Pulmonary Function Testing Part II
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Learning Objectives:
- Describe the purposes, physiologic bases, devices and methods for diffusing capacity testing.
- Describe the purposes, physiologic bases, devices and methods for specialized testing regimens.
- Describe the purposes, physiologic bases, devices and methods for cardiopulmonary exercise testing.
- Describe the purposes, physiologic bases, devices and methods for metabolic testing.
- Interpret results from diffusing capacity tests, specialized testing regimens, cardiopulmonary exercise tests and metabolic tests.

Specialized testing regimens
- Bronchodilator benefit
- Bronchial challenge testing
- Exhaled nitric oxide analysis
- Preoperative testing
- Testing for disability

Diffusing Capacity Testing

Diffusing capacity
- Measures the rate of diffusion of gas across alveolar-capillary membrane
- Measured as mL (gas)/min/mm Hg (pressure gradient)

Anatomic diffusion pathway
- Alveolar air
- Alveolar wall
  - Surfactant layer
  - Alveolar epithelium
  - Alveolar basement membrane
- Interstitial space

Click to see animation of diffusion (0.25 min)
http://www.youtube.com/watch?v=1J8KFmoylEs
Anatomic diffusion pathway

- Capillary wall
  - Capillary basement membrane
  - Capillary endothelium
- Plasma
- RBC
  - Erythrocyte membrane
  - Intracellular erythrocyte fluid
- Hemoglobin

Click for illustration of diffusion pathway
http://www.meddean.luc.edu/Lumen/MedEd/MEDICINE/PULMONAR/images/phys/physi17.jpg

Physical laws governing diffusion

- Henry's law - amount of gas dissolving in a liquid is proportional to the partial pressure of the gas ==> derives the solubility coefficient (Ks) of the gas.

Physical laws governing diffusion

- Graham's law - rate of diffusion through a liquid is:
  - directly proportional to its Ks
  - inversely proportional to its GMW
  => CO2 diffuses 20X the rate of O2
  - high solubility of CO2 ==> diffusion defects will not affect CO2 exchange

Physical laws governing diffusion

- Fick's law - gas diffusion is:
  - directly proportional to:
    - alveolar surface area
    - pressure gradient
  - inversely proportional to:
    - alveolar thickness
    - gram molecular weight of gas

Diffusion limitations of gases

- O2 can be diffusion and/or perfusion limited
- CO is diffusion limited, only ==> ideal gas to measure diffusing capacity
- Lung diffusing capacity is measured as DL_{CO} - diffusion in lung of carbon monoxide

Diffusion tests

- DL_{CO_{sb}} (single breath) - most common method
  - advantages
    - simple technique
    - rapid analysis
  - disadvantages
    - sensitive to V/Q mismatching
    - patient must be capable of breath holding for 10 sec.
### Diffusion tests

- **DL\textsubscript{CO}rb (rebreathing)**
  - **Advantages**
    - Most accurate method
    - Least sensitive to V/Q mismatching
    - Can be used during exercise
  - **Disadvantage**
    - Requires rapid analyzers
    - Complex calculations

- **DL\textsubscript{CO}ib (intrabreath)** - analysis during a single exhalation
  - **Advantages**
    - Does not require breath hold
    - Can be used during exercise
  - **Disadvantage**
    -Sensitive to VQ mismatch
    - Complex calculations

### DL\textsubscript{CO} testing indications

- Evaluation and follow-up of parenchymal lung diseases
- Evaluation and follow-up of emphysema and cystic fibrosis
- Evaluation of cardiovascular diseases
- Evaluation of pulmonary involvement in systemic inflammatory and collagen vascular diseases

### Contraindications for diffusion tests

- CO toxicity
- Severe hypoxemia (O2 removed during test)
- Inability to cooperate; e.g., breath holding
- Large meal or vigorous exercise immediately before the test
- Smoking within 24 hours of test

### DLCOs equipment

- Spirometer
- Automatic valve - for gas delivery, breath holding and sampling
- End-tidal sampler
- Gas analyzers - CO and He
- Gas mixture:
  - 0.3% CO
  - 10% He
  - 21% O2
  - Balance N2
DLCOsb procedure
- patient performs FVC maneuver
- inspires to TLC
- holds breath for 9 - 11 sec.
- exhales
- alveolar sample collected between 750 - 1000 mL

