical characteristics of the respiratory system. Finally, as the subject can relax on the closed glottis instead of the mechanical shutter of the respiratory apparatus, measuring the mouth pressure does not necessarily indicate whether the respiratory technician's directions are being followed in the maneuver.

Any increase in alveolar pressure is liable to decrease DLCOsb at least through a decrease in capillary blood volume.[6] To a lesser degree, an alveolar pressure increase may decrease DLCOsb through the increase in the alveolar pressure of O_2.[7]

An earlier ATS recommendation let the patient relax on the shutter or on the glottis or maintain a full inspiration, as follows: "the subject . . . should either try to relax against a closed glottis or a closed valve during the breath-hold or else maintain a full inspiratory position without straining. Excessive positive or negative intrathoracic pressure (*ie*, obvious Valsalva or Muller maneuvers) should be avoided during breath-hold."[2] The new recommendation issued by the ERS/ATS Task Force[1] indirectly avoids relaxation, as follows: "The intrapulmonary pressure during the breath hold should thus be near atmospheric, and this is best accomplished by having the subject voluntarily maintain full inspiration using only the minimal effort necessary."

The aim of the study was to measure DLCOsb in a group of healthy subjects in the two conditions originally proposed in the ATS guidelines (*ie*, relaxation against the shutter and full inspiration without straining), and to determine how the instruction is carried out and whether it affects the measurement. Our results support the ERS/ATS Task Force choice of standardization of single-breath determination of carbon monoxide uptake in the lung.

Materials and Methods

Subjects and Protocol

Data were collected on medical students during practical teaching sessions following a procedure that was approved by the University Council. The 86 students in the class (second year of medical school) gave their informed consent and served as volunteers, but only the data of the 76 students (50 women and 26 men; age range, 18 to 30 years; mean [± SD] age, 20.4 ± 1.4 years) with no history of cardiac or respiratory disease were used in the study.

The tests were conducted between 10:00 AM and 1:30 pm. All measurements were completed in 2 months. The linearity of the carbon monoxide and helium analyzers was checked before the session. Error was $< 1\%$ full scale for both analyzers.

As the measurements were taken during a teaching session, the students had to come to the laboratory in pairs. Subjects underwent whole-body plethysmography. Then the first student of the pair trained for the DLCOsb measurements undergoing five practice trials in condition 1 (relaxed or nonrelaxed) followed by five practice trials in condition 2 (relaxed or nonrelaxed). In order to reproduce the usual conditions of respiratory functional testing, no effort was made for the students to achieve a precise mouth pressure, and no visual feedback control of mouth pressure was given. The aim was to have them "clinically" relax in the relaxed condition (this was hardest to obtain). The instructions were explained with reference to respiratory physiology, as follows: "you relax if your lungs empty spontaneously when the shutter opens." Subjects were also encouraged to let their shoulders droop and their abdomen puff out. Since all of them were familiar with the respiratory physiology, they were reminded that relaxing on the shutter should increase mouth pressure, while maintaining an inspiratory effort without straining ought to leave the mouth at atmospheric pressure.

Two technically acceptable measurements of DLCOsb were then made in each condition in the same order as for training (condition 1 then condition 2). The second student of the pair subsequently underwent with the same sequence (five training trials in each condition then two technically acceptable measurements of DLCOsb in each condition) except that the order was