Coaching Diffusion Studies

to meet ATS/ERS criteria for
acceptability, repeatability, and quality control

AARC Approved for 1 CRCE

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Speaker

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2024 AARC SPOTY for Pulmonary Diagnostics

Disclaimer / Conflict of Interest

- None

Learning Objectives

At the conclusion of this presentation the learner shall be able to…

1. describe the basics of **diffusion context**
2. **instruct, demonstrate, practice, and coach** through five phases of the single breath DLCO maneuver
3. list and explain ATS/ERS criteria for **Acceptability, Usability, Repeatability,** and **Quality Grading**
4. use **troubleshooting** and **coaching to** correct common technical and patient-related errors

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Not Included:

- PFT Prescribing : indications, contraindications, diagnostic investigation protocols
- PFT Theories: history, theory, and math of how & why the testing works
- Intrabreath and rebreathing methods for DLCO measurement
- PFT Laboratory Administration: equipment, calibration, quality systems, reporting
- PFT References, interpretation
- PFT Clinical implications – diagnostic / therapeutic

Learning Objectives

At the conclusion of this presentation the learner shall be able to…

1. describe the basics of **diffusion context**
   - **A. History of Diffusion Standardization**
   - **B. Definitions, Acronyms, and Key Terms**
   - **C. Spirometry: 4 volumes, 4 capacities, 4 levels**
   - **D. Quality Spirometry**
   - **E. Diffusion anatomy & physiology**
   - **F. Factors that determine how well oxygen transfers from your lungs to your blood**
   - **G. Role of hemoglobin in carbon monoxide binding**
   - **H. Patient Preparation**

History of Diffusion Standardization

- 2017 ERS/ATS standards for single-breath carbon monoxide uptake in the lung. Eur Respir J. 2017;49(1) Epub 2017 Jan 3.

European Respiratory Society (ERS)

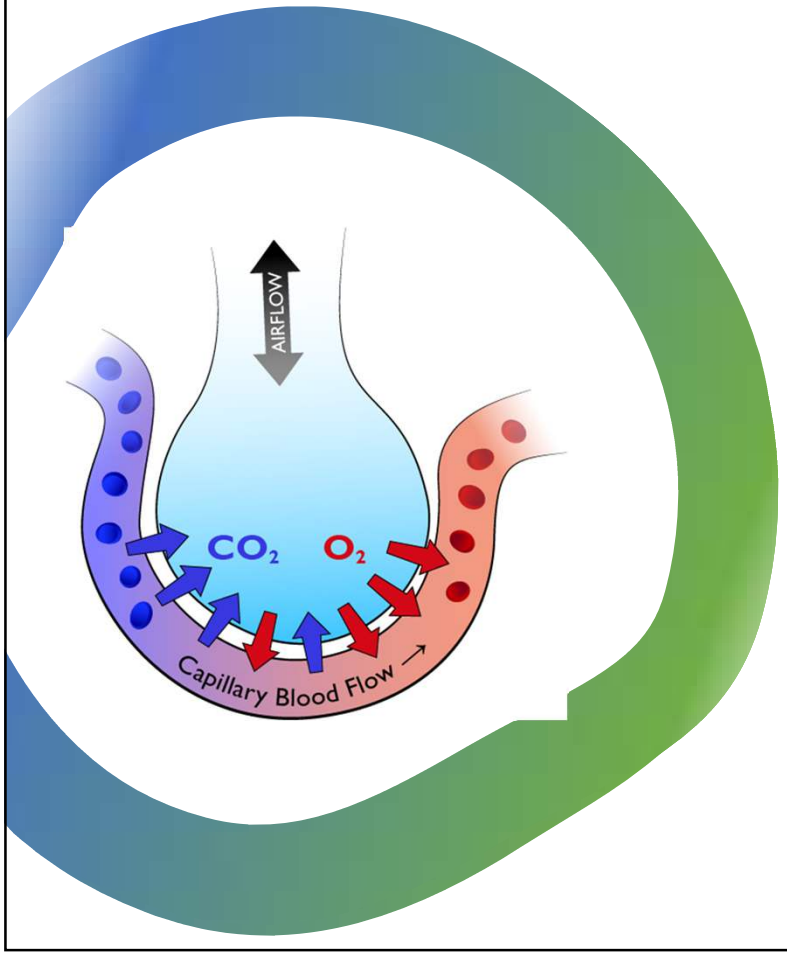
American Thoracic Society (ATS)

- *2005 Standardisation of the single-breath determination of carbon monoxide uptake in the lung. Eur Respir J. 2005;26(4):720.*

- *1987 Single breath carbon monoxide diffusing capacity (transfer factor). Recommendations for a standard technique. Statement of the American Thoracic Society.*

PFT History

- Courtesy of PFT Forum - The diverse, quirky and mostly forgotten history of Pulmonary Function testing
  - https://www.pftforum.com/history/



Definitions

- **Lung diffusion** is the process by which carbon dioxide and oxygen are exchanged between the alveoli in the lungs and the blood in the pulmonary capillary circulation.
- Called **"diffusing capacity"** in North America but is more appropriately called **"transfer factor"** in Europe.
- The test of diffusing capacity of the lungs for carbon monoxide **(DLCO)**, also known as transfer factor for carbon monoxide **(TLCO)**, measures the ability of the lungs to transfer gas from inhaled air to the red blood cells in pulmonary capillaries.
  - DLCO assesses a-c membrane conductance and pulmonary capillary blood volume

Acronyms & More

- American Thoracic Society (ATS) https://site.thoracic.org/
- European Respiratory Society (ERS) https://www.ersnet.org/
- “Operator” is the person conducting the test
- “Patient” is the person being tested
- “Maneuver” is the term used for the inspiratory and expiratory VC excursions.
- “Must” is used to indicate a requirement
- “Should” is used to indicate best practice

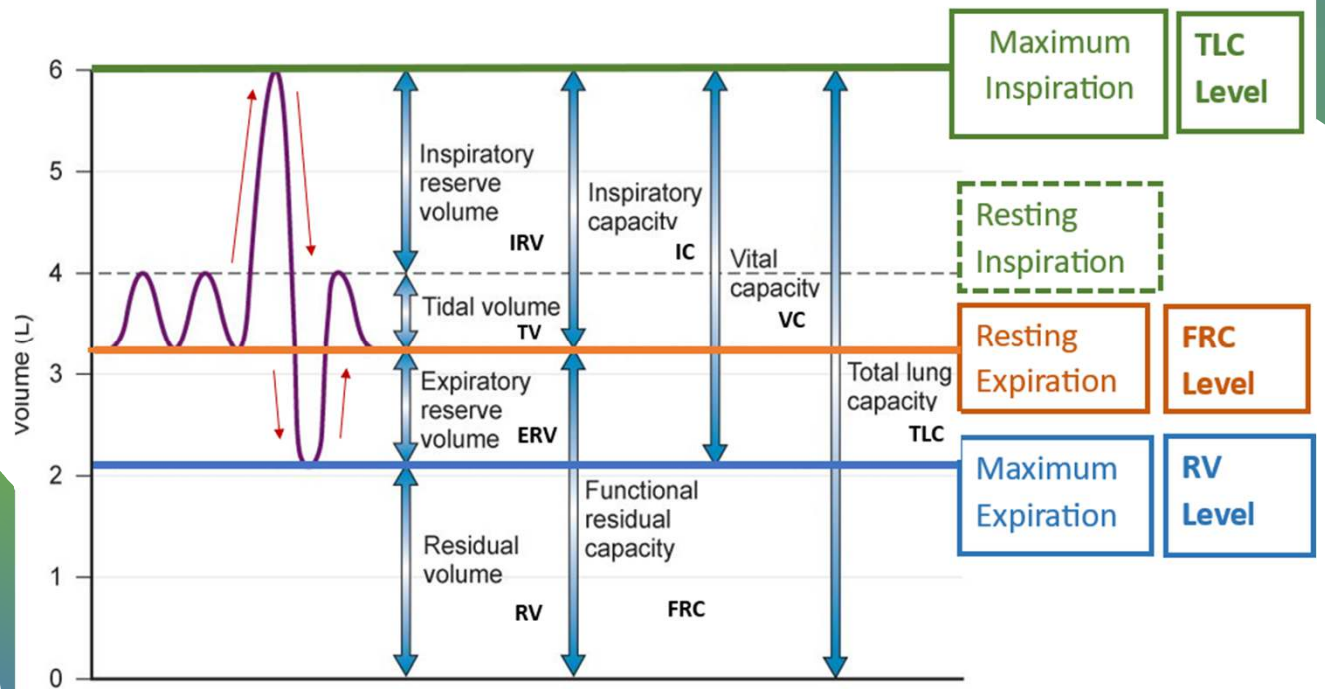
Key Terms & More

- DLCOunc (ml/min/mmHg) - The Transfer Factor for Carbon Monoxide as the volume of gas transferred per minute.
  - *"unc" for uncorrected*
  - *Also referred to as absolute*
- DLCOcor (ml/min/mmHg) - Transfer factor **corrected** for
  - Hgb and/or
  - COHb
- VA - The Alveolar Volume is measured in Liters and is a single breath determination of total lung capacity.
- DL/VA - Transfer factor relative to Alveolar Volume

Diffusion Studies Definitions & Acronyms

- DLCO
- D_LCO_{SB}
- Must
- COHB
- Hb
- Should
- t_{BH}
- Lung diffusion
- Operator
- CO
- V_A
- BHT
- Patient
- Lung diffusion study
- V_I/VC
- P_IO_2
- Manoeuvre (ERS)
- ATS
- ERS
- Tracer Gas

Spirometry: 4 Volumes, 4 Capacities, 4 Levels

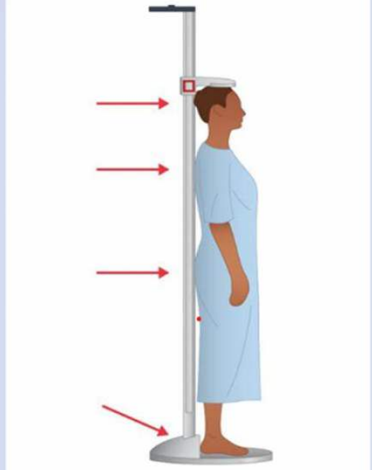


Procedure - Prepare the Patient: Height **is CRITICAL**

- The height must be measured against a wall or **stadiometer**
  - **without shoes!**
  - with the **feet together and touching the wall**
  - standing as tall as possible
  - eyes level and looking straight ahead
  - Back flush against the wall
- Height in centimeters to one decimal place or in inches
- 25 years or older - within 1 year
- *Don't use the height on the driver's license!*
- *Don't use the height the patient tells you.*

Procedure - Prepare the Patient: Height is CRITICAL

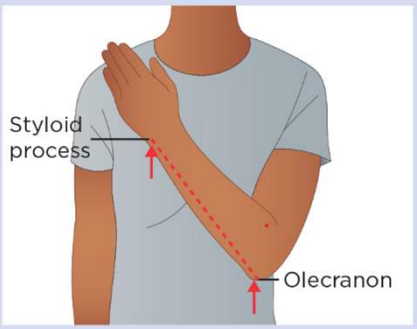
Fig 1. **Standing height**



The back of the head, shoulder blades, buttocks and heels should touch the stadiometer

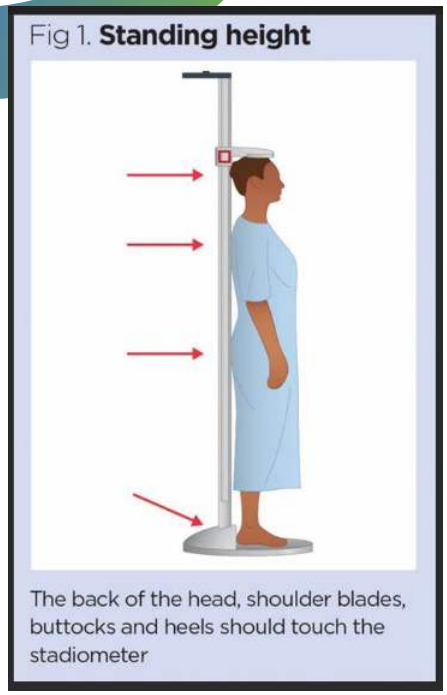
- The height must be measured against a wall or **stadiometer** - **without shoes!**