FYI - Click for AARC CPG on DLCO testing

DLCOsb procedure
- Calculation
  ◆ VA - alveolar volume
  ◆ 60 - correction from sec. to min.
  ◆ PB - barometric pressure
  ◆ T - breath hold time (sec)
  ◆ Ln - natural logarithm
  ◆ FCOI - initial fraction of CO
  ◆ FCOF - final fraction of CO
  \[ DLCOsb = \frac{VA \times 60 \times Ln FCOI}{(PB - PH2O) \times T \times FCOF} \]

DLCOsb acceptability criteria
- Test volume must be >90% previously measured VC
- End-inspiratory breath hold must be 9-11 sec
- Expiration to RV ≤ 4 sec
- V̄O must clear before alveolar sampling
- Reproducibility criteria- two tests within 10% or 3.0 ml CO/min/mmHg
- Report- mean value of two tests

DLCO predicted value
- Normal DLCO = 25 ml/min/mmHg ± 20%
- Predicted based on:
  ◆ BSA
  ◆ Hb - 1 mg/dL ==> 7% change in DLCO
  ◆ Age - inverse relationship
- Interpretation must consider lung volume

Factors affecting DLCO
- Alveolar surface area
- V/Q abnormalities
- Parenchymal thickening, e.g. fibrosis
- Edema
- Consolidation
- Pulmonary capillary pressure
- RBC, Hb quantities
- Pulmonary capillary quantity

Conditions with increased DLCO
- Obesity
- Asthma
- Left-to-right shunt
- CHF (without edema)
- Early polycythemia
- Large lung volume
- Exercise
- Supine position
FYI - click to download article on significance of elevated DLCO
http://chestjournal.chestpubs.org/content/125/2/446.full.pdf+html
Conditions with decreased $DL_{CO}$
- Decreased surface area
  - emphysema
  - lung resection
- Increased wall thickness
  - hypersensitivity pneumonitis
  - fibrosis
  - sarcoidosis
- Decreased carrying capacity - anemia

Prognostic value of $DL_{CO}$
- Determines when COPD develops into emphysema
- Predicts complications after surgical resection of lung
- Predicts mortality in pulmonary arterial hypertension

Bronchodilator benefit & Bronchial Challenge Testing

Bronchodilator benefit testing
- Purpose: determine value of bronchodilators in patient management
- Indications
  - clinical evidence of reactive airways
  - wheezing
  - dyspnea
  - FEV$_1$% <70%

Bronchodilator benefit testing
- Preconditions for testing
  - No short-acting beta agonists or anticholinergics for 4 H
  - No long-acting beta agonists for 12 H
  - No long-acting anticholinergic for 24 H
  - No cromlyn, nedocromil for 24 H
  - No leukotriene modifiers for 24 H
  - Maintain inhaled steroids

Bronchodilator benefit testing
- Laboratory requirements
  - Cooperative patient
  - Skilled technologist
  - Maintained & calibrated equipment
  - ACLS capabilities
  - Patient care capabilities in institution
Bronchodilator benefit testing

- Pretests - may include:
  - spirometry; e.g., FEV₁
  - sGaw measurement
  - lung volumes
  - diffusing capacity

- Medication administration
  - beta agonist - 1 pf Q30s x 4
  - ipratropium - 1 pf Q30s x 4

- Interval before post-testing
  - beta agonist - 10-15 min.
  - ipratropium - 30 min.

Bronchodilator benefit testing

- Significant improvements
  - > 12% and 200 mL increase in FEV₁ or FVC
  - > 30% increase in sGaw

- Insignificant improvement
  - may test after time using a medication
  - may test with a different medication
  - check for symptomatic improvement

- Decreased posttest parameters
  - paradoxical drug response
  - fatigue

Bronchodilator benefit testing

- Calculating % change
  \[
  \%\text{FEV}_1 \text{ change} = \frac{\text{Post FEV}_1 - \text{Pre FEV}_1}{\text{Pre FEV}_1} \times 100
  \]

  Example: Pre = 1.2L; Post = 1.7L
  \[
  \%\text{FEV}_1 \text{ change} = \frac{1.7L - 1.2L}{1.2L} \times 100 = 42\%
  \]

Bronchial challenge testing

- Purposes
  - detect airway hyperreactivity
  - isolate cause of hyperreactivity
  - quantify severity of bronchospasm
  - assess changes in bronchoreactivity
### Bronchial challenge testing

**Indications**
- Exclude a diagnosis of airway hyperreactivity
- Evaluate occupational asthma
- Assess the severity of bronchospasm
- Determine the relative risk of developing asthma
- Assess response to therapeutic interventions

**Contraindications**
- Symptoms; e.g., wheeze, cough
- Ventilatory impairment
- Recent cardiac event or stroke
- Cerebral aneurysm
- Uncontrolled hypertension
- Current use of anticholinesterase agent
- Pregnancy, lactation

**Provocative agents**
- Methacholine - parasympathetic stimulator
  - Most common
  - Prepared by pharmacy
- Histamine - mechanism of action uncertain
- Exercise - exercise-induced bronchospasm (EIB)

FYI - click for AARC CPG on methacholine challenge

**Side effects**
- Methacholine
  - Headache
  - Itching
  - Signs and symptoms of severe allergic reaction
- Histamine
  - Same as for methacholine
  - Flushing

FYI - click for ATS standards on challenge testing
http://ajrccm.atsjournals.org/cgi/reprint/161/1/309

**Preconditions**
- No bronchodilators, as for bronchodilator benefit test
- No systemic steroids for 12 hours
- No cromolyn for 48 hours
- No antihistamines for 48 hours
- No exercise, cold air for 2 hours
- No smoking for 6 hours
- No caffeine for 6 hours
- No beta-blocking agents

**Procedure**
- 5 breath dosimeter
  - Standardizes dose by volume
  - Most precise
  - Requires dosimeter
- 2 minute tidal breathing
  - Standardizes dose by time
  - Requires only small volume nebulizer

Click to see dosimeter
Click to see another dosimeter
http://www.resplatinhealth.com/default.asp?LINKNAME=KOKODOSIMETER

FYI - click for AARC CPG on methacholine challenge

FYI - click for ATS standards on challenge testing
http://ajrccm.atsjournals.org/cgi/reprint/161/1/309
Methacholine challenge testing
- Procedure
  - Baseline mechanics - FVC, FEV₁, sGaw, etc.
  - Inhaled NSS (control dose)
  - Wait 3 minutes
  - Repeat measure
  - FEV₁ < 80% (of pretest) ==> stop test
  - FEV₁ ≥ 80% (of pretest) ==> non-reactivity ==> proceed

Methacholine challenge testing
- Procedure - 5 breath dosimeter
  - 5 breaths methacholine - 0.0625 to 16 mg/mL
  - wait 3 minutes
  - repeat, until:
    - FEV₁ ≤ 80% control
    - methacholine concentration = 16 mg/mL

Methacholine challenge testing
- Procedure - 2 min. tidal breathing
  - administer NSS control dose
  - posttest, as for dosimeter
  - administer methacholine in five, quadrapled doses or ten doubled doses from 0.0625 - 16 mg/mL
  - wait 3 minutes between,
  - repeat, until:
    - FEV₁ ≤ 80% control
    - methacholine concentration = 16 mg/mL

Methacholine challenge testing
- Evaluation of results
  - provocative dose (PC20)
    - where FEV₁ decreased by 20%
    - calculated using last and next-to-last dosages
  - sGAW decrease of 35% ==> positive response

Histamine challenge testing
- Preconditions similar to methacholine challenge, with addition of abstention from antihistamines and H1 receptor antagonists (48 H)
- Procedure similar to methacholine, with ascending, double-dosing from .03 to 10 mg/mL

Exercise challenge testing
- Purpose - to diagnose exercise induced bronchospasm (EIB)
- Indicated for patients with normal resting PFTs who report dyspnea on exertion


**Exercise challenge testing**

**Preconditions**
- withhold activity and medications, as for methacholine challenge
- pretest ECG
- pretest FEV1 ≥ 65% predicted
- room temperature < 25°C
- relative humidity ≤ 50%

**Procedure**
- baseline mechanics
- nose clips to remove nasal conditioning
- continuous ECG and BP
- exercise on treadmill or bicycle ergometer

**Evaluation of results**
- greatest response usually 5-10 min. after exercise - may be severe
- key value = % decrease in mechanics produced by exercise
- EIB signified by decrease >10%
- normal response is for FEV1 and sGAW to increase (improve)

**Nitric oxide (NO) physiology**

NO - multipurpose molecule that mediates many physiologic processes, including:
- smooth muscle relaxation
- platelet inhibition
- neurotransmission
- apoptosis (programmed cell death)
- immune regulation

FYI - click to see Nobel prize awarded to Louis Ignarro

FYI - click to download article on eNO and asthma
Nitric oxide (NO) physiology
- NO synthesis catalyzed by NO synthases
  - endothelial
  - neural
  - induced by inflammatory cytokines; e.g., as in asthma

- eNO is noninvasive marker for airway inflammation, that:
  - increases in patients with atopic (allergic) asthma
  - decreases in asthmatic subjects treated with inhaled corticosteroids
  - correlates with the sputum eosinophil quantity

Diagnostic utility of eNO
- FENO for lung transplant patient may detect infection, rejection and bronchiolitis obliterans
- FENO reflects degree of asthma control by steroids
- Asthma diagnosis based on FENO is less expensive than standard methods

FENO analysis
- Chemiluminescent analyzer
- FENO reported in parts per billion (ppb) @ L/sec
- Measurement techniques:
  - off-line - sample collected in device for later analysis
  - online - sample collected at the mouth
  - nasal sampling

FYI - click to download article with asthma management algorithm using FENO
http://www.thepcrj.org/journ/vol18/18_4_320_327.pdf

- Smoking does NOT devalue FENO in asthma control
- FENO analysis is NOT validated for acute exacerbations
- FENO reflects inflammation, NOT bronchospasm

FENO analysis
- Off-line sampling
  - patient inhales to TLC from NO scrubber or reservoir of NO-free gas
  - exhalés VC with 5 cm H2O resistance @ 0.35 L/sec
  - sample collected in mylar balloon
  - analysis within 12 H

FYI - click for information on chemiluminescent analyzer
http://www.brandgaus.com/NOxAnalyzerTechnology.htm
FENO analysis

✓ Online sampling
  ◆ patient inhales to TLC through scrubber
  ◆ patient exhales VC into analyzer at controlled resistance

NIOX MINO™ FENO analyzer

Image courtesy of Aerocrine

FYI - Link to Aerocrine NIOX MINO web site with video (4 min)

FENO analysis

Click to see GE Sievers 280iT™ FENO analyzer
Click to see Eco Medics CLD88™ FENO analyzer

FENO interpretation

✓ Normal values
  ◆ adults ≤ 35 ppb
  ◆ children ≤ 25 ppb
✓ Elevated levels reflect eosinophilic inflammation
✓ Downward trends reflect effects of steroid therapy
✓ COPD does NOT elevate FENO

Preoperative testing:

✓ Purposes - for abdominal, chest procedures, to:
  ◆ assess risk (operability?)
  ◆ predict postoperative function
  ◆ plan postoperative patient care
Preoperative testing:

- Postoperative function may improve in some lung resection cases
- Function testing does not predict postoperative quality-of-life

FYI - click to download article on post-op QOL
http://ats.ctsnetjournals.org/cgi/reprint/84/2/410

Preoperative tests:

- Lung volumes, including V_{TG} for pulmonary resection for emphysema
- Spirometry with maximal bronchodilation
- Perfusion, V/Q scans, contrast MRI - can be used to estimate postoperative FEV_{1} for lung resections
- Measurement of FEV_{1} on first day post-op is good predictor of morbidity

Interpretation guidelines

<table>
<thead>
<tr>
<th>Test</th>
<th>Increased risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>FVC</td>
<td>&lt;50% pred</td>
</tr>
<tr>
<td>FEV1</td>
<td>&lt;2.0 L or &lt;50% pred</td>
</tr>
<tr>
<td>MVV</td>
<td>NA</td>
</tr>
<tr>
<td>PaCO2</td>
<td>NA</td>
</tr>
<tr>
<td>DLCO</td>
<td>&lt;60% pred</td>
</tr>
<tr>
<td>VO_{2}\text{max} (O2 uptake)</td>
<td>&lt;20 mL/kg/min</td>
</tr>
</tbody>
</table>

Preoperative testing:

- Indications
  - history of smoking (>20 pk/yrs.)
  - active pulmonary symptoms
  - abnormal physical examination
- Conditional indications
  - evidence of pulmonary infection
  - morbid obesity
  - debilitation, malnourishment
  - age > 70 yrs.

Preoperative tests:

- DLCO - lung resection
- arterial blood gases - patients with documented pulmonary disease
- bronchodilator benefit - patients with obstructive disease
- exercise stress testing
  - cardiac surgery
  - borderline predicted post-op lung function

Interpretation guidelines

<table>
<thead>
<tr>
<th>Test</th>
<th>Increased risk</th>
<th>Significant risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>FVC</td>
<td>&lt;50% pred</td>
<td>&lt;1.5 L</td>
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<tr>
<td>FEV1</td>
<td>&lt;2.0 L or &lt;50% pred</td>
<td>&lt;1.0 L</td>
</tr>
<tr>
<td>MVV</td>
<td>NA</td>
<td>&lt;50% pred</td>
</tr>
<tr>
<td>PaCO2</td>
<td>NA</td>
<td>&gt;45 mm Hg</td>
</tr>
<tr>
<td>DLCO</td>
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<td></td>
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Testing for Disability

Disability - the inability to perform tasks required for employment, due to impairments:
- Mental
- Physical

FVI - link to Guide to PFT under Social Security Programs
http://www.ssa.gov/disability/professionals/pfs-pub055.htm

Testing for disability
- History
- Physical examination
- Imaging studies
- PFTs
  - Spirometry
  - Diffusing capacity
  - Arterial blood gases
  - Exercise testing

Algorithm for disability

History & Physical Exam

- Forced vital capacity
  - FVC < 50% pred
  - FEV1 < 40% pred
  - FEV1/FVC < 40% pred

- Diffusing capacity
  - DLCO < 40% pred (normal = 25 ml/mmHg/min)

Exercise studies

- Measured work capacity
- Required work capacity

Disability evaluation
- Obstruction (COPD) - FEV1
- Restriction - FVC
- Asthma
  - FEV1
  - Episode frequency

PaO2 = 85 mm Hg on 0.21 O2
PaO2 = 60 mm Hg on 0.21 and 50% N2
Pulmonary hypertension OR
Erythrocytosis OR
Hypoxemia worsened with mild exercise
Disability evaluation

Blood gases & impairment
- PaO2 < 55 mm Hg on 0.21 OR
- PaO2 < 60 mm Hg on 0.21 AND
  - pulmonary hypertension OR
  - cor pulmonale OR
  - erythrocytosis OR
  - hypoxemia worsened with mild exercise

Disability evaluation

Additional factors to consider
- Subject cooperation (malingering)
- Hx of emergency treatment for asthma
- Failure to receive appropriate care
- Deconditioning (couch potato)
- Coexisting disorders
- Impairment that is difficult to measure

Indications for exercise testing:

Diagnose cardiopulmonary disorders, often, to distinguish between cardiac, vs. pulmonary dx
Measure impairment (disability)
Evaluate therapy
Develop exercise prescriptions (rehabilitation)
Assess fitness for occupations, physical activities, etc.

Contraindications for exercise testing

Limiting neurologic, neuromuscular or orthopedic conditions
Pulmonary contraindications:
- FEV₁ < 30%
- room air PaO2 < 40 mm Hg
- PaCO₂ > 70 mm Hg
- severe pulmonary hypertension

Contraindications for exercise testing

Cardiovascular conditions:
- acute pericarditis
- CHF
- recent MI
- heart block - 2nd or 3rd degree
- tachydysrhythmias
- uncontrolled hypertension
- unstable angina
- recent systemic or pulmonary embolus
- aortic stenosis
Pulmonary changes with exercise
- TV increases early
- Respiratory rate increases late
- Vd/Vt decreases
- V/Q equalizes
- Capillary transit time decreases - increased velocity of blood

Cardiovascular changes with exercise
- Cardiac output
  - Stroke volume- increases to maximum value
  - \( HR_{\text{MAX}} \)
    - reached at exhaustion
    - \( HR_{\text{MAX}} = 220 - \text{age} \)

Cardiovascular changes with exercise
- Blood pressure
  - systolic increases
  - diastolic remains stable
  - pulse pressure increases
- Distribution of circulation - increased
  - perfusion of musculature & skin
- O2 pulse (mL O2 per heart beat) - increases.
  - \( O2 \text{ pulse} = \frac{VO2}{HR} \)

Metabolic changes with exercise
- O2 consumption
  - Normal VO2 = 250 ml/min (3.5 ml/kg BW)
  - VO2\( _{\text{MAX}} \) = greatest O2 consumption a person can reach
  - Normal VO2\( _{\text{MAX}} \) = 7 times resting value
  - METS - unit relating VO2\( _{\text{MAX}} \) to resting value

Metabolic changes with exercise
- 1 MET -- rest
- 4 METS -- housework, bowling
- 6 METS -- farming, tennis
- 8 METS -- heavy manual labor, skiing
- 12 METS -- hockey
- 18 METS -- rowing, swimming

Metabolic changes with exercise
- \( \text{METS} = \frac{VO2_{\text{MAX}}}{3.5 \text{ ml/min x BW}} \)
- Normal METS (sedentary) = 7
- Normal VO2\( _{\text{MAX}} \) = (7 x 3.5) = 24.5 ml/min/kg
Metabolic changes with exercise

- CO₂ production increases proportional to VO₂, up to anaerobic threshold, then increases at faster rate to buffer lactic acid.
- RQ (VCO₂/VO₂) - increases to 1.0, just before exhaustion
- pH - becomes acid after anaerobic threshold is reached.

Exercise limits

- Anaerobic threshold (AT)
  - Point at which anaerobic metabolism begins in response to exercise
  - Greatest work level, or O₂ consumption that can be produced before lactic acid is produced.
- Physical exhaustion normally occurs shortly after passing the AT.

Causes of exhaustion

- Work to eliminate CO₂ becomes excessive - ventilation produces more CO₂ than excretion
- Cardiovascular system cannot oxygenate tissues
- Depletion of glycogen - energy need
- Excessive perception of symptoms; e.g., dyspnea, dizziness, chest tightness

General types of tests

- Tests to evaluate fitness
- Tests to evaluate effects of exercise on oxygenation
- Tests to evaluate exercise tolerance (stress tests)

Testing for general fitness

- 12 minute walking distance
  - Subject walks as far and fast as possible for 12 min.
  - Distance walked reflects fitness

Testing for general fitness

- Harvard step test
  - Subject steps up and down platform for five minutes
  - Recovery heart rate measured 1 min after exercise - lower rate => greater fitness

Click for video on step test (4.5 min.)
http://www.youtube.com/watch?v=mekPTS_LVv4&feature=related
Testing to evaluate desaturation

Purposes:
- to detect diffusion defect
- to evaluate effects of O2 therapy on exercise tolerance

If pre-exercise SaO2 < 90, then supplemental O2 is needed during test

Parameters monitored:
- Pre-exercise SaO2, SpO2 correlate values
- Exercise SpO2
- ECG
- Blood pressure

Results
- Normally, SpO2 increases, due to improved VQ matching
- SpO2 > 90% after 6 minutes ==> no desaturation
- SpO2 decreased by 5% or drops to less than 85%, test terminated and results are positive for desaturation and likely diffusion defect

Types of exercise tolerance tests

- Constant work
- Incremental work- more common
  - staged increments - stepwise
  - ramp increments - constant

Exercise testing equipment

- Treadmill
  - Advantages
    - familiar exercise
    - typical activity (ADL)
  - Disadvantages
    - subject weight is a factor
    - large, heavy, noisy
    - expensive
    - safety issues
  - FYI - click to see treadmill misadventures (2 min)

- Bicycle ergometer
  - Advantages
    - workload unaffected by weight
    - workload precisely measured
    - small, portable
    - inexpensive
    - safer than treadmill
**Exercise testing equipment**
- Bicycle ergometer
  - Disadvantages
    - unfamiliar exercise
    - not ADL
  - yields results slightly different from treadmill

FYI - click to download article on exercise testing in clinical practice
http://erj.ersjournals.com/cgi/reprint/29/1/185

**Exercise testing equipment**
- Gas volume measurement device
- Gas collection, mixing devices
- Gas analyzers - O2, CO2
- Pulse oximeter
- ECG monitor - filtered for motion artifact
- Blood pressure monitor
- Crash cart

FYI - click to download presentation on exercise stress testing, with case studies

**Exercise tolerance testing**
- Preparation of subject
  - comfortable clothes
  - no meal within 2 H
  - no smoking, coffee within 2 H
  - continue medications as prescribed
  - orient to equipment & procedures - include hand signals

**Exercise tolerance testing**
- Preliminary assessment
  - Hx & Px
  - 12 lead ECG
  - PFTs
    - Spirometry
    - MVV
    - DLCO

**Exercise tolerance testing**
- Obtain resting values
  - arterial blood gas
  - lactate (in some labs)
  - SpO2 - correlate with SaO2
  - TV, f, VE
  - PetCO2, PetO2
  - HR, BP, ECG pattern

**Exercise tolerance testing**
- Practice at minimal work- check monitors & equipment
- Exercise- increase workload
  - intervals
  - ramp
- Monitor continuously or sample at each work level- depends on system

Click for 2nd image of exercise testing
Exercise tolerance testing

- Indicators to stop test:
  - Exhaustion - desired endpoint
  - CNS symptoms- vertigo, etc.
  - Nausea, vomiting
  - Chest pain, SOB
  - SpO2 drop >5%
  - Dysrhythmias- frequent PVCs, etc.
  - PSYS > 250 mm Hg
  - Equipment failure

- Posttest cool down period
  - minimal exercise
  - final measurements

Indicators of maximal effort

- VO2max ≥ 85% pred
- VEmax ≥ 70% MVV
- HRmax > 90% pred
- Blood lactate ≥ 4 mM/L

Data reported

- VE, TV, f
- VO2 = (FIO2 x VI) - (FEO2 x VE)
- METS = VO2MAX/3.5 ml /min x BW
- CO2 production = (FECO2 - FICO2)VE
- O2 pulse = VO2 x 1000/HR
- Vd/Vt = (PaCO2 - PetCO2)/PaCO2
- R = VO2/VCO2

Normal responses

- VO2max ≥ 95% pred
- VEmax ≥ 70% MVV
- PaO2, SpO2 WNL
- Vd/Vt values decreases
- HRmax > 90% pred
- O2 pulse increases

Interpretation of abnormal results

<table>
<thead>
<tr>
<th>Parameters at Maximal Exercise</th>
<th>Poor Conditioning</th>
</tr>
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<tbody>
<tr>
<td>VO2max</td>
<td>Low</td>
</tr>
<tr>
<td>METS</td>
<td>Low</td>
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<tr>
<td>VEmax/MVV</td>
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<td>SvO2</td>
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<td>Vd/Vt</td>
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<td>HRmax/workload</td>
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<td>O2 pulse</td>
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<td>VO2max</td>
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</tr>
<tr>
<td>VEmax/MVV</td>
<td>Low</td>
<td>High (low MVV)</td>
</tr>
<tr>
<td>SpO2</td>
<td>Normal</td>
<td>Low (if diffusion limited)</td>
</tr>
<tr>
<td>Vd/Vt</td>
<td>Normal</td>
<td>Normal-High (if VDA)</td>
</tr>
<tr>
<td>HRmax/workload</td>
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**Interpretation of abnormal results**

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**Purposes of metabolic testing:**

- Measure nutritional requirements
- Measure relative metabolic contributions of:
  - carbohydrates
  - lipids
  - protein

**Rationale for bedside assessment**

- Critically ill patients have highly variable metabolic needs
- Patients often are NPO and receive all nourishment via total parenteral nutrition (TPN)

**Specific indications for testing**

- COPD
- Multiple trauma
- Acute pancreatitis
- Organ transplant patients
- Morbid obesity
- Hyper or hypo-metabolism
- Prolonged mechanical ventilation and NPO status (weaning)
### Sources of nutritional depletion
- Vomiting, NG suctioning
- Diarrhea
- Malabsorption
- Elevated metabolism, due to:
  - fever
  - surgery
  - trauma

### Complications of malnourishment
- Impaired function of all organ systems
- Immunocompromise
- Delayed wound healing
- Increased ventilatory load due to:
  - increased oxygen demand
  - increased CO2 production

FYI - click for article on calorimetry and weaning  

### Methods for nutritional assessment
- Anthropometric
  - skin fold thickness
  - arm circumference
- Laboratory assessment - serum proteins
- Calorimetry

### Calorimetry methods
- Direct- complete enclosure of body & measurement of heat production
- Indirect- uses VO2, VCO2, VE to calculate energy expenditure
  - Closed circuit method
  - Open circuit method

FYI - click for AARC CPG on indirect calorimetry during mechanical ventilation  

### Closed circuit method
- Subject rebreathes in closed system
- CO2 is absorbed
- O2 measured volumetrically with spirometer ==> VI - VE = VO2
- Not compatible with current ventilators

### Open circuit method
- Hood or canopy for spontaneously breathing patients
- Ventilator - attaches at airway
- Measured parameters:
  - FIO2 & FEO2
  - FICO2 & FECO2
  - VE

Click to see open circuit calorimetry with hood  
http://www.sportlab.lv/img/kalor2.jpg
Open circuit method

Calorimeters

Click to see MedGraphics calorimeters & CPET systems
http://www.medgraph.com/products_cpx.html
Click to see Datex-Ohmeda Deltatrac II metabolic monitor

Test administration

Patient preparation
◆ Avoid stimulants prior to test
◆ Fast for 2 - 4 H, if PO
◆ Continuous feedings, if NPO
◆ No ventilator adjustments immediately before testing (within 90 min)

Neutral thermal environment must be maintained - no thermal stress
Measurements made during steady state

Calculated parameters

resting energy expenditure (REE)
◆ VO2
◆ VCO2
◆ UN (urinary N2) - not critical to test
Caloric equivalents for:
◆ carbohydrates
◆ lipids
◆ protein
respiratory quotient (RQ)

Significance of results

RQ < 0.67 or RQ > 1.3 ==> error
RQ < 0.7 ==> starvation or ketosis
RQs for predominant substrate
◆ carbohydrates = 1.0
◆ lipids = 0.71
◆ protein = 0.82
REE > caloric intake ==> underfeeding
REE < caloric intake ==> overfeeding

Summary & Review

Diffusing capacity
gas laws
pathophysiology
DLCOs - most common
normal DLCOs = 25 mL/min/mm Hg
increased with obesity, asthma
decreased with emphysema, fibrosis

Summary & Review
Bronchodilator benefit - before and after bronchodilator tests
indications
preconditions
procedure
significant improvement -
  ➤ 12% FEV₁ increase and 200 mL FEV₁ or FVC increase
  ➤ 30% sGAW increase
**Summary & Review**

- **Bronchial challenge testing** - detects and measures airway reactivity
  - provocative agents - methacholine, histamine or exercise
  - preconditions, procedure
  - significant results
    - PC20 - dose where FEV$_1$ decreased by 20%
    - decrease in mechanics produced by exercise

**Summary & Review**

- **Exhaled nitric oxide (eNO) analysis**
  - production of NO increased by allergic asthma - noninvasive marker for inflammation
  - sampled on-line or off-line
  - normals = ≤ 35 ppb for adults and ≤ 25 ppb for children
  - increased ==> eosinophilic inflammation
  - decreased trend ==> effective steroid therapy

**Summary & Review**

- **Preoperative testing** - for risk, postoperative function and care planning
  - Indications; e.g., smoking history
  - tests; e.g., spirometry, DLCO, ABGs imaging, CPET
  - increased risk; e.g., FVC ≤ 50% pred.
  - significant risk; e.g., FVC ≤ 1.5 L

**Summary & Review**

- **Testing for disability** - to detect and measure physical impairment
  - battery - Hx & Px, spirometry, DLCO, ABGs, CPET
  - obstruction - FEV$_1$
  - restriction - FVC
  - asthma - FEV$_1$, episodes
  - oxygenation - PaO$_2$, comorbidities; e.g., pulmonary hypertension

**Summary & Review**

- **Cardiopulmonary exercise testing**
  - purposes:
    - diagnose cardiopulmonary disease
    - distinguish pulmonary vs. cardiac dx
    - assess fitness
    - develop exercise prescriptions
  - normal changes with exercise - cardiac pulmonary, metabolic
  - parameters - VO2max, METS, O2 pulse, HRmax

**Summary & Review**

- **Cardiopulmonary exercise testing**
  - types of tests - fitness, evaluation of oxygenation, stress tests
  - fitness - Harvard step, 12 min. walking
  - oxygenation - 6 min. exercise with continuous SpO2
### Summary & Review

**Cardiopulmonary exercise testing**
- stress testing - treadmill or bicycle ergometer exercise to exhaustion
- monitors:
  - expired O2 and CO2
  - SpO2
  - TV, f, VE
  - HR, BP, ECG
  - lactate (optional)

**Cardiopulmonary exercise testing**
- indicators of maximal effort; e.g., HRmax > 90% pred.
- normal responses - oxygenation stable or improved, O2 pulse increases

**Interpretation**
- poor conditioning - normal pulmonary parameters and O2 pulse
- pulmonary disease - low pulmonary parameters
- cardiac disease - low O2 pulse

**Metabolic testing**
- to measure nutritional requirements and determine metabolic contributions
- indications; e.g., prolonged mechanical ventilation
- calorimetry methods
  - direct vs. indirect
  - indirect - closed, vs. open circuits

**Results may detect:**
- measurement error
- starvation or ketosis
- contributions from carbohydrates, lipids, proteins
- underfeeding
- overfeeding
References

- Madama VC. Pulmonary function testing and cardiopulmonary stress testing 2nd ed. Chaps. 6, 8, 14, 15. 1998; Delmar; Albany.

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