Respiratory Assessment
for Occupational Medicine
2024 Update

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Learning Objectives

Participants will be able to:

1. Describe the performance of Basic Spirometry
2. Identify the spirometric pattern
3. Describe the impact of air trapping on spirometry
4. Use Lung Volumes to transition from "pattern" to Diagnosis
5. Describe the impact of changing from NHANES ethnically-based to GLI ethnically-based to GLI Global in assessing spirometry results
6. Describe the difference between acceptable and usable maneuvers in spirometry

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Case: 74 YOM, 64.5" Tall

	% Pred	Actual	LLN
FVC	74	2.18 L	2.59 L
FEV1	70	1.70 L	1.76 L
FEV1/FVC	------	0.78	0.63
TLC	86%	5.12 L	4.74 L
RV	147%	3.05 L	1.78 L

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Case: 74 YOM, 64.5" Tall

	% Pred	Actual	LLN	
FVC	74	2.18 L	2.59 L	< LLN
FEV1	70	1.70 L	1.76 L	
FEV1/FVC	------	0.78	0.63	> LLN
TLC	86%	5.12 L	4.74 L	> LLN
RV	147%	3.05 L	1.78 L	

- **Restrictive Pattern**
- **MOD Air Trapping suggested by elevated RV**
- **NOT true Restrictive Disease**

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Spirometry Update for the Occupational Medicine Practitioner

SPIROMETRY BASICS

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Spirometry Testing

Note:
- Seated
- Nose Clip
- Active Coaching
  - (OK to Yell!)
- Large Screen to monitor maneuver

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Performing the Maneuver - 2019

- **Breathe normally**
- Inspire completely and rapidly with a pause of <2 seconds at full capacity
  - **Patient should look moderately uncomfortable**
- **Forcefully blow out with maximal effort until no more air can be expelled while maintaining an upright posture**
- **Inspire with maximal effort until completely full**
- Repeat for a minimum of three maneuvers, usually no more than eight for adults
- Check FEV_1 and FVC repeatability and perform more maneuvers as necessary

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Standing vs Seated?

- Standing yields a slightly higher results than seated
- NHANES/Hankinson predicted equation are based on standing spirometry
- ATS/ERS (2005 & 2019) recommends seated
- ACOEM statement on Spirometry in the workplace (2020) recommends standing
- GLI is agnostic (includes both seated and standing data in their dataset)
- Changing may impact serial spirometry interpretation

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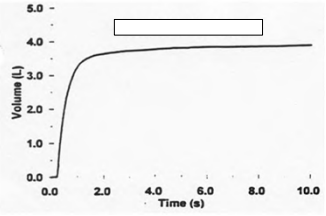
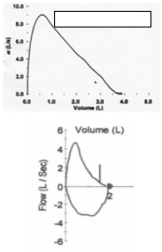
Spirometry Curves

Volume-Time Curve



Flow Volume "Loop"



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Maneuver Acceptable?

- Back Extrapolated Volume (BEV)
- End of Test Criteria
  - Plateau
  - ≥ 12 Seconds
- Disqualifying Changes
  - Additional Breaths
  - Cough
  - Glottic Closure

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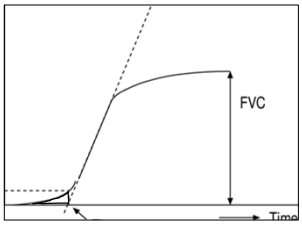
Back Extrapolated Volume

- Maximum 0.1L or 5% of FVC
- NOTE: was 0.15L or 5%. Most software still uses old rules
- "fail" of BEV clearly invalidates FEV1 – but what about FVC?



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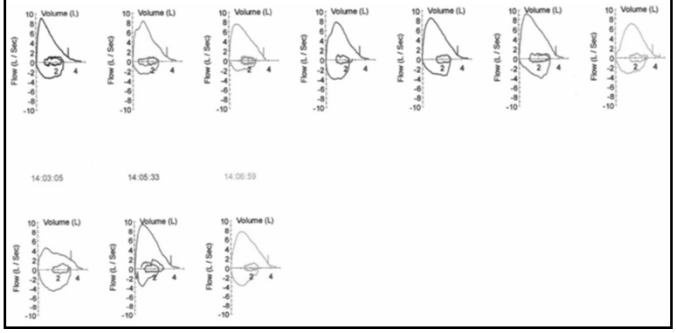
Hesitation, effort, cough(?)



