Pulmonary Function Testing Part II

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This Presentation is Approved for
2.0 CRCE Credit Hours

Learning Objectives

- Describe the purposes, physiologic bases devices & methods for diffusing capacity testing
- Describe the purposes, physiologic bases devices & methods for specialized testing regimens
- Describe the purposes, physiologic bases devices & methods for cardiopulmonary exercise testing
- Describe the purposes, physiologic bases devices & methods for metabolic testing
- Interpret results from diffusing capacity tests, specialized tests, cardiopulmonary exercise tests & metabolic tests

Specialized Testing

- 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)

See links below to view animation of diffusion

Anatomic Diffusion Pathway

- Alveolar air
- Alveolar wall
  - Surfactant layer
  - Alveolar epithelium
  - Alveolar basement membrane
- Interstitial space

Anatomic Diffusion Pathway

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

See links below for illustration of diffusion pathway

Physical Laws Governing Diffusion

- Henry's law: the 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: the rate of diffusion through a liquid is
  - Directly proportional to its Ks
  - Inversely proportional to its GMW → CO_2 diffuses 20x the rate of O_2
  - High solubility of CO_2 → diffusion defects will not affect CO_2 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

- O_2 can be diffusion &/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

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

Diffusion Tests

- $DL_{CO}ib$ (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_{CO} Testing Indications

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

DL_{CO} Testing Indications

- Evaluation of the effects of chemotherapy agents or other drugs, e.g. amiodarone
- Evaluation of pulmonary hemorrhage
- Evaluation for pneumonectomy or lung reduction surgery
- Evaluation for disability

Contraindications for Diffusion Tests

- CO toxicity
- Severe hypoxemia (O_2 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

$DL_{CO}sb$ Equipment

- Spirometer
- Automatic valve - for gas delivery, breath holding, & sampling
- End-tidal sampler
- Gas analyzers - CO & He
- Gas mixture
  - 0.3% CO
  - 10% He
  - 21% O_2
  - Balance N_2

DL_{CO}sb Procedure

- Patient performs FVC maneuver
- Inspires to TLC
- Holds breath for 9 - 11 sec
- Exhales
- Alveolar sample collected between 750 - 1000 mL

FYI see links below for AARC CPG on DL_{CO} testing

DL_{CO}sb Procedure

- Calculation
  - VA - alveolar volume
  - 60 - correction from sec to min
  - PB - barometric pressure
  - T - breath hold time (sec)
  - Ln - natural logarithm
  - F_{COI} - initial fraction of CO
  - F_{COF} - final fraction of CO

$$DL_{CO}sb = \frac{VA\ (STPD) \times 60}{(PB - PH_2O)\ (T)} \times \ln \frac{FCOI}{FCOF}$$

DL_{CO}sb Acceptability Criteria

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

DL_{CO}sb Predicted Value

- Normal DL_{CO} = 25 ml/min/mm Hg ± 20%
- Predicted based on
  - BSA
  - Hb - 1 mg/dL → 7% change in DL_{CO}
  - Age - inverse relationship
- Interpretation must consider lung volume

Factors Affecting DL_{CO}

- 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 DL_{CO}

- Obesity
- Asthma
- Left-to-right shunt
- CHF (without edema)
- Early polycythemia
- Large lung volume
- Exercise
- Supine position

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. FEV_1
  - sGaw measurement
  - Lung volumes
  - Diffusing capacity

Bronchodilator Benefit Testing

- 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% & 200 mL increase in FEV_1 or FVC
  - > 30% increase in sGaw

Bronchodilator Benefit Testing

- Insignificant improvement
  - May test after time using a medication
  - May test with a different medication
  - Check for symptomatic improvement
- Decreased post-test parameters
  - Paradoxical drug response
  - Fatigue

Bronchodilator Benefit Testing

- Calculating % change

$$\%FEV_1 \text{ change} = \frac{\text{Post } FEV_1 - \text{Pre } FEV_1}{\text{Pre } FEV_1} \times 100$$