Fig 2. **Ulna length**

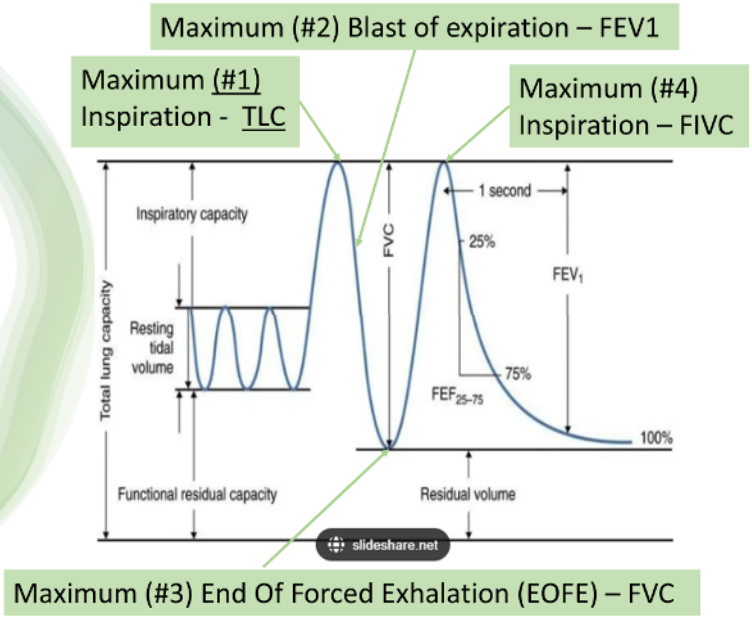


Measure from the olecranon process of the elbow to the midpoint of the styloid process of the wrist

Quality Spirometry



Four Maximums "Within Maneuver"



Quality Spirometry

Application of Acceptability and Repeatability Criteria

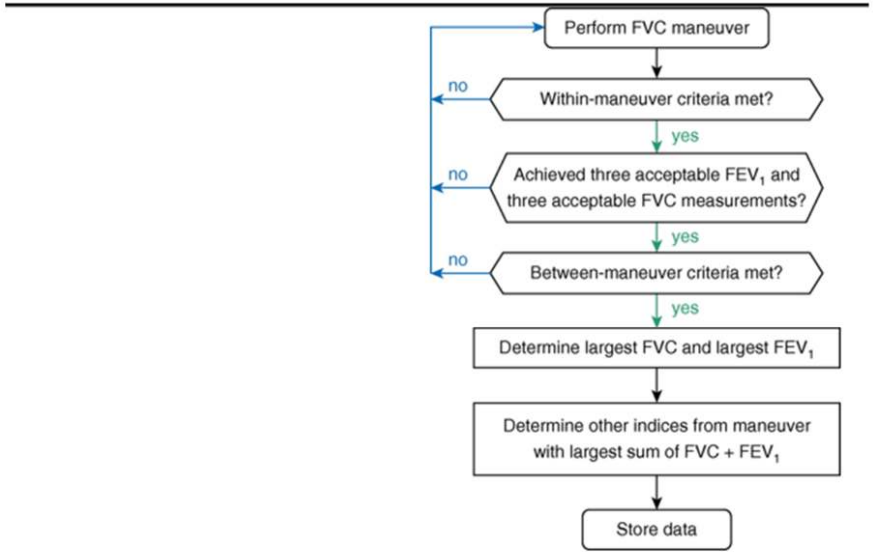
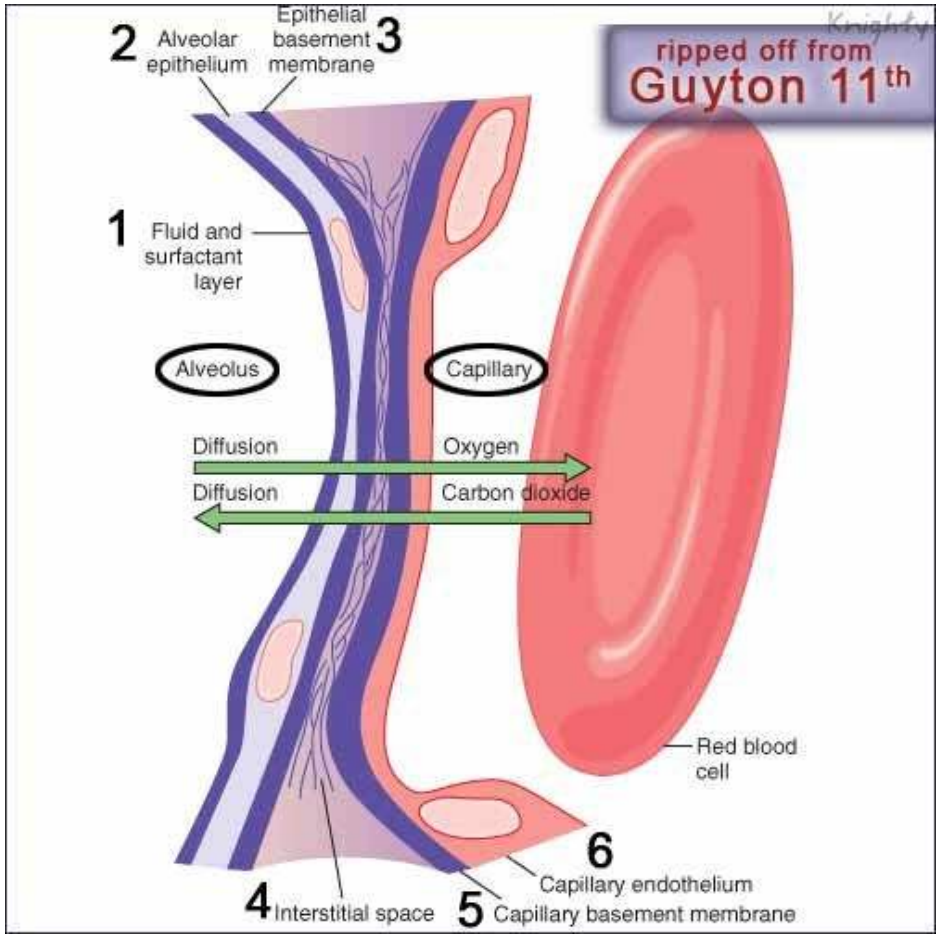


Figure 3. Flowchart outlining application of acceptability and repeatability criteria.

Am J Respir Crit Care Med, 2019

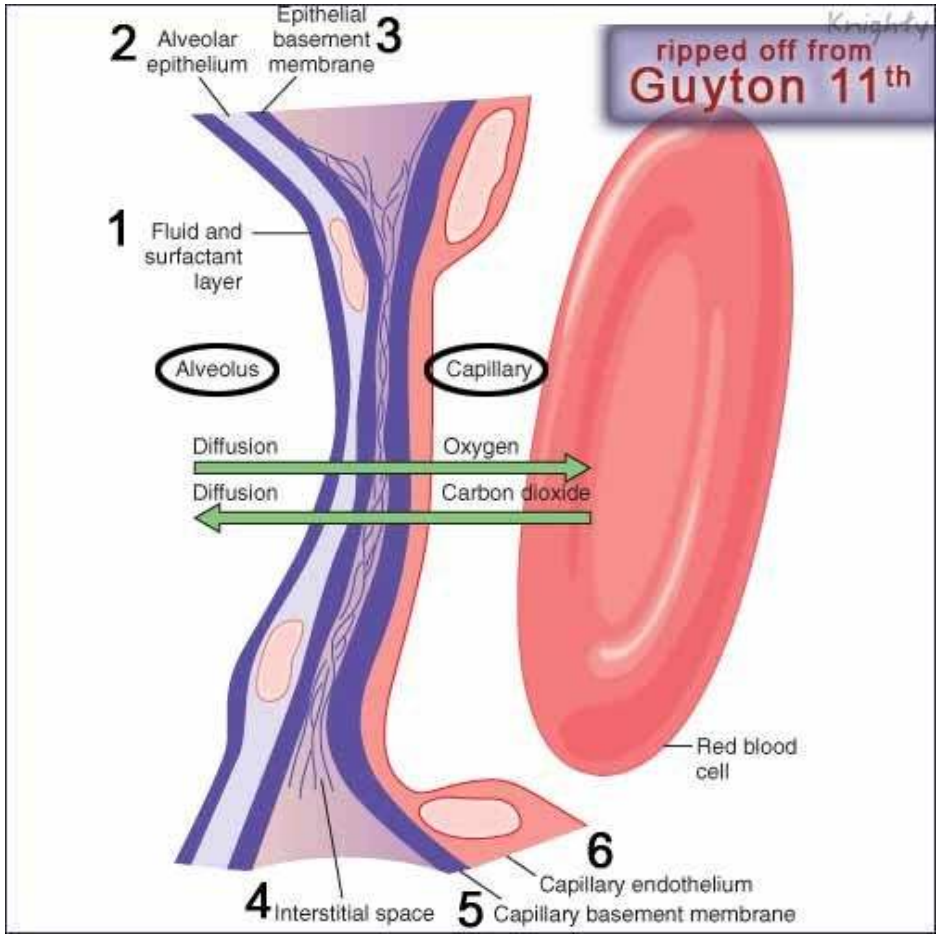


Anatomy

1. Alveolus: Fluid and surfactant layer
2. Alveolus: Epithelium
3. Alveolus: Epithelial basement membrane
4. Interstitial space:
5. Capillary: Basement Membrane
6. Capillary: Endothelium
7. Red blood cell

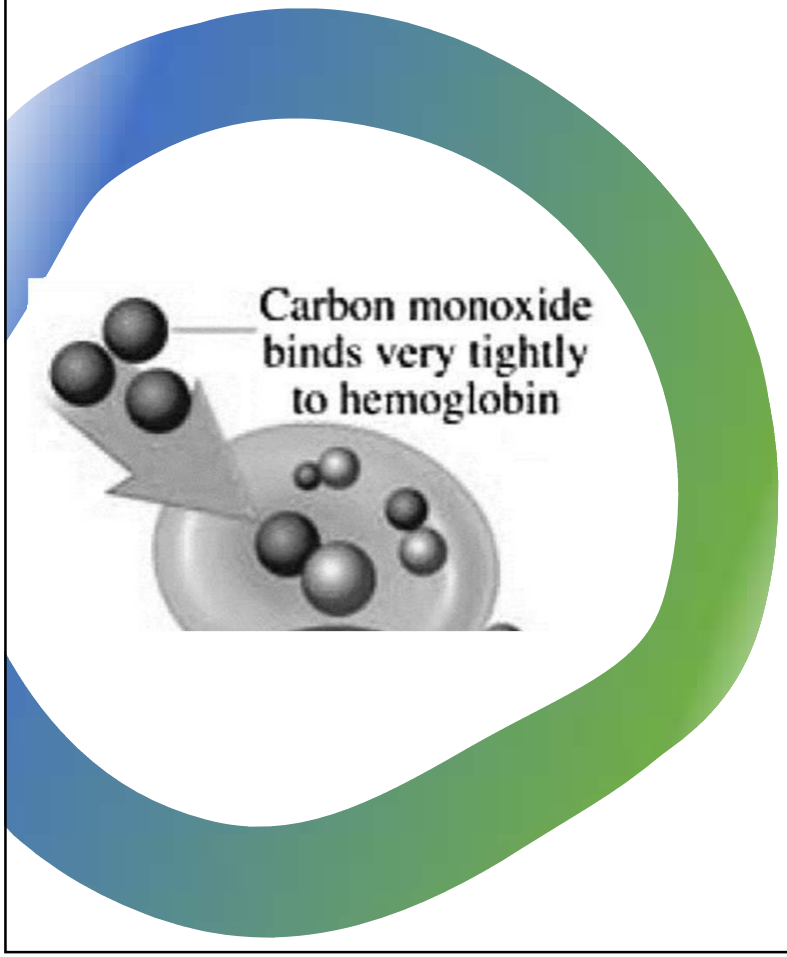
Physiology

The diffusing capacity of the lungs for carbon monoxide (DLCO) measures the ability of the lungs to transfer gas from inhaled air in the alveoli to the red blood cells in pulmonary capillaries.



Factors that determine how well oxygen transfers from your lungs to your blood

- The amount of fluid in the alveoli.
- The amount of surface area in the alveoli.
- The thickness of the membrane between the alveoli and the capillaries.
- The **amount of blood in the capillaries.**
- The concentration of hemoglobin (a protein that carries oxygen) in the blood.



Role of Hemoglobin in Carbon Monoxide Binding

Carbon monoxide has
210 times greater affinity for
haemoglobin than oxygen

The diffusing capacity of the lungs for carbon monoxide (DLCO) changes with anemia, carboxyhemoglobin levels, altitude, and lung volume, so adjustments for variances in these factors may be needed prior to interpretation.

User / Operator

Three key elements:
- Instrumentation
- Patient
- Operator

Requires:
training
experience

It is the responsibility of the operator to observe and engage with the patient to achieve optimal results

Patient Preparation

A. No cigarette smoking on the day of the test

- *or note the timing of the last cigarette smoked before testing*

B. No supplemental oxygen for at least 10 (-15) minutes prior to and during the test

- *The DLCO test cannot be performed in patients who are unable to discontinue supplemental oxygen*

In addition, when using **exercise** or the **supine** position to assess the ability of the lung to increase gas transfer [18, 28–31], the level of exercise and/or the duration of the supine position must be noted.

Testing Sequence

A. Spirometry

- **There is no recommendation against use of a bronchodilator prior to D_{LCO} tests.**
- Spirometry is a form of exercise [59], which could conceivably impact on D_{LCO} values; however, no studies were found which support a recommendation for a rest interval following spirometry.

B. Diffusion

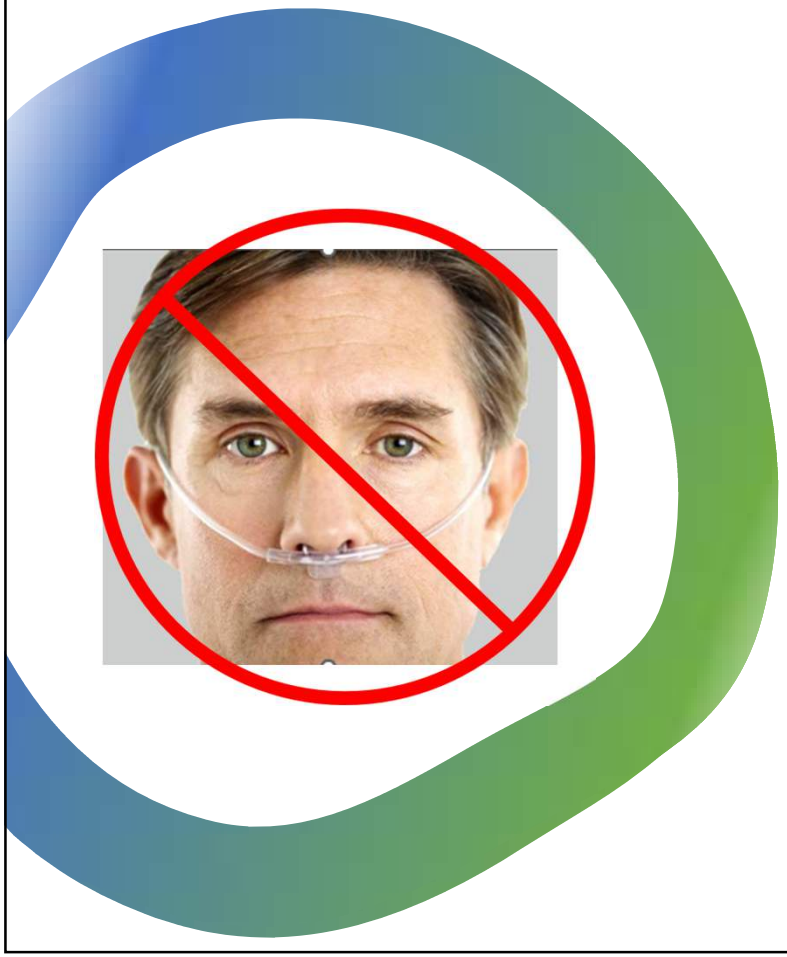
C. Nitrogen Washout

- It is recommended that D_{LCO} measurements be made before any multi-breath nitrogen washout tests.
- If the order of testing includes measuring absolute lung volumes using nitrogen washout, during which 100% oxygen is inspired [89] prior to D_{LCO} manoeuvres, ample time is required for alveolar oxygen levels to return to normal. For nitrogen to wash back in to normal levels, allow a rest interval equal to twice the time required for the nitrogen washout test to be completed [90].

Procedure - Prepare the Patient: Key Messages from Patient Survey

- **Pts don't want to have to ask for water, tissues & sputum pots**

- Privacy
- Encouraging
- Feel prepared
- Recovery



10 to 15 Minutes off oxygen

. Use of supplemental oxygen will decrease measured DLCO by interfering with COHb binding.

Learning Objectives

At the conclusion of this presentation
the learner shall be able to…

2. instruct, demonstrate, practice, and coach through five phases of the single breath DLCO maneuver

1. Relaxed normal tidal breathing on mouthpiece
2. Exhale completely to Residual Volume
3. Inhale test gas rapidly to Total Lung Capacity
4. Hold breath for 10 seconds
5. Exhale

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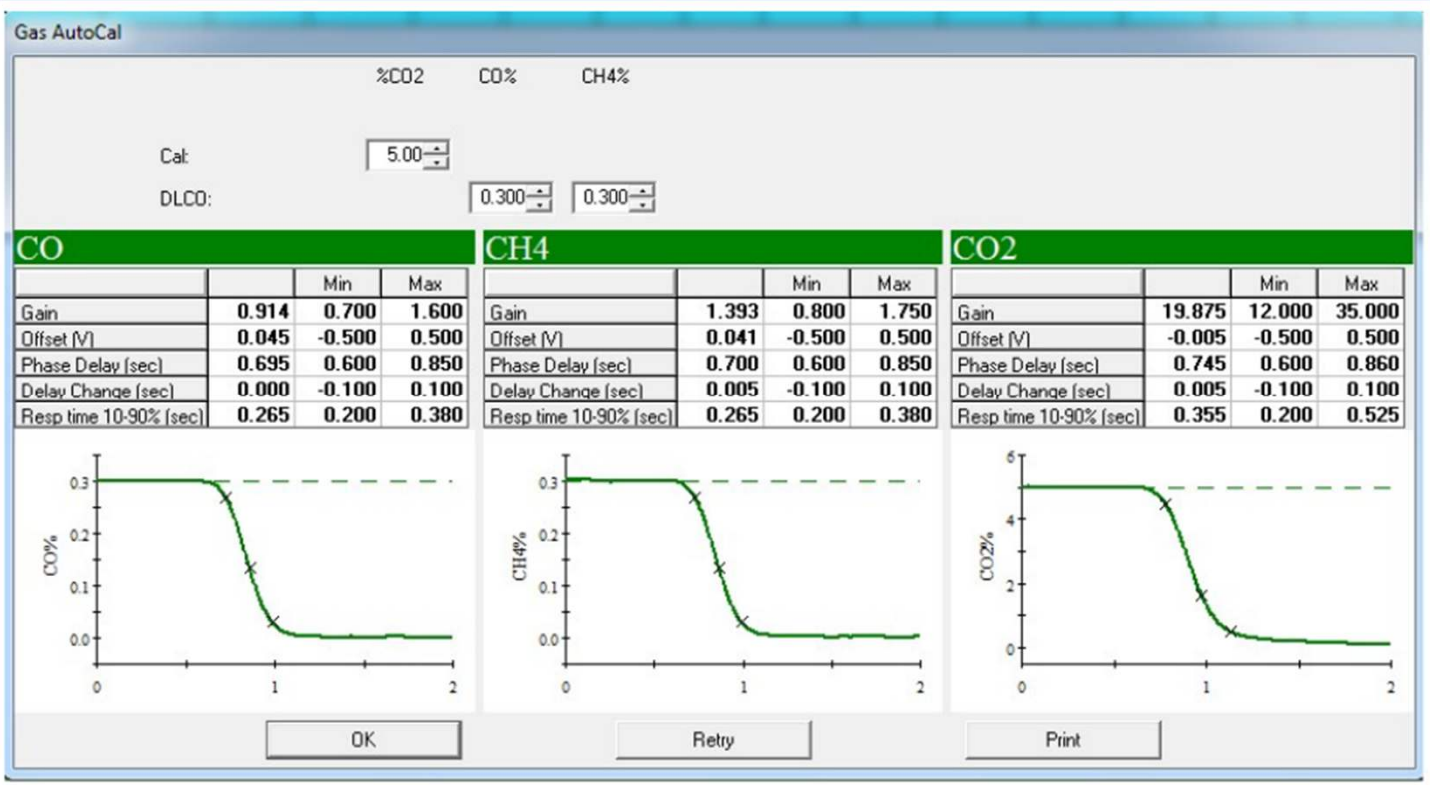
Calibrate DLCO gases before every maneuver



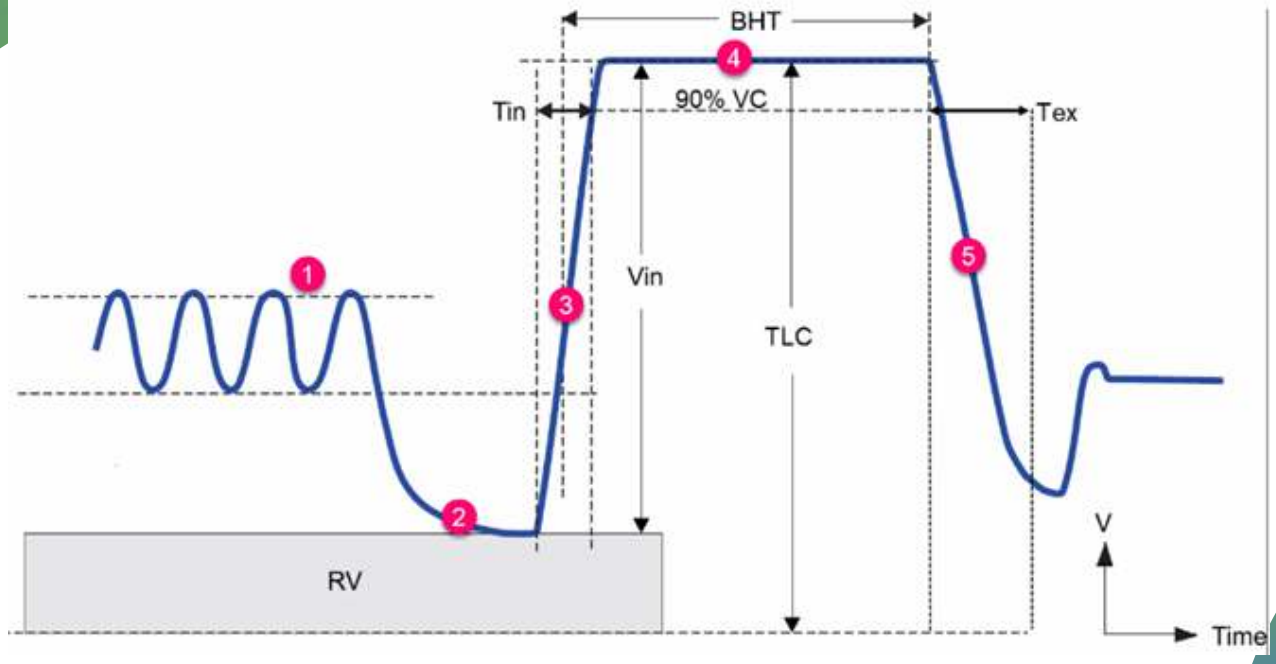
Instruct, Demonstrate,
& Practice BEFORE

Coach
DURING

Instruct, Demonstrate, and Practice:

- **Instruct** or Explain
  - Using words to **tell** the patient
  - Tell them "What" and "Why"
- **Demonstrate**
  - Using action / behavior /body language to **show** the patient
  - Show them "How" and "When"
- **Five Phases**
- Ask for and answer patient questions
- Confirm that patient understands and is willing to comply
- **PRACTICE**

FIVE PHASES:



Five Phases:

- *Phase 1:* Normal breathing – several breaths
- *Phase 2:* Breathe everything out to completely empty
  - Keep blowing out - wait for the machine to “Click”
- *Phase 3:* Deep breath in, fast, all the way to completely full
- *Phase 4:* Hold… Hold… Count down: 3…2…1..
- *Phase 5:* Blow out – keep blowing

Demonstrate and Practice:

- Sit tall, put your nose clips on and mouthpiece in
- Normal breathing – several breaths
- Breathe everything out to completely empty
- Wait for the machine to “Click”
- Deep breath in all the way to completely full
- Hold… Hold… Hold
- 3…2…1..
- Blow out – keep blowing
- Relax, come off, park your nose clip

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Demonstrate &Practice

- Sit tall, put your nose clips on and mouthpiece in
- Normal breathing – several breaths
- Breathe everything out to completely empty
- Wait for the machine to “Click”
- Deep breathe in all the way to completely full
- Hold… Hold… Hold
- 3…2…1..
- Blow out – keep blowing
- Relax, come off, park your nose clip

Coach Maneuver: Overview

- *Have patient assume the correct posture*
- **"Mouthpiece & Nose clip"**

1. **"Normal Breathing"**
2. **"Blow out…out…out"**
3. **"Deep breath in…more"**
4. **"Hold it…hold it…hold it"**

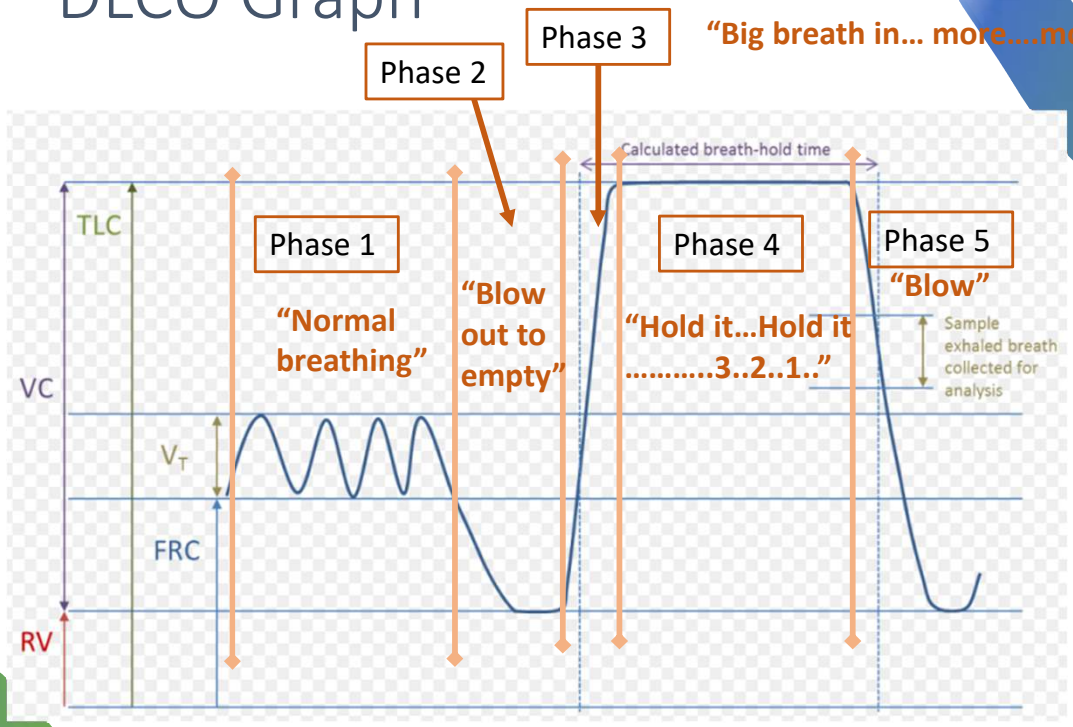
   "3… 2… 1…"
5. **"Blow out"**

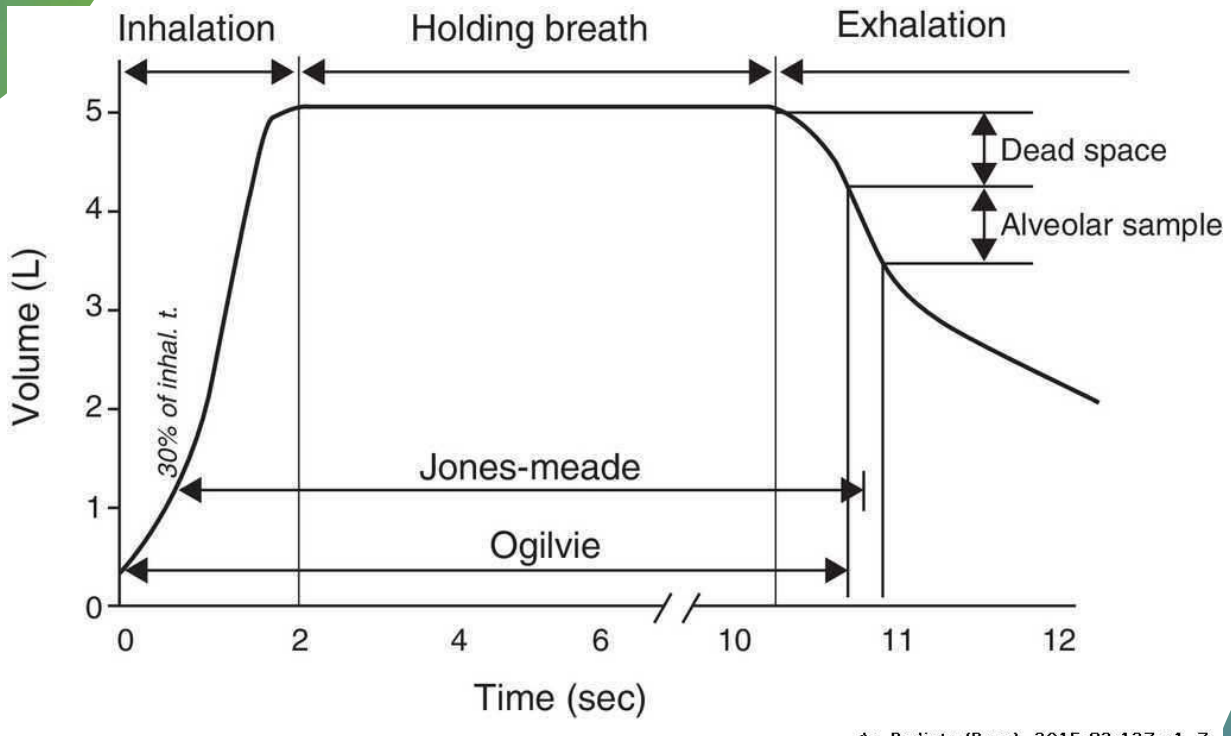
Coach Maneuver: Overview

- *Have patient assume the correct posture*
- **"Mouthpiece & Nose clip"**

1. **"Normal Breathing"**
2. **"Blow out…out…out"**
3. **"Deep breath in…more"**
4. **"Hold it…hold it…hold it"**
   "3… 2… 1…"
5. **"Blow out"**

DLCO Graph


Phase 2
Phase 3
"Big breath in… more….more"
Calculated breath-hold time
TLC
Phase 1
"Normal breathing"
"Blow out to empty"
Phase 4
"Hold it…Hold it ……..3..2..1.."
Phase 5
"Blow"
Sample exhaled breath collected for analysis
VC
V_T
FRC
RV

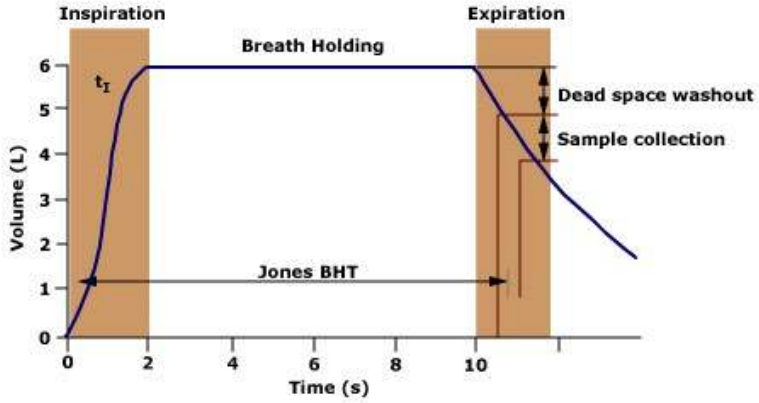


An Pediatr (Barc). 2015;83:137.e1-7

Repeat the test

- After a **minimum of four minutes**, the test is repeated; *a longer interval may be needed if the patient has obstructive airways disease.*
- **Not more than five tests** should be done in the course of one session, *as five tests can decrease the measured DLCO by 3 to 3.5 percent*

Single breath DLCO maneuver

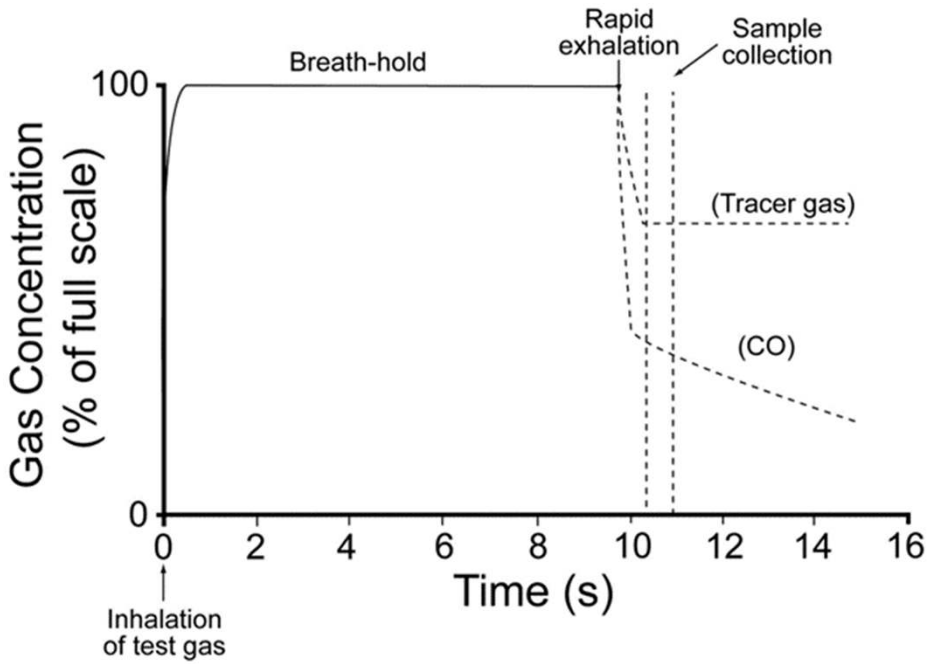


The patient quickly inhales a deep breath of test gas, holds his or her breath for 10 seconds, and then exhales quickly. The Jones method measures breathhold time (BHT) starting at 30 percent of inspiratory time (t_I) and extending to half of sampling time.

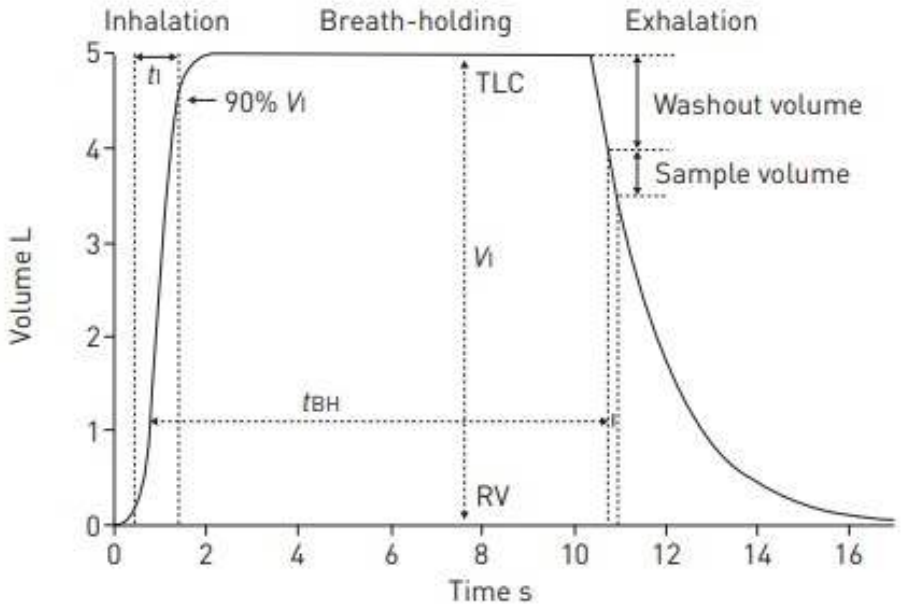
RV: residual volume; TLC: total lung capacity.

Adapted from Am J Respir Crit Care Med 1995; 152:2185.

Graphic 60988 Version 1.0


Rapid
exhalation
Sample
collection
Breath-hold
100
Gas Concentration
(% of full scale)
(Tracer gas)
(CO)
0
0
2
4
6
8
10
12
14
16
Time (s)
Inhalation
of test gas

40


Inhalation
Breath-holding
Exhalation
t_I
90% V_I
TLC
Washout volume
Sample volume
V_I
t_{BH}
RV
Volume L
Time s
0
1
2
3
4
5
0
2
4
6
8
10
12
14
16

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Learning Objectives

At the conclusion of this presentation
the learner shall be able to…

3. list and explain ATS/ERS criteria for **Acceptability, Usability, Repeatability,** and **Quality Grading**
   A. ≥ 4 minutes between efforts
   B. 5 phases
      1. Relaxed tidal breathing
      2. Exhale completely
      3. Inhale test gas rapidly to completely full
      4. Hold breath 8 – 12 seconds
      5. Exhale
   C. VA ≤ TLC

Learning Objectives

At the conclusion of this presentation
the learner shall be able to…

3. list and explain ATS/ERS criteria for **Acceptability, Usability, Repeatability,** and **Quality Grading**

DLCO Acceptability Criteria

Volume Inspired (VI) must be **90%** of **largest known VC** in the same PFT session

-OR-

An Inspired Volume (VI) of ≥ **85%** of the largest known VC in the same session

AND

A VA within **200 mL** or **5%** (whichever is greater) of the largest VA from other acceptable DLCO maneuvers

The subject must inhale **85%** of the test gas VI < **4 seconds** and the Sample collection is to be completed within **4 seconds** of the start of exhalation with adequate tracer gas plateau, correct sample volume, correct dead-space washout For RGA systems, virtual sample collection should be initiated after dead-space washout is complete

Breath Hold Time (BHT) should be between **8** and **12** seconds, with no evidence of leaks, Valsalva, or Muller maneuvers

DLCO Acceptability Criteria

TABLE 3

Acceptability, repeatability and quality control in D_{LCO} testing

Criteria for acceptability
A V_I ≥90% of the largest VC in the same test session; alternatively a V_I ≥85% of the largest VC in the same test session and V_A within 200 mL or 5% (whichever is greater) of the largest V_A from other acceptable manoeuvres
85% of test gas V_I inhaled in <4 s
A stable calculated breath-hold for 10±2 s with no evidence of leaks or Valsalva/Müller manoeuvres during this time
Sample collection completed within 4 s of the start of exhalation. For RGA systems, virtual sample collection should be initiated after dead-space washout is complete

DLCO Usability

A maneuver is usable if:

- The alveolar sample is valid
- No major leaks
- Breath hold is within range
- Volumes meet minimum thresholds

Even if:

- Effort is slightly suboptimal
- VC < 85% predicted but is the patient's maximum
- Timing is slightly prolonged but still technically interpretable

DLco Acceptability Criteria

Volume Inspired (VI) must be ≥90% of VC performed prior to DLco test

or

An Inspired Volume of ≥85% of the largest VC in the same session

&

A VA within 200ml or 5% (whichever is greater) of the largest VA from other acceptable maneuvers

Breath hold time should be between 8 and 12 seconds, with no evidence of leaks, Valsalva or Muller maneuvers

The subject must inhale 85% of the test gas VI within 4 seconds and, the Sample collection is to be completed within 4 seconds of exhalation

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DLCO Repeatability Criteria

At least <u>two</u> acceptable D_{LCO} measurements within 2 mL·min^{-1}·mmHg^{-1} (0.67 mmol·min^{-1}·kPa^{-1}) of each other

or within 3% of mean DLCO when DLCO > 10

Report the average of two acceptable DLCO measurements

An interval of at least 4 minutes should elaps
between repeated tests

DLco Repeatability Criteria

At least 2 acceptable tests

An interval of at least 4 minutes should elapse between repeated tests

At least 2 acceptable tests that meet the repeatability requirement of either being within $2ml.min^{-1}.mmHg^{-1}$ or $0.67mmol.min^{-1}.kPa^{-1}$ of each other.

Quality grading for DLCO measurements

Score of A: (1) VI/VC 90% or VI/VC > 85% and VA within 0.2 L or 5% of largest VA from another acceptable maneuver; (2) breath hold time of 8-12 seconds; and (3) sample collection < 4 seconds **NOTE: only grade A manoeuvres meet all acceptability criteria**

Score of B: (1) VI/VC greater than 85%; (2) breath hold time of 8-12 seconds; and (3) sample collection < 4 seconds

Score of C: (1) VI/VC greater than 80%; (2) breath hold time of 8-12 seconds; and (3) sample collection < 5 seconds

Score of D: (1) VI/VC greater than 80%; (2) breath hold time of < 8 seconds or > 12 seconds; and (3) sample collection ≤5 seconds

Score of F: (1) VI/VC less than 80%; (2) breath hold time of < 8 seconds or >12 seconds; and (3) sample collection > 5 seconds **NOTE: Manoeuvres of grade F are not useable.**

Quality grading for DLCO measurements

Quality control grading[#]			
Score	**V_I/VC**	**t_{BH}**	**Sample collection**
A	≥90%[¶]	8–12 s	≤4 s
B	≥85%	8–12 s	≤4 s
C	≥80%	8–12 s	≤5 s
D	≤80%	<8 or >12 s	≤5 s
F	≤80%	<8 or >12 s	>5 s

V_I: inspired volume; VC: vital capacity; V_A: alveolar volume; t_{BH}: breath-hold time; D_{LCO}: diffusing capacity of the lung for carbon monoxide. [#]: only grade A manoeuvres meet all acceptability criteria. The average D_{LCO} values from two or more grade A manoeuvres that meet the repeatability criterion should be reported. If only one grade A manoeuvre is attained, the D_{LCO} value from that manoeuvre should be reported. If no grade A manoeuvre is obtained, manoeuvres of grades B to D might still have clinical utility. The average of such manoeuvres should be reported but these deviations from the acceptability criteria must be noted to caution the interpreter of the test results. Manoeuvres of grade F are not useable. [¶]: or V_I/VC≥85% and V_A within 200 mL or 5% (whichever is greater) of the largest V_A from another acceptable manoeuvre.

Quality grading for DLCO measurements -- Cont.

Only grade A maneuvers meet all acceptability criteria.

The average DLCO values from two or more grade A maneuvers that meet repeatability criterion should be reported.

If only one grade A maneuver is obtained, the DLCO value from that maneuver should be reported.

If no grade A maneuver is obtained, maneuvers of grades B to D might still have **clinical utility,** and the average of such maneuvers should be reported. However, these deviations from the acceptability criteria must be noted to caution the interpreter of the test.

Maneuvers of grade F are not useable.

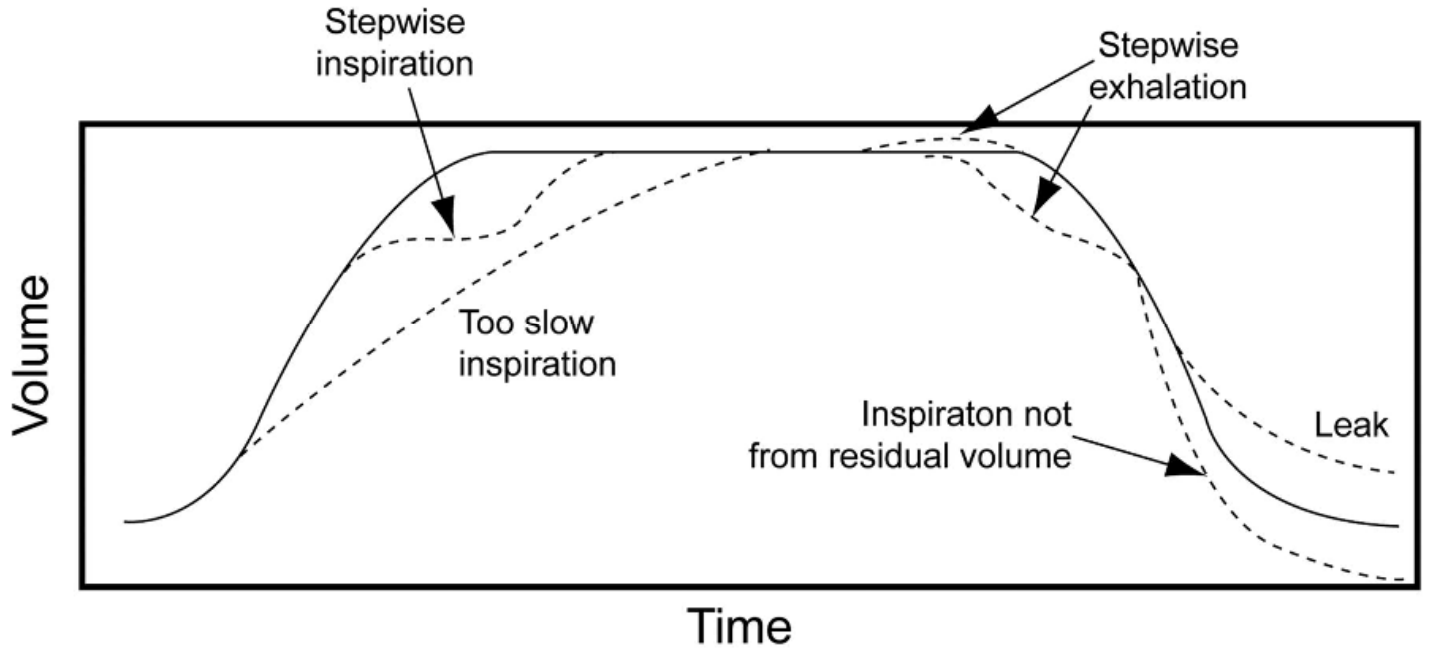
Learning Objectives

At the conclusion of this presentation
the learner shall be able to…

4. use **troubleshooting** and **coaching to** correct common technical and patient-related errors

- ✓ **Phase 1 Tidal breathing:** Stable FRC level
- ✓ **Phase 2 Exhalation to RV:**
  - Plateau ≥1-2 sec -- *OR* -- ≤12 sec
- ✓ **Phase 3 Inhalation to TLC:**
  - Vi < 90% VC / Too fast / Too slow / Stepwise /
  - VA within 200 mL or 5%, whichever is greater, of largest VA
  - VA > TLC
- ✓ **Phase 4 Breath Hold:** 8-12 sec / Leaks / Valsalva / Muller
- ✓ **Phase 5 Exhale:** volume (VC < 1.5L) / time (4 seconds)

Some Performance Errors



Troubleshooting and Coaching Phase ONE

- Pt comfortable and **no leaks** yield stable FRC line
- Typically, 3-5 breaths but may be several more
- Beware of TV moving left with air-trapping

- Use simple, concrete language:
- Instruct What & Why: "**Relax & keep breathing normal"**
- Demonstrate How:
- Coach: **"Breathe normally"**

Troubleshooting and Coaching Phase TWO

- Not getting ALL the air out, down to RV, means VI will be less than max and the VA and DLCO results may be artificially low

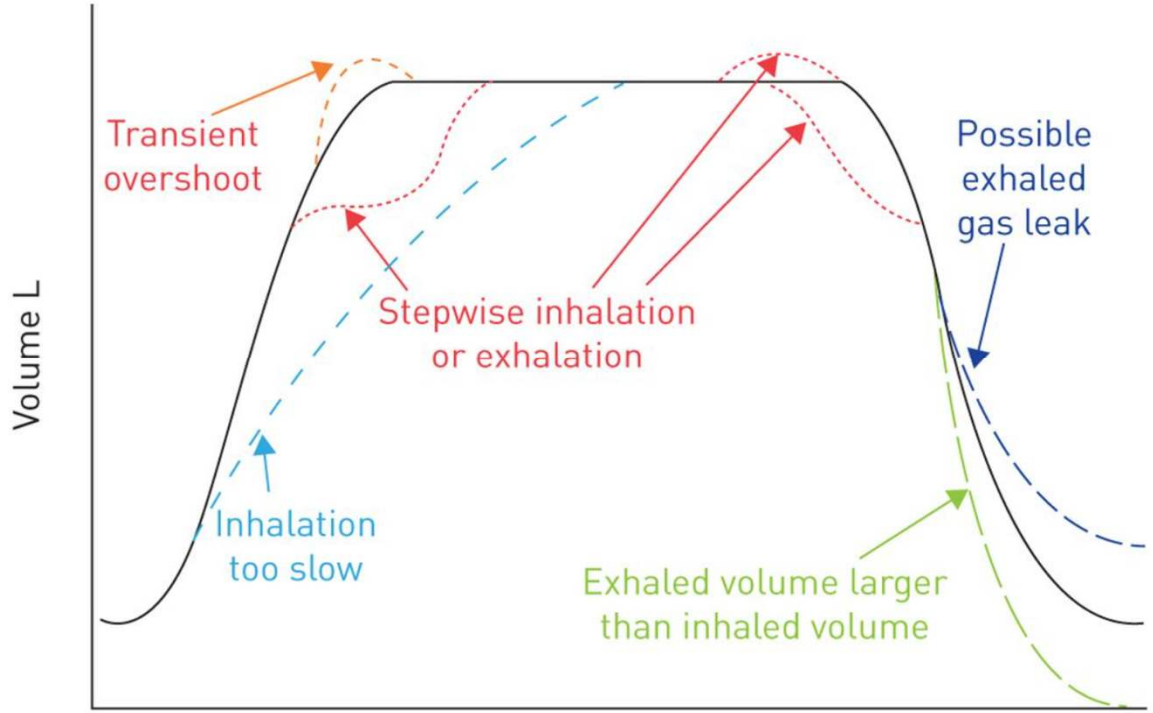
- Instruct What & Why: Explain that totally empty lungs may be new and is uncomfortable and that in order to get an accurate test, **"I need you to blow out ALL your air" "empty your lungs completely"** otherwise the results may be artificially low.
- Demonstrate How: Unforced, *Long… to RV*
- Coach: **"Blow out…out…out…out"** *until 1-2 seconds plateau or 12 sec*

Troubleshooting and Coaching Phase THREE

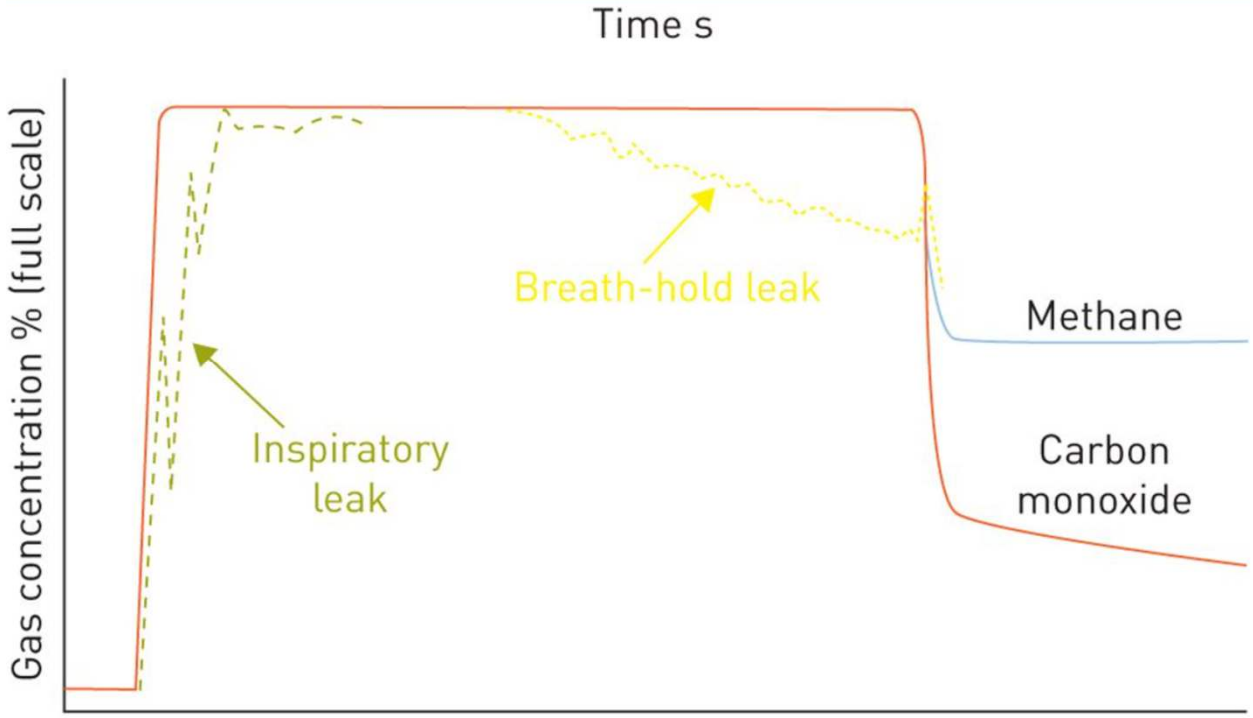
- The VI should be **≥90 %** of the largest measurement for VC.
  - Incomplete inhalation increases ratio error and underestimates DLCO
- A maneuver may be deemed acceptable if the VI is <90 %, but ≥85 % of the largest VC and the VA is within 200 mL or 5 % (whichever is greater) of the highest VA among acceptable maneuvers
- At least 85 percent of the test gas VI must be inhaled in <4 seconds
- Uniform smooth and rapid inspiration without hesitation
  - Slow inspiration (>2 sec) underestimates VA and falsely elevates DLCO

- Instruct What & Why: "Now take a BIG FAST breath all the way in"
- Demonstrate How: *demonstrate a fast, sharp sniff-like inhale*
- Coach: Deep breath IN…more!

Troubleshooting and Coaching Phase THREE



Troubleshooting and Coaching Phase THREE



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Troubleshooting and Coaching Phase THREE quote from the 2017:

- Due to these effects, it is important that the inspired volume of test gas, V_I, be as close to the known VC as possible. Data from a large patient population have shown that the V_I during D_{LCO} measurement averages ~90% of the VC [22]. Since the introduction of the 2005 guidelines and subsequent implementation of quality-control checks by equipment manufacturers, there has been an improvement in test quality such that **90% of the largest known VC** as the lower limit of acceptability for V_I has been shown to be attainable [67]. Furthermore, as noted above, ***V*$_I$ will be improved by allowing up to 12 s for exhalation prior to inhalation** of test gas. V_I must be at least 90% of the largest VC in the same pulmonary function testing session. However, a manoeuvre may be deemed to be acceptable if V_I is within 85% of the largest VC and the V_A is within 200 mL or 5% (whichever is greater) of the highest V_A among acceptable D_{LCO} manoeuvres.

Troubleshooting and Coaching Phase THREE quote from the 2017:

- The inspiration must be **rapid,** since the D_{LCO} calculations assume instantaneous lung filling [27, 68–74]. Slower lung filling decreases the amount of time the lung is at full inspiration with a consequent reduction in carbon monoxide uptake. Although various sample timing techniques address the issue of lung filling and emptying time, inspiration of test gas should be **sufficiently rapid such that that 85% of V_I must be inspired in <4.0 s.** If longer inspiratory times are needed to inspire 85% of V_I, this must be noted on the test report.

Troubleshooting and Coaching Phase THREE – Cont.: VA & TLC

- The average VA of the tests used to generate the reported DLCO should be reported.
- VA *(alveolar volume)* should be < TLC
- **PROBLEM:** VA > TLC is physiologically impossible

1- Verify TLC: air leaks, improper plethysmogramph shutter use, incomplete inspiration

2- Verify DLCO: RV to TLC full inspiration, leaks (nose clips / mouthpiece), BHT 8-12 sec w/o leaks, Valsalva or Mueller,

3- Equipment: calibration, leaks

4- Rare Physiologic

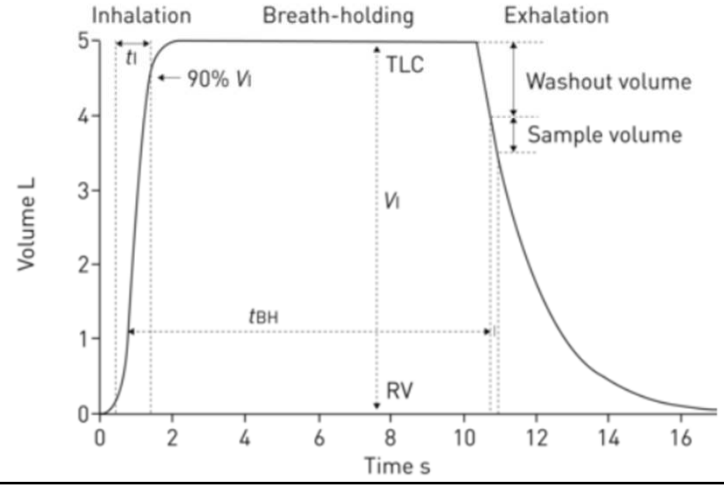
Troubleshooting and Coaching Phase FOUR

- The calculated breath-hold time should be 10±2 seconds.
  - Short – falsely high DLCO
  - Long – falsely low DLCO
- **No LEAKS:** no visible/audible bubbling in mouthpiece during hold, no visible facial movement, nose clip in place
  - Leaks underestimate DLCO
  - Common with dentures and facial structure discrepancies
- Instruct What & Why: "Hold your breath for ten seconds while keeping your cheeks firm"
- Demonstrate How:
- Coach: **"Hold…hold..3…2..1.."**
- **Fixing leaks:**
  - Adjust mouthpiece angle, try different mouthpiece or flange
  - Have patient press lips tighter
  - Support cheeks gently if they puff

Troubleshooting and Coaching Phase FOUR Calculating BHT

FIGURE 5

Schematic illustration of measuring breath-hold time for the single-breath diffusing capacity of the lung for carbon monoxide. The JONES and MEADE [72] breath-hold time includes 0.7 of inspiratory time and half of sample time. V_I: inspired volume; t_I: time of inspiration (defined from the back-extrapolated time 0 to the time that 90% of the V_I has been inhaled); t_{BH}: breath-hold time; TLC: total lung capacity; RV: residual volume. Reproduced from [4].



Troubleshooting and Coaching Phase FOUR

There should be no evidence of leaks, or a Mueller or Valsalva maneuver based on **observation** of the patient during the maneuver and review of the mouth pressure **tracing**.

Valsalva Maneuver

- Increased Intrathoracic pressure
  - Like MEP
  - Bearing down
- Decreased pulmonary capillary blood volume
- Falsely decreased DLCO

Mueller Maneuver

- Deep negative pressure
  - Like a NIF or MIP
- Falsely increased DLCO

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Troubleshooting and Coaching Phase FIVE

- In classic systems,
  - the first **0.75 to 1 L** is discarded as **dead space gas** and then
  - a **sample gas volume** of **0.5 to 1 L** is collected for analysis.
- In newer systems that use real-time rapid gas analyzers (RGA), the standards require measurement of dead space washout;
  - collection of a **sample as low as 85 mL** can be analyzed immediately after the dead space washout.
- Most DLCO instruments are unable to measure the DLCO when the patient's vital capacity is less than approximately 1.5 L.

- Instruct What & Why:
- Demonstrate How:
- Coach:

Curious Tidbit

- Over the past several decades, measurement of pulmonary diffusing capacity using **nitric oxide (DLNO)** has been introduced to provide additional information about the alveolar membrane diffusing capacity [88,89]. Since NO has a much faster rate of reaction with hemoglobin and the red blood cell resistance approaches zero, DLNO remains **unaffected by fluctuations in pulmonary capillary blood volume and reflects the alveolar-capillary membrane diffusing capacity.** The DLNO/DLCO ratio can be measured in a single maneuver and is inversely related to the thicknesses of the alveolar membrane and capillary sheet [88,90]. At present, this measurement is not widely available in clinical laboratories and is mostly used in research settings.

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Thank You

- Any Questions?

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Thank you

Any Questions?

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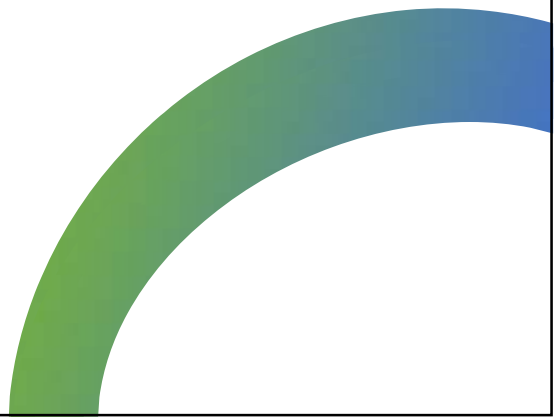

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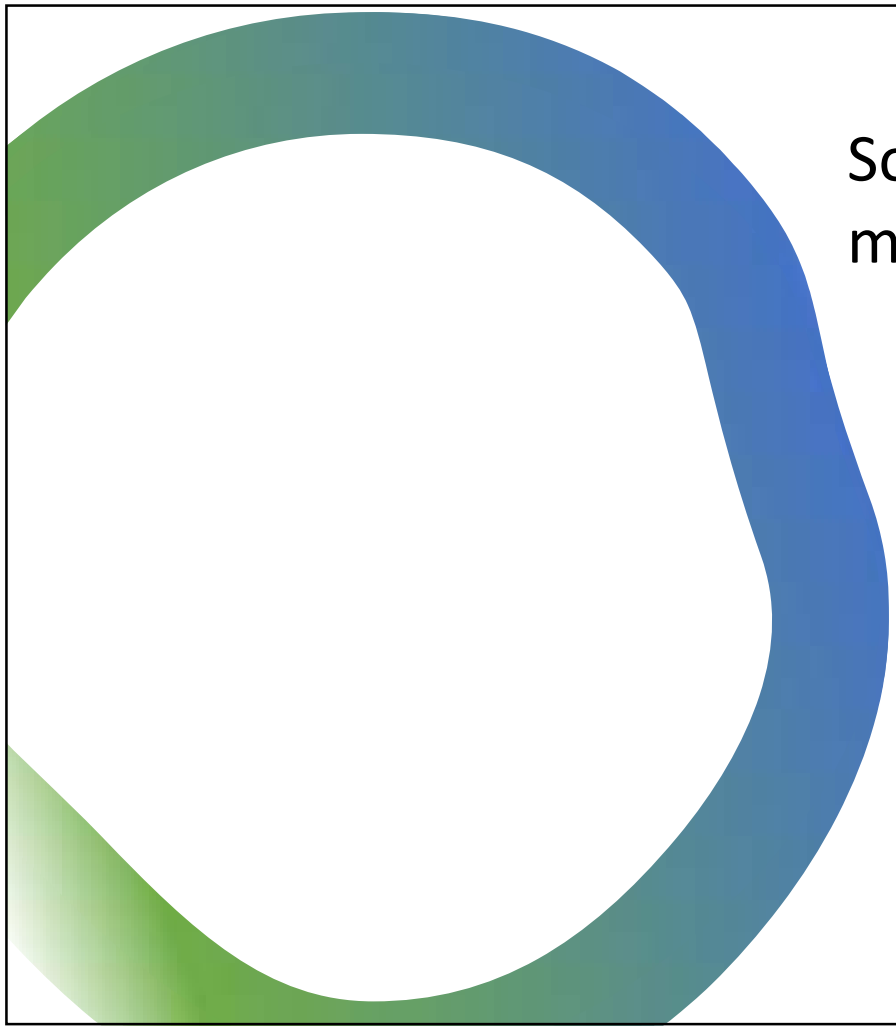

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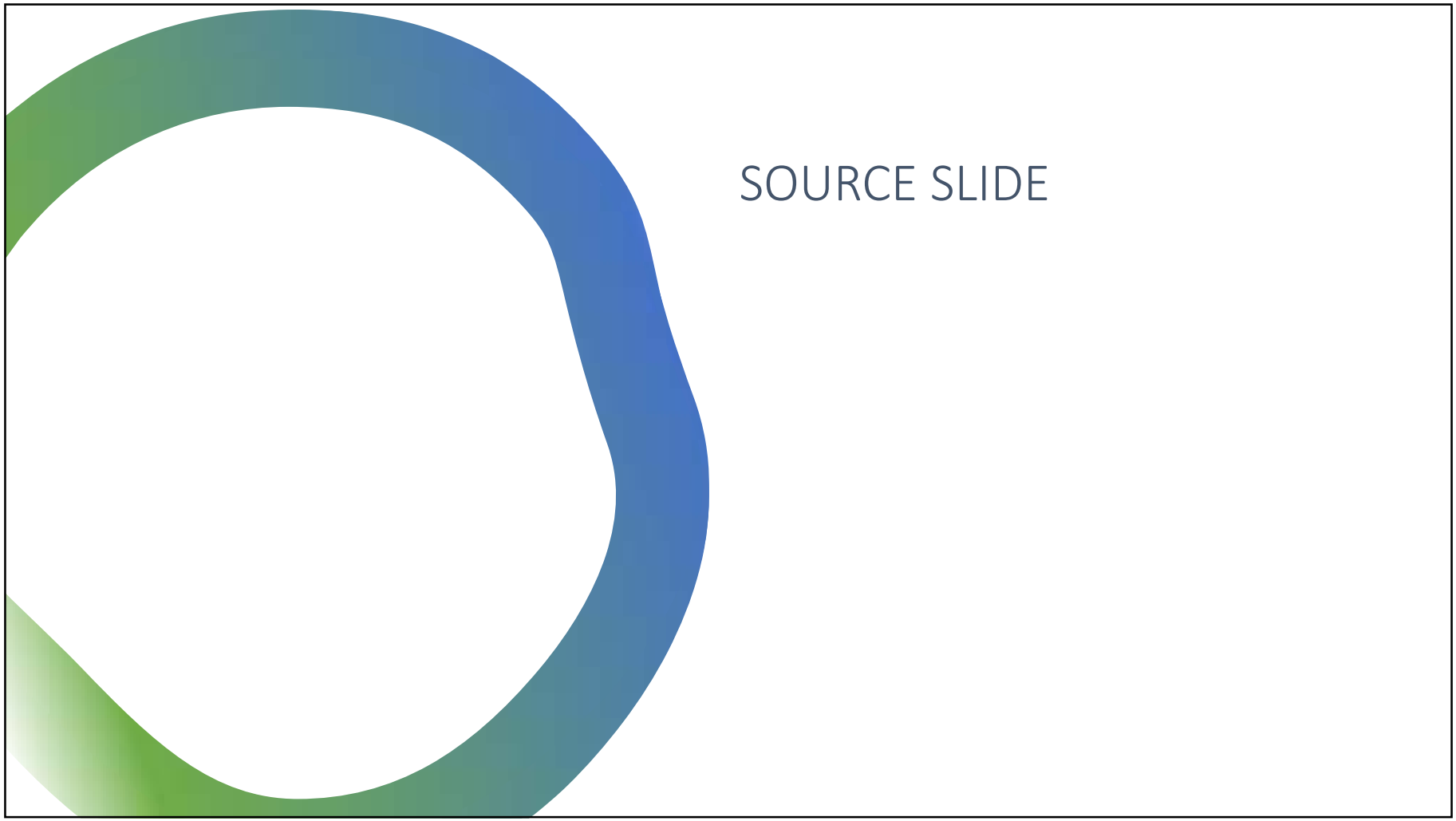

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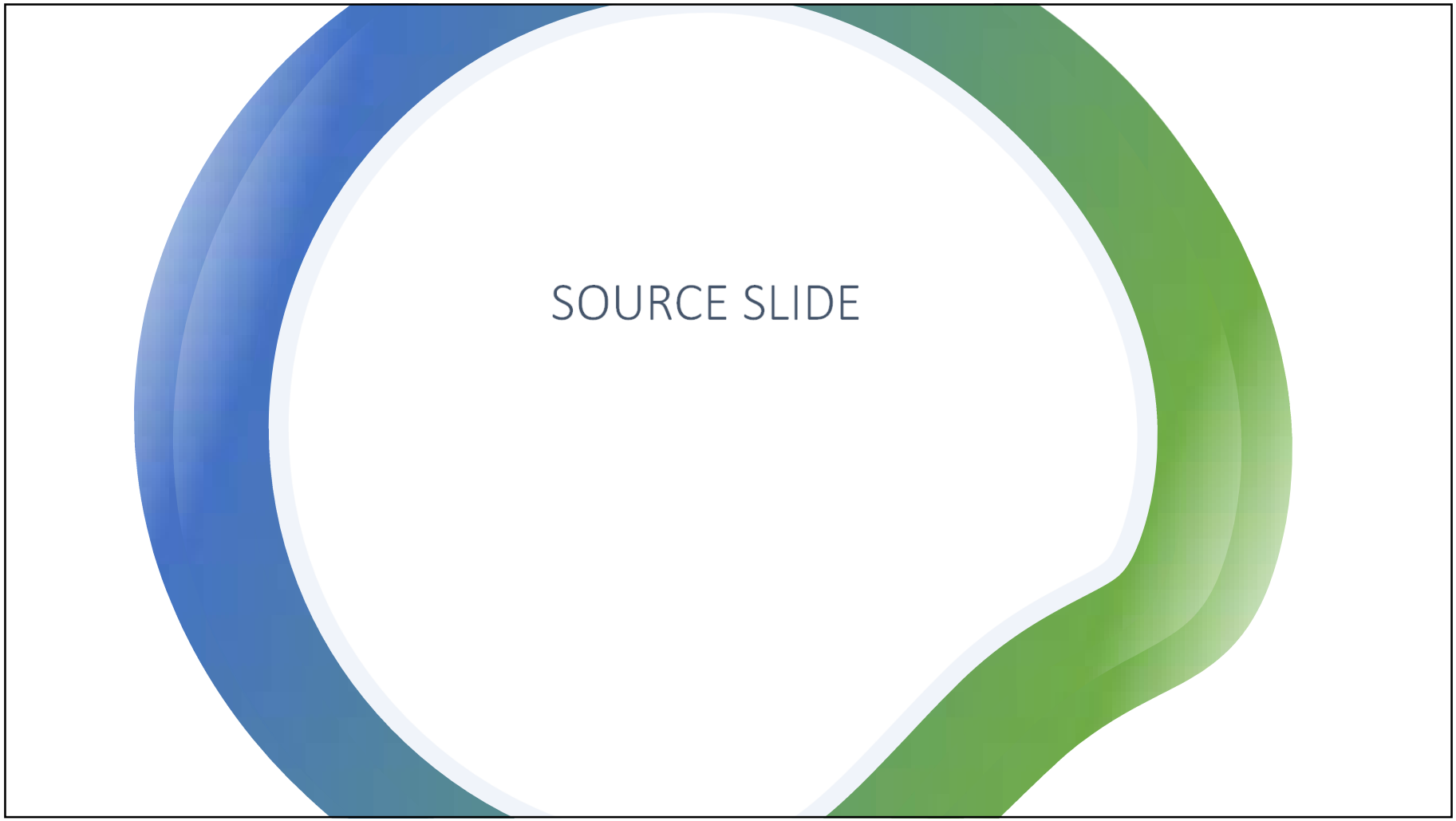

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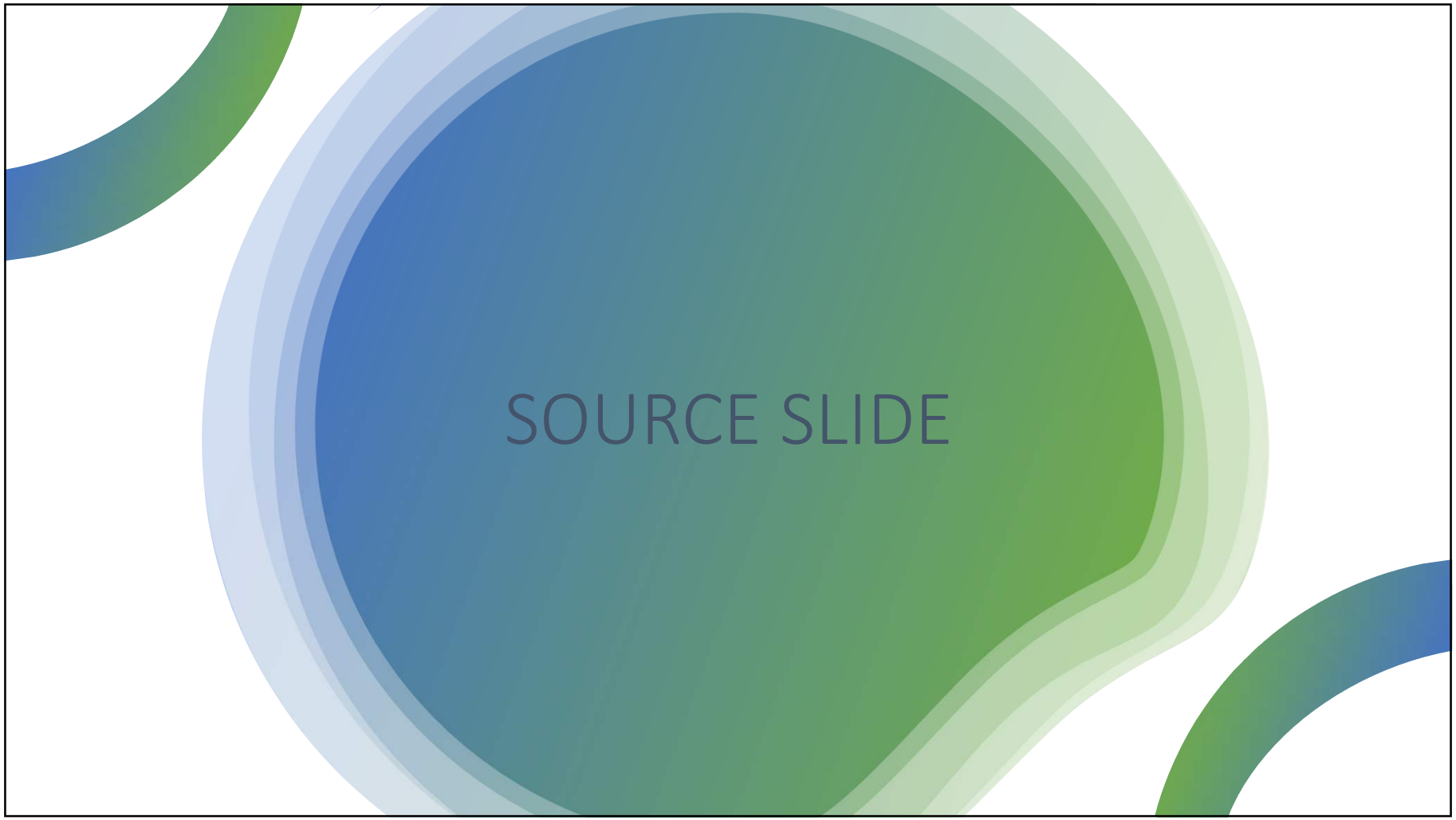

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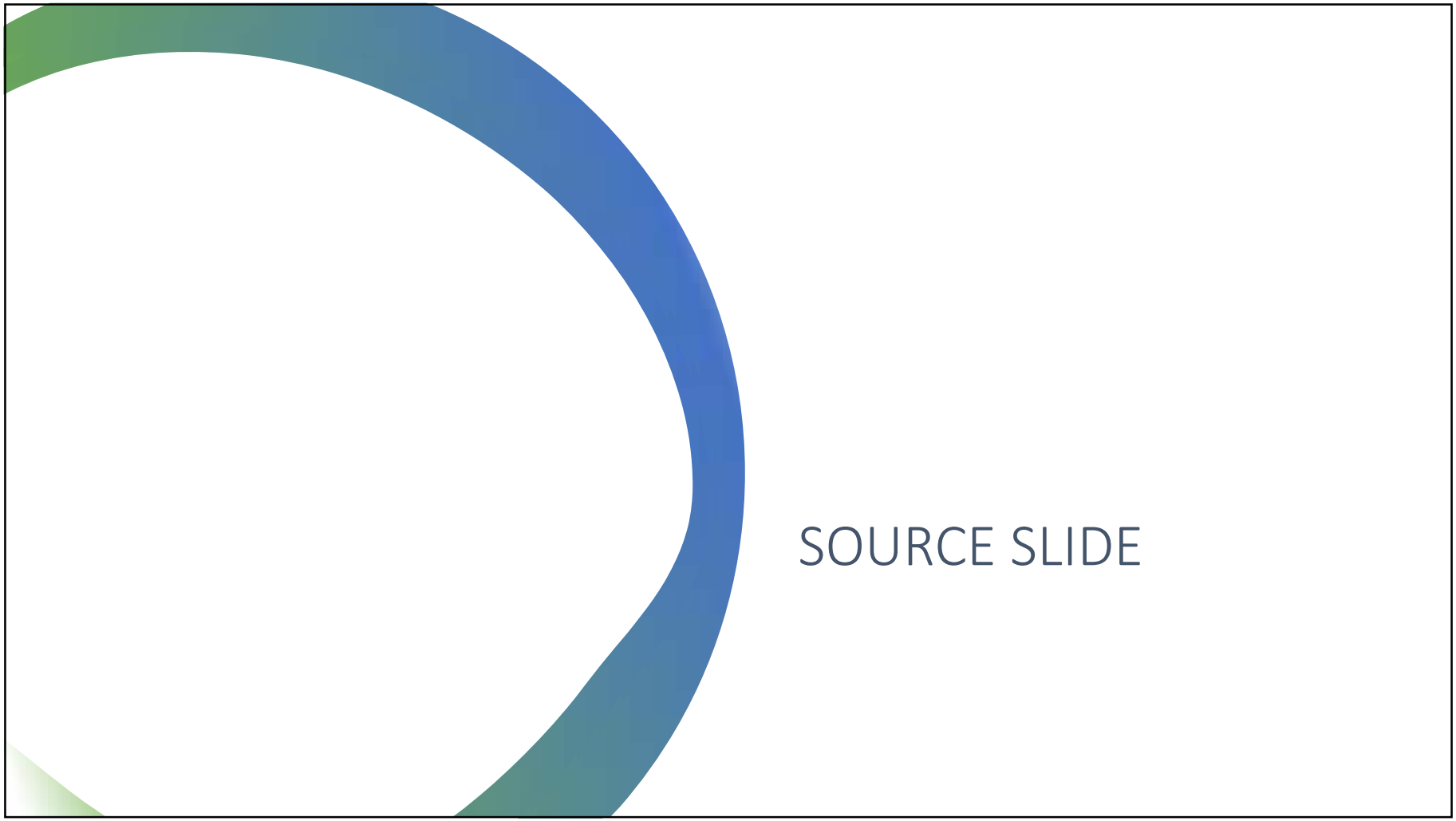
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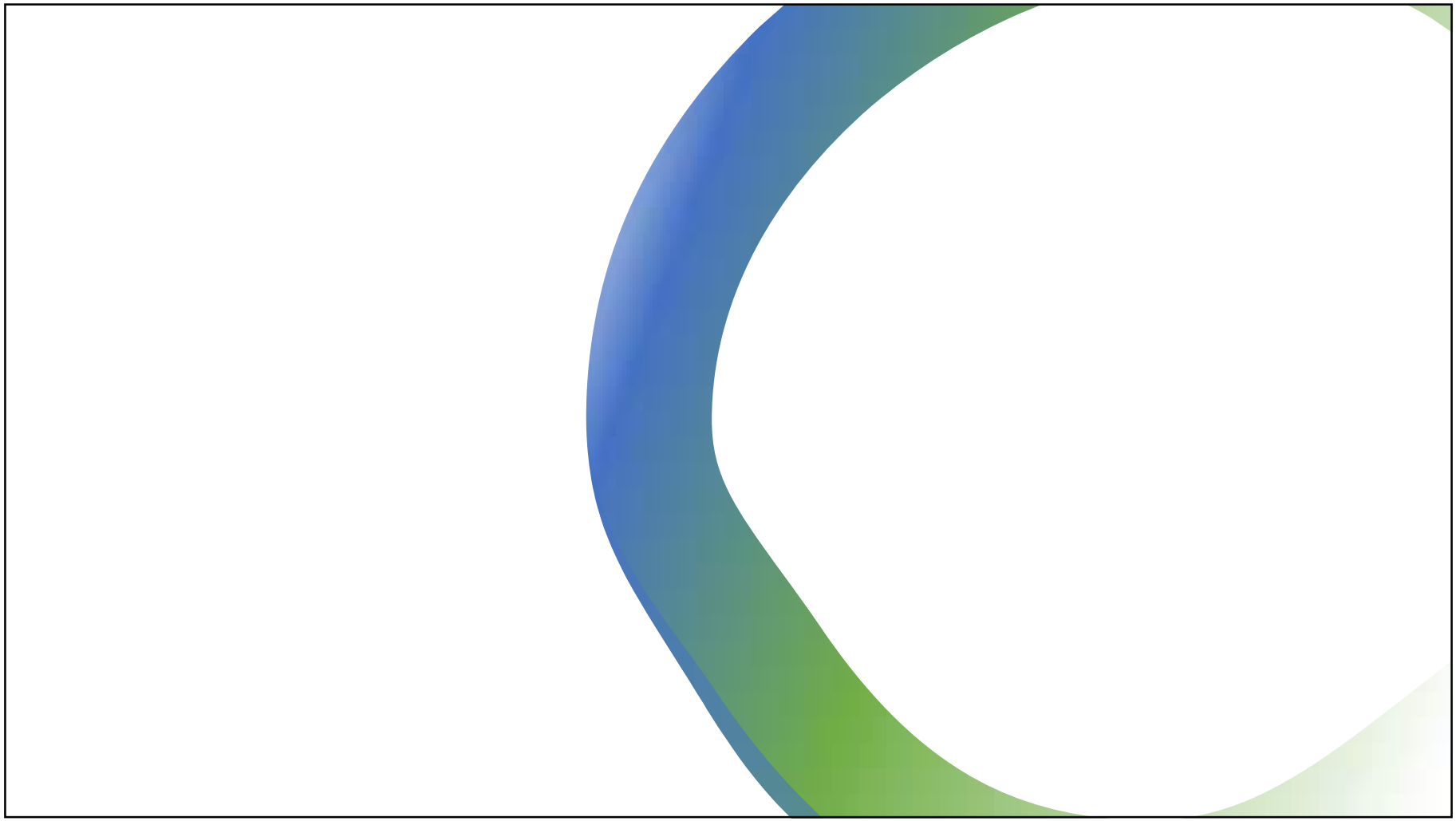

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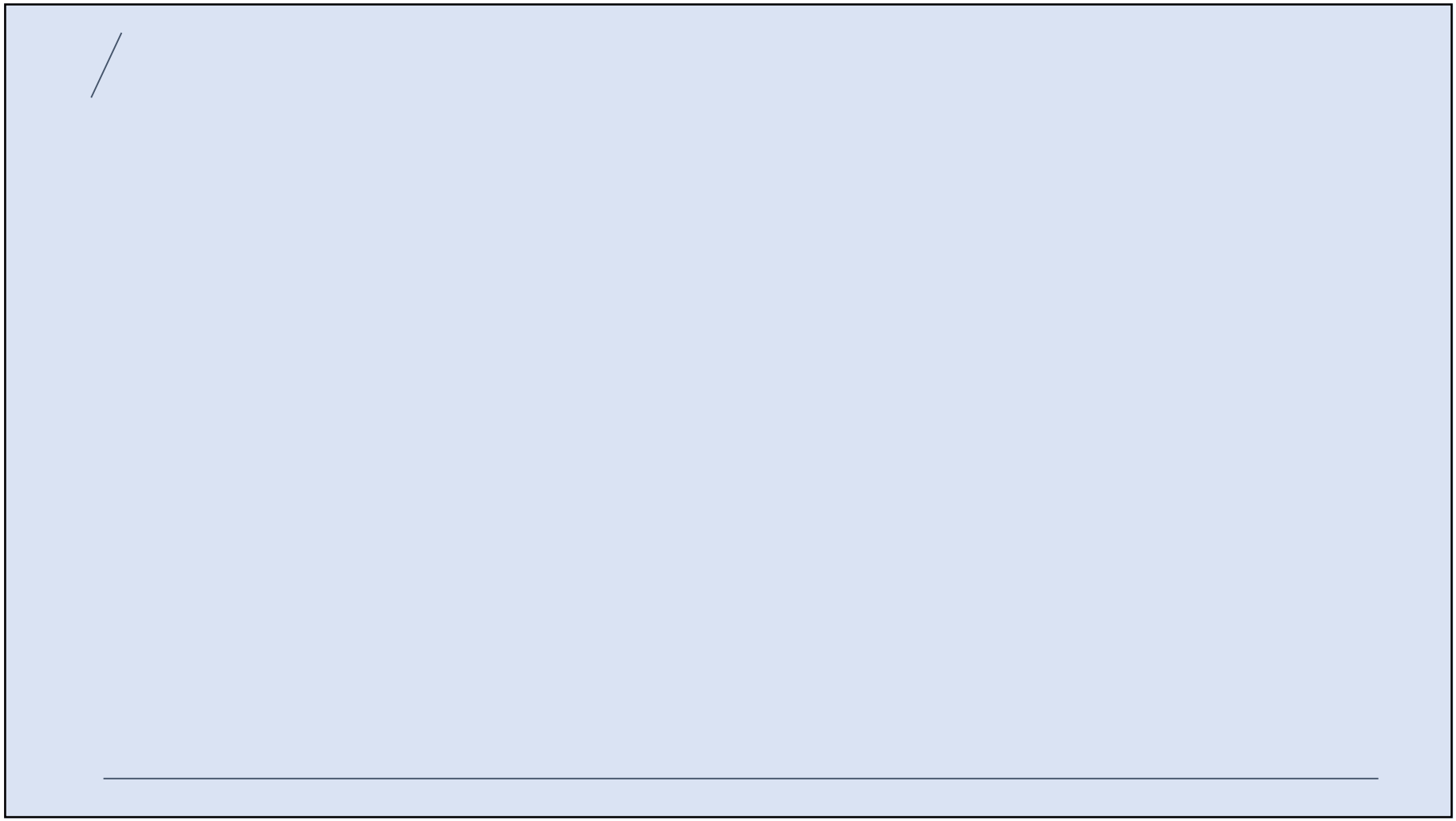

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