

# Noninvasive Measurement of Carboxyhemoglobin Levels for Adjustment of Diffusion Capacity Measured During Pulmonary Function Testing

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**BACKGROUND:** The diffusing capacity of the lungs for carbon monoxide ( $D_{LCO}$ ) is commonly measured during pulmonary function testing (PFT). Although adjustment of the measured  $D_{LCO}$  for an elevated baseline carboxyhemoglobin level is recommended, carboxyhemoglobin is not routinely measured, which may reduce the accuracy of  $D_{LCO}$  measurements. We sought to assess the utility of routine carboxyhemoglobin measurement and subsequent  $D_{LCO}$  correction in patients referred for PFT. **METHODS:** We retrospectively reviewed 100 consecutive PFT results, including  $D_{LCO}$  assessment. We used a pulse CO-oximeter (recently approved by the Food and Drug Administration) to noninvasively measure baseline carboxyhemoglobin ( $S_{pCO}$ ). We used simple descriptive statistics to compare the  $S_{pCO}$  values. In subjects with elevated  $S_{pCO}$  ( $> 2\%$ ) we adjusted the percent-of-predicted  $D_{LCO}$ . Interpretation of  $D_{LCO}$  was categorized according to the American Thoracic Society classification scheme for respiratory impairment. **RESULTS:** The self-reported smokers had higher average  $S_{pCO}$  than did self-reported nonsmokers (1.6% vs 3.5%,  $p < 0.001$ ), although 14% of nonsmokers had an elevated  $S_{pCO}$  and 26% of smokers had normal  $S_{pCO}$ . When the  $D_{LCO}$  was corrected for elevated  $S_{pCO}$ , 2 patients moved from a category of moderate impairment to mild impairment. Both were smokers. **CONCLUSIONS:** The noninvasive measurement of carboxyhemoglobin is easy to perform during PFT. When precise measurement of  $D_{LCO}$  is important, noninvasive measurement of carboxyhemoglobin may be of value. If routine  $S_{pCO}$  measurement is considered, the highest yield is among current smokers. *Key words:* respiratory function tests, carboxyhemoglobin, pulmonary diffusing capacity, pulse oximetry, CO-oximetry. [Respir Care 2007; 52(12):1741–1743. © 2007 Daedalus Enterprises]

## Introduction

Pulmonary function tests (PFTs) are an important tool to investigate respiratory complaints and diagnose lung

disease. PFTs are also frequently performed to assess operative risk and pulmonary impairment for disability. The diffusing capacity of the lungs for carbon monoxide ( $D_{LCO}$ ) is commonly measured during PFTs. The  $D_{LCO}$  reflects the ability of the lungs to transfer inhaled gas to hemoglobin in the pulmonary capillary bed. The severity of pulmonary impairment is ascertained by comparing the subject's  $D_{LCO}$  to a predicted value from normals without lung disease. The American Thoracic Society (ATS) defined a  $D_{LCO} < 40\%$  of the predicted normal value as evidence of severe pulmonary impairment.<sup>1</sup> Threshold values for less severe  $D_{LCO}$  reductions indicate mild and moderate pulmonary impairment.

$D_{LCO}$  depends on a number of physiological factors, including age, sex, and height.  $D_{LCO}$  also is affected by pulmonary capillary hemoglobin content, the presence of

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circulating carboxyhemoglobin, lung volume, and altitude. Carboxyhemoglobin reduces the binding sites for lung carbon monoxide uptake, and carbon monoxide back-pressure in the blood reduces the pressure gradient for CO transfer across the alveolar-capillary membrane. For these reasons, the ATS/European Respiratory Society Task Force on Standardization of Lung Function Testing recommended adjusting the measured  $D_{LCO}$  for both hemoglobin and elevated baseline carboxyhemoglobin levels.<sup>2</sup> However, this latter correction is not commonly performed because of the need to obtain a blood sample to measure the carboxyhemoglobin level, or to have sophisticated test equipment capable of measuring carbon monoxide back-pressure in exhaled gas. Because individuals who smoke often have elevated carboxyhemoglobin, the accuracy of  $D_{LCO}$  measurement in that group may be reduced.

