An iconoclastic review of spirometry: a new approach to interpretation

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Disclosure Information

- I have no relevant financial relationships with the manufacturers of any commercial products and / or provider of commercial services discussed in this CME activity.
- I do not intend to discuss any unapproved / investigative use of a commercial product / device in my presentation

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Objectives

- Review the performance and interpretation of spirometry
- Revisit traditional approaches to the evaluation of:
  - adjustment for “race”
  - FEV1/FVC ratios
  - % predicted values vs. z scores
  - FEF 25-75
  - expiratory times and
  - spirometry in the evaluation of vocal cord dysfunction

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SPIROMETRY

- Breath (spiro-) measuring (-metry)
- Measurement of air flow (how fast) and volume (how much) during forced expiration into a spirometer

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FORCED EXPIRATORY EFFORT

- Inhale completely (to total lung capacity, TLC)
- Seal mouth around mouthpiece
- BLAST the air out (exhale forcefully)
- Continue to BLOW, BLOW, BLOW

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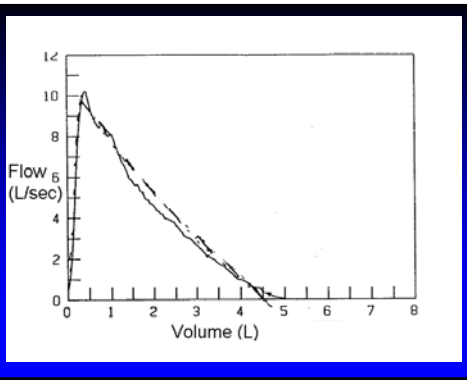

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COMMON ERRORS IN SPIROMETRY

- Weak effort (no blast)
- Short effort (quit too soon)
- Efforts not reproducible

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REPRODUCIBLE EFFORTS

- Must do at least 2-3 efforts which are reproducible giving flow-volume curves which are superimposable
- Reproducible efforts are maximal efforts because you cannot exactly reproduce a submaximal effort
- It's not the patient, it's the coach!

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Criteria for acceptable efforts (i.e., did the patient do a good job blowing in the machine?)

1. Peak: does each effort (flow-volume curve) have a sharp initial peak?
2. Finish: does each effort extend all the way down to the baseline at the end?
3. Reproducible: are at least 2 of the efforts superimposable?

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Only 3 numbers matter

- FVC
  - Forced vital capacity
  - The total volume of air exhaled (no time limit)
- FEV1
  - Forced expiratory volume in one second
  - The volume of air exhaled in the first second
- FEV1/FVC
  - Of all the air exhaled (no matter how long it takes), the portion exhaled in the first second

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PREDICTED EQUATIONS

- Formulas/equations used to predict spirometry results based on patient characteristics
- Sets of equations typically named for the 1st author (e.g., Hankinson) or study (e.g., NHANES)
- The Global Lung Function Initiative (GLI)-2012 multiethnic spirometry equations are recommended/preferred
  - include the largest samples of healthy subjects (i.e., never-smokers, without a history of respiratory disease)
  - applicable across all ages

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NORMAL (PREDICTED) VALUES

- Given certain information about the patient, the spirometry software equations calculate predicted values based on:
  - Age (uphill while growing, all downhill after reaching adult height)
  - Height (tall > short)
  - Sex (M > F)
  - Race (Caucasian, Hispanic > Black, Asian) …controversy

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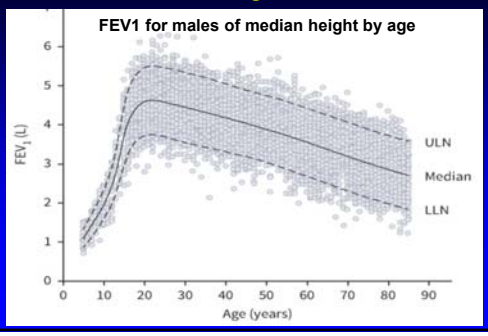
Age



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Height

- Height is not a direct determinant of lung size but is a reasonable proxy for chest size. However,…
- Differences in height and body proportions (e.g., leg length and trunk length) have been observed between populations

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Sex

- Sex is an important predictor of lung size, even after accounting for differences in height
- The appropriate reference equations for transgender individuals is currently not known
  - The effect of gender-affirming hormonal therapy on lung function is poorly understood
  - Timing of gender reassignment, especially during adolescence, may impact lung growth
  - However, until more is known, while gender identity should be respected, use of biological sex recommended

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- "Race is a social construct with no biologic definition."
- Use "race-neutral equations"

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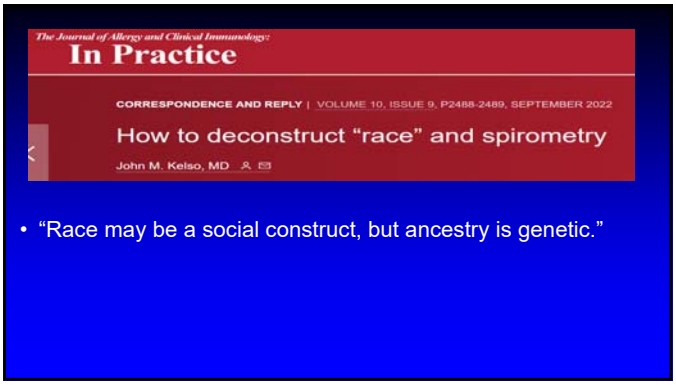

- "Race may be a social construct, but ancestry is genetic."

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"Race"

- Lower absolute lung volumes are observed in patients who identify as being of African or Asian descent when compared to those who identify as White or Caucasian
- The specific pattern of these lower lung volumes is a proportionally lower FVC and FEV1 such that FEV1/FVC is not affected (a restrictive pattern)
- The predicted values have traditionally been "corrected" for "race" based on patients' self-identified race or ethnicity on the assumption that the lower observed values are due to genes associated with "race"

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"Race"

- More recently, this assumption has been questioned given the imprecise association of "race" and genetics or ancestry and the possibility that the lower lung volumes are due to social determinants of health stemming from social determinants of health more likely to affect persons of color such as poverty, lack of access to healthcare, exposure to toxic or polluted environments, etc.

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"Race"

- If the lower lung volumes observed in persons of African or Asian descent are due to these social determinants of health, rather than genes or ancestry, it would *not* be appropriate to apply "racial corrections" to spirometry because this would mask underlying lung pathology
- If, however, the lower lung volumes observed in persons of African or Asian descent are in fact due to genetics associated with such ancestry, the application of such corrections *would* be appropriate
- Furthermore, assigning race/ethnicity is challenging

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"Race"

- Studies have supported associations between both ancestry and social determinants of health and spirometry values, however, a precise contribution of each is unknown at a population level and, in particular, at an individual patient level
- Various approaches have been suggested to accurately assess spirometry in persons of African or Asian descent including abandoning "racial corrections" altogether and instead using predicted values for a conglomerate of subjects of all self-identified races and ethnicities, or comparing spirometry results in an individual patient to both "uncorrected" values and "corrected" values

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"Race": ATS Recommendations

- GLI has different equations for different "races" or "ethnicities" e.g., Caucasian, Black, Asian
- Now more appropriately referred to as "ancestral origins"
- Also has an "other" category of all data combined
- Acknowledge that "The differences by population groupings that were observed in the GLI data may represent genetic differences or health disparities", however,…
- "At this time employing the appropriate GLI spirometry equations based on self-reported ancestral origins, if known, should be used. If ancestral origins are unknown or uncertain, the GLI "other" equation should be used"

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PERCENT PREDICTED VALUES

- The software calculates predicted values based on various equations
  - e.g., FEV1 = *x* times **height** in inches + *y* times **age** in years – *z*
- Different equations for male and female
- Different equations for different races / ethnicities / ancestral origins

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PERCENT PREDICTED VALUES

- Once the patient has performed the PFT and the actual values are known, these values can be compared to the predicted values
- Actual value/predicted value = percent predicted (% predicted)
- Normal values:
  FEV1 or FVC: 80-120 % of predicted
  FEV1/FVC: >90 % of predicted

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FEV1/FVC: Not a fixed value!

Spirometry

		Pre	Pre%Pred
FVC	L	3.70	82 %
FEV 1	L	2.21	58 %
FEV1/FVC	%	60	
PEF	L/s	9.95	107 %

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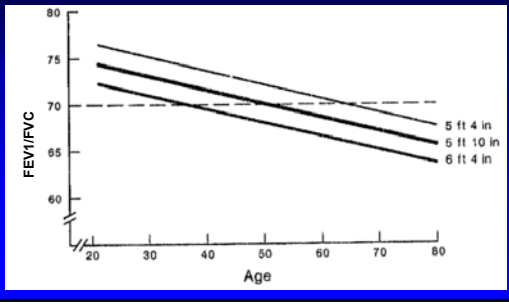
FEV1/FVC: Not a fixed value!



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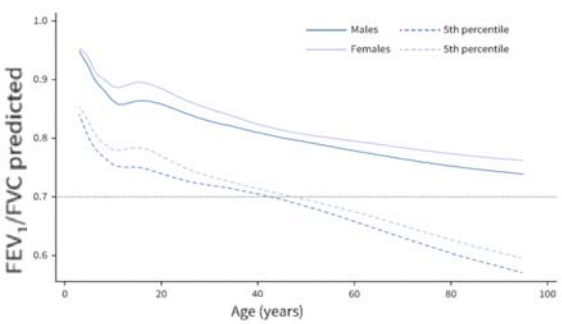
FEV1/FVC: Not a fixed value!



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FEV1/FVC

- "The fixed value commonly used (0.70 for FEV1/FVC) is an estimate based on middle-aged adults, and therefore erroneous clinical decisions based on this fixed cutoff is likely to occur in children and in older adults." *
- "The widely used cut-off of 0.70 for FEV1/FVC ratio is strongly discouraged" #

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

#Stanojevic S, et al. ERS/ATS technical standard on interpretive strategies for routine lung function tests. Eur Respir J. 2022;60(1).

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FEV1/FVC AS PERCENT PREDICTED

- FEV1/FVC: >90 % *of predicted*
- *Example:*

predicted	observed	% predicted
0.75	0.75	100%
0.75	0.6	80%

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FVC and/or FEV1 ≥ 120%

- Recheck patient age, height, sex and race/ethnicity
- 5 feet 6 inches ≠ 56 inches

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PERCENT PREDICTED VALUES

- "The respiratory community is familiar with using the percent predicted value to describe lung function results, however, the true LLN is age- and/or height-dependent and therefore will occur at varying percent values in different individuals"

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

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z scores

- "Percent predicted does not take into account the observed age-related changes in measurement variability
  - For example, the LLN for FEV1 varies from 81% predicted at the age of 10 years to 68% predicted at the age of 85 years
- The widely used cut-off of 80% of predicted for FEV1 is strongly discouraged"

Stanojevic S, et al. ERS/ATS technical standard on interpretive strategies for routine lung function tests. Eur Respir J. 2022;60(1).

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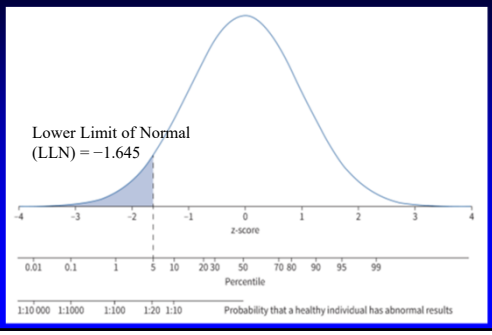
z scores



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SERIAL SPIROMETRY

- Follow spirometry over time
- “Best ever” PFT in % predicted (or z score) is benchmark for life

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RESPONSE TO BRONCHODILATOR

- The FEV1 may improve within about 10 minutes of using an inhaled bronchodilator
- If the FEV1 improves by ≥12%,
- "reversibility" or "bronchial hyperresponsiveness" has been demonstrated
- If reversible, suggests asthma
- If not reversible, does not exclude asthma

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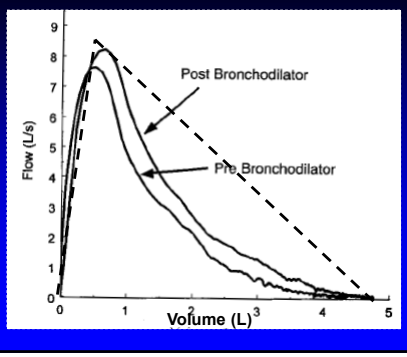

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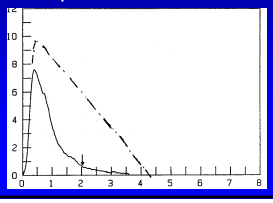
OBSTRUCTIVE LUNG DISEASE

- E.g., asthma
- Obstruction to airflow
- Trouble getting air out
- "Scoop" on flow-volume curve



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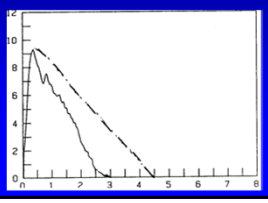
RESTRICTIVE LUNG DISEASE

- E.g., Pulmonary fibrosis
- Restriction to full inhalation
- Trouble getting air in
- Small triangle on flow-volume curve



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Criteria for a normal test (after you determine that the patient did a good job blowing in the machine)

1. Is the downward limb of the flow-volume curve (nearly) straight? (if scooped = obstructive)
2. Is the triangle as big as the expected curve? (if too small = restrictive)

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Abnormal Spirometry Patterns

	Obstructive	Restrictive
FVC	**NL or ↓**	↓
FEV1	↓	↓
FEV1/FVC	↓	**NL or ↑**

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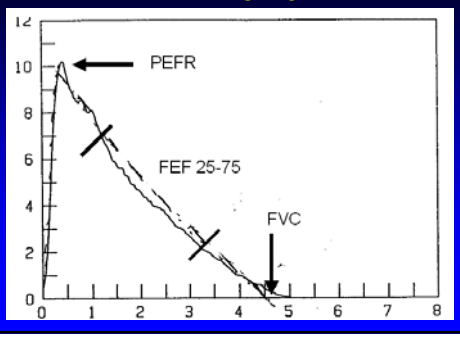
FEF 25-75



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FEF 25-75

- Forced expiratory flow between 25% and 75% of FVC
- The middle portion of the downward limb of the flow-volume curve
- Reflects small airways function and…
- Relatively effort independent but…
- Large normal variation; Normal value: >50 % of predicted
- Capture same information if use FEV1/FVC *percent predicted or z score*

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FEF 25-75

- "FEF25–75% has not demonstrated added value for identifying obstruction in adults or children, and therefore is not recommended for routine use"

Culver BH, Graham BL, Coates AL, et al. Recommendations for a Standardized Pulmonary Function Report. An Official American Thoracic Society Technical Statement. Am J Respir Crit Care Med 2017;196:1463-1472.

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Volume-Time curve

- Technically supposed to blow for ≥ 6 seconds to ensure all air exhaled (i.e., reached FVC)
- However, with normal lung function and especially in children, FVC reached at ≤ 6 seconds, so a shorter effort is acceptable
- If plateau, have reached FVC

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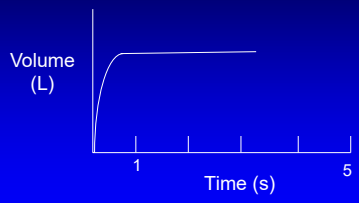
Volume-Time curve



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Clinical and lung-function variables associated with vocal cord dysfunction

Watson MA, King CS, Holley AB, et al.

Respir Care 2009;54:467-73.

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Spirometry and VCD

SUBJECTS

- 226 patients referred to a pulmonology clinic for suspected VCD (53%), unexplained dyspnea (21%), abnormal flow-volume loops (18%), chronic cough (15%), and hoarseness (10%).

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Spirometry and VCD

METHODS

- Spirometry
- Direct laryngoscopy with a flexible rhinolaryngoscope
  - VCD provocations (deep or rapid breathing, smelling salts, methacholine, or exercise)
  - From the laryngoscopy reports obtained the VCD diagnosis

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Spirometry and VCD

METHODS

- 3 pulmonologists blinded to the laryngoscopy results graded the likelihood that flow-volume loops indicated VCD
- Given no instruction as to what inspiratory-curve appearance suggests VCD

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Spirometry and VCD

METHODS

- Each inspiratory curve scored on a Likert scale:
  - 1 = normal
  - 2 = minimally suggestive VCD
  - 3 = moderately suggestive of VCD
  - 4 = highly suggestive of VCD

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Spirometry and VCD

RESULTS

Table 2. Pulmonologists' Interpretation of Likelihood That the Flow-Volume Loop Represented a Patient With Vocal Cord Dysfunction

Pulmonologist	Likert Scale Rating* (mean ± SD)		
	VCD Absent† (mean ± SD)	VCD Present† (mean ± SD)	*P*
1	2.5 ± 1.3	2.8 ± 1.2	.10
2	2.2 ± 1.0	2.4 ± 1.0	.15
3	1.9 ± 1.1	2.0 ± 1.0	.45

* Likert scale: 1 = normal, 2 = minimally suggestive of vocal cord dysfunction (VCD), 3 = moderately suggestive of VCD, and 4 = highly suggestive of VCD.
† Diagnosed via laryngoscopy.

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Spirometry and VCD

CONCLUSIONS

- "If VCD is suspected, normal flow-volume loop patterns should not influence the decision to perform laryngoscopy."

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National Jewish Health

A detailed evaluation is needed to correctly diagnose vocal cord dysfunction (VCD).

The diagnosis will also help determine the most effective treatment of VCD or inducible laryngeal obstruction (ILO).

VCD/ILO diagnosis usually includes:

- **Exam:** Your health care provider will complete a detailed medical history and physical exam.
- **Spirometry:** Breathing tests like spirometry can be useful in diagnosing VCD/ILO. Breathing tests need to be done when you are having symptoms. When you aren't having symptoms you may have a normal test result. Other conditions such as asthma may also affect your breathing test results.

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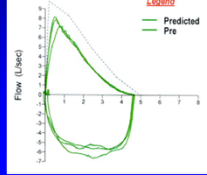
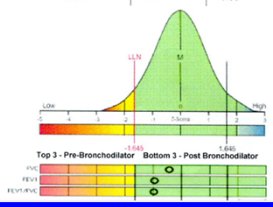
Spirometry

Parameter	Units	Pred	LLN	Pre	% Pred	Z-score
FVC	L	4.97	3.88	4.68	94	-0.44
FEV_1	L	3.92	3.05	3.43	88	-0.93
FEV_1 / FVC	%	79	68	73	92	-0.94
FEF_{25-75} [ISO]	L/s	3.55	1.90	2.55	72	-0.94
PEFR	L/s	9.80	7.47	8.13	83	
FET	sec			6.72		

Best 3 Efforts (ranked by ATS)

Best	%Pred	2nd	%Pred	3rd	%Pred
4.68	94	4.63	93	4.58	92
3.43	88	3.39	86	3.36	86
73	92	73	92	73	92
2.55	72	2.49	70	2.50	70
8.13	83	7.19	73	7.85	80
6.72		7.27		6.56	





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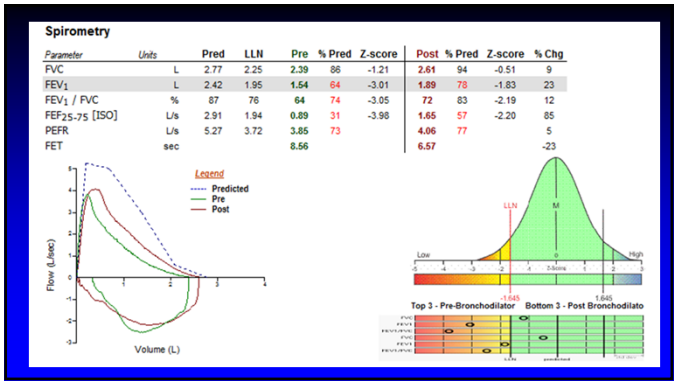
Spirometry
Parameter Units Pred LLN Pre % Pred Z-score Post % Pred Z-score % Chg
FVC L 2.77 2.25 2.39 86 -1.21 2.61 94 -0.51 9
FEV1 L 2.42 1.95 1.54 64 -3.01 1.89 78 -1.83 23
FEV1 / FVC % 87 76 64 74 -3.05 72 83 -2.19 12
FEF25-75 [ISO] L/s 2.91 1.94 0.89 31 -3.98 1.65 57 -2.20 85
PEFR L/s 5.27 3.72 3.85 73 4.06 77 5
FET sec 8.56 6.57 -23
Legend
Predicted
Pre
Post
Flow (L/sec)
Volume (L)
LLN
M
Low
High
Z-score
-1.645
1.645
Top 3 - Pre-Bronchodilator
Bottom 3 - Post Bronchodilato

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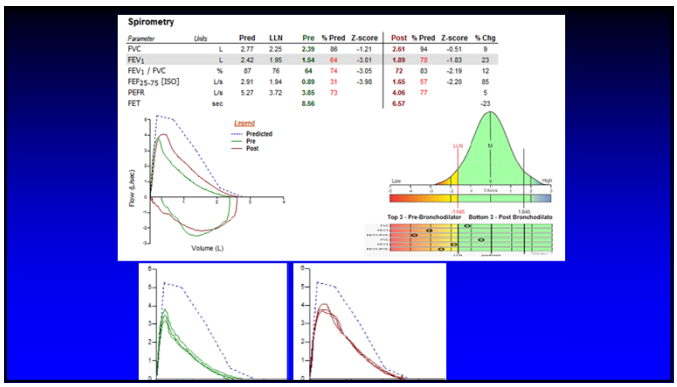
Spirometry
Legend
Predicted
Pre
Post
Volume (L)
Top 3 - Pre-Bronchodilator
Bottom 3 - Post Bronchodilato

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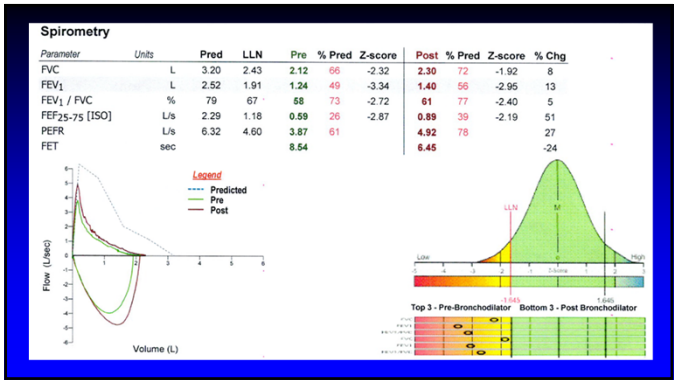
Spirometry
Parameter Units Pred LLN Pre % Pred Z-score Post % Pred Z-score % Chg
FVC L 3.20 2.43 2.12 66 -2.32 2.30 72 -1.92 8
FEV1 L 2.52 1.91 1.24 49 -3.34 1.40 56 -2.95 13
FEV1 / FVC % 79 67 58 73 -2.72 61 77 -2.40 5
FEF25-75 [ISO] L/s 2.29 1.18 0.59 26 -2.87 0.89 39 -2.19 51
PEFR L/s 6.32 4.60 3.87 61 4.92 78 27
FET sec 8.54 6.45 -24
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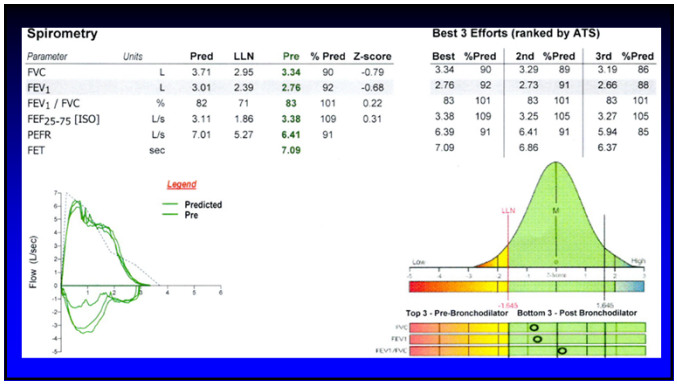

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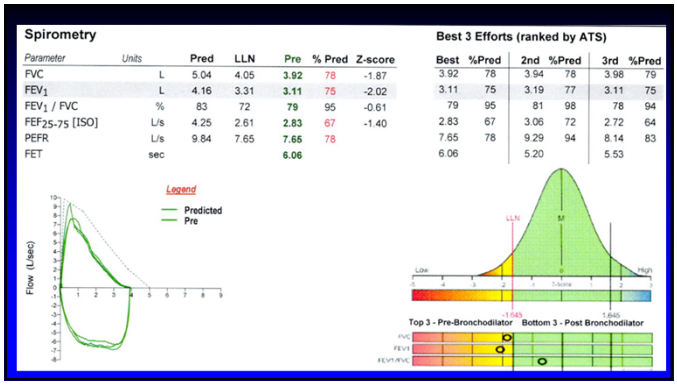

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Changes you may wish to make in practice

- Enter accurate patient data
- Use GLI predicted equations
- Coach patients to BLAST and then blow, blow, blow…
- Judge technical acceptability (peak, finish, reproducibility) before abnormality
- Judge abnormality based on the flow volume curve
  - Normal = triangle near the expected curve
  - Obstructive = “scoop”
  - Restrictive = triangle to small
- Use the numbers only to confirm your impression of the curve

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Changes you may wish to make in practice

- Use equations based on self-reported ancestral origin (if “multiracial”, “multiethnic”, unknown or uncertain, use “other”), but be aware of genetics vs. social determinants of health
- Use % predicted values or z scores rather than 0.7 for FEV1/FVC ratio
- FEF 25-75…fuggedaboutit
- < 6 sec expiratory time OK if plateau on volume–time
- Don’t try to diagnose VCD based on asymptomatic spirometry

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Changes you may wish to make in practice

- Normal values: % of predicted
  FEV1 ≥ 80
  FVC ≥ 80
  FEV1/FVC ≥ 90
- Normal values: **z scores are best!**
  z ≥ -1.645

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References

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