Considerations for DLCO testing and interpretation

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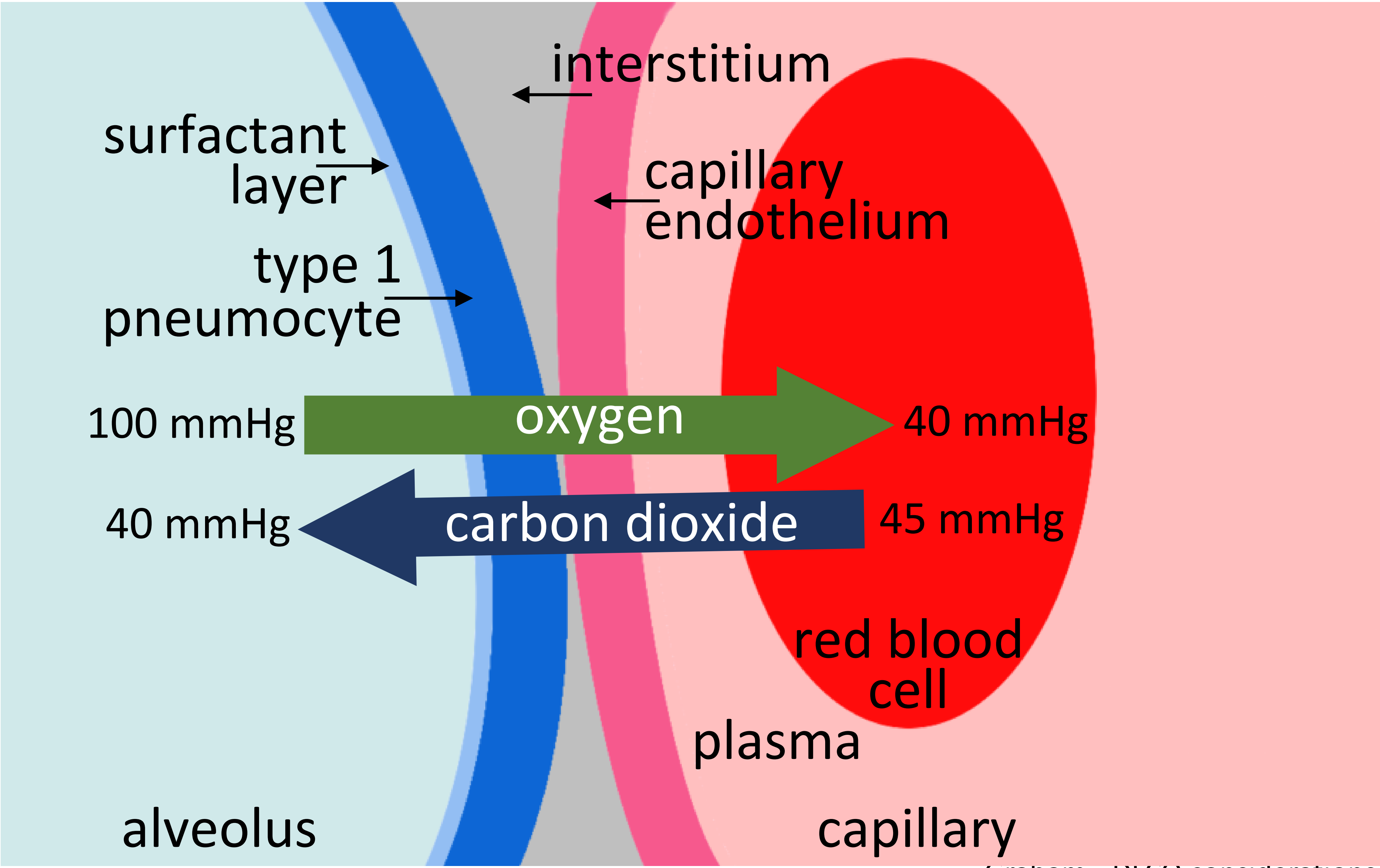
