Considerations for DLCO testing and interpretation

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CACPT Pulmonary Function Testing Symposium 2019
Objectives

• Review the principles of the DLCO test
• Review the 2017 DLCO Standards
• Review physiologic factors that affect DLCO
Graham - DLCO considerations

Surfactant layer

Type 1 pneumocyte

100 mmHg oxygen

40 mmHg carbon dioxide

Alveolus

Capillary

Interstitium

Capillary endothelium

Red blood cell

Plasma

Granam - DLCO considerations 3/29
Factors affecting gas exchange

- Hb (anemia↓ or polycythemia↑)
- Increase↑ or decrease↓ in blood flow (exercise↑, position↑ ↓)
- Decreased alveolar volume↓ (restrictive or neuromuscular)
- Ventilation-perfusion mismatch↓ (embolism)
- Pulmonary edema↓
- Static blood in lung [↑_{DLCO}]
- Pulmonary capillary bed disorders↓
- Barometric pressure↓ [↑_{DLCO}]
How to measure gas exchange

flow = driving pressure / resistance

driving pressure = alveolar – pulmonary capillary partial pressure of the gas

For oxygen, the pulmonary capillary partial pressure over the course of a vital capacity inspiration and 10 s breath hold is very difficult to estimate.

DLCO is used as a proxy for DLO$_2$
Why use CO to measure gas exchange?

• The affinity of CO for Hb is about 230 times the affinity of O₂ for Hb
• CO molecules that cross into the pulmonary capillaries are quickly and tightly bound to Hb so that the pulmonary capillary partial pressure of CO is assumed to be zero
• If the pulmonary capillary partial pressure of CO is not zero, we can measure it and compensate for it
Why use CO to measure gas exchange?

flow = driving pressure / resistance
conductance = 1 / resistance
DLCO = conductance = flow / driving pressure

flow = decrease in alveolar volume of CO / time
driving pressure = alveolar partial pressure of CO
   = alveolar CO concentration x barometric pressure

Volume of CO = alveolar concentration of CO x alveolar volume
Alveolar CO concentration decays exponentially during breath-hold
DLCO \[\text{mL/min/mmHg}\] = \(\frac{V_{ASTPD}}{t_{bh} \cdot (P_B - 47)} \cdot \ln \left( \frac{F_{Ico}}{F_{Aco}} \cdot \frac{F_{ATr}}{F_{ITr}} \right) \cdot 60000\)
Pre-Manoeuvre Considerations

• Monitor tracer gas and CO during exhalation
• Check washout from previous test (< 2% tracer gas) & use the pre-inspiratory tracer gas concentration in calculating $V_A$
• Use exhaled CO concentration to adjust for CO back pressure
• Adjust for residual effects of $H_2O$ and $CO_2$ if necessary
• Optionally use exhaled CO to estimate COHb
• Exhale to RV for up to 12 s prior to inhaling test gas
Factors affecting DLCO – procedural

- Breath hold time
- Inspired and expired flow rates
- Inspired O$_2$ concentration
- Barometric pressure
- COHb (back pressure and anemia effects)
- Valsalva or Müller manoeuvre
Gas analyser linearity check

• In the absence of a DLCO simulator and high-precision test gases, system checks can be done using a 3 litre calibrating syringe in ATP mode.

• IF ATP mode is not available, the check can be done in the regular patient mode, but conversions to ATP and consideration of dead space is required.
Gas analyser linearity check

• Connect the 3-litre syringe to the
• Simulate tidal breathing with the syringe with an FRC of about 1.5 L (may not be necessary in some systems)
• When prompted to exhale, empty the syringe to approximately 1 L
• Fill the syringe with test gas (approximately 2L)
• Following a breath hold, empty the syringe
Gas analyser linearity check

• Mixing of gas in the syringe will be incomplete, even after a 10 s breath hold
• Gas mixing in the syringe can be improved by using low flow rates and extending the breath hold time. The effects of incomplete mixing in the syringe can be minimised by using a larger sample volume.
Gas analyser linearity check

• The calculation of $VA_{ATPH}$ must be within 300 mL of 3 L with the syringe dead space being used for the anatomic dead space in the VA calculation.

• The absolute value of DLCO must be < 0.5 mL/min/mmHg.

• If the system does not have an ATP mode option:
  - VA will be reported in BTPS and must be converted to ATPH
  - the dead space used by the system to calculate VA must be adjusted to the dead space of the syringe: (e.g. entering a “patient” weight of 16 kg results in a 35 mL dead space)
Acceptability of Manoeuvres

• $V_l \geq 90\%$ of largest VC in the same test session
  
  OR

  $V_l \geq 85\%$ of largest VC in the same test session AND $V_A$ within 200 mL or 5% (whichever is greater) of largest $V_A$ from other acceptable manoeuvres

• 85% of test gas $V_l$ inhaled in <4 s
Quality Control Grading for DLCO Manoeuvres

<table>
<thead>
<tr>
<th>Score</th>
<th>( V_I/VC )</th>
<th>( t_{BH} )</th>
<th>Sample collection</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>( \geq 90%^{\dagger} )</td>
<td>8-12s</td>
<td>( \leq 4s )</td>
</tr>
<tr>
<td>B</td>
<td>( \geq 85% )</td>
<td>8-12s</td>
<td>( \leq 4s )</td>
</tr>
<tr>
<td>C</td>
<td>( \geq 80% )</td>
<td>8-12s</td>
<td>( \leq 5s )</td>
</tr>
<tr>
<td>D</td>
<td>( \leq 80% )</td>
<td>(&lt; 8 \text{ or } &gt;12s)</td>
<td>( \leq 5s )</td>
</tr>
<tr>
<td>F</td>
<td>( \leq 80% )</td>
<td>(&lt; 8 \text{ or } &gt;12s)</td>
<td>( &gt; 5s )</td>
</tr>
</tbody>
</table>

\(^{\dagger}\)OR \( V_I/VC \geq 85\% \text{ AND } V_A \text{ within 200 mL or 5\% of the largest } V_A \) from another acceptable manoeuvres
Quality Control Grading for DLCO Manoeuvres

<table>
<thead>
<tr>
<th>Score</th>
<th>( V_1/VC )</th>
<th>( t_{BH} )</th>
<th>Sample collection</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>( \geq 90% )†</td>
<td>8-12s</td>
<td>( \leq 4s )</td>
</tr>
<tr>
<td>B</td>
<td>( \geq 85% )</td>
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<td>&lt;8 or &gt;12s</td>
<td>( \leq 5s )</td>
</tr>
<tr>
<td>F</td>
<td>Any test not meeting Grade A, B, C, or D</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

†OR \( V_1/VC \geq 85\% \) **AND** \( V_A \) within 200 mL or 5% of the largest \( V_A \) from another acceptable manoeuvres

Repeatability of Manoeuvres

• At least 2 acceptable DLCO measurements within 2 mL/min/mmHg of each other

• The desired outcome is to have 2 grade A manoeuvres that are within 2 mL/min/mmHg of each other
Adjust DLCO for barometric pressure

The adjustment for $P_B$ assumes a $P_{O2}$ of 150 mmHg (20 kPa) at standard pressure:

$$DLCO[P_{B\text{adjusted}}] \approx DLCO (0.505 + 0.00065 \cdot P_B)$$

For DLCO reference values that do not provide $P_B$ data, the altitude of the centre in which the reference values were obtained can be used to estimate $P_B$, using the following formula where $h$ is the altitude above sea level in m:

$$P_B \text{ (mmHg)} = 760 (1 - 2.25577 \cdot 10^{-5} \cdot h)^{5.25588}$$
Percent increase in DLCO due to decrease in $P_B$

Altitude (m)

Mexico City 2250 m – 10.8%

Atlanta, Edmonton, Tucson, Boise, Las Vegas, Saskatoon, Pittsburgh, Salt Lake City, Denver, Toronto, Montréal, Chicago, Winnipeg, Ottawa.
Adjust DLCO for hemoglobin

DLCO decreases about 4.4% with a 10% reduction in Hb

\[
\text{DLCO,\textit{predicted for Hb}} = \text{DLCO,\textit{predicted}} \times \frac{1.7 \cdot \text{Hb}}{0.7 \cdot \text{Hb}_{\text{ref}} + \text{Hb}}
\]
Graham - DLCO considerations

NHANES III data from Hollowell JG. *Vital Health Stat* 2005; 11: 1–156

- white males
- men ≥ 15yr – 146

- white females
- women and children – 134
Predicted DLCO for a male (ht = 180 cm)

- Gutierrez
  - Pred
  - LLN
- GLI
  - Pred
  - LLN
QUESTION:
Which element of pulmonary function testing most frequently impacts test quality?

A. Patient (person being tested)
B. Equipment (hardware)
C. Operator (person conducting the test)
D. Procedure (the prescribed manoeuvre)
E. Analysis (software)
Which element of pulmonary function testing has the most impact on test quality?

“There are 3 key elements to obtain high quality pulmonary function data: accurate and precise instrumentation, a patient/subject capable of performing acceptable and repeatable measurements, and a motivated technologist to elicit maximum performance from the patient. In the realm of standardization, the technologist has received the least attention.”

- Ruppel GL, Enright PL. Pulmonary function testing. *Respir Care* 2012;57:165-75.