Example: Pre= 1.2L, Post = 1.7L

$$\%FEV_1 \text{ change} = \frac{1.7L - 1.2L}{1.2L} \times 100 = 42\%$$

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

Bronchial Challenge Testing

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

Bronchial Challenge Testing

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

FYI see links below for AARC CPG on methacholine challenge

Bronchial Challenge Testing

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

FYI see links below for ATS standards on challenge testing

Bronchial Challenge Testing

- 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

Methacholine Challenge Testing

- 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

See links below to view dosimeter

Methacholine Challenge Testing

- Procedure
  - Baseline mechanics - FVC, FEV_1, sGaw, etc.
  - Inhaled NSS (control dose)
  - Wait 3 minutes
  - Repeat measure
  - $FEV_1 \leq 80\%$ (of pretest) → reactivity → stop test
  - $FEV_1 \geq 80\%$ (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
    - $FEV_1 \leq 80\%$ control
    - Methacholine concentration = 16 mg/mL

Methacholine Challenge Testing

- Procedure: 2 min tidal breathing
  - Administer NSS control dose
  - Post-test, as for dosimeter
  - Administer methacholine in five quadrupled doses or ten doubled doses from 0.0625 - 16 mg/mL
  - Wait 3 minutes between
  - Repeat, until
    - $FEV_1 \leq 80\%$ control
    - Methacholine concentration = 16 mg/mL

Methacholine Challenge Testing

- Evaluation of results
  - Provocative dose (PC20)
    - Where FEV_1 decreased by 20%
    - Calculated using last & next-to-last dosages
  - sGAW decrease of 35% → positive response

Histamine Challenge Testing

- Preconditions similar to methacholine challenge, with addition of abstention from antihistamines & H1 receptor antagonists (48 H)

- Procedure similar to methacholine, with ascending double-dosing from 0.03 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 & medications, as for methacholine challenge
  - Pretest ECG
  - Pretest $FEV_1 \geq 65\%$ predicted
  - Room temperature < 25 C°
  - Relative humidity ≤ 50%

Exercise Challenge Testing

- Procedure
  - Baseline mechanics
  - Nose clips to remove nasal conditioning
  - Continuous ECG & BP
  - Exercise on treadmill or bicycle ergometer

Exercise Challenge Testing

- Procedure
  - Low level exercise for 1 - 2 min
  - Vigorous exercise
    - 85% HR max - maximum heart rate = (220 - age)
    - 6 - 8 minutes
  - Post-test mechanics

Exercise Challenge Testing

- 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 FEV_1 & sGAW to increase (improve)

Exhaled Nitric Oxide Analysis

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 see links below for article on eNO & asthma

Nitric Oxide (NO) Physiology

- NO synthesis catalyzed by NO synthases
  - Endothelial
  - Neural
  - Induced - by inflammatory cytokines, e.g. as in asthma

Nitric Oxide (NO) Physiology

- eNO is a 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, & bronchiolitis obliterans
- FeNO reflects degree of asthma control by steroids
- Asthma diagnosis based on FeNO is less expensive than standard methods

FYI see links below for article with asthma management algorithm using FeNO

Diagnostic Utility of eNO

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

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 see links below for information on chemiluminescent analyzer

FeNO Analysis

- Off-line sampling
  - Patient inhales to TLC from NO scrubber or reservoir of NO-free gas
  - Exhales VC with 5 cm H_2O resistance @ 0.35 L/sec
  - Sample collected in mylar balloon
  - Analysis within 12 H

FeNO Analysis

- Online sampling
  - Patient inhales to TLC through scrubber
  - Patient exhales VC into analyzer at controlled resistance

NIOX MINO™ FeNO Analyzer

FYI see links below for Aerocrine
NIOX MINO website with video

FeNO Analysis

See links below to view GE Sievers 280i™ FeNO analyzer & Eco Medics CLD88™ FeNO analyzer

FeNO Interpetation

- 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

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 see links below for article on post-op QOL

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

- 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

Preoperative Tests

- DL_{CO}: 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

Test	Increased risk
FVC	<50% pred
FEV1	<2.0 L or <50% pred
MVV	NA
PaCO2	NA
DLCO	<60% pred
$VO2_{MAX}$ (O2 uptake)	<20 mL/kg/min

Interpretation Guidelines

Test	Increased risk	Significant risk
FVC	<50% pred	<1.5 L
FEV1	<2.0 L or <50% pred	<1.0 L
MVV	NA	<50% pred
PaCO2	NA	>45 mm Hg
DLCO	<60% pred	
$VO2_{MAX}$ (O2 uptake)	<20 mL/kg/min	<10 mL/kg/min