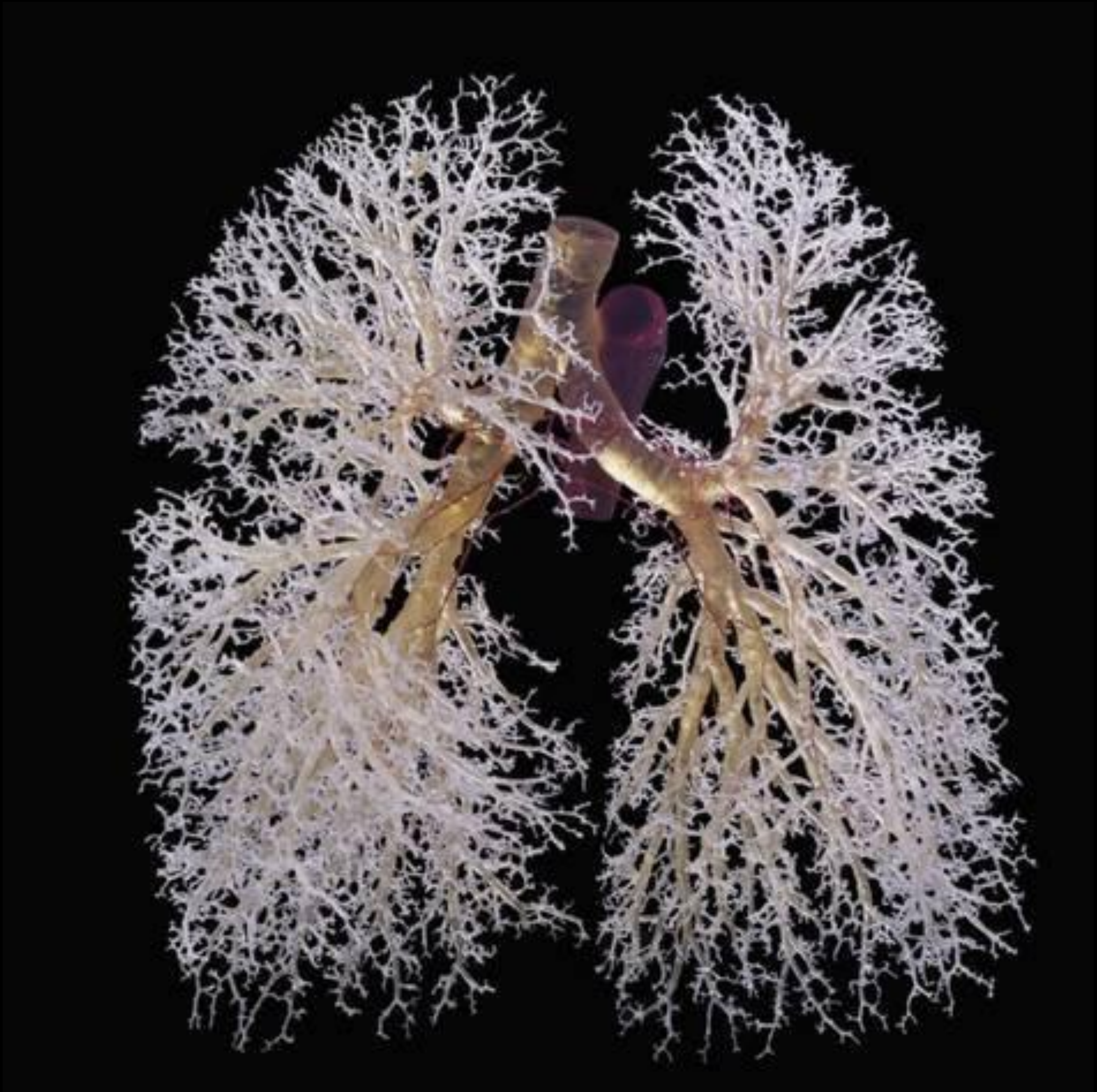
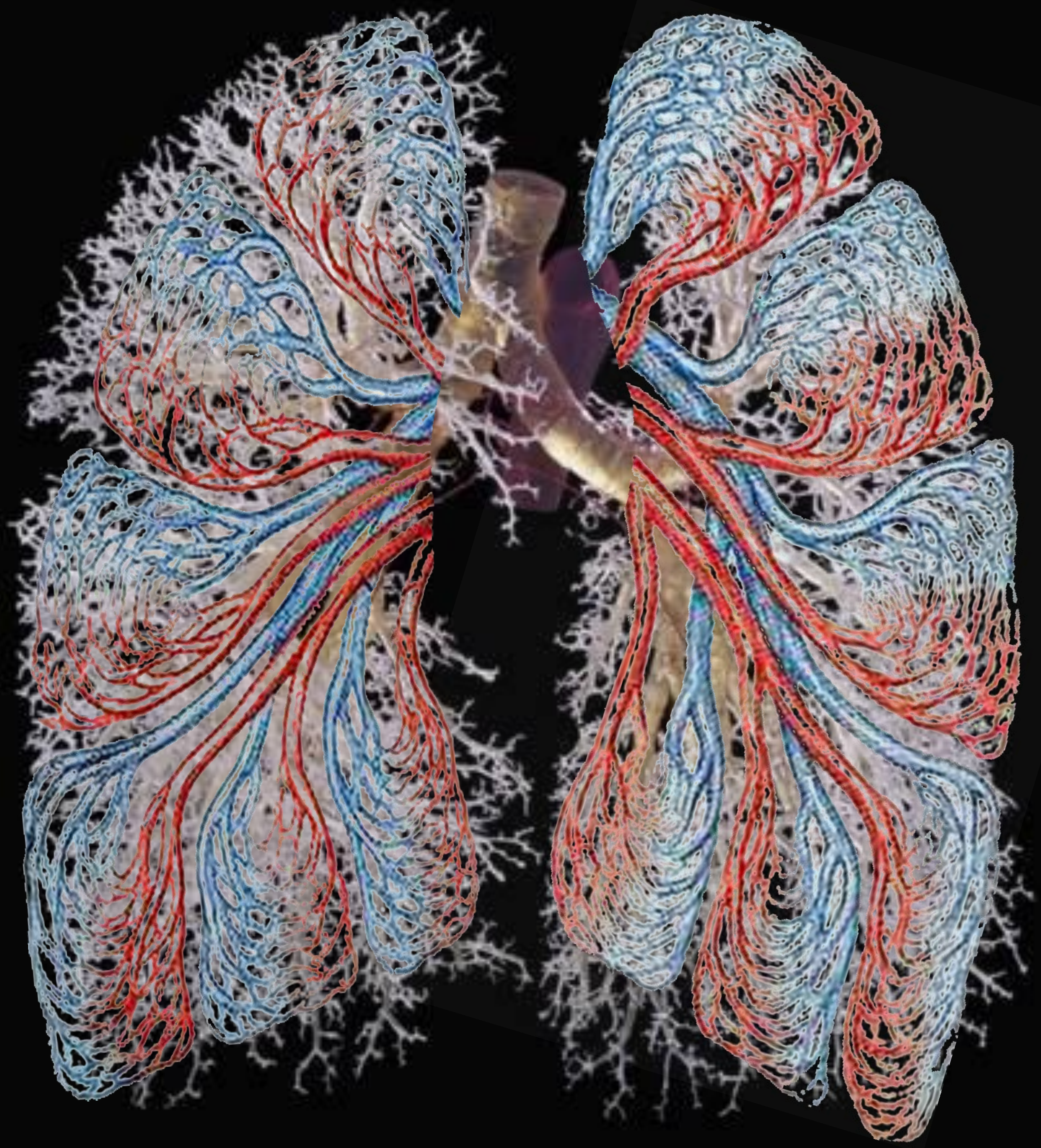
CACPT Pulmonary Function Testing Symposium 2019

