

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

Anne M Mahoney MD MSc, Claudia L Stimpson CPFT, Karen L Scott MA, and Neil B Hampson MD

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.¹ 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

Anne M Mahoney MD MSc, Claudia L Stimpson CPFT, Karen L Scott MA, and Neil B Hampson MD are affiliated with the Section of Pulmonary and Critical Care Medicine, Virginia Mason Medical Center, Seattle Washington.

Dr Hampson has served as a consultant for Masimo, Irvine, California. The other authors report no conflicts of interest in the content of this paper.

Correspondence: Anne M Mahoney MD MSc, Section of Pulmonary and Critical Care Medicine, Virginia Mason Medical Center, 1100 Ninth Avenue, C7-PUL, Seattle WA 98101. E-mail: cida2m@vmc.org.

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.² 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.¹ 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).³ 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-

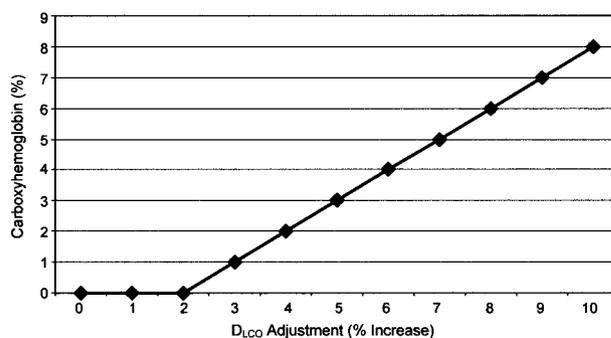


Fig. 1. Upward adjustment of measured diffusing capacity of the lung for carbon monoxide (D_{LCO}) by carboxyhemoglobin measured via pulse CO-oximetry.

strated up to an S_{pCO} measurement of 40%, with an accuracy of 3%.³ 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.⁴

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 $> 2\%$,⁴ 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.¹ 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.⁵ 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.

REFERENCES

- Pellegrino R, Viegi G, Brusasco V, Crapo RO, Burgos F, Casaburi R, et al. Interpretive strategies for lung function tests. *Eur Respir J* 2005; 26(5):948–968.
- MacIntyre N, Crapo RO, Viegi G, Johnson DC, van der Grinten CP, Brusasco V, et al. Standardisation of the single-breath determination of carbon monoxide uptake in the lung. *Eur Respir J* 2005;26(4):720–735.
- Masimo Corporation. Rad-57 Pulse CO-oximeter: noninvasive measurement of methemoglobin, carboxyhemoglobin, oxyhemoglobin and pulse rate in seconds. <http://www.masimo.com/rad-57/index.htm>. Accessed Oct 8, 2007.
- Barker SB, Curry J, Redford D, Morgan S. Measurement of carboxyhemoglobin and methemoglobin by pulse oximetry. *Anesthesiology* 2006;105(5):892–897.
- American Medical Association. Guides to the evaluation of permanent impairment, 5th ed. Cocchiarella L, Andersson GB, editors. Chicago: AMA Press;2001:87–115.