A handheld pulse CO-oximeter is now available that can noninvasively measure carboxyhemoglobin. Such pulse-CO-oximetry measurements have been called “ $S_{pCO}$ ” values. We conducted a retrospective review of PFTs in our laboratory, where  $S_{pCO}$  was routinely measured with a pulse CO-oximeter in all patients referred for  $D_{LCO}$  measurement. Our goals were (1) to describe the  $S_{pCO}$  values in patients who present for PFTs, and (2) to determine the impact of elevated  $S_{pCO}$  on the interpretation of  $D_{LCO}$  test results. For comparison we also report the frequency with which correction of  $D_{LCO}$  for hemoglobin resulted in a change of the categorization of impairment of the diffusing capacity.

### Methods

We performed a retrospective review of 100 consecutive PFTs that included  $D_{LCO}$  measurement. All the PFTs were performed by the same personnel (all of whom are RRTs or CPFTs) in one pulmonary laboratory in a hospital-based out-patient setting where the testing equipment and software met ATS standards and recommendations.  $D_{LCO}$  was measured with a single-breath method, in compliance with ATS standards.<sup>1</sup> PFT reports also included basic demographic information, including age, sex, patient self-report of smoking history, and hemoglobin level, if available at time of testing. The PFT reports did not provide information regarding race of the subjects.

At the time of the PFT we noninvasively measured carboxyhemoglobin with a pulse CO-oximeter (Rad-57, Masimo, Irvine, California).<sup>3</sup> This Food and Drug Administration-approved device uses 8 wavelengths of light to measure carboxyhemoglobin and the conventional oximetry variables: blood oxygen saturation and heart rate. The  $S_{pCO}$  measurement is obtained within seconds of applying the fingertip sensor. This battery-powered instrument is approximately the same size as a traditional handheld pulse oximeter. The accuracy of the device has been demon-

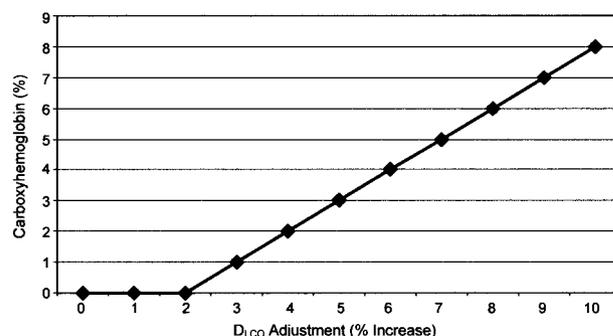


Fig. 1. Upward adjustment of measured diffusing capacity of the lung for carbon monoxide ( $D_{LCO}$ ) by carboxyhemoglobin measured via pulse CO-oximetry.

strated up to an  $S_{pCO}$  measurement of 40%, with an accuracy of 3%.<sup>3</sup> In a recent human volunteer study, Barker et al independently validated the device’s accuracy and reliability; they found that it measured carboxyhemoglobin with an uncertainty of  $\pm 2\%$  within the range of 0–15% carboxyhemoglobin.<sup>4</sup>

We used simple descriptive statistics to describe the mean and range of the  $S_{pCO}$  levels in all the patients, as well as in the subsets of self-described smokers and non-smokers. For subjects with an elevated  $S_{pCO}$ , defined as  $> 2\%$ ,<sup>4</sup> the percent-of-predicted  $D_{LCO}$  was adjusted upward in accordance with the ATS/European Respiratory Society Task Force recommendations. Figure 1 shows the relationship between carboxyhemoglobin and  $D_{LCO}$ :

$D_{LCO}$  predicted for COHb

$$= D_{LCO} \text{ predicted} \times (102\% - \text{COHb}\%)$$

in which COHb is carboxyhemoglobin. We interpreted the  $D_{LCO}$  measurements according to the ATS classification scheme for respiratory impairment, which is based on percent of predicted, and in which “normal” is  $> 80\%$  of predicted, “mildly impaired” is 60–79% of predicted, “moderately impaired” is 41–59% of predicted, and “severely impaired” is  $\leq 40\%$  of predicted.<sup>1</sup> These categories are identical to the cut-points used by the American Medical Association to define Class I, Class 2, Class 3 and Class 4 levels of pulmonary impairment for disability purposes.<sup>5</sup> We then calculated the number of times that the correction of  $D_{LCO}$  for elevated  $S_{pCO}$  level led to a change in interpretation category (severe to moderate, moderate to mild, mild to normal).

We also examined the 28 PFTs that included a reported hemoglobin level, to determine the frequency with which adjustment for hemoglobin affected the interpretation of the  $D_{LCO}$ .

There were no other inclusion or exclusion criteria. The study was conducted at Virginia Mason Medical Center, a

Table 1. Carboxyhemoglobin Values in Patients Who Underwent Diffusing Capacity Measurements\*

	Entire Group (n = 100)	Nonsmokers (n = 85)	Smokers (n = 15)
Carboxyhemoglobin mean $\pm$ SD %	1.9 $\pm$ 1.3	1.6 $\pm$ 0.9	3.5 $\pm$ 1.9
range %	1–8	1–5	1–8

\*Measured via pulse CO-Oximetry

Table 2. Number of Patients in Each Category of  $D_{LCO}$  Impairment Severity Before and After Correction for  $S_{pCO}$ 

	AMA Class 1 ATS Normal	AMA Class 2 ATS Mild	AMA Class 3 ATS Moderate	AMA Class 4 ATS Severe
Before	9	42	43	6
After	9	44	41	6

 $D_{LCO}$  = diffusing capacity of the lung for carbon monoxide $S_{pCO}$  = carboxyhemoglobin measured via pulse CO-oximetry

AMA = American Medical Association

ATS = American Thoracic Society

private academic medical center in Seattle, Washington, and was approved by the institutional review board. The pulse CO-oximeter we used was provided by Masimo, but no other funding was received.

## Results

The average  $S_{pCO}$  among all 100 patients was 1.9%, and the highest measured  $S_{pCO}$  was 8% (Table 1). Eighty-five percent of the patients were self-reported nonsmokers, and 15% reported current tobacco use. The nonsmokers had a lower average  $S_{pCO}$  than did the self-reported smokers (1.6% vs 3.5%,  $p < 0.001$ ). Twenty-three subjects had an elevated  $S_{pCO}$ . Among the nonsmokers, 14% had an elevated  $S_{pCO}$ , whereas 26% of the self-reported smokers had a normal  $S_{pCO}$ .

When the  $D_{LCO}$  was adjusted for the 23 patients in whom  $S_{pCO}$  was elevated, only 2 changed interpretation category (Table 2). Both of those subjects, who were self-reported smokers, moved from a category of moderate impairment to mild impairment. For the remaining 21 patients, adjustment of their  $D_{LCO}$  measurement for elevated  $S_{pCO}$  did not change their impairment category.

Twenty-eight patients had a hemoglobin level reported at the time of their PFT. The correction of  $D_{LCO}$  for measured hemoglobin led to a change in the  $D_{LCO}$  impairment category of 3 subjects.

## Discussion

PFT is an important tool for diagnosing lung disease and assessing operative risk and pulmonary disability.  $D_{LCO}$  is often measured for these purposes. Although it is recommended that  $D_{LCO}$  be adjusted for elevated carboxyhemoglobin, the magnitude of the correction for carboxyhemoglobin is small, and it is not routinely done. A noninvasive method of measuring carboxyhemoglobin is now available, which makes  $S_{pCO}$  easy to measure at the time of PFT.

Our study indicates that, as expected, smokers have higher carboxyhemoglobin than do nonsmokers. Nonetheless, 26% of self-reported smokers had normal  $S_{pCO}$  and 14% of self-reported nonsmokers had elevated  $S_{pCO}$ . Adjusting for elevated  $S_{pCO}$  did impact the interpretation of the  $D_{LCO}$  in some patients; however, the magnitude of this effect was small. Using the ATS classification (which is the same as the American Medical Association Impairment Guide), the severity class changed in only 2 of 100 patients. However, both those subjects were self-reported smokers, so the frequency of a changed interpretation in that population was 13%. In comparison, when  $D_{LCO}$  was adjusted for hemoglobin level, the frequency of change in impairment category was 11%.

## Conclusions

Our study suggests that adjustment of  $D_{LCO}$  for elevated carboxyhemoglobin in a smoking population may be as clinically important as adjustment for hemoglobin. We conclude that when precise assessments of  $D_{LCO}$  are required, such as in the evaluation of pulmonary disability or preoperative assessment for lung resection surgery, the  $S_{pCO}$  measurement may be of value, especially in individuals who smoke.

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