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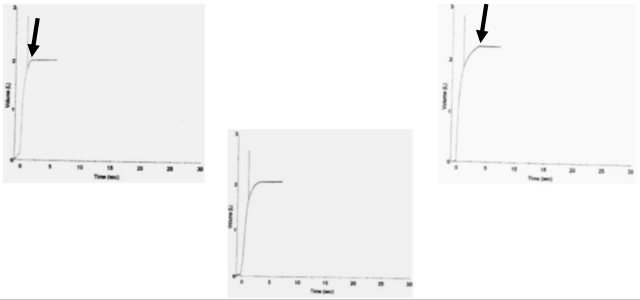
Glottic Closure



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Optional Maneuver Check (New - ATS 2019)

- Transition from Expiratory-only to Expiratory-Inspiratory loop
- Use Post-Expiratory maximal inspiration to verify full expiration
  - Goal < 0.2L
  - **NOT a requirement at present**

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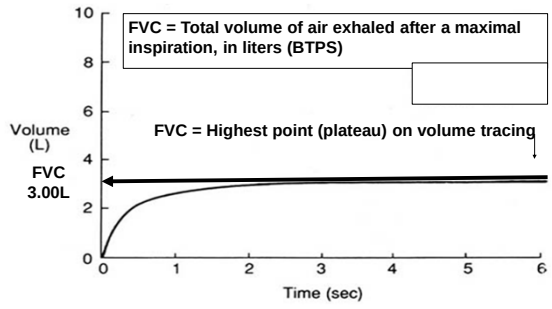
Forced Vital Capacity (FVC)



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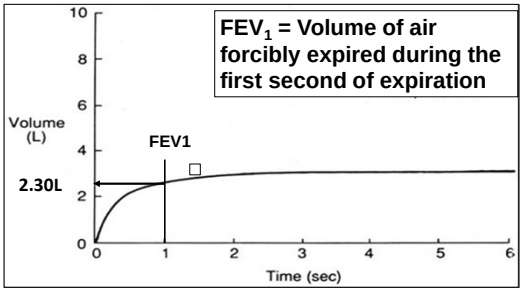
Forced Expiratory Volume in 1 Second (FEV_1)



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FEV_1/FVC Ratio

- Volume of air exhaled in one second as a percentage of the total volume expired
- Expressed as a DECIMAL percentage (ex: 0.73)
- Calculate using
  - Largest valid FEV_1 (In Liters)
  - Largest valid FVC (In Liters)
  - (FEV_1 and FVC may be from different tracings)
  - FEV1/FVC Ratio
  - For my **Example 1.70L / 2.18L = 0.78**
- DO NOT calculate **(or ever think about)** percent predicted for the FEV_1/FVC ratio

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End of Forced Exhalation (EOFE)

Meet one of the EOFE indicators:

1. Expiratory plateau (<0.025L in the last 1 s of expiration)
2. Expiratory time >15 s
3. FVC is within the repeatability tolerance of or is greater than the largest prior observed FVC

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Quality Review – Example 2

Tech: K. Critchfield, RRT | Height: 68.50 | Age: 63 | Sex: Male
Doctor: | Weight: 137.70 | DOB: 12/17/1956 | Race: Caucasian
Temp.(F): 67 | BP (inHg):742 | RH (%): 67 | Calibration: 09/29/2020 10:01:55 AM
Predicted Set: Knudson | Occupational: 17.5 yrs coal dust exp | Testing Position: Sitting

Time	Select	Test	ATS ATS	FVC absolut	FVC % p/	FEV1 absolu	FEV1 % p/c	FEV1/FVC absolute	FEV6 absolu	FEF Max absolute	Back Ext absolute	Expiratory Time absolute
Pre												
09:58:50	*			2.23	50	0.63	18	28	1.66	2.33	0.04	12.76
09:54:43	*		end o	1.98	44	0.62	18	31	1.52	2.73	0.03	10.52
09:49:47	*		end o	1.54	34	0.63	18	41	1.50	2.47	0.04	6.82
Composit		Pre	B ER1R EA	2.23	50	0.63	18	28	1.66	2.73	0.04	12.76
Post												
10:26:46	*		end o	3.04	+35	0.68	+7	22	1.84	2.38	0.02	20.13
10:23:01	*		end o	2.96	+32	0.70	+11	24	1.88	2.18	0.02	17.89
10:20:04	*		end o	2.72	+21	0.70	+11	26	1.92	2.53	0.02	13.75
Composit		Post	ER1R EA	3.04	+35	0.70	+11	23	1.84	2.53	0.02	20.13

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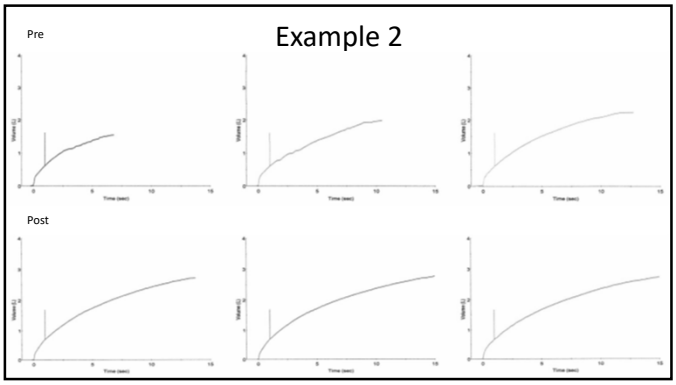
Example 2



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Acceptable vs Usable

- In some cases
  - Maneuvers that do not meet all of the criteria may be the best that the patient is able to do on that occasion
  - FEV_1 and/or FVC measurements that are not technically acceptable may still be clinically useful (i.e. "usable")

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(Fatal) Errors Negating Usability
[Neither FEV_1 nor FVC acceptable or usable]

- **Leak at the mouthpiece**
- **Obstruction of the mouthpiece** (e.g., by tongue, teeth, or distortion from biting)
- **Obstruction of the exit** of the sensor
- **Zero Flow Errors**

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Usability for FEV_1

- **Review Volume/Time curve**
  - Good Effort
  - Back Extrapolated Volume meets standards
  - Ignore End of Test criteria
- **Review Flow/Volume loop**
  - No Cough, extra breaths, etc.
  - Good effort in 1st second (compare to other maneuvers)

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Usability for FVC

- Primary review of **Volume/Time** curve
  - Good Effort (compare to other efforts)
  - Good termination of effort (plateau or time)
  - No extra breaths, Glottic Closure
- Ignore
  - Back Extrapolated Volume
  - Minor abnormalities in first second
- **Limited attention on Flow/Volume Loop**

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Spirometry Update for the Occupational Medicine Practitioner

INTERPRETING SPIROMETRY (PATTERN RECOGNITION)

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What results are "Normal"

- Historic
  - "Normal" ≡ 80% – 120% Predicted
- NEW$_{ish}$ (ATS - Pellegrino 2005)
  - Lower Limit of Normal (LLN) ≡ 5th percentile of no lung Dz
- Newest (ATS 2019)
  - Z Score more positive than -1.645 is normal
  - Z Score of -1.645 = LLN = lowest 5%

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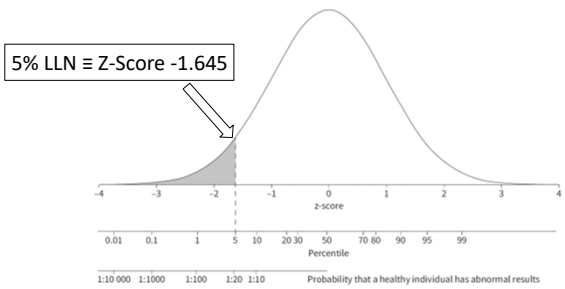
Lower Limit of Normal



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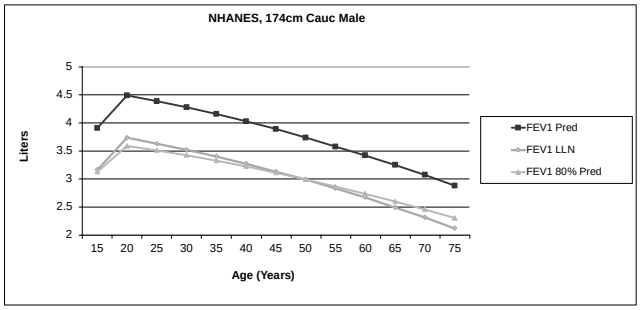
Example: FEV_1 LLN vs 80% Predicted