Testing for Disability

Testing for Disability

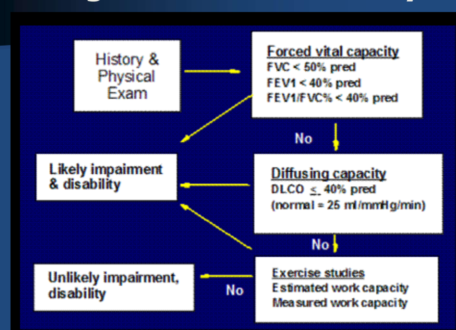
- Disability: the inability to perform tasks required for employment, due to impairments
  - Mental
  - Physical

FYI see links below for guide to PFT under Social Security programs

Testing for Disability

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

Algorithm for Disability



Disability Evaluation

- Obstruction (COPD): FEV_1
- Restriction: FVC
- Asthma
  - FEV_1
  - Episode frequency

Disability Evaluation

- Blood gases & impairment
  - PaO_2 < 55 mm Hg on 0.21 OR
  - PaO_2 < 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

Cardiopulmonary Exercise Testing (CPET)

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
  - FEV_1 < 30%
  - Room air PaO_2 < 40 mm Hg
  - $PaCO_2$ > 70 mm Hg
  - Severe pulmonary hypertension

Contraindications for Exercise Testing

- Cardiovascular conditions
  - Acute pericarditis
  - CHF
  - Recent MI
  - Heart block: 2^{nd} or 3^{rd} 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 max
    - Reached at exhaustion
    - HR max = 220 - age

Cardiovascular Changes With Exercise

- Blood pressure
  - Systolic increases
  - Diastolic remains stable
  - Pulse pressure increases
- Distribution of circulation: increased perfusion of musculature & skin
- O_2 pulse (mL O_2 per heart beat): increases
  - O_2 pulse = VO_2 / HR
  - Index of stroke volume

Metabolic Changes With Exercise

- O_2 consumption
  - Normal VO_2 = 250 ml/min (3.5 ml/kg BW)
  - VO_2 max = greatest O_2 consumption a person can reach
  - Normal VO_2 max = 7 times resting value
  - METS: unit relating VO_2 max to resting value

Metabolic Changes With Exercise

$$\text{METS} = \frac{VO_2\text{ max}}{3.5\text{ ml/min x BW}}$$

Normal METS (sedentary) = 7

Normal VO_2 max = (7 x 3.5) = 24.5 ml/min/kg

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

- CO_2 production increases proportional to VO_2, up to anaerobic threshold, then increases at faster rate to buffer lactic acid
- RQ (VCO_2 / VO_2): 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 O_2 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 CO_2 becomes excessive - ventilation produces more CO_2 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 & fast as possible for 12 min
  - Distance walked reflects fitness

Testing for General Fitness

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

Up next: Video on step test

Testing to Evaluate Desaturation

- Purposes
  - To detect diffusion defect
  - To evaluate effects of O_2 therapy on exercise tolerance
- If pre-exercise SaO_2 < 90, then supplemental O_2 is needed during test

Testing to Evaluate Desaturation

- Subject exercises on treadmill or ergometer for 6 min
  - Parameters monitored
    - Pre-exercise SaO_2, SpO_2 : correlate values
    - Exercise SpO_2
    - ECG
    - Blood pressure

Testing to Evaluate Desaturation

- Results
  - Normally, SpO_2 increases due to improved VQ matching
  - SpO_2 > 90% after 6 minutes → no desaturation
  - SpO_2 decreased by 5% or drops to less than 85%, test terminated & results are positive for desaturation & 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 see links below for video on treadmill misadventures

Exercise Testing Equipment

- 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 see links below for article on exercise testing in clinical practice

Exercise Testing Equipment

- Gas volume measurement device
- Gas collection, mixing devices
- Gas analyzers: O_2, CO_2
- Pulse oximeter
- ECG monitor: filtered for motion artifact
- Blood pressure monitor
- Crash cart

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
    - DL_{CO}

Exercise Tolerance Testing

- Obtain resting values
  - Arterial blood gas
  - Lactate (in some labs)
  - SpO_2: correlate with SaO_2
  - TV, f, VE
  - $PetCO_2$, $PetO_2$
  - HR, BP, ECG pattern

Exercise Tolerance Testing

- Practice at minimal work level: check monitors & equipment
- Exercise: increase workload
  - Intervals
  - Ramp
- Monitor continuously or sample at each work level - depends on system

See links below for image of exercise testing

Exercise Tolerance Testing

- Indicators to stop test
  - Exhaustion: desired endpoint
  - CNS symptoms: vertigo, etc.
  - Nausea, