Updates in Pulmonary Function Testing

Matthew Huang, MD
Assistant Professor of Internal Medicine
Division of Pulmonary, Critical Care, and Sleep Medicine
The Ohio State University Wexner Medical Center

MedNet21
Center for Continuing Medical Education

The Ohio State University
Wexner Medical Center

Objectives

- Understand **key updates** in PFT interpretation.
- Recognize the impact of the **new reference standards**.
- Learn about the revised criteria for **classifying severity** and significant **bronchodilator response**.
- To understand common **physiologic impairments** on PFTs.
- To develop an approach to **interpreting** PFTs.

Why Were the Guidelines Updated?

- Advances in research and understanding of lung physiology.
- Need for improved standardization and accuracy in interpretations.
- More accurate physiological assessment of lung disease.
- New severity classifications that standardize lung function impairment across patient populations.

Stanojevic S et al. ERS 2022

General Updates in PFT Interpretation

- 2005: PFTs used to aid clinical diagnosis.
- 2022: Emphasis on using PFTs for physiological classification and not clinical diagnosis.
- Greater emphasis on uncertainty of interpretation, especially near the lower limit of normal.
- PFTs represent only a **snapshot in time**.

Stanojevic S et al. ERS 2022

Defining Normal Ranges in PFTs

- 2005: LLN = 5th percentile
- 2022:
  - LLN = 5th percentile.
  - ULN = 95th percentile.
- $FEV_1/FVC < 0.7$ not recommended by ATS/ERS.
- 80% predicted threshold for normal not recommended.

Stanojevic S et al. ERS 2022

Update in Reference Equations

PFT Aspect	ERS/ATS 2005		ERS/ATS 2022
	USA	Europe	
Spirometry	NHANES III recommended	No specific equations recommended	GLI (Global Lung Function Initiative) equations
Lung Volumes	No specific equations recommended		GLI equations
DLCO			GLI equations

Stanojevic S et al. ERS 2022

Understanding GLI Reference Equations

- Global Lung Function Initiative (GLI) reference equations were developed to provide a standardized, global approach to PFT interpretation.
- Based on a large multiethnic dataset from healthy individuals worldwide.
- Provides continuous age-related equations rather than discrete age groups.
- More accurate and applicable across different populations.

Stanojevic S et al. ERS 2022

GLI: Modernizing Reference Standards

- GLI equations are now available for: Spirometry, lung volumes, and DLCO
- Support standardized interpretation across an expansive age range (3-95 years old).

Stanojevic S et al. ERS 2022

Comparing GLI vs NHANES III

Aspect	GLI	NHANES III
Age Range	3-95 years	8-80 years
Population	International, large, multi-ethnic cohorts	U.S. (White, Black, Mexican-American)
Equations for…	Spirometry, DLCO, lung volumes	Spirometry only
Racial/ethnic grouping	4 ancestry-based + "Other" composite	Fixed race-specific equations

Stanojevic S et al. ERS 2022

GLI Reference Populations

Reference Population	Data source	Population/ancestral origin
White	Europe, Israel, Australia, USA, Canada, Brazil, Chile, Mexico, Uruguay, Venezuela, Algeria, Tunisia	White (European); Hispanic (European)
Black	African American	Black (North American)
South East Asian	Thailand, Taiwan, China	Asian
North East Asian	Japan, Korea	
Multiethnic	Average of the other four GLI groups	Multiracial; Black South Africa, India, Unknown

Stanojevic S et al. ERS 2022

Applying GLI in Clinical Practice

- Use appropriate equations base on self-reported ancestry, if known.
- If unknown or uncertain: use GLI “Other” equation.
- Report the specific equation used in clinical documentation.
- Ensure consistency across serial measurements for an individual.
- No single equation fits all – interpret results in clinical context.

Stanojevic S et al. ERS 2022

Limitations of the GLI Equations

- Not all global populations represented in the GLI datasets.
- GLI DLCO & lung volumes primarily based on European ancestry.
- No validated guidance for transgender individuals.
- “Other” composite equation is a mathematical blend, not a universal norm.
- Body proportions, environmental, & socioeconomic factors can affect interpretation.

Stanojevic S et al. ERS 2022

Changes in Bronchodilator Response (BDR)

- **Old Approach (2005)**
  - BDR defined by absolute and relative changes based on consensus expert opinion.
- **New Approach (2022)**
  - Report BDR as relative change, based on predictive values.

Stanojevic S et al. ERS 2022

Rationale Behind Updated BDR Criteria

- Reduced biases from baseline lung function differences (age, height, sex).
- More accurate reflection of physiological response rather than consensus expert opinion.

Stanojevic S et al. ERS 2022

Bronchodilator Response Criteria

- **2005**: ≥ 12% and 200 mL increase in FEV_1 or FVC
- **2022**: > 10% increase in FEV_1 or FVC relative to the individual's predicted value.

$$\frac{(Postbronchdilator\ value\ \ -Prebronchodilator\ value) * 100}{Predicted\ value}$$

Stanojevic S et al. ERS 2022

Bronchodilator Response Example

- 50 yo male, height 170 cm, has pre-bronchodilator FEV_1 of 2 L and a post-bronchodilator FEV_1 or 2.4 L. The predicted FEV_1 is 3.32 L.

$$\frac{(Postbronchdilator\ value\ \ -Prebronchodilator\ value) * 100}{Predicted\ value}$$

$$\frac{(2.4-2.0) * 100}{3.32} = 12\%$$

Stanojevic S et al. ERS 2022

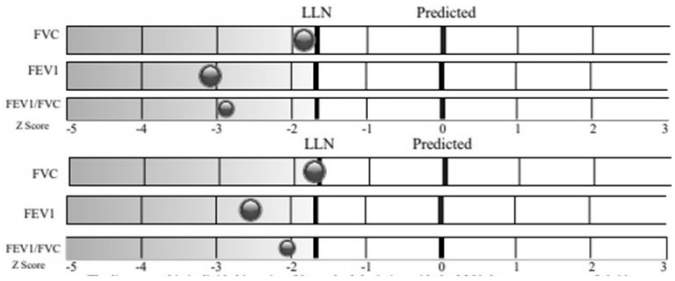
Redefining Severity Classification

- **2005:** Severity defined using % predicted values.
- **2022:** Severity now based on z-scores.

Stanojevic S et al. ERS 2022

Z-Score Severity Classifications

- 3-Tier Severity Scale
  - Mild: -1.65 to -2.5
  - Moderate: -2.51 to -4
  - Severe: < -4.1



Stanojevic S et al. ERS 2022

Recap of Major Updates

- Greater emphasis on physiological classification over diagnosis.
- Standardized reference equations with GLI.
- Shift to z-score classifications of severity.
- Bronchodilator response is now relative to an individual's predicted value.

Stanojevic S et al. ERS 2022

Updates in Pulmonary Function Testing

Gennie (Jing) Wang, MD
Assistant Professor of Internal Medicine
Medical Director of Pulmonary Function Testing Lab
Division of Pulmonary, Critical Care, and Sleep Medicine
The Ohio State University Wexner Medical Center

MedNet21
Center for Continuing Medical Education

The Ohio State University
Wexner Medical Center

Interpreting PFTs

PFTs should be used to **identify abnormal physiology** rather than to make a specific clinical diagnosis.

Interpreting PFTs

PFTs should be used to **identify abnormal physiology** rather than to make a specific clinical diagnosis.

Lung function	Impairment classification
Airflow (inspiratory, expiratory)	Obstructive

Stanojevic S et al. ERS 2022.

Interpreting PFTs

PFTs should be used to **identify abnormal physiology** rather than to make a specific clinical diagnosis.

Lung function	Impairment classification
Airflow (inspiratory, expiratory)	Obstructive
Lung volumes & capacities (TLC, RV, FRC)	Restrictive

Stanojevic S et al. ERS 2022.

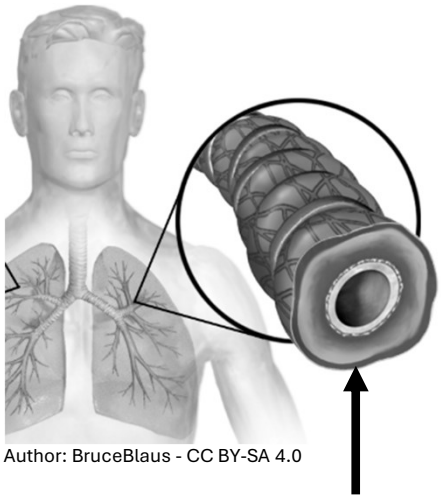
Interpreting PFTs

PFTs should be used to **identify abnormal physiology** rather than to make a specific clinical diagnosis.

Lung function	Impairment classification
Airflow (inspiratory, expiratory)	Obstructive
Lung volumes & capacities (TLC, RV, FRC)	Restrictive
Alveolar-capillary gas transfer (CO uptake over time)	Gas transfer

Stanojevic S et al. ERS 2022.

Physiologic impairments



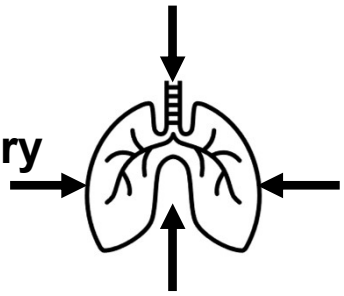
Author: BruceBlaus - CC BY-SA 4.0

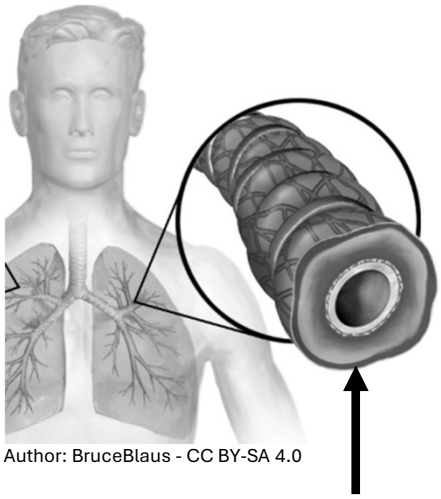
Obstructive ventilatory impairment

Stanojevic S et al. ERS 2022.

Physiologic impairments

Restrictive ventilatory impairment



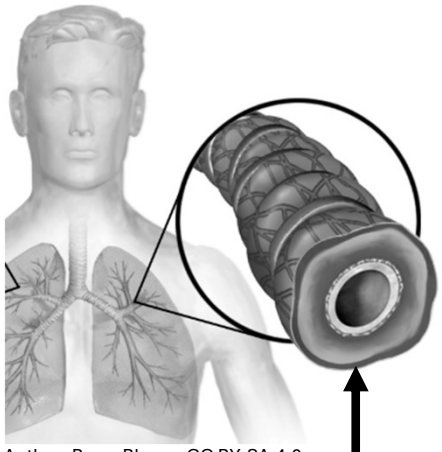


Author: BruceBlaus - CC BY-SA 4.0

Obstructive ventilatory impairment

Stanojevic S et al. ERS 2022.

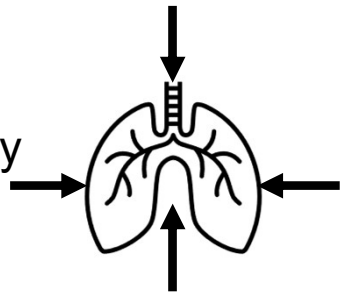
Physiologic impairments

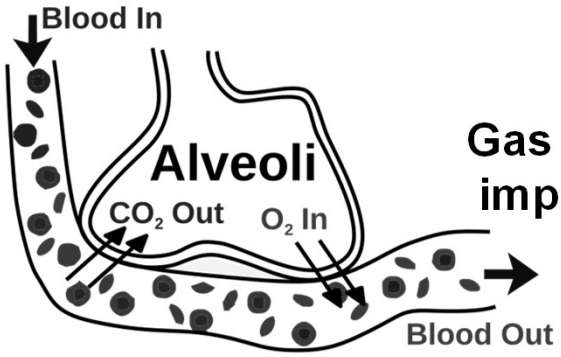


Author: BruceBlaus - CC BY-SA 4.0

Obstructive ventilatory impairment

Restrictive ventilatory impairment





Author: helix84 - CC BY-SA 3.0

Gas transfer impairment

Stanojevic S et al. ERS 2022.

Obstructive ventilatory impairment

- Obstructive impairment is assessed by **spirometry.**
- **Main parameters: FEV_1 and FVC.**

Author: DataBase Center for Life Science (DBCLS) - CC BY 4.0

Stanojevic S et al. ERS 2022.

Obstructive ventilatory impairment

- Obstructive impairment is assessed by **spirometry.**
- **Main parameters: FEV_1 and FVC.**

- Obstructive impairment may be due to:
  1. Impaired expiratory muscle function

Author: DataBase Center for Life Science (DBCLS) - CC BY 4.0

Stanojevic S et al. ERS 2022.

Obstructive ventilatory impairment

- Obstructive impairment is assessed by **spirometry.**
- **Main parameters: FEV_1 and FVC.**

- Obstructive impairment may be due to:
  1. Impaired expiratory muscle function
  2. Obstruction of central airways

Author: DataBase Center for Life Science (DBCLS) - CC BY 4.0

Stanojevic S et al. ERS 2022.

Obstructive ventilatory impairment

- Obstructive impairment is assessed by **spirometry.**
- **Main parameters: FEV_1 and FVC.**

- Obstructive impairment may be due to:
  1. Impaired expiratory muscle function
  2. Obstruction of central airways
  3. Small airways obstruction

FEV_1/FVC < LLN

Stanojevic S et al. ERS 2022.

Obstructive ventilatory impairment

- Obstructive impairment is assessed by **spirometry.**
- **Main parameters: FEV_1 and FVC.**

- Obstructive impairment may be due to:
  1. Impaired expiratory muscle function
  2. Obstruction of central airways
  3. Small airways obstruction

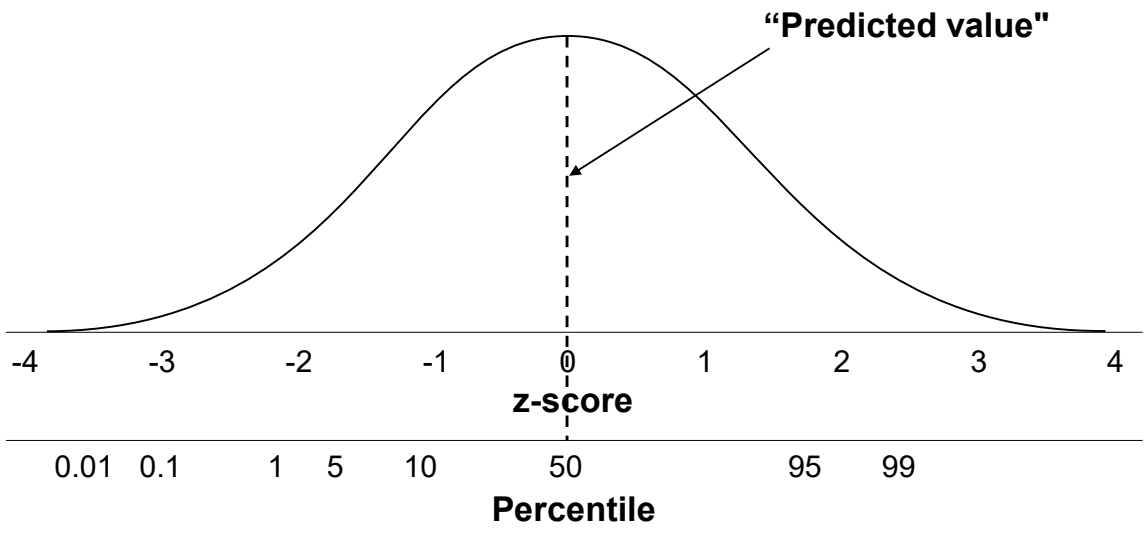
FEV_1/FVC < LLN
FEV_1 determines severity of obstruction

Stanojevic S et al. ERS 2022.

Severity of lung function impairment

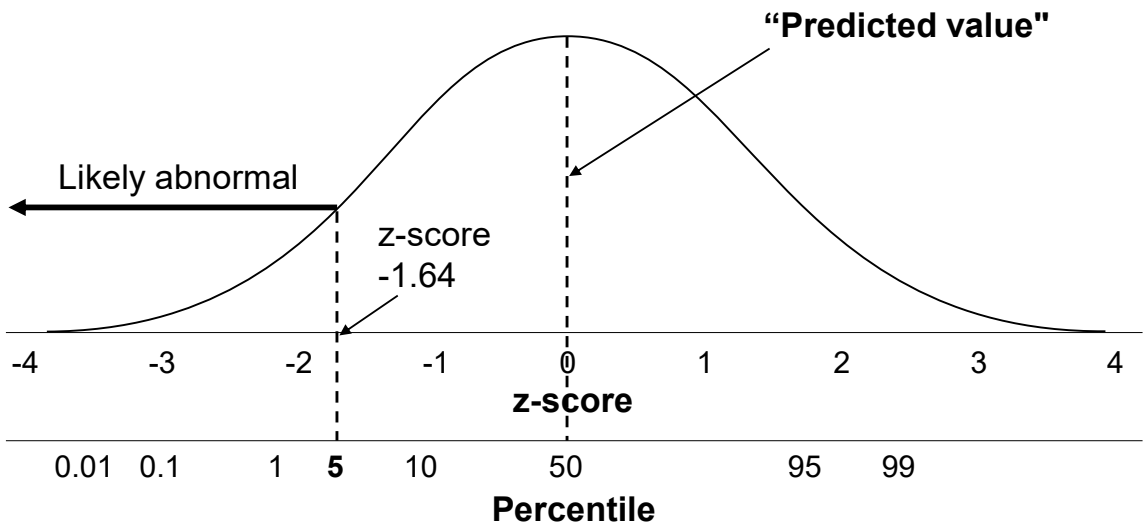
- New 2022 ERS/ATS standards **recommend against categorizing impairment using % predicted cut-offs.**
- Instead, recommend using **z-scores:** how far a lung function value is from the predicted value.
  - Accounts for sex, age, height, ancestry.
- Z-scores are expressed as a **standard deviation**.
- More consistent across age and sex than % predicted.

Z-score



Stanojevic S et al. ERS 2022.

Z-score



Stanojevic S et al. ERS 2022.

Severity of lung function impairment

ERS/ATS 2005		ERS/ATS 2022	
FEV_1 % predicted	**Severity classification**	**z-score**	**Severity classification**
>70%	Mild	-1.65 to -2.5	Mild
60-69%	Moderate	-2.51 to -4	Moderate
50-59%	Moderately severe	< -4.1	Severe
35-49%	Severe		
<35%	Very severe		

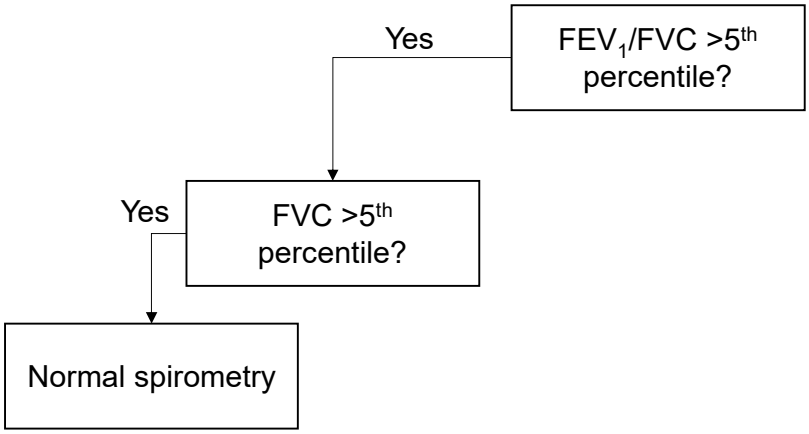
- **Note:** Severity of **lung function impairment** is not necessarily equivalent to **disease severity**!

Approach to interpreting spirometry

$FEV_1/FVC > 5^{th}$ percentile?

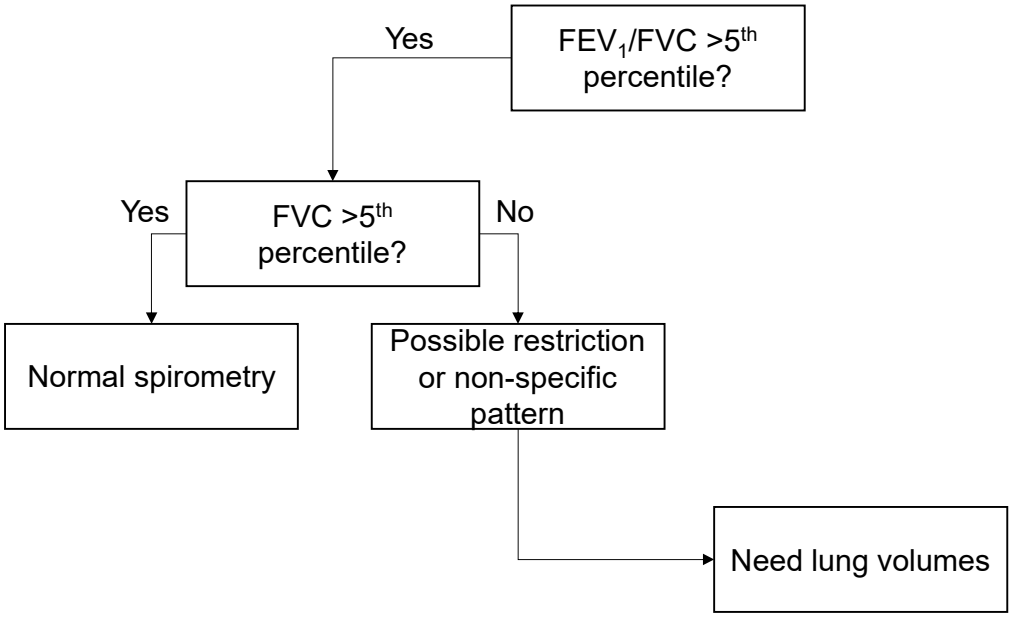
Stanojevic S et al. ERS 2022.

Approach to interpreting spirometry



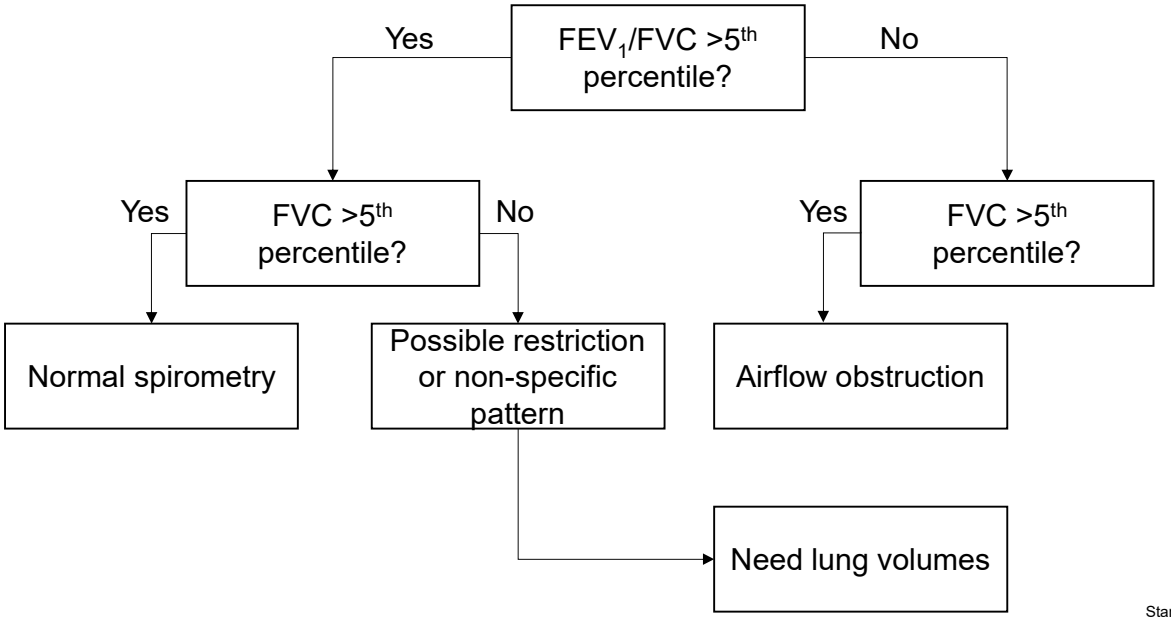
Stanojevic S et al. ERS 2022.

Approach to interpreting spirometry



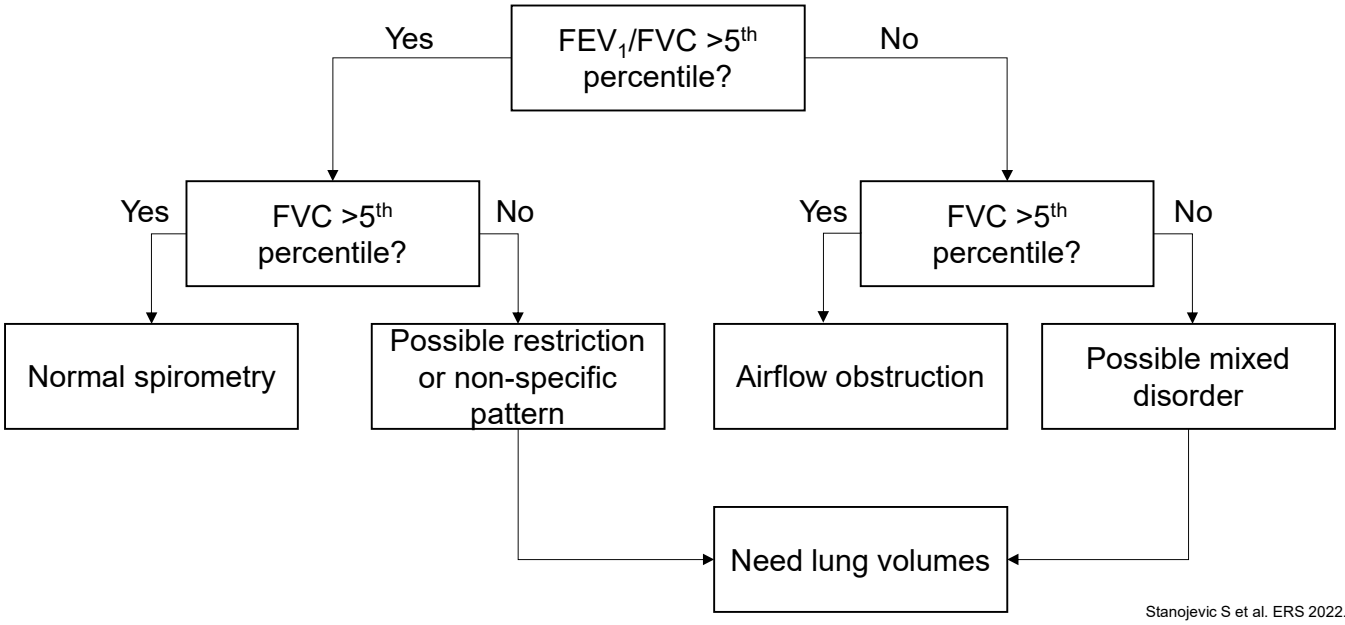
Stanojevic S et al. ERS 2022.

Approach to interpreting spirometry



Stanojevic S et al. ERS 2022.

Approach to interpreting spirometry



Stanojevic S et al. ERS 2022.

Restrictive ventilatory impairment

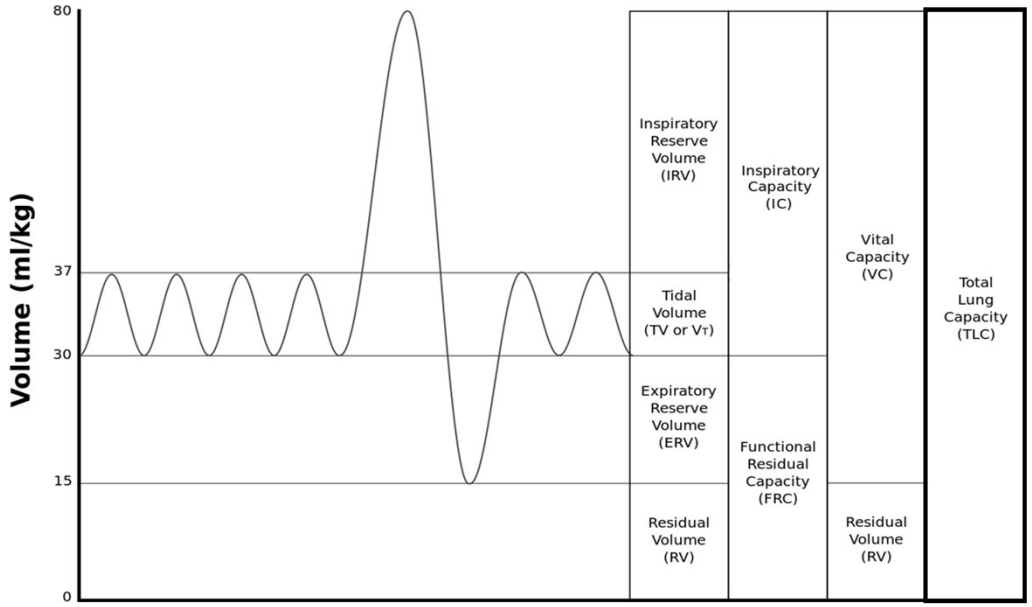
- Lung volumes are required to assess for **restrictive impairment**.
- May be assessed using:
  - Body plethysmography, or
  - Nitrogen wash-out

Author: Joe Mabel - CC BY-SA 3.0

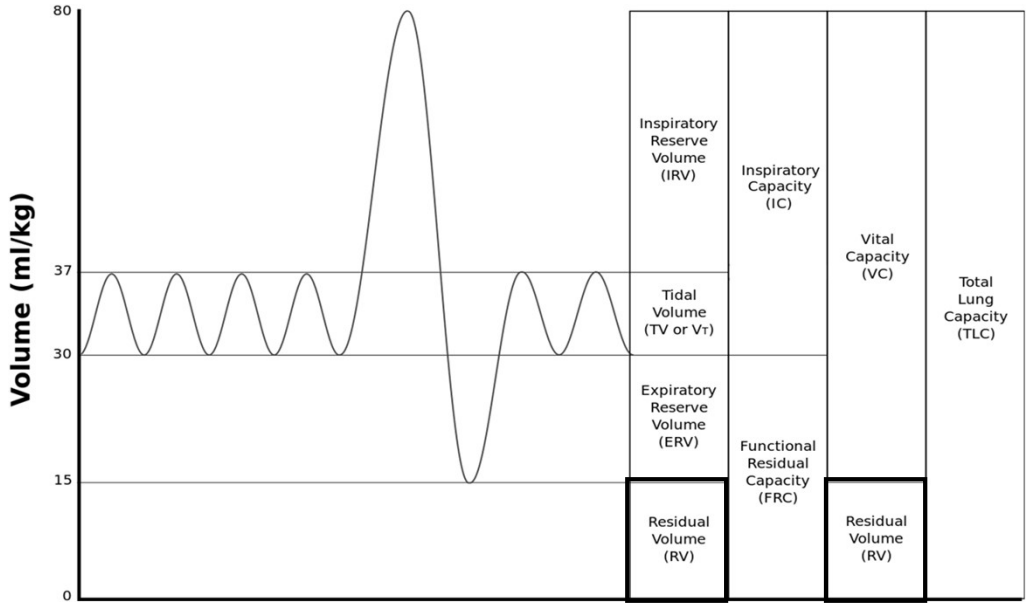
TLC < LLN

Stanojevic S et al. ERS 2022.

Lung volume measurements



Lung volume measurements

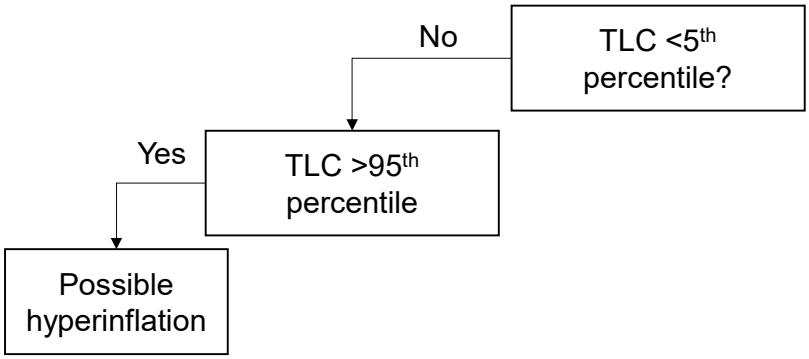


Approach to interpreting lung volumes

TLC <5th percentile?

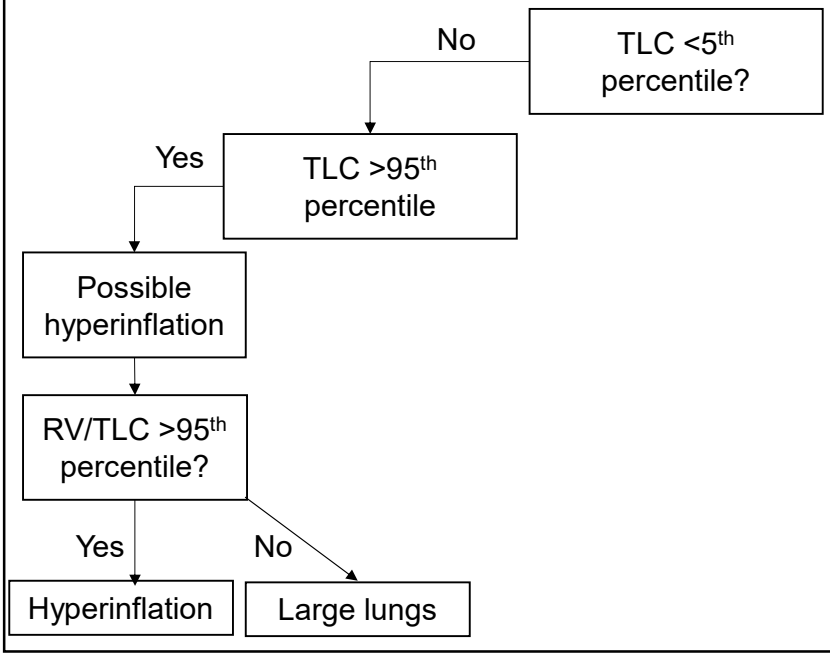
Stanojevic S et al. ERS 2022.

Approach to interpreting lung volumes



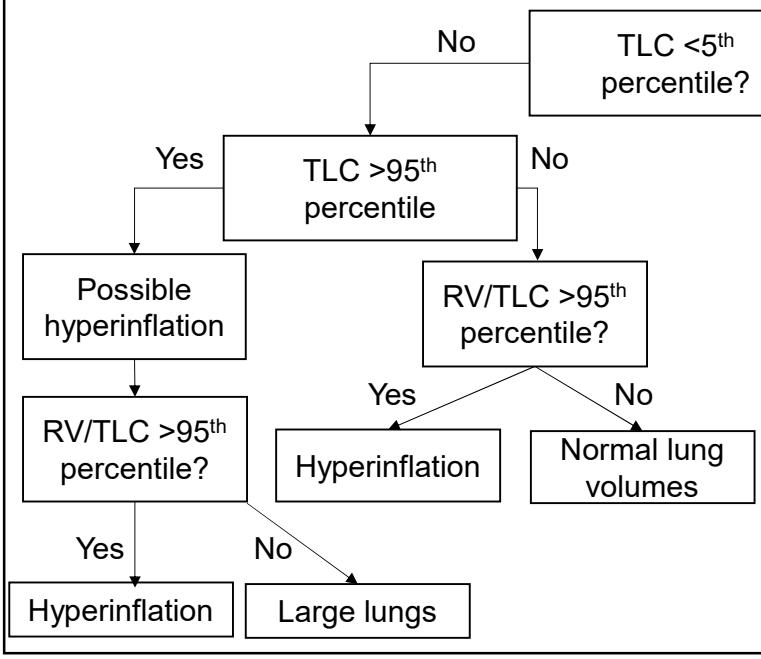
Stanojevic S et al. ERS 2022.

Approach to interpreting lung volumes



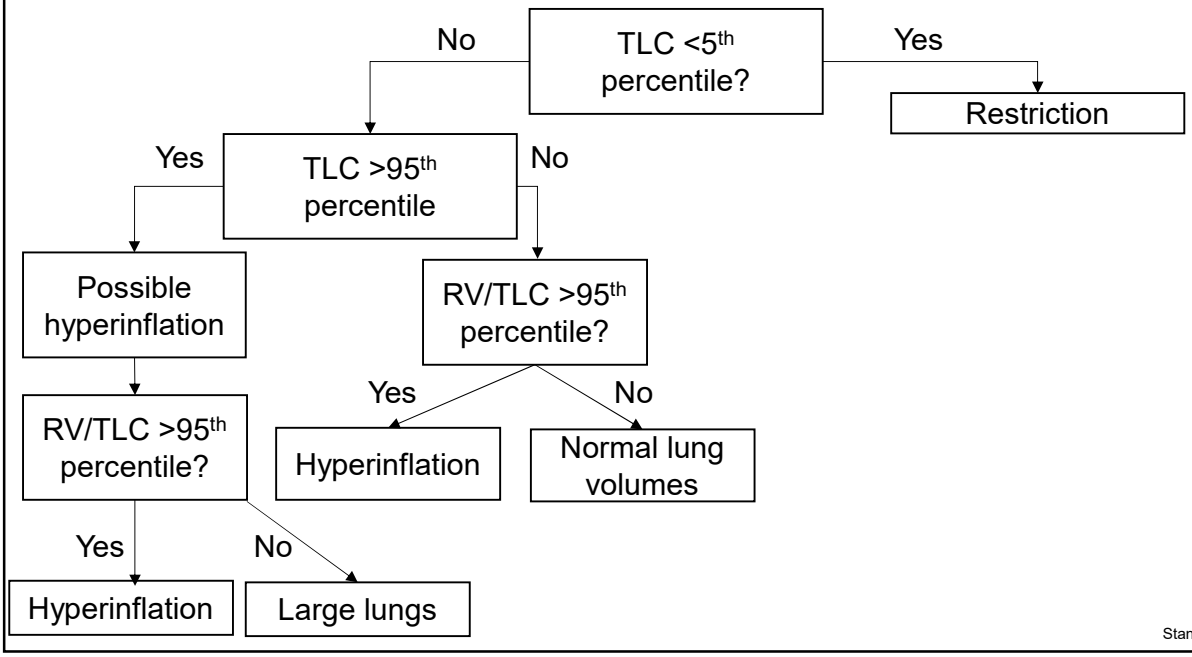
Stanojevic S et al. ERS 2022.

Approach to interpreting lung volumes



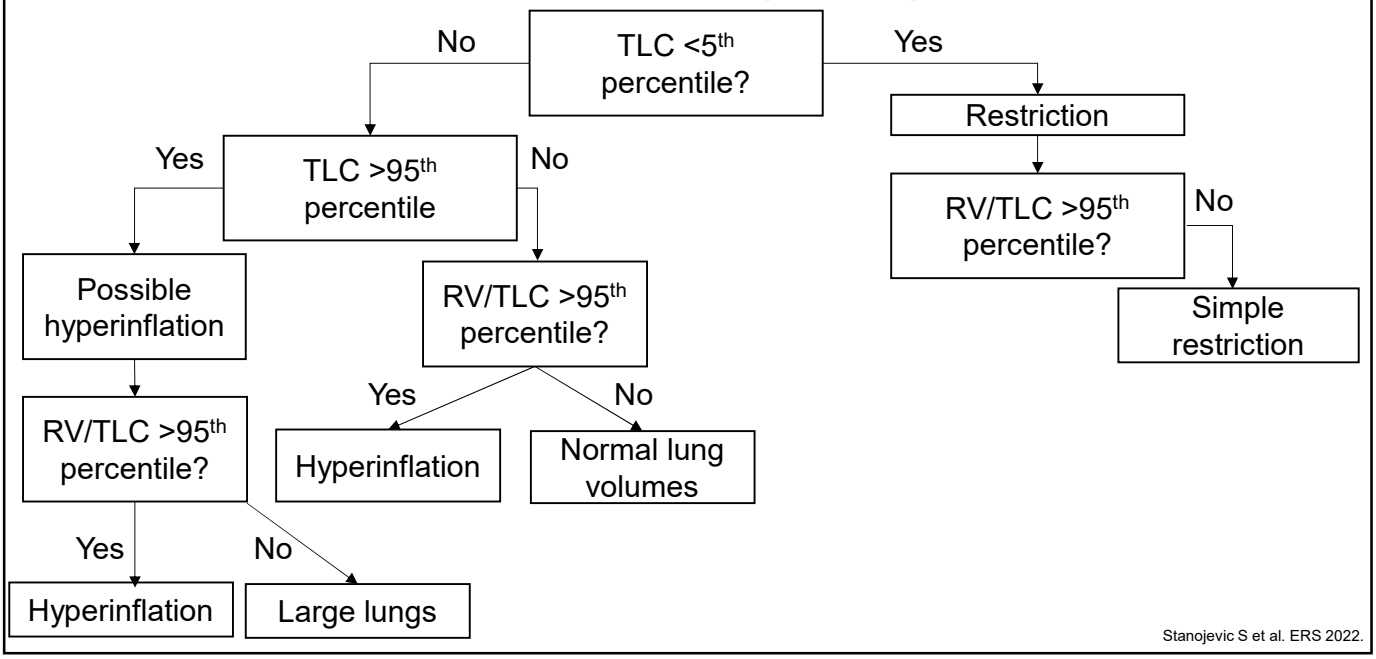
Stanojevic S et al. ERS 2022.

Approach to interpreting lung volumes



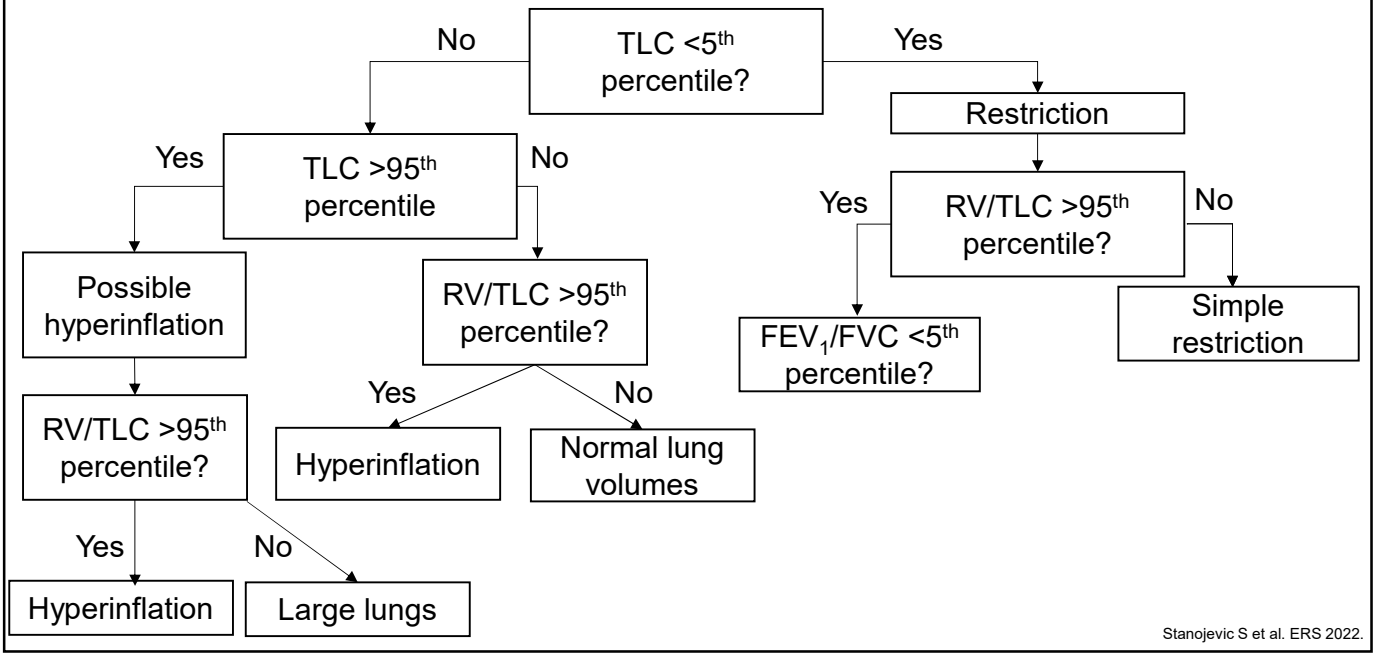
Stanojevic S et al. ERS 2022.

Approach to interpreting lung volumes



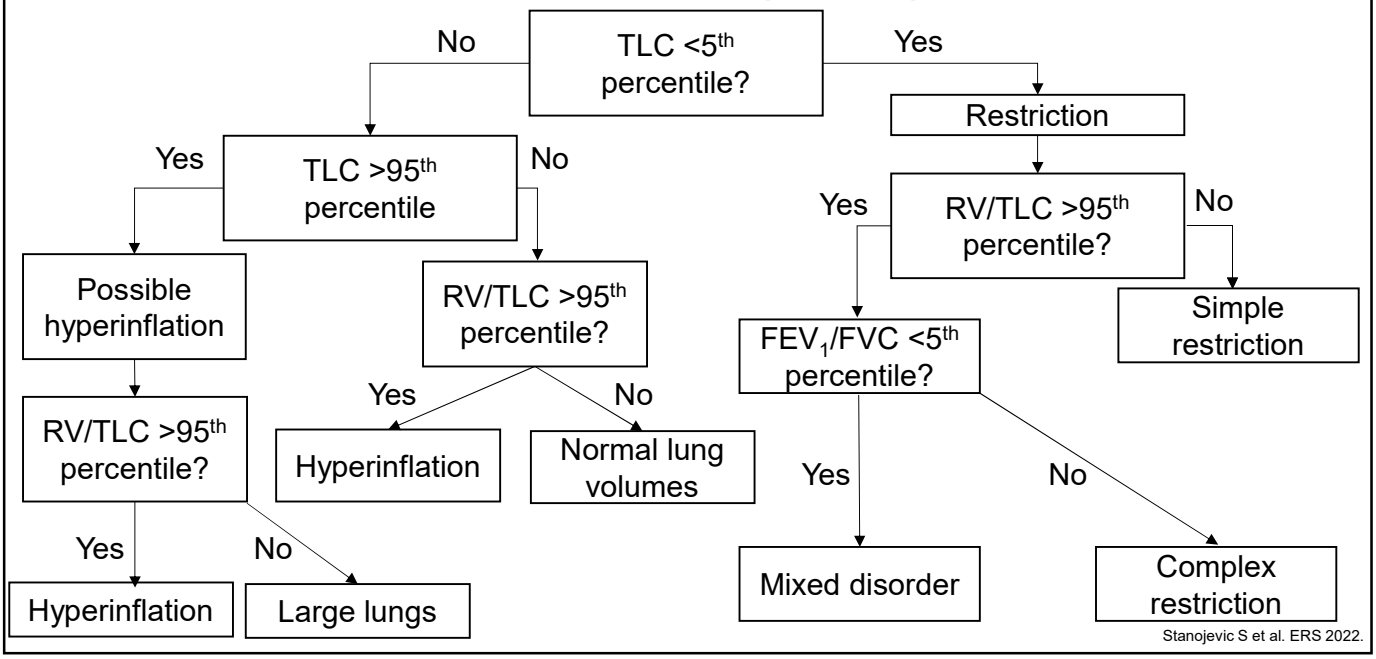
Stanojevic S et al. ERS 2022.

Approach to interpreting lung volumes



Stanojevic S et al. ERS 2022.

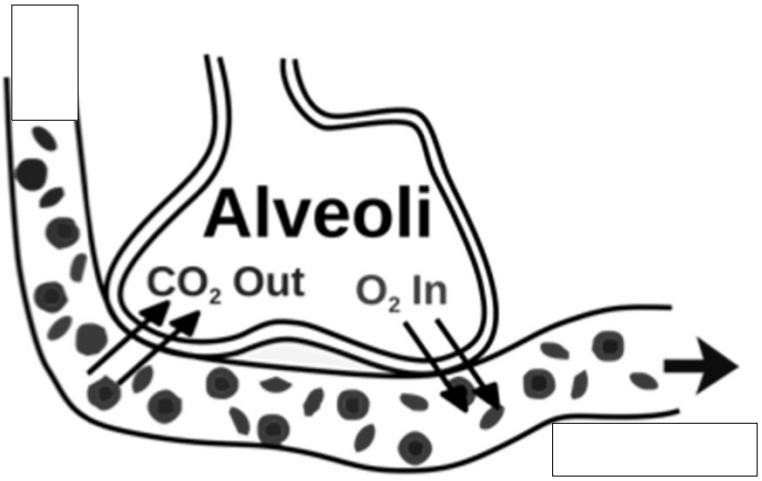
Approach to interpreting lung volumes



Stanojevic S et al. ERS 2022.

Gas transfer impairment

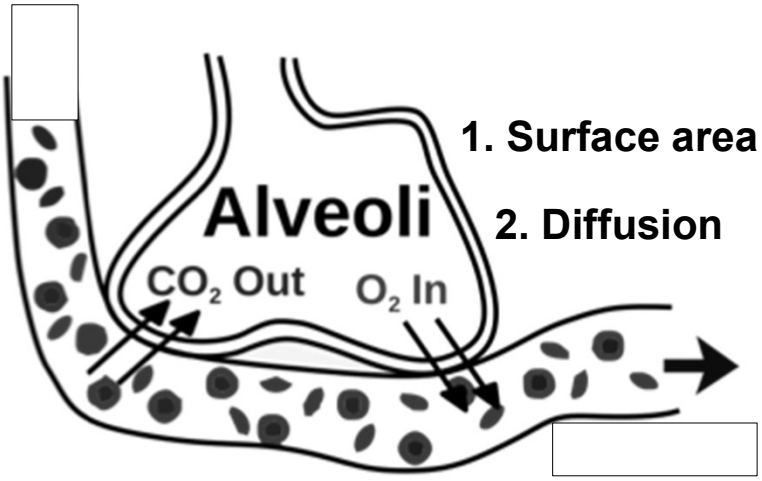
- Assessed by measuring the uptake of CO (surrogate for O_2) by the lungs ($\mathbf{D_{LCO}}$).



Stanojevic S et al. ERS 2022.

Gas transfer impairment

- Assessed by measuring the uptake of CO (surrogate for O_2) by the lungs ($\mathbf{D_{LCO}}$).



1. Surface area

2. Diffusion

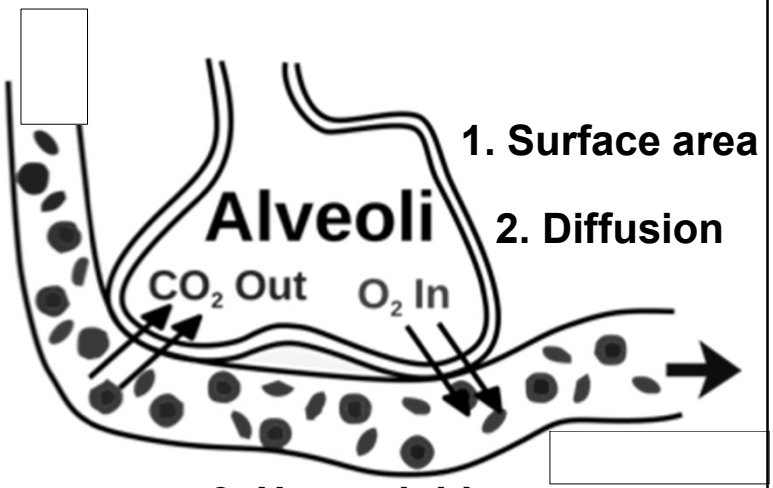
3. Hemoglobin

Stanojevic S et al. ERS 2022.

Gas transfer impairment

- $D_{LCO} = K_{CO} \times V_A$
  - K_{CO}: Measured CO change over time
  - V_A: Volume of gas containing CO

$D_{LCO} < LLN$



Stanojevic S et al. ERS 2022.

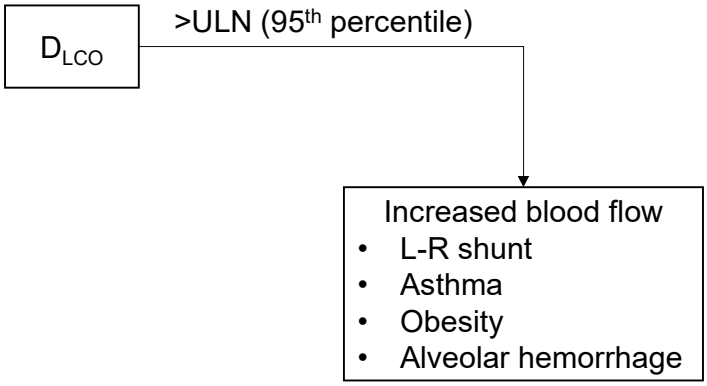
Image Author: helix84 - CC BY-SA 3.0

Approach to interpreting DLCO

D_{LCO}

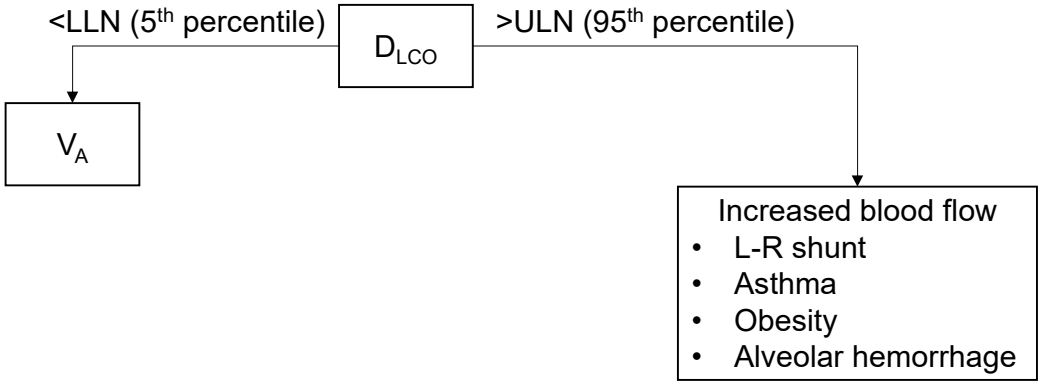
Stanojevic S et al. ERS 2022.

Approach to interpreting DLCO



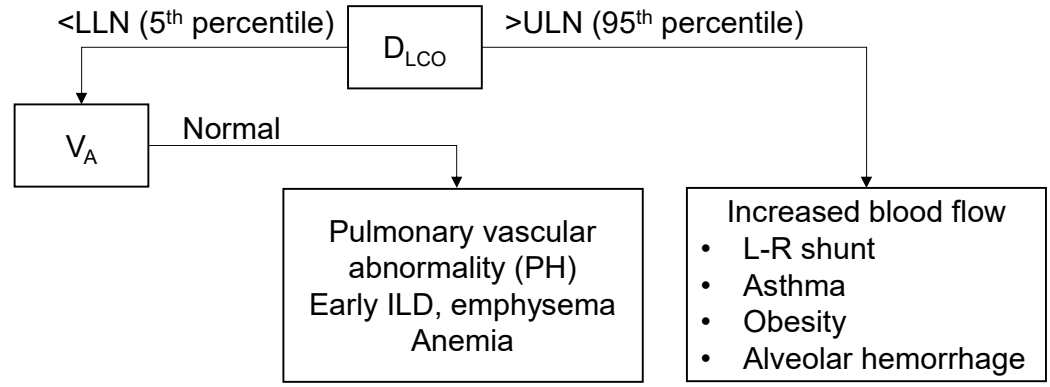
Stanojevic S et al. ERS 2022.

Approach to interpreting DLCO



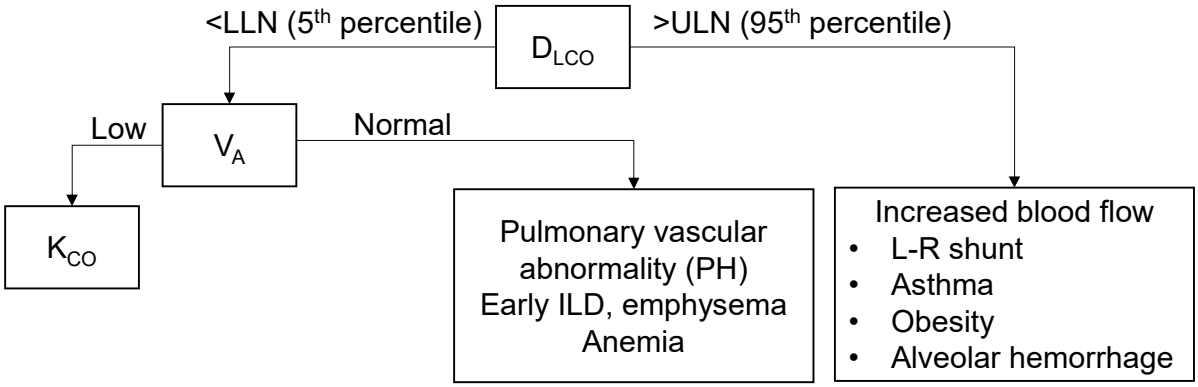
Stanojevic S et al. ERS 2022.

Approach to interpreting DLCO



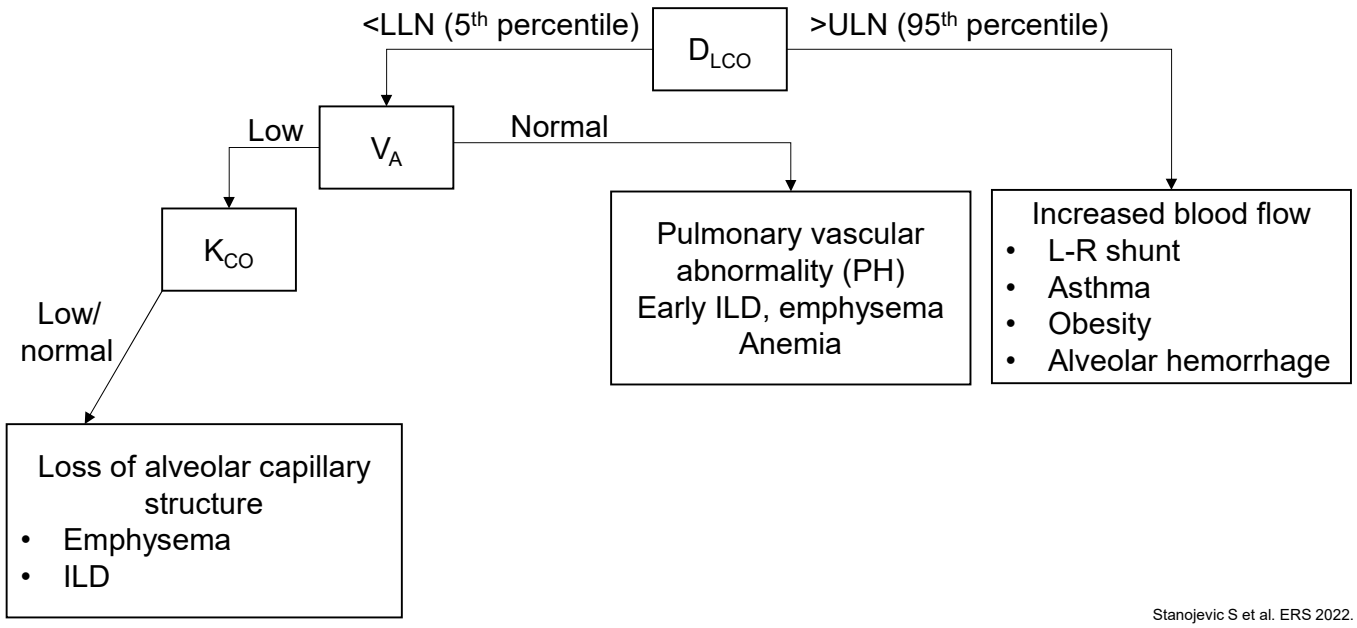
Stanojevic S et al. ERS 2022.

Approach to interpreting DLCO



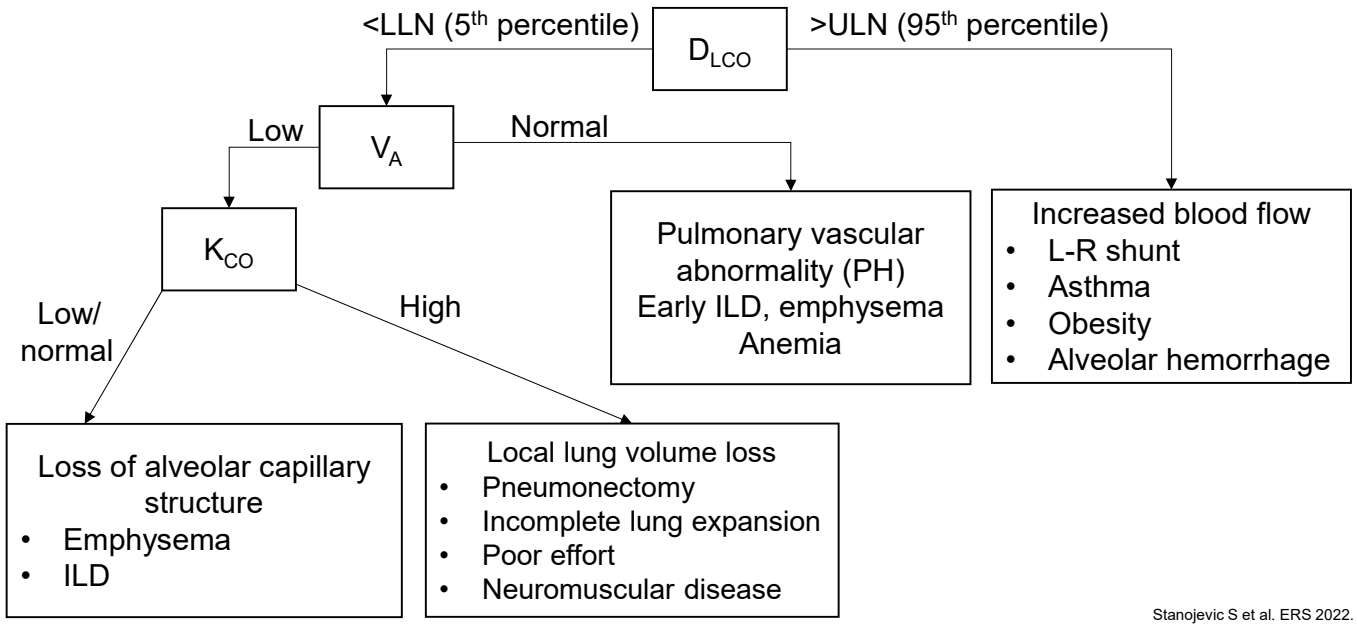
Stanojevic S et al. ERS 2022.

Approach to interpreting DLCO



Stanojevic S et al. ERS 2022.

Approach to interpreting DLCO



Stanojevic S et al. ERS 2022.

42 yo F with chronic cough

42 yo F with chronic cough

Test Data

	Pred	LLN	Pre	Pre %Pred	Pre ZScore	Post	Post %Pred	Post ZScore	Post %Change
--- SPIROMETRY ---									
FVC	2.35	1.66	1.43	61	-2.21	1.65	70	-1.67	9
FEV1	1.85	1.29	0.40	21	-3.91	0.48	25	-3.75	4
FEV1/FVC	0.80	0.67	0.28	35	-4.30	0.29	36	-4.27	2
Expired Time			11.92			11.40			-4
PEF L/s	5.08	3.56	1.49	29	-3.90	1.93	38	-3.41	30
FIF50			2.35			2.53			7
FVC/FEV1 Grade ATS			AA			AA			
MIP	-56	-17	-38	67	-0.77				

42 yo F with chronic cough

Test Data

	Pred	LLN	Pre	Pre %Pred	Pre ZScore	Post	Post %Pred	Post ZScore	Post %Change
--- SPIROMETRY ---									
FVC	2.35	1.66	1.43	61	-2.21	1.65	70	-1.67	9
FEV1	1.85	1.29	0.40	21	-3.91	0.48	25	-3.75	4
FEV1/FVC	0.80	0.67	0.28	35	-4.30	0.29	36	-4.27	2
Expired Time			11.92			11.40			-4
PEF L/s	5.08	3.56	1.49	29	-3.90	1.93	38	-3.41	30
FIF50			2.35			2.53			7
FVC/FEV1 Grade ATS			AA			AA			
MIP	-56	-17							

FEV_1/FVC < LLN
Obstructive impairment

42 yo F with chronic cough

Test Data

	Pred	LLN	Pre	Pre %Pred	Pre ZScore	Post	Post %Pred	Post ZScore	Post %Change
--- SPIROMETRY ---									
FVC	2.35	1.66	1.43	61	-2.21	1.65	70	-1.67	9
FEV1	1.85	1.29	0.40	21	-3.91	0.48	25	-3.75	4
FEV1/FVC	0.80	0.67	0.28	35	-4.30	0.29	36	-4.27	2
Expired Time			11.92			11.40			-4
PEF L/s	5.08	3.56	1.49	29	-3.90	1.93	38	-3.41	30
FIF50			2.35			2.53			7
FVC/FEV1 Grade ATS			AA			AA			
MIP	-56								

FEV_1 z-score -3.91
Moderate obstructive impairment

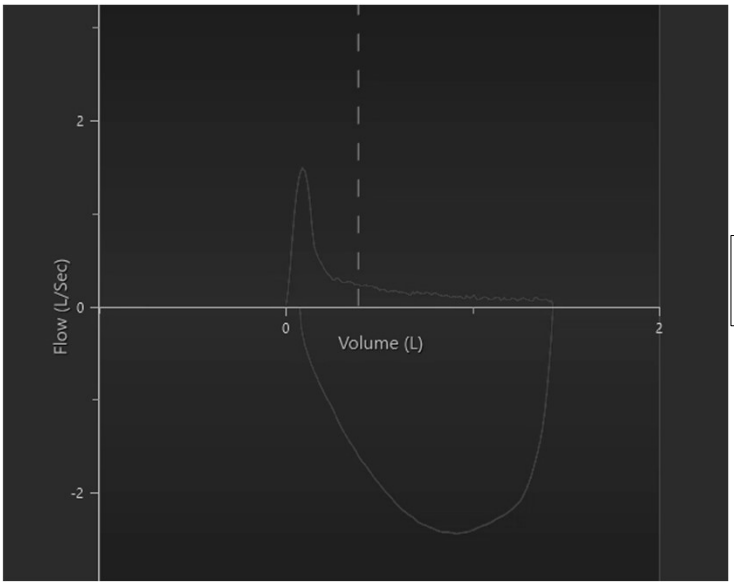
42 yo F with chronic cough

Test Data

	Pred	LLN	Pre	Pre %Pred	Pre ZScore	Post	Post %Pred	Post ZScore	Post %Change
--- SPIROMETRY ---									
FVC	2.35	1.66	1.43	61	-2.21	1.65	70	-1.67	9
FEV1	1.85	1.29	0.40	21	-3.91	0.48	25	-3.75	4
FEV1/FVC	0.80	0.67	0.28	35	-4.30	0.29	36	-4.27	2
Expired Time			11.92			11.40			-4
PEF L/s	5.08	3.56	1.49	29	-3.90	1.93	38	-3.41	30
FIF50			2.35			2.53			7
FVC/FEV1 Grade ATS			AA			AA			
MIP	-56								

No significant BD response

42 yo F with chronic cough



Scooping of expiratory limb consistent with obstruction

42 yo F with chronic cough

--- LUNG VOLUMES ---	pred	LLN	pre	%predicted	z-score
SVC	2.35	1.66	1.45	61	-2.16
IC	1.56		0.89	57	
ERV	0.78		0.49	62	
TGV	2.54	1.68	4.64	182	4.01
RV (Pleth)	2.00	1.38	4.08	203	5.46
TLC (Pleth)	4.49	3.61	5.53	123	1.94
RV/TLC (Pleth)	44	35	74	169	5.54
ATS (SVC)					

Elevated TLC
Mild hyperinflation

42 yo F with chronic cough

--- LUNG VOLUMES ---	pred	LLN	pre	%predicted	z-score
SVC	2.35	1.66	1.45	61	-2.16
IC	1.56		0.89	57	
ERV	0.78		0.49	62	
TGV	2.54	1.68	4.64	182	4.01
RV (Pleth)	2.00	1.38	4.08	203	5.46
TLC (Pleth)	4.49	3.61	5.53	123	1.94
RV/TLC (Pleth)	44	35	74	169	5.54
ATS (SVC)					

Elevated RV & RV/TLC
Severe air trapping

42 yo F with chronic cough

--- DIFFUSION ---	pred	LLN	pre	%predicted	z-score
DLCOunc	17.21	12.95	5.03	29	-6.37
DLCOcor	17.21	12.95	4.99	28	-6.41
VA	4.00	3.20	3.51	87	-0.99
Kco	4.31	3.29	1.42	33	-5.56
BHT			11.28		
TLC (SB)			3.59		
DLCO Grade			CD		
ATS (DLCO)					

42 yo F with chronic cough

--- DIFFUSION ---	pred	LLN	pre	%predicted	z-score
DLCOunc	17.21	12.95	5.03	29	-6.37
DLCOcor	17.21	12.95	4.99	28	-6.41
VA	4.00	3.20	3.51	87	-0.99
Kco	4.31	3.29	1.42	33	-5.56
BHT			11.28		
TLC (SB)			3.59		
DLCO Grade			CD		
ATS (DLCO)					

Low DLCO
Severely reduced diffusion capacity

42 yo F with chronic cough

--- DIFFUSION ---	pred	LLN	pre	%predicted	z-score
DLCOunc	17.21	12.95	5.03	29	-6.37
DLCOcor	17.21	12.95	4.99	28	-6.41
VA	4.00	3.20	3.51	87	-0.99
Kco	4.31	3.29	1.42	33	-5.56
BHT			11.28		
TLC (SB)			3.59		
DLCO Grade			CD		
ATS (DLCO)					

VA normal = preserved lung volumes
K_{CO} reduced = alveolar-capillary impairment

PFT interpretation reference

ERS/ATS technical standard on interpretative strategies for routine lung function tests
2022

Sanja Stanojevic, David A. Kaminsky, Martin R. Miller, et al.
European Respiratory Journal 2022 60(1): 2101499;
doi: https://doi.org/10.1183/13993003.01499-2021.

Stanojevic S et al. ERS 2022.