PPU Self-Study and Curriculum

Suggested time line

- Week 1
    - Complete pre-test and score yourself.
    - Familiarize yourself with interpretation "cheat sheets" – should have received via email

- Week 2
    - Review the Cherniack "Ventilatory Function" teaching module
    - Read ERJ guideline #5 – Interpretative strategies for lung function tests
    - Read ERJ guideline #1 – General considerations for lung function test testing

- Week 3
    - Review the Cherniack "Gas Exchange" teaching module
    - Read ERJ guideline #2 – Standardisation of spirometry
    - Read ERJ guideline #3 – Sandardization of measurement of lung volumes
    - Read ERJ guideline #4 – Standardization of DLCO

- Week 4
    - Review the Cherniack "Exercise" teaching module
    - Read ATS/ACCP Statement on Cardiopulmonary exercise testing

- Week 5
    - Read ATS guidelines for methacholine challenge
    - Read ATS guidelines for 6-minute walk
    - Have PFTs done on yourself
    - Best cases

- Week 6
    - Best cases
    - Board questions
    - Perform an Exercise Test (sometime between week 6 and week 8)

- Week 7
    - Best cases
    - Board questions

- Week 8
    - Best cases
    - Post-test – record score and compare to start
    - Board questions

Pulmonary Function Tests and Exercise Studies

NJ Pulmonary Fellows and NJ Attendings

June 9, 2011

Spirometry

- **Patient Characteristics:**
  - Body Mass Index (Obesity)
    - FRC and ERV decrease exponentially with increasing BMI. Morbidly obese subjects breathe near residual volume (1). They have restrictive physiology.
    - At BMI ~30: FRC=~75% predicted; ERV=~47% predicted (1)
  - Age: over 70 (especially female): No large population normal values for body box TLC
  - Race
    - Lung volumes ~10-15% less than predicted for African Americans , Asians, East Indians (2,3)
      - No normals: recommend using 0.88 TLC pred., 0.93 FRC predicted
    - Predicted normals for spirometry only available for African Americans (NHANES III) (4)

- **Testing:**
  - Start by looking at the comments made by the technicians
  - Acceptability
    - Three attempts must meet ATS acceptability criteria **and** the two largest acceptable values of FVC and FEV1 must be within 150 mL of each other
      - ♦ Values should be within 100 mL if the FVC is less than or equal to 1L
      - **"Acceptable"** Meets ATS standards
      - **"Suboptimal"** Does not meet ATS standards but I can interpret
      - **"Questionable"** I can't interpret, needs confirmation (avoid unless unreadable)
    - Start of test: back extrapolated volume should be less than 5% of the FVC or 150 mL whichever is greater. (5)
    - During test: The flow-volume loops of different attempts must be similar in appearance and without artifact on the expiratory limb. Cough or artifact in first second of expiratory loop renders test unacceptable. (5) "suboptimal" if can interpret
    - End of test: 6 second forced expiratory time (FET) or a plateau of the volume-time curve of greater than or equal to 1 second is required (5)
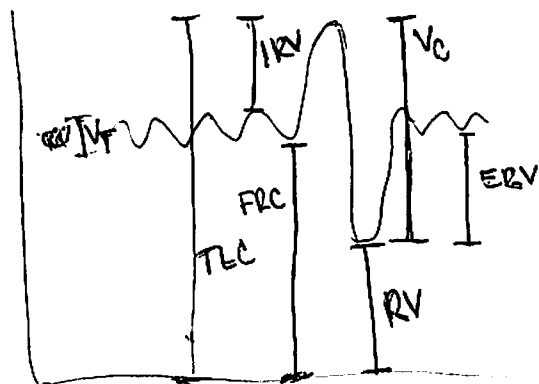
- **Flow-Volume Loops:**

Pulmonary Function Tests and Exercise Studies

Recommended start for PFT evaluation. Nearly everything is in this diagram.
- o Always start with the graph of the flow volume loop (fig 1).
- o Look at TLC: high, normal range, or reduced; Look where the FRC is located. (31,32)
- o Look at the effort independent part of the flow volume loop- last ½ of expiration.
    - Are flows greater during tidal breathing than forced expiration? (called negative effort dependence or dynamic collapse).
    - Expiratory flows at high lung volume are effort dependent; all inspiratory flows are effort dependent.
- o Look at the loops- a complete picture of obstruction, restriction, or a mixed disorder can be determined. Pay attention to **flows at absolute lung volumes.**
    - Supranormal flows suggest restriction, reduced flows suggests obstruction.
        - ♦ Supranormal should be clearly above the predicted flows implying an increase in elastic recoil and low resistance at that lung volume.
    - Obstruction based on "reduced flow at absolute volumes" is more suggestive if the forced expiratory loop is near or touching the tidal expiratory loop (fig 1). To use this designation, the flows must be convex up. This designation is used to designate air flow limitation when the FEV1/FVC might be in the range of normal.
    - If body box lung volumes are not measured, expiratory flows are plotted independent of patients actual FRC, i.e. the placement of the loop along the volume axis is arbitrary. Therefore, you cannot compare the patient's flow loop to the predicted expiratory flow loop. You cannot compare "flows at absolute lung volume".
- o Decide what the overall physiologic abnormality is and then include the supporting evidence in the report.
    - Normal
    - Restrictive
    - Obstructive
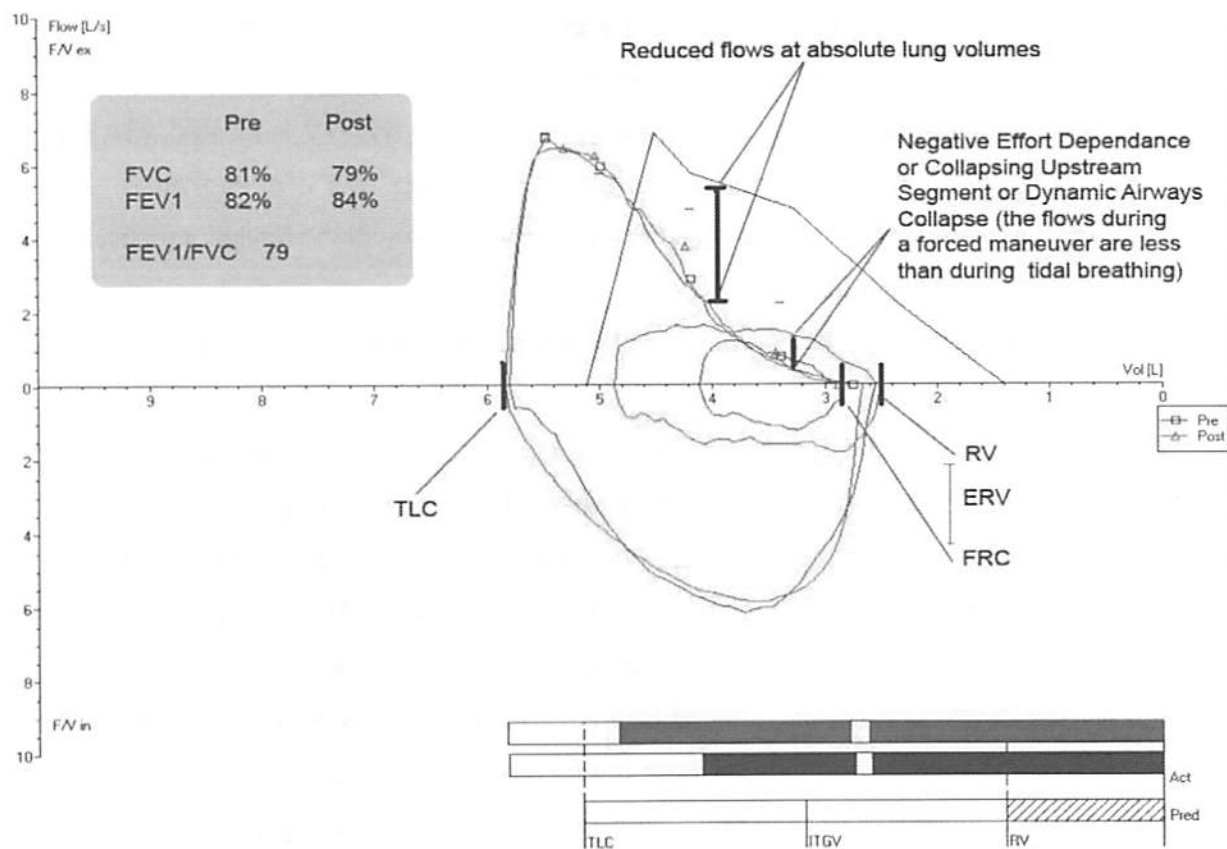   - Mixed restrictive and obstructive

Figure 1. Flow-volume loop explained

- o Flows higher than predicted at higher lung volumes and lower than predicted at lower lung volumes suggest a mixed process of obstruction and restriction. (fig 2)
- o Comment on patterns of obstruction (variable or fixed, intra or extra-thoracic) (6,7)
- o VCD suggested by flow less then 2L/sec during the last 1/3rd of the inspiratory loop (this translates into a flow limited segment with a 4 mm diameter) (fig 3) (8)

The example above demonstrates airflow limitation with normal spirometry.

Fig 4.   An example of a saw-tooth pattern

- **Lung Volumes:** (17)
    - TLC and FRC ±20% and RV up to 140% predicted = Normal range
    - **Hyperinflation** = Increase in FRC >120%; TLC >120%; RV >140% (need two out of the three to qualify for hyperinflation)
        - Marked hyperinflation = increase in both FRC and TLC
        - TLC (body box) > VA (gas diffusion) by >800 ml = poor gas distribution
            - May allow for >1 liter if patient has very large lung volumes
            - In normals these values should be within 500 ml of each other
    - **Restriction** = TLC <80% (ATS Criteria), FRC <80%
        - Isolated reduction in FRC (TGV) and ERV (<25%) with normal TLC may suggest body habitus e.g. Obesity. For obesity to effect lung volumes the BMI should be >30.
        - Reduced ERV: (<40%) obesity, neuromuscular disease, markedly decreased elastic recoil

- **Airflows**

- o Shape of the flow-volume loop (as above)
- o FEV1/FVC ratio (Normal=)
  - greater than **74% up to age 60** ; Kids probably closer to 80%
  - greater than **70% over age 60**
    - Note: The use of 70% as a lower limit of the FEV1/FVC ratio as recommended by the GOLD group results in a significant number of false positive results in males over 40 yrs and females over 50 and underestimates airflow limitation in young adults (11).
    - The lower limit of normal (LLN) uses ratio values below the 5th percentile of the NHANES data. This significantly reduces the number of false positives in elderly and false negatives in younger populations (11). However, it also has its problems in that it will also cause additional false negatives. The NHANES standards for "normal" were developed via a questionnaire in which patients reported themselves as being normal or abnormal with regard to having COPD. There was no physician assessment, CT scan, measurement of lung volumes, or measurement of gas distribution. These values are the best we have. The NHANES criteria uses spirometry as the sole means of defining obstructive disease, but likely under diagnoses true obstructive lung disease (false negatives). If you have additional measurements don't use spirometry alone to diagnose obstructive lung disease. Consider airflow at absolute lung volumes, specific conductance, and gas distribution to determine whether a patient has obstruction instead of just spirometry.
    - The population sampled to determine LLN was likely quite different from those attending a pulmonary clinic, which would likely have a higher value to exclude COPD. Specificity of a cut off valve to differentiate normal versus abnormal will depend on the population being studied.
    - Airflow limitation can also be suggested by:
      - Reduced flow at absolute lung volume (12)
      - Specific conductance (sGaw) less than 60% predicted (13) But why would you want to diagnose obstructive lung disease during a panting maneuver?
      - Significant response to bronchodilator (see below)

- ♦ Poor gas distribution (TLC greater than VA by more 800 ml)
- ♦ Unfortunately, there are no large and age adjusted population based studies to evaluate the sensitivity and specificity of these other secondary features to diagnose airflow limitation.
  - o Dynamic Airflow Obstruction (Air Trapping) = SVC> FVC by more than 500 cc
  - o $FEF_{25\%-75\%}$: Specificity poor in identifying asthma or COPD
  - o **Obstructive** = Low FEV1/FVC and usually reduced FEV1 > FVC
  - o **Restrictive** = Normal FEV1/FVC and Low FEV1 and Low FVC
  - o **Mixed** = refer to section below "Integrated Interpretation of PFTs"

- **DLCO**
  - o Absolute and DLCO/VA: **80% -120% = normal**
  - o DLCO/VA often normalizes in ILD, may be elevated in asthma
  - o Decreased in anemia, emphysema, ILD and many forms of chronic lung disease
  - o Increased in processes that increase diffusing capacity:
    - ▪ Increased pulmonary blood volume: transient increases in left atrial pressure, exercise, increased negative intrathoracic pressure (asthma), obesity, supine positioning, L→R shunt
      - • Epidemiologically asthma and obesity are most common causes (14)
    - ▪ Increased O2 binding capacity: polycythemia, acute pulmonary hemorrhage

- **Muscle strength**
  - o Extremely effort dependent. Arbitrary lower threshold for normal = >60% pred.

- **Bronchodilator Response**
  - o 12% increase in FEV1 and/or FVC **AND** 200 cc increase in absolute volume (5)
  - o 40% increase in sGaw (13)
  - o **Isovolume shift** = Reduction in FRC post bronchodilators by 500cc or >=15%
  - o Use of spirometry alone (FEV1 and FVC) fails to identify reversibility in around 15% of patients with reversible airflow obstruction (15)

- **Integrated Interpretation of PFTs**
  - o **Obstruction:**
    - Low FEV1/FVC and reduced FEV1>FVC
    - Grades based on FEV1 as per GOLD criteria (for COPD). (Other gradation systems available as well. e.g. BTS, ATS, ERS) (16)
      - Mild = 70-80% of predicted
      - Moderate = 50-70% of predicted
      - Severe = 30-50% of predicted
      - Very Severe <30%
    - Shape of the curve (also flows at absolute lung volumes)
    - +/- Hyperinflation
    - +/- Dynamic Airflow Obstruction (Air trapping)
    - +/- Significant response to Bronchodilators

  - o **Restriction:**
    - Defined by ATS as TLC <80% (often FRC and RV decreased as well)
    - Gradation based on TLC values
      - Mild 70-80% of predicted
      - Moderate 50-70% of predicted
      - Severe <50% of predicted
    - A significantly reduced ERV (<25%) in this setting helps dissect out obesity and neuromuscular disorders from intrinsic lung diseases such as ILD
    - FEV1 and FVC reduced (commonly symmetrically reduced)
    - Supra-normal flow rates at high normal lung volumes (High flow rates at absolute lung volumes = increase elastic recoil)
    - No response to bronchodilators
    - Low lung volumes (Hyperinflation rules out significant restriction)
    - No dynamic airflow obstruction

  - o **Mixed Restrictive and Obstructive Disease:**

- Usually difficult to call unless clearly evident
- TLC usually between 80-100% of predicted but not elevated (>120%)
- Shape of the flow-volume loop shows high flows for absolute lung volume at higher lung volumes (first 30% of FVC) and reduced flow at low lung volumes (last 30% of FVC).
- Restrictive lung volumes but significant response to bronchodilators
- FEV1/FVC ratio usually close to or normal.
- Increased RV with evidence for dynamic air trapping in the setting of reduced TLC and FRC.
- How do you diagnose airflow limitation in an obese patient? What happens to TLC, FRC, and the FEV1/FVC ratio in obesity? In obesity with airflow limitation, TLC falls or can't increase much, FRC falls or can't increase much and the FVC and FEV1 tend to decrease proportionately which often keeps their ratio unchanged.

Exercise Testing (18-22)

Tip: The guidelines are not clear for asserting a specific limitation. Tell the referring physician what you would want to be told, if you were the referring physician. We only interpret maximal exercise tests and not the steady state exercise tests.

Major points to be addressed
- Normal or abnormal
- If the test is abnormal, what is the major limiting factor?
- Is there cardiac reserve? Is there ventilatory reserve?
- What are the significant abnormalities even if not limiting?
- Normally exercise is limited by cardiac output, which in essence means heart rate.

Be sure to look at all the data. Some values are averaged over a minute (sheets) and some are averaged over 10 seconds. Don't over interpret the last 10 seconds of exercise.

Pulmonary Function Tests and Exercise Studies

NJ Pulmonary Fellows and NJ Attendings

Muscle/Uptake	Cardiac	Gas Exchange	Ventilation
O2 Utilization	HR	ABG	RR
Anaerobic Threshold	O_2 Pulse	pO_2	Vt
Lactate	ECG	$AaDO_2$	Vd/Vt
	Hct	O_2 saturation	Vent Ceiling
	BP		pCO2
			Vent Efficiency

Some important parameters in each of the major groups

VO2 and Work Load:

At maximal exercise VO2 >84% is normal (ATS standard) (22)

Use oxygen consumption not workload to judge normality of exercise tolerance (oxygen consumption trumps workload)

- RQ should increase. Any decrease is likely due to a leak. The workload at which the RQ increases indicates the anaerobic threshold.
- RQ = CO2 production/O2 consumption
- There is a higher CO2 production with the metabolism of carbohydrates vs lipids (Carbohydrates are partially oxidized calories)
- RQ Fat = 0.7; RQ Protein = 0.8 and RQ Carbohydrate = 1.0

Rough guide to exercise tolerance in ml O_2/kg/min (not adjusted for age or obesity)

Degree of Limitation	Range	Comments
Very limited	7-14	Cardiac transplant <14, severe COPD 12, poor lung resection toleration at 10
Limited	15-20	
Mild Limitation	21-30	Good level for a clinic patient: >25
Normal 40 yr old male	35-40	
Normal 40 yr old female	30-35	

Elite soccer player	60	
Endurance athlete	80	

Most of our patients fall within 10-20 ml O_2/kg/min range.

(See if you can estimate the oxygen consumption from the spirometry)

Oxygen consumption and activities of daily living

Estimated Metabolic Costs for Selected Physical Activities and the Corresponding Vo_2 Values for a 70-kg Adult of Normal Body Habitus

Activities	Estimated METs	Vo_2 for ~70-kg Adult (mL/min/kg)
Rest, seated	1.0	3.8
Light Cleaning, Dusting	2.5	8.9
Walking, 3 mph on level ground	3.3	11.8
Walking, 3 mph carrying load of <25 lbs	4.0	14.3
Playing Golf, general	4.5	16.1
Mowing lawn, walking power mower	5.5	19.6
Jogging, <5 mph	7.0	25
Firefighting, climbing a ladder with gear	11.0	39.3
Running, 7 mph	11.5	41

*Kathy Seitsma, Murray and Nadel 5th Edition, 2010

Heart, Circulation and O2 delivery:

Heart Rate:

- Normal - >= 60 and <=100
- Predicted maximum = 220-age or 210-(age x 0.65)
- HR (%Pred) > VO2 by 20% = excessive for VO2 achieved
- HR (%Pred) < VO2 by 20% = low for VO2 achieved

- Normally at maximal exercise there should be only limited heart rate reserve (HR>80-90% of predicted; heart rate reserve <15 bpm;). Excessive HR reserve indicates another limitation, which should be identified.
- HR by itself does not usually limit exercise unless there is an altered rhythm with an excessive HR due to which the test gets stopped. E.g. SVT or VT
- Stroke volume increases early in exercise but cardiac output towards end of exercise is limited predominately by rate
- In normals the cardiac output limits exercise tolerance; there should be ventilatory reserve

O2 Pulse:

- Calculated by dividing the VO2 by the simultaneously measured heart rate
  - o Can be informative in terms of a patient's ability to augment stroke volume with exercise.
- Normal > 80% predicted (ATS) (usually should be within 20% of actual VO2 max)
- Look for plateau of the O2 pulse/VO2 on the graphs (suggests cardiac limitation)
  - o Should double with exercise if normal cardiac reserve
  - o Should NOT plateau within the first 1/3 of the exercise period
  - o Caveat: there are no widely accepted standards for this, but the above is a general guideline
- Prompt increase in O2 pulse in recovery phase should raise suspicion for exercise induced myocardial ischemia
  - o In normal cardiac function the O2 pulse should drop quickly into recovery
- If O2 pulse is normal for VO2 but HR is excessive for VO2 – suggests deconditioning
- Note absolute value not corrected for patient size.

Blood Pressure:

- Normal @ rest < 140/90
- With maximal exercise
  - o Systolic Hypertension >=200; Diastolic Hypertension >= 90
- Test to be stopped if BP >220/110

- Diastolic should not increase with exercise. May remain the same or decrease a little.
  - If patient has HTN with exercise but not at rest make comment "abnormal BP response to exercise predicts future development of HTN"
- Systolic should rise with exercise. Failure to rise by >15 points = blunted response (usually meds e.g. B-blockers)
- Blood pressure abnormalities usually DO NOT limit exercise unless the test was stopped due to a hypertensive response. (in which case they DO limitexercise)

EKG:

- See the comments made by the tech who supervised the study and also the EKG interp.
- Go through the EKGs, which accompany the study, yourself and DO NOT rely solely on the EKG interpretation.
- Document abnormal ECG findings on the baseline and exercise tracings
- If the test was stopped due to arrhythmias or chest pain with EKG changes, indicate that there was concern for ischemia and send ECG to cardiology.
- Send EKG to Cardiology if any questions/concerns.
- Any EKG change that results in stopping the test = "a significant cardiovascular abnormality which limits exercise."

Ventilation:

Minute Ventilation:

- >12 L/min at rest = elevated/excessive
- VE > or < 20% of the VO2 max at max exercise = Excessive or Low response for the VO2 achieved (e.g. VO2= 70% and VE > 91% predicted is excessive)
- Excessive response is usually seen with COPD or other lung diseases
- Ventilatory Ceiling (Further explained in **"Ventilation Integrated"**)

Ventilatory Efficiency:

- Defined by the relationship of the liters of ventilation required to eliminate a liter of CO_2
- Expressed as either a ratio or a slope of the following factors:

- o Dead space volume-tidal volume ratio, $PaCO_2$, VCO_2, VE, and a constant
  - $VE/VCO2 = k/[PaCO_2 \times (1-VD/VT)]$
- Nonspecific: can be affected by anxiety, breathing pattern, metabolic demand, matching of ventilation and perfusion, arterial or mixed alveolar PCO_2, intensities of H+, CO_2, and O_2 stimulation of the carotid bodies and the responsiveness of ventilatory control mechanisms.
- This ratio is very sensitive to V/Q abnormalities and low Q can be due to low cardiac output as well as pulmonary vascular disease and wasted ventilation. Hence, this is very predictive of cardiac mortality.
  - o Cardiac mortality and hospitalizations increase at a value >35-40
- At AT the VE/VCO_2 should be less than 30. If it is > 35, a notation should be made that there was inefficient ventilation with exercise.

Ventilatory Ceiling

- The ventilatory ceiling for an individual is about 85% of the patient's MVV. The ventilatory ceiling is "approached" at 80% of patient's MVV.
- In a normal exercise test, there should be some ventilatory reserve at the end exercise. (The patient's maximum ventilation should not exceed about 70-75% MVV). There is a wide range of ventilatory reserve in normals (72+/- 15% of MVV). In interpreting exercise tests, note whether there is appropriate ventilatory reserve left at the termination of exercise.
- If the patient develops CO2 retention, this is a clear indicator of ventilatory failure (unless the increase in CO2 is due to previous hyperventilation at the beginning of exercise).

Tidal Volume (VT):

- Normal recruitment at max exercise = hockey stick shape on RR/VT graph. Tidal volume should increase with little RR change for the first 60% of maximal exercise
- Tidal volume should reach **50% of patient's predicted FVC.**
  - o Failure to recruit tidal volume is a common abnormal response to exercise for pulmonary patients (VT increases to less than 50% of predicted FVC).

- Literature suggests using 45% for women and 55% for men or simply using 50% for both.
- In restrictive disease patient will increase tidal volume to 50% of their FVC but are obviously limited in their ability to recruit tidal volume compared to normals.

Respiratory Rate (RR):

- Normal at rest = 15 or less
- Excessive >45 (This is an arbitrary number but is a reasonable one and helps define things) what is "excessive" rate
  - If rate greater than 45, it may account for a less-than-expected drop in VD/VT

VD/VT (need arterial gas measurements): (33)

- Age >40 is <0.45 at rest and <0.28 at max exercise
- Age <40 is <0.40 at rest and <0.21 at max exercise
- Cannot be reliably interpreted without an A-line; don't use expired gas measurements
- If you are considering pulmonary vascular disease, examine the VD at all stages of exercise. A value greater that 450 ml is likely abnormal. VD/VT in the presence of significant parenchymal disease is very hard to interpret in reference to specific pulmonary vascular disease. In theory as you increase cardiac output and tidal volume; there should not be much increase in physiologic dead space. (25)

Ventilation Integrated:

- Recruitment of VE with exercise is initially by an increase in the VT to 50% of the patient's FVC, which is then followed by an increase in the RR resulting in a "hockey stick" shaped curve on the RR vs VT graph.
- Ventilatory efficiency: comment if evidence of inefficient ventilation
- Abnormalities that may "limit exercise tolerance" in the right setting are:
  - Excessive RR with low VT, which is usually seen in restrictive processes or in obstructive patients with significant dynamic hyperinflation.
    - Look for changes in inspiratory capacity with exercise if measured

Pulmonary Function Tests and Exercise Studies

- Note this is on a separate sheet at the end of the exercise report but is indicated in the description of the study
  - o Rise in pCO2 (assure yourself on flow sheets that it is not just withdrawal of initial hyperventilation from A-line placement); confirm by looking at end tidal expiratory PCO_2. Check this if there is no arterial line to see if there is CO_2 retention
  - o Reaches or exceeds - 16 -entilator ceiling (85% of actual MVV for maximal sustainable ventilation)
- Ventilatory Ceiling (several estimates) (some estimate at 85% MVV)
  - o If reached, limits exercise and presumably hits this before CO2 retention
  - o Look at the green line on the graph
  - o Ceiling reached if CO2 retention or VO2 increases with no increase in VCO2
  - o Rate above 45 (Others use 55 as ceiling)
  - o Check the curve of VE versus oxygen consumption
  - o Ventilatory Reserve = MVV-VE > 11 lit/min (ATS) This is only for very fit normals
  - o MVV in our exercise protocol is actually measured for 15 seconds; not calculated from the FEV1.

Gas Exchange:
- **PO2**
  - o Any decrease is abnormal (>2% for measurement error)
  - o O_2 sat <88% sat < pO_2 55 = abnormal and hypoxemic at rest (ATS).
  - o Drop of 4% O_2 sat is significant (or if the value drops less than 90%)
  - o O_2 Sat (max exercise) less than 85% or p02 less than 50 = abnormal and usually limiting

- **A-a Gradient**
  - o AaDO2→ 2.5+(.21 x age (years)) = Normal (best modeling of normal A-a gradients at different ages and altitudes (while at rest) comes from Crapo et al. "Clinical Pulmonary Function Testing, Intermountain Thoracic Society, 2nd edition; see chart on wall in PPU).

- Normal for A-a gradient to rise with exercise, due to V/Q mismatching, low mixed venous O_2, and potentially (in elite athletes or at high altitude) diffusion limitation. However, how much of a rise, especially at Denver's altitude, is a subject of some debate
- ATS cites <35 in the CPET summary as normal, based on limited data. We tend to use a value of <25 in our patients. This number is an estimation, and will likely vary with the patient's age. There are a number of patients in Denver that will desaturate with an A-a gradient between 25 and 35 mm.
- A few small studies have been done to look at effect of altitude on A-a gradient at exercise. All study subjects are young and healthy. The maximum A-a gradient occurred in 4 natives of Lima, Peru (sea level) who travelled to Cerra de Pasco, Peru (4,350m) and then exercised within 2 days. The mean A-a gradient was 28.5 +/- 2.3. (23,24)

- **PCO2**
  - Should remain the same or fall.
  - Look at all the blood gases, not just the values listed on the front sheet.
  - Sometimes it may rise if the patient has been hyperventilating at baseline secondary to anxiety/a-line placement.

Anaerobic Threshold:
- Normal = at least 40% or greater
- Calculate by inflection point on the lactate and/or the VO2/CO2 production graph.
- Usually low when there is a problem with conditioning and O2 delivery (muscle)
  - However, a low anaerobic threshold may result from any of the elements in series, i.e. lung or heart, microcirculation, muscle, mitochondria. A low threshold does not give a mechanism and may improve with rehabilitation. Muscle is not getting enough oxygen for the workload.
- Lactate should be >8 meq/L at peak exercise. Useful to judge if the patient exercised sufficiently to determine an anaerobic threshold.

Dynamic Hyperinflation (27, 28)

Defined as a decrease in IC that occurs with exercise. Inspiratory capacity should remain constant or even increase slightly in normals. In COPD, there is a loss of elastic recoil, the equal pressure point moves up into smaller airways, and regions with long time constants can't empty appropriately. The usual compensatory response is prolonged expiration, but this often can't occur in the tachypnea associated with exercise. The cutoff point for calling dynamic hyperinflation is, somewhat arbitrarily defined, has been defined as 300mL based on 105 patients with COPD and 25 healthy age matched controls (30). It is thought that dynamic hyperinflation is a major contributor to patient's dyspnea with exertion. Several studies have shown reduction in dynamic hyperinflation and improved exercise duration with treatment with long-acting bronchodilators (27, 31,32, 34, 35). Therefore it may be an important objective marker for treatment in COPD patients. Inspiratory capacity during exercise cannot be accurately measured in patients while they are using supplemental oxygen.

Some tips on the comments on the Interpretation section of the Report:

- If done without an A-Line the first line could be "Interpretation limited by lack of A-Line"
- An abnormal exercise test is based on inability to achieve 84% (ATS 84%) of the predicted oxygen consumption. "Exercise limited predominately by....(symptoms and major physiologic abnormality)" . Other contributing abnormalities include.......
- Write in complete sentences!!
- Be specific and definite if possible
- What do you want to tell the referring physician and patient

Pressure Volume Curve

Shifted up and to the left or shifted down and to the right (26,29)

> Note: some diagrams give variance for pressure but not volume
>
> When examining the PV curve, first look at the TLC and then the maximal inspiratory pressure (1 kPa is 10 cm H_2O)

- Total lung Capacity
  - 80-120% predicted   25 cm H_2O Elastic recoil

- Maximal transpulmonary pressure
  - Coefficient of retraction <8.0 cm/L Maximal static transpulmonary pressure/TLC (2.5-8.0) >8.0 seen in pulmonary fibrosis
- Slope or shape
  - K 0.1-0.2
- Static compliance at FRC = 0.26 L/cm H_2O range 0.15-0.38

Upstream resistance is a calculated value to estimate disease in airways distal (upstream) to the equal pressure point. Flows are determined by the ratio of driving pressure (elastic recoil) and resistance. The PV curve gives the value for the driving pressure and the flow volume curve at absolute lung volume gives the flow rates. The PV curve sets the specific lung volume. The upstream resistance is calculated from these values. In the normal dog the equal pressure point for almost all flow rates is in large bronchi or trachea and only goes to small airways at the very end of expiration (31,32). In man it is not known with certainty. With airway disease in man the equal pressure point will migrate peripherally as resistance increases in the small airways (driving pressure will fall to overcome the resistive load) and at the end of the FVC as elastic recoil decreases. The equal pressure point (and upstream resistance) in man probably goes into small airways only with significant airway disease and at lung volumes below FRC

Challenge Testing:

Methacholine (metabisulfite)
- PC_{20} = A decrease in FEV1 by 20%
- PC_{40} = A decrease in sGaw by 40%
  - **At a conc <= 8 mg/ml methacholine** (Arbitrary NJC number). Hence, a PC_{20} of 9 mg/ml is normal) ATS uses 4-16 mg/ml as borderline and less than <4 as increased
- For acceptability of the test
  - Both FEV1 and FVC should fall
  - The ratio of FEV1/FVC should also fall
  - If the FEV1/FVC ratio does not fall, the fall in FEV1 alone may be due to suboptimal effort
- The TLC should not change

- Check the response to bronchodilator in recovery
- Check inspiratory loops for VCD and comment if indicated
- Check to see if a laryngoscopy is done (usually done with the methacholine test). Include the result in the report.
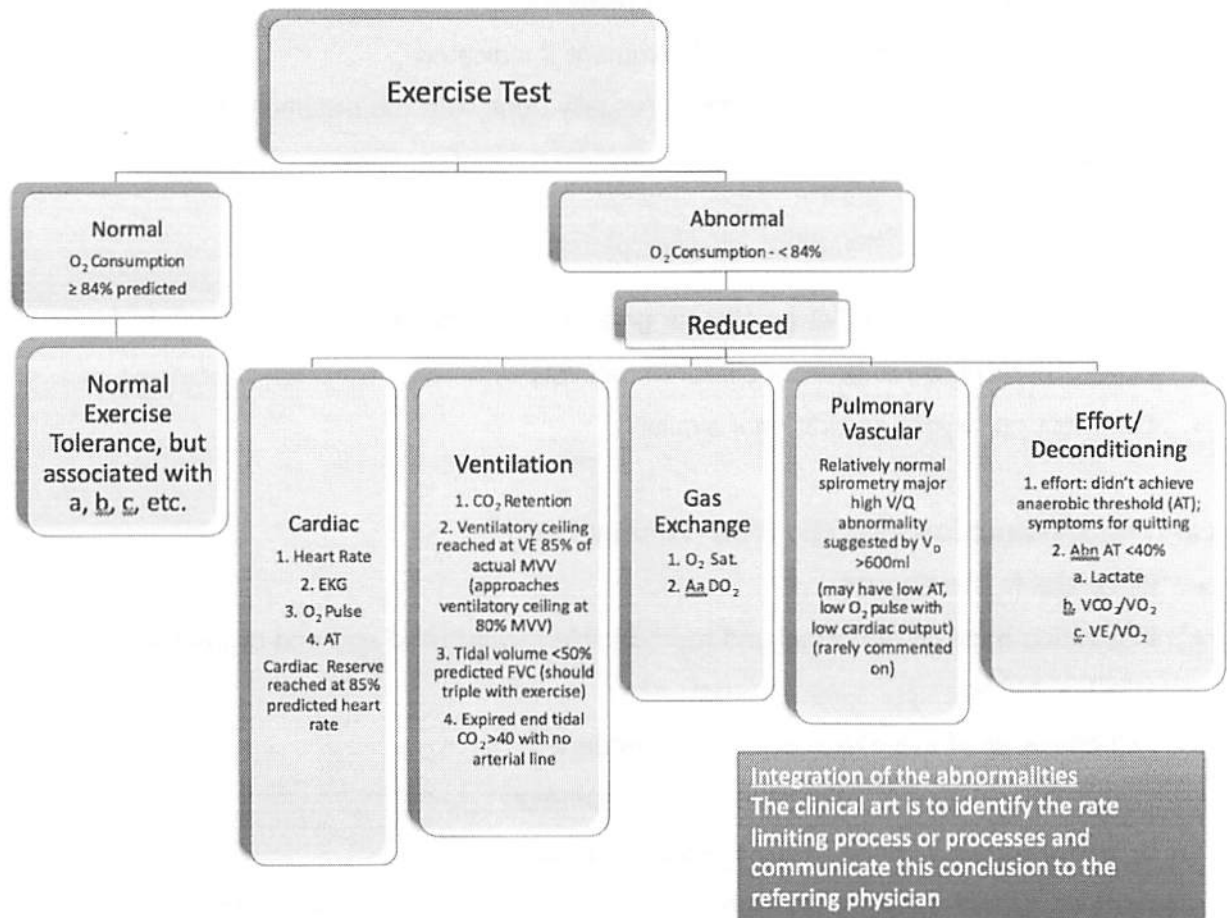
Exercise

- Abnormal decrease in FEV1 by 10% or greater with exercise
- Check the response to bronchodilator in recovery
- Comment on oxygen saturation if available

Vocal Cord Dysfunction - On the Flow-Volume Loop

- Be careful in the diagnosis
- Inspiration must be abnormal and reproducible towards mid and end of inspiration (last 1/3rd), <2 l/sec
- Remember all of inspiration is effort dependent
- Kids commonly slow down at the end of inspiration
- If you don't coach, inspiratory flows will look flat!
- If the early part is normal and the later part flat, this is most likely due to lack of effort
- A flow of 2 L/s is the equivalent of a flow limiting segment of a tube 4 mm in diameter with a driving pressure of >40 cm/H_2O (Diagram 4th edition Murray and Nadel W Gold chapter)
- A flow of 4 L/s is a tube of 6 mm in diameter (flow limiting segment)
- If all loops are normal, state so since the reader won't have the tests but only your comments
- A safe statement to make is "Reduced flow at end of inspiration compatible with unsustained effort or VCD."

Pulmonary Function Tests and Exercise Studies

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Exercise Test

Normal
O_2 Consumption
≥ 84% predicted

Abnormal
O_2 Consumption - < 84%

Reduced

Normal Exercise Tolerance, but associated with a, b, c, etc.

Cardiac
1. Heart Rate
2. EKG
3. O_2 Pulse
4. AT

Cardiac Reserve reached at 85% predicted heart rate

Ventilation
1. CO_2 Retention
2. Ventilatory ceiling reached at VE 85% of actual MVV (approaches ventilatory ceiling at 80% MVV)
3. Tidal volume <50% predicted FVC (should triple with exercise)
4. Expired end tidal CO_2 >40 with no arterial line

Gas Exchange
1. O_2 Sat.
2. Aa DO_2

Pulmonary Vascular
Relatively normal spirometry major high V/Q abnormality suggested by V_D >600ml

(may have low AT, low O_2 pulse with low cardiac output) (rarely commented on)

Effort/ Deconditioning
1. effort: didn't achieve anaerobic threshold (AT); symptoms for quitting
2. Abn AT <40%
   a. Lactate
   b. VCO_2/VO_2
   c. VE/VO_2

Integration of the abnormalities
The clinical art is to identify the rate limiting process or processes and communicate this conclusion to the referring physician

Pulmonary Function Tests and Exercise Studies

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Last updated 06/10/2011   Robert Mason and numerous pulmonary fellows

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