Objectives

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


interstitium
surfactant layer
capillary endothelium
type 1 pneumocyte
100 mmHg
oxygen
40 mmHg
40 mmHg
carbon dioxide
45 mmHg
red blood cell
plasma
alveolus
capillary





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 [$\uparrow_{DLCO}$]
- Pulmonary capillary bed disorders↓
- Barometric pressure↓ [$\uparrow_{DLCO}$]

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 O_2 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

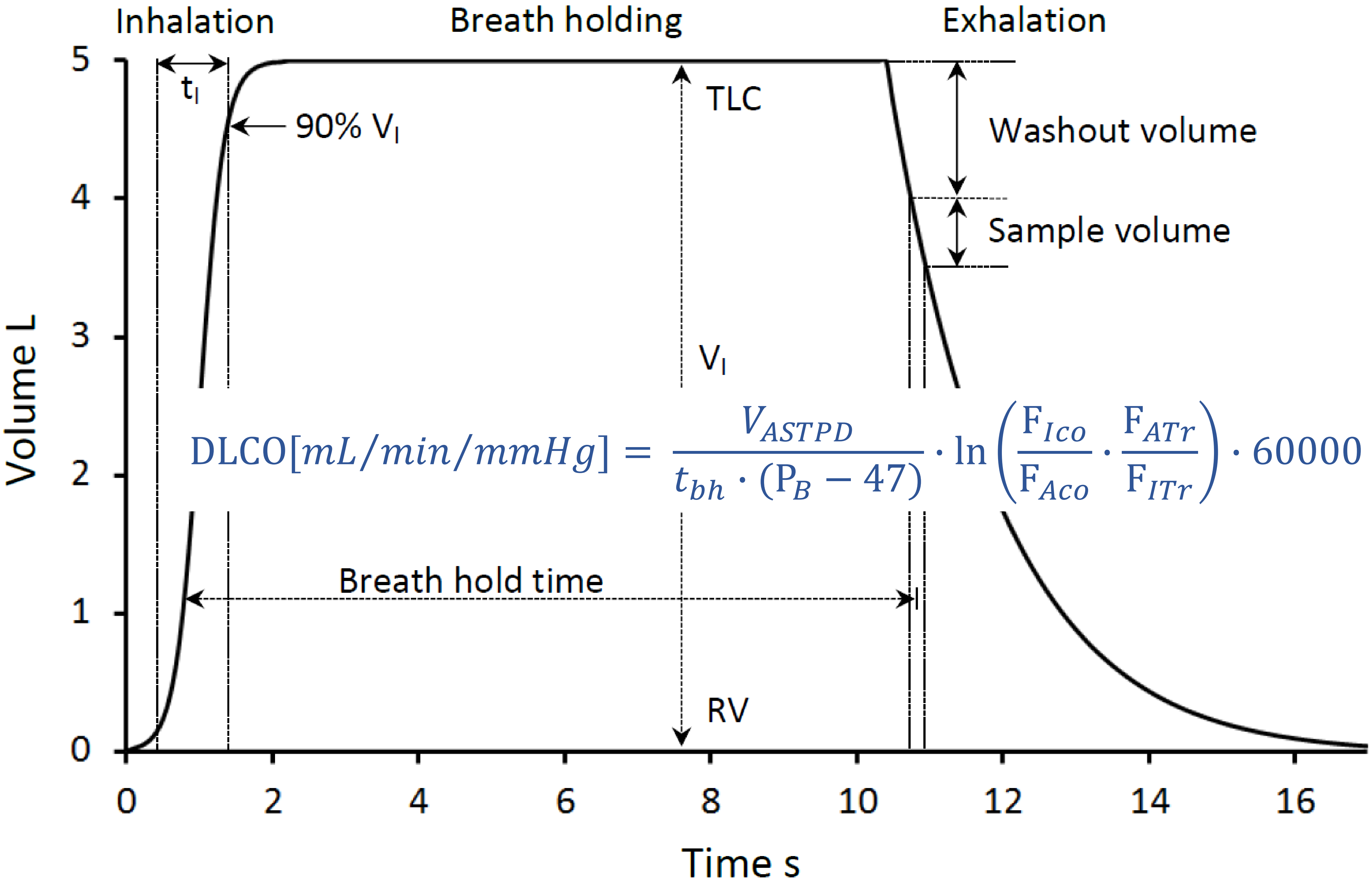
flow = decrease in alveolar volume of CO / time

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



$$\mathrm{DLCO}[mL/min/mmHg] = \frac{V_{ASTPD}}{t_{bh} \cdot (\mathrm{P}_B - 47)} \cdot \ln\left(\frac{\mathrm{F}_{Ico}}{\mathrm{F}_{Aco}} \cdot \frac{\mathrm{F}_{ATr}}{\mathrm{F}_{ITr}}\right) \cdot 60000$$

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

- $V_I \geq 90\%$ of largest VC in the same test session

  OR

  $V_I \geq 85\%$ 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_I inhaled in <4 s

Quality Control Grading for DLCO Manoeuvres

Score	V_I/VC	t_{BH}	Sample collection
A	≥90%†	8-12s	≤ 4s
B	≥85%	8-12s	≤ 4s
C	≥80%	8-12s	≤ 5s
D	≤80%	<8 or >12s	≤ 5 s
F	≤80%	<8 or >12s	> 5s

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

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F	Any test not meeting Grade A, B, C, or D		

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

Culver BH. Recommendations for a Standardized Pulmonary Function Report. An Official American Thoracic Society Technical Statement. *Am J Respir Crit Care Med* 2017;196:1463-1472

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

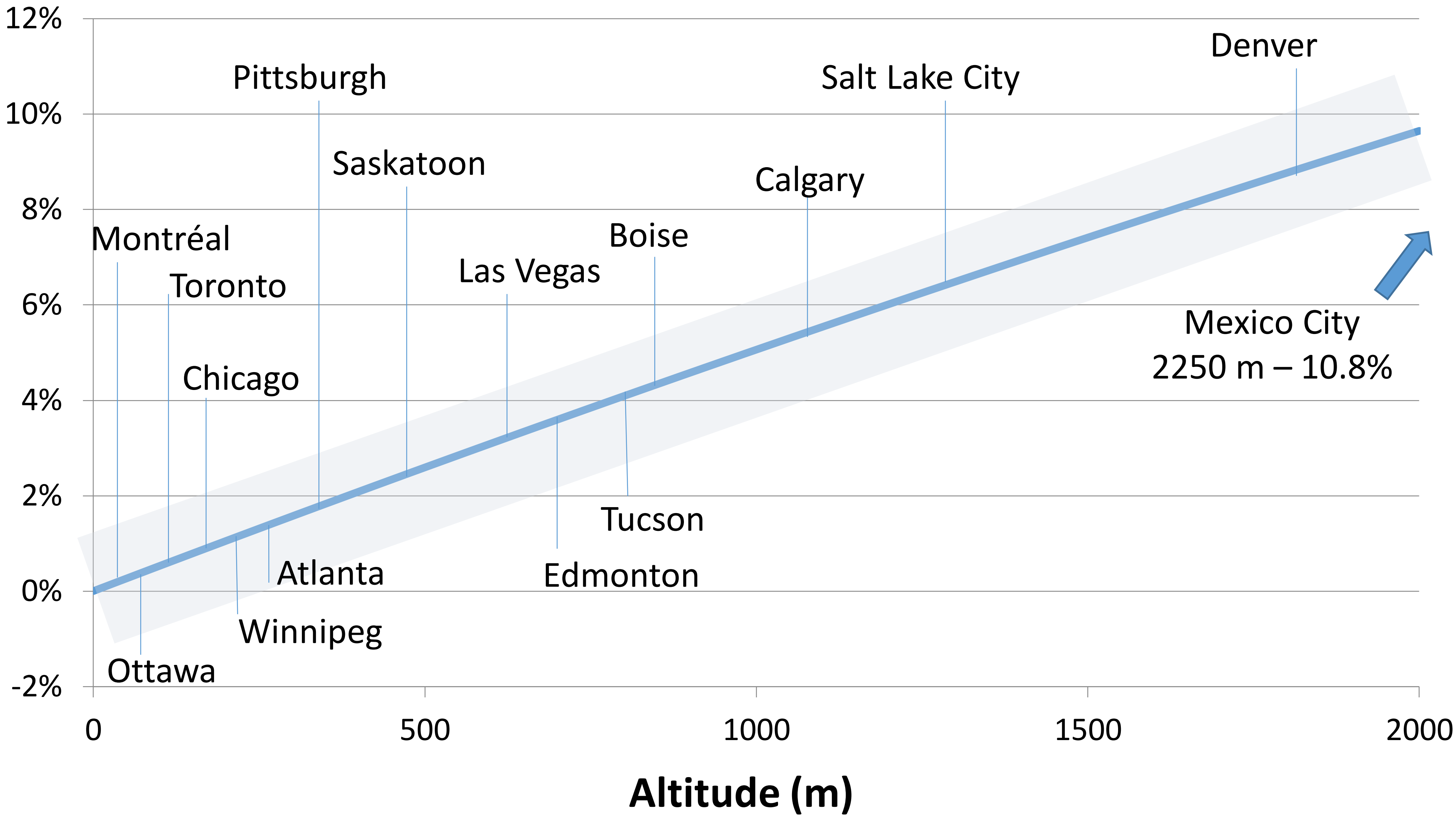
The adjustment for P_B assumes a P_{IO2} of 150 mmHg (20 kPa) at standard pressure:

$$DLCO[P_B adjusted] \approx DLCO\ (0.505 + 0.00065\ P_B)$$

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:

$$P_B(\text{mmHg}) = 760\ (1 - 2.25577 \cdot 10^{-5}\ \cdot h)^{5.25588}$$

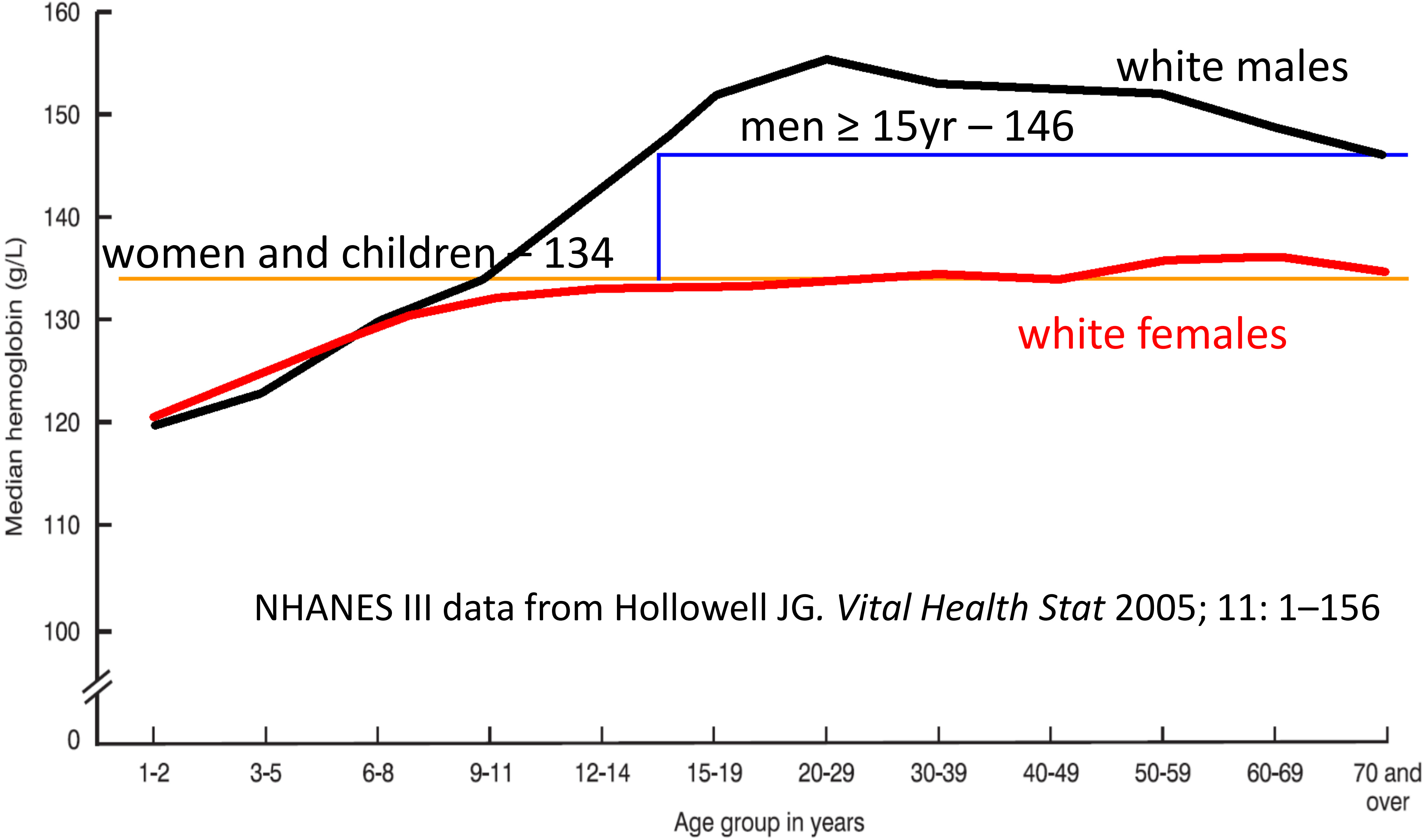
Percent increase in DLCO due to decrease in P_B

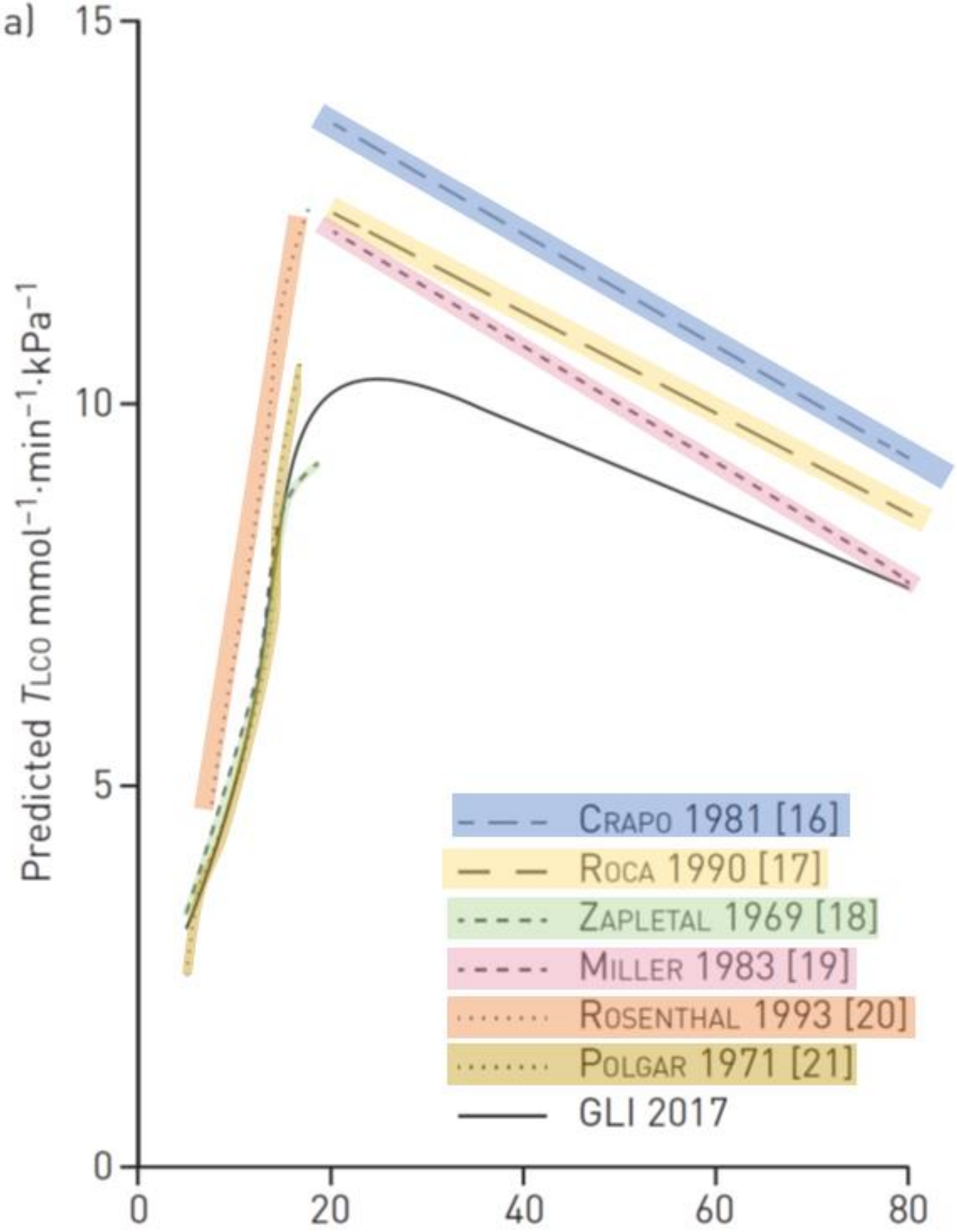


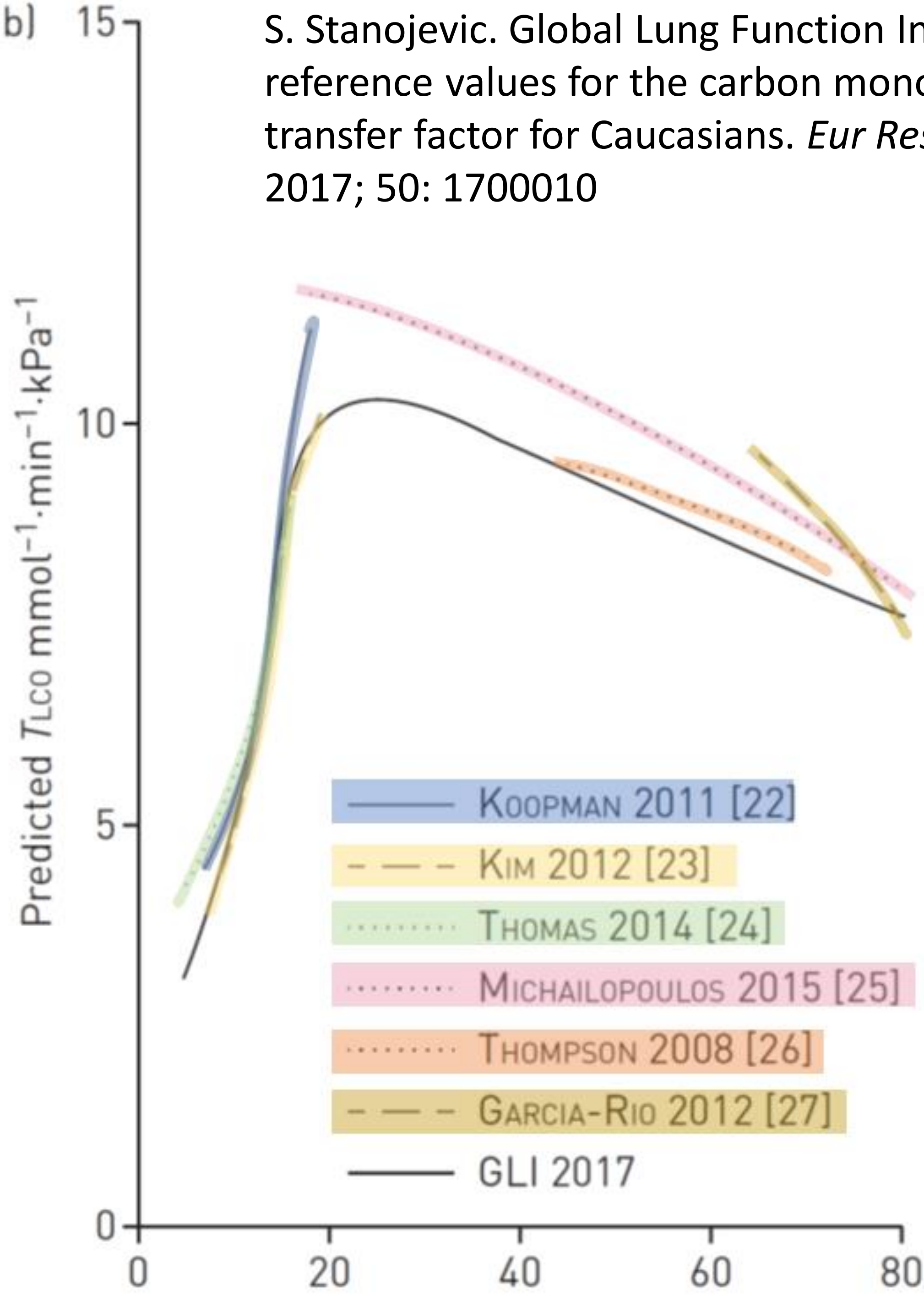
Adjust DLCO for hemoglobin

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

$$\text{DLCO},\textit{predicted for Hb} = \text{DLCO},\textit{predicted} \times \frac{1.7 \cdot \text{Hb}}{0.7 \cdot \text{Hb}_{ref} + \text{Hb}}$$

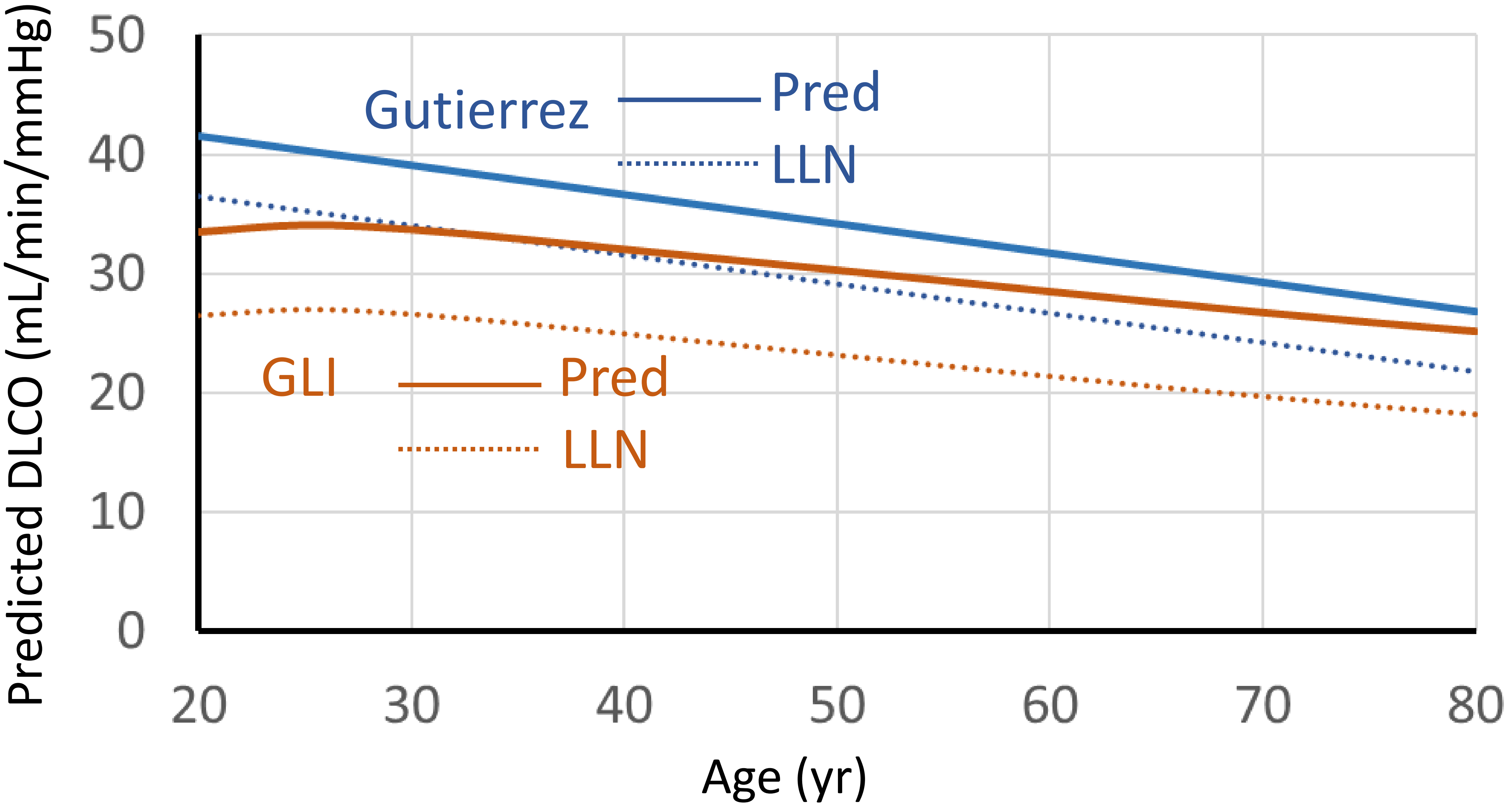

white males
men ≥ 15yr – 146
women and children – 134
white females
NHANES III data from Hollowell JG. *Vital Health Stat* 2005; 11: 1–156
Median hemoglobin (g/L)
160
150
140
130
120
110
100
0
1-2
3-5
6-8
9-11
12-14
15-19
20-29
30-39
40-49
50-59
60-69
70 and over
Age group in years





S. Stanojevic. Global Lung Function Initiative reference values for the carbon monoxide transfer factor for Caucasians. *Eur Respir J* 2017; 50: 1700010

Predicted DLCO for a male (ht = 180 cm)



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.