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Pattern Recognition - First Steps

- Determine LLN (Usually on report or look up)
- Compare Patient result with LLN
  - Either
    - Is Measured Volume (Liters) less than LLN on report, or
    - Is "z-score" more negative than -1.645?
- Need to Compare:
  - FVC
  - FEV_1/FVC Ratio
  - [Ignore FEV_1]

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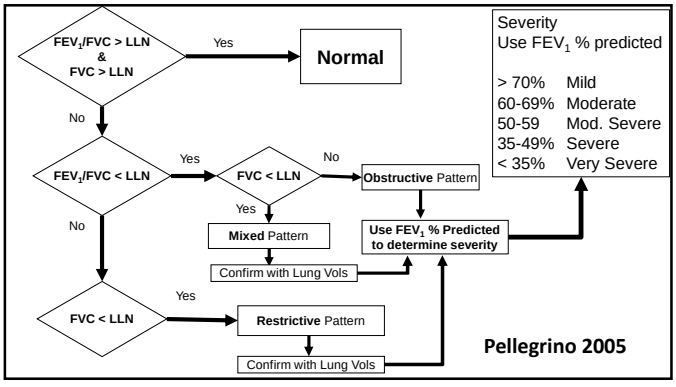

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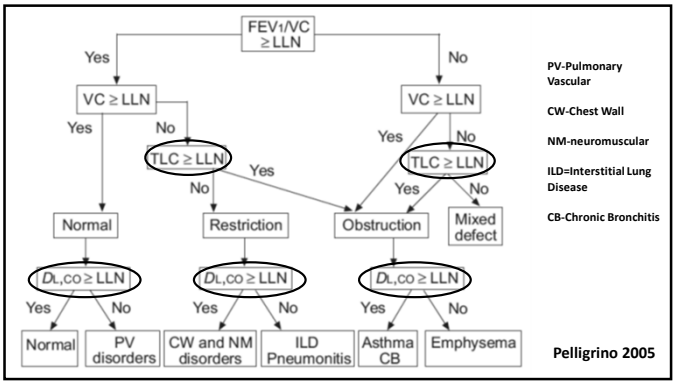

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Spirometry Interp - ATS 2019 (Graham)

TABLE 8 Summary of types of spirometrically defined and lung volume defined ventilatory impairments

Ventilatory impairments	Patterns
Obstruction	• FEV_1/FVC <5th percentile • Decrease in flow at low lung volume may reflect small airway disease in individuals [100, 101, 108] • Concomitant decrease in FEV_1 and FVC most commonly due to poor effort but may reflect airflow obstruction or a restrictive pattern; recommend lung volumes • Measurement of absolute lung volumes may assist in diagnosis and assessment of hyperinflation [108] • Measurement of airflow resistance may assist in diagnosis [139]
Restriction	• TLC <5th percentile • Reduced FVC does not prove restrictive impairment but may be suggestive of restriction when FEV_1/FVC is normal or increased • Low TLC from single-breath test not reliable, especially with low FEV_1/FVC [125] • A normal FVC usually excludes restriction [153]
Mixed	• FEV_1/FVC and TLC both <5th percentile

FEV_1: forced expiratory volume in 1 s; FVC: forced vital capacity.

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Spirometry Update

LUNG VOLUMES

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Goal of Spirometry – What Test(s) do I Need?

- Diagnose Lung Disease
  - Spirometry + Lung Volumes + Diffusing Capacity (DLCO)
- Pre-Employment Evaluation
  - Use great caution – Generally not needed
  - I only even consider for workers in IDLH environments
- Monitoring workers with workplace
  - Spirometry only
- Potential Reactive Airways
  - Spirometry – If Abnormal administer albuterol & re-test (pre- & post) - if normal, do methacholine challenge testing

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Goal of Spirometry – How Lung Volumes Help

- Without Lung Volumes you are limited to identifying the "Pattern" of spirometry (which is data, but not a diagnosis)
- With lung volumes you can:
  - Look for air trapping
  - Diagnose Restrictive disease
- Air Trapping can impact spirometry
  - Pseudo-Obstruction
  - Pseudo-Restriction

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Example – What is Pattern?

	Pre-Bronch			Post Bronch		
	Actual	Pred	%Pred	Actual	%Pred	LLN
---- SPIROMETRY ----						
FVC (L)	2.74	3.86	70	2.98	77	2.87
FEV1 (L)	1.69	2.95	57	1.84	62	2.14
FEV1/FVC (%)	61.86	76.66	80	61.91	80	63.28
FEF 25% (L/sec)	2.97	6.91	42	3.27	47	4.32
FEF 75% (L/sec)	0.35	0.63	56	0.58	92	0.23
FEF 25-75% (L/sec)	0.78	2.32	33	1.08	46	1.03
FEF Max (L/sec)	4.66	7.80	59	5.16	66	5.67
FIVC (L)	2.48			2.72		
FIF Max (L/sec)	3.50			2.81		
Expiratory Time (sec)	11.21			9.70		

FVC < LLN **FEV1/FVC < LLN**

Mixed Obstructive & Restrictive Pattern

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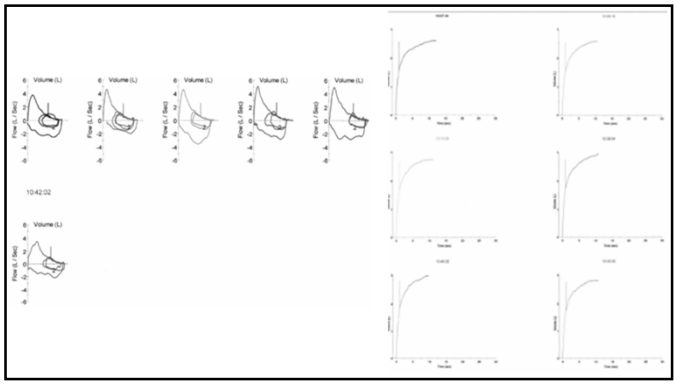

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Lung Volume Example

	Pre-Bronch			Post Bronch		
	Actual	Pred	%Pred	Actual	%Pred	LLN
---- LUNG VOLUMES ----						
SVC (L)	2.54	4.15	61			
IC (L)	1.36	2.62	51			
ERV (L)	1.18	1.31	90			
TGV (L)	5.33	3.36	158			1.93
RV (Pleth) (L)	4.15	2.26	183			1.52
TLC (Pleth) (L)	6.69	6.42	104			4.83
RV/TLC (Pleth) (%)	62.05	35.38	175			26.62
Trapped Gas (L)						

Normal TLC → Not TRUE Restrictive Disease
RV >> 120% Predicted (ULN) → Air Trapping
Pseudo-Obstructive Lung Disease

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Spirometry Update for the Occupational Medicine Practitioner

PREDICTED VALUES & ETHNICITIES

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Predicted Values

- Tested many (non-smokers) with no known lung disease
- Crafted equations to predict "normal" using population data
- Mostly single equations using inputs:
  - Age
  - Height
  - Sex
- Most address ethnicity (somehow)

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Why are there so many predicted value sets?

- 1961 Kory
- 1967 Morris
- 1971 Morris
- 1976 Knudsen
- 1983 Knudsen
- 1989 Crapo
- 1999 NHANES / Hankinson
- 2012 GLI (Global Lung Initiative) – with ethnicities
- 2019 GLI "Global"

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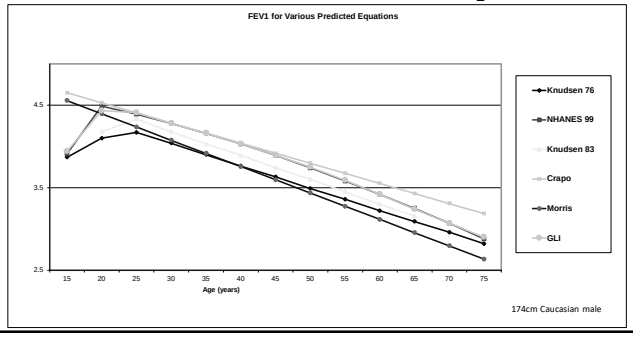
Comparison Predicted FEV_1



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Are the newer predicted value equations better?

	Number in Database	Ages Included	Ethnicities Included
Knudsen 1976	746 Non-Mexican White Americans (pregnancy excluded)	18-65	Caucasians African American = 85% of Caucasian
NHANES / Hankinson	7,429	8 - 80	Caucasian African American Mexican American [Asian = 88% Caucasian]
GLI [Global Lung Initiative]	> 74,000 (Includes NHANES) No uniform QC on data submitted	3 - 95	Caucasian (Includes "Hispanics") African American Northeast Asia Southeast Asia Other / Mixed (average of all data sets)

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Racial Differences

- Confounded researchers since 1869 (yes, right after US civil war)
  - Research continues trying to eliminate the need for these "silos"
- African-Americans have lower Total Lung Capacity (TLC) than European-Americans.
- Osteology finds "flatter" ribcage in African-Americans, while European-Americans have a more rounded ribcage
- Equations do not correlate better using sitting height, BMI, or "wing-span"
- Correcting using TLC fixes this issue – hard to implement

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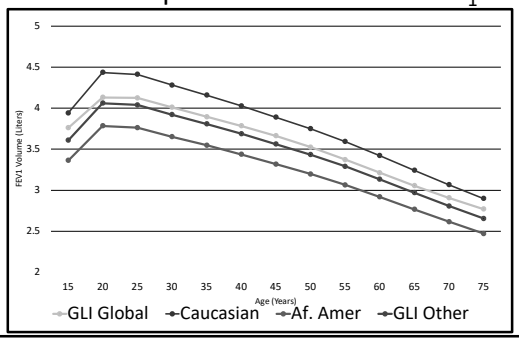
GLI - Comparison of Predicted FEV_1



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Racial "Correction"

- Which equation to use for multi-ethnic heritage patients ?¿?
  - GLI proponents initially recommend using "GLI other"
  - No specific advice for NHANES
- Recommendations for **WORKPLACE PROGRAMS** using NHANES:
  1. Pick a predicted equation that reflects the ethnic diversity of your patient population & know which "ethnicities" are included
  2. Create a page listing ethnic choices for your equipment
  3. Have the patient select their ethnicity from your list
  4. Above all, **NEVER CHANGE** the racial designation for a worker!

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Predicted Equation Conundrum

- Problem: Which predictive equation to use?
  1. Differences between ethnic groups known since 1869
     - Some earlier comparisons used term "inferior" to describe the smaller lungs of African Americans
  2. There are equations for some ethnic groups, but not others
  3. Traditionally (Knudsen), African American = 88% of Caucasian
  4. How are multi-ethnic people addressed?

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Predicted Equation Conundrum

- 1990's NHANES sampled enough African Americans & Mexican Americans to yield specific predictive equations
  - NHANES 1999 (aka Hankinson)
- Global Lung Initiative (2012)
  - Smoother curves using statistical tools (¿Multiple Splines?)
  - NHANES data was incorporated into GLI, and are almost identical

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"Woke" Spirometry

- ATS late 2022: [NR Bhakta, et al, Chest 2022;161:288–297]
  - Spirometric differences between racial groups may reflect socioeconomic disadvantages and structural racism, rather than anatomic differences
  - Using lower predicted values for African Americans may lead to under-diagnosis of lung disease (and thus less healthcare for their lungs)
- ATS 2023 Official Statement
  [NR Bhakta, et al, Am J Respir Crit Care Med 2023;207:978–995]
  - Use GLI Global for **EVERYONE**

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Spirometry Update for the Occupational Medicine Practitioner

GOLD CRITERIA

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GOLD Criteria

- **G**lobal Initiative for Chronic **O**bstructive **L**ung **D**isease
- **"The presence of postbronchodilator $FEV_1/FVC < 0.70$ confirms the presence of airflow limitation"**
- **YOU** then need to identify the diagnosis causing the limitation
- GOLD criteria are useful to assess treatment in patients who already have a **COPD diagnosis**

FEV_1/FVC Ratio < 0.70 <u>ALONE</u> is <u>not DIAGNOSTIC of Anything</u>

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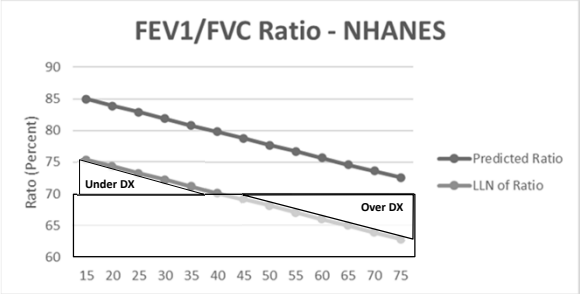
GOLD Criteria



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Spirometry Update for Occupational Medicine

SERIAL SPIROMETRY

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Serial Monitoring

- Unlike hearing conservation, many programs do not follow spirometry over time
- Many Programs: Anything > 80% predicted is OK
- Is it OK for a worker to go from 120% predicted to 81% predicted before any investigation / intervention?

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ACOEM Recommendations

- If Baseline > 100% predicted
  - Method 1 – Follow change in % Predicted
    - If < 85% of baseline predicted value → Investigate
- If Baseline < 100% predicted
  - Method 2 – Follow change in actual volumes
    - If < 85% of baseline volume → Investigate
- * If selecting 1 method for simplicity
  - Use Method 2

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NIOSH Recommendations

- Research into normal variability over time to guide workplace investigations
- Use actual volumes
  - Determine % change over past year
  - > 9% predicted → "A significant change"
  - > 330 ml loss → "A significant change"
  - However, **NIOSH recommends using 15% decrease as a clinical threshold for further investigation**
- ~~SPIROLA https://www.cdc.gov/niosh/topics/spirometry/spirola-software.html~~

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ATS 2022 – FEV_1Q

- FEV_1Q is a measure very useful in predicting death
- FEV_1Q = Measured FEV_1 / 0.5L (men) or 0.4L (women)
- Math (male): $\frac{FEV_1}{1\%\ FEV_1} = \frac{2.8L}{0.5L} = 5.6$ (no units)
- Recommend to follow the change in FEV_1Q over time…
  - But currently no current recommendation on how much change is important (vs benign inter-test variability)

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Cautions – Serial Spirometry

- There is a learning curve for subjects on first few tests
  - Some researchers "ignore" first 3 test sessions when looking at serial spirometry
- Be cautious early in the work life. Change will be very difficult to interpret
- Become aware of where the "knee" is in the predicted value equation you are using and use caution in interpreting changes in folks with ages near the "knee".

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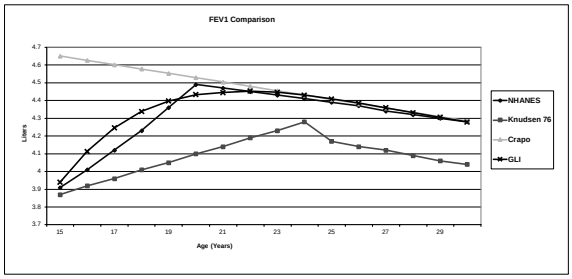
Comparison of FEV_1 Prediction

Transition from Youth to Adulthood



174cm Male Caucasian

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Spirometry Update

2022 - ERS/ATS TECHNICAL STANDARD ON INTERPRETIVE STRATEGIES FOR ROUTINE LUNG FUNCTION TESTS

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

- Emphasis on using PFTs to classify physiology, not make a clinical diagnosis
- Uncertainty of interpretation, especially near LLN
- General use of LLN & ULN
- Report Z-Scores & Use to assess severity
- Bronchodilator Response: 10% increase in **Predicted Value** of FEV_1 or FVC
  - Math: Post (L) – Pre (L) / Predicted (L) Ex: 2.80L - 2.60L / 3.00L = 0.2L / 3.00L = 7%

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TABLE 7 Classification of ventilatory impairments defined by lung volumes

	TLC	FRC	RV	FRC/TLC	RV/TLC	Comments
Large lungs	↑	↑	↑	Normal	Normal	Normal variant above ULN
Obstruction	Normal/↑	Normal/↑	↑	Normal/↑	↑	Hyperinflation if FRC/TLC and RV/TLC elevated; gas trapping if only RV/TLC elevated (*e.g.* COPD)
Simple restriction	↓	↓	↓	Normal	Normal	*e.g.* ILD
Complex restriction [156]	↓	↓	Normal/↑	Normal	↑	When FEV_1/FVC is normal, complex refers to the process contributing to a restrictive process that disproportionally reduces FVC relative to TLC (*e.g.* small airway disease with gas trapping and obesity)
Mixed disorder	↓	Normal/↓	Normal/↑	Normal/↑	Normal/↑	Typically, FEV_1/FVC is reduced (*e.g.* combined ILD and COPD)
Muscle weakness	↓	Normal/↓	↑	↑	↑	When effort appears sufficient; TLC is reduced especially with diaphragm weakness; RV is increased especially with expiratory muscle weakness
Suboptimal effort	↓	Normal	↑	↑	↑	Especially when effort appears insufficient
Obesity	Normal/↓	↓	Normal/↑	Normal/↓	Normal/↑	ERV low; reduced TLC at very high BMI (>40 kg·m^{-2}) [37]

TLC: total lung capacity; FRC: functional residual capacity; RV: residual volume; ULN: upper limit of normal; COPD: chronic obstructive pulmonary disease; ILD: interstitial lung disease; ERV: expiratory reserve volume; BMI: body mass index.

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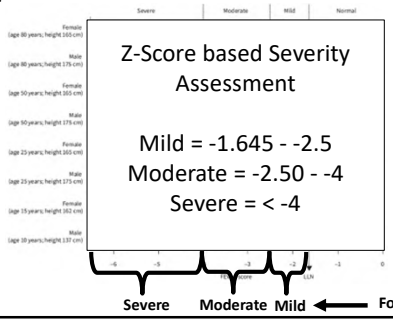
Severity of Impairment - NEW

Age

80
50
25
15
10



Z-Score based Severity Assessment

Mild = -1.645 - -2.5
Moderate = -2.50 - -4
Severe = < -4

Severe Moderate Mild ← For Each Measurement

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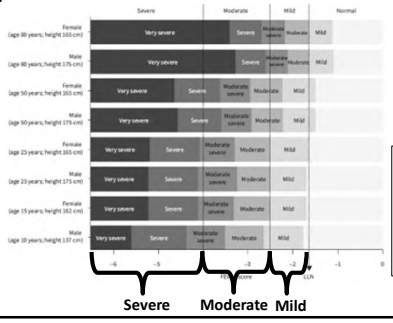
Severity of Impairment - OLD

Age

80
50
25
15
10



Z-score of 2005 ATS recommended thresholds for lung function **for various ages**

Using FEV1%	Predicted:
Mild	≥70%
Moderate	60-69%
Moderately Severe	50-59%
Severe	35-49%
Very Severe	<35%

Severe Moderate Mild

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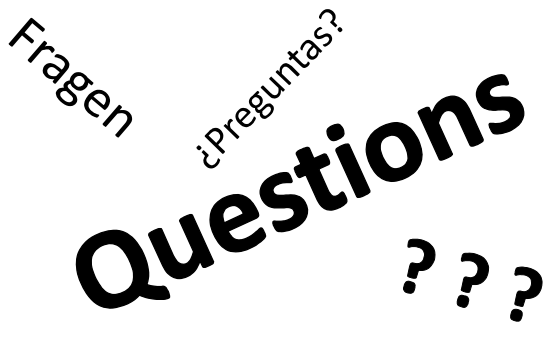

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Reference Literature

- ATS/ERS Task Force Standardisation of Lung Function Testing:
  - General considerations for lung function testing (2005)
  - **Interpretative strategies for lung function tests (Pellegrino, 2005)**
  - Standardisation of spirometry (2005)
- Reporting Spirometry Results (Culver, 2017)
- ATS Spirometry Update (Graham 2019)
- Spirometry in Occupational Health (ACOEM/Townsend 2020)
- ERS/ATS technical standard on interpretive strategies for routine lung function tests (Stanojevic 2022)

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Where can I get LLN data ?

- Might be on printout of spirometers (Needs to be turned on?)
- Equations Published (Hankinson, et al, 1999)
- In AMA Guides - 5th Edition (NHANES)
- Online Calculators
  - NHANES
    - Calculator on NIOSH website (NHANES & Knudsen 76)
      - http://www.cdc.gov/niosh/topics/spirometry/RefCalculator.html
    - Hankinson Consulting (NHANES)
      - http://hankconsulting.com/RefCal.html
  - Global Lung Initiative (GLI)
    - http://gli-calculator.ersnet.org/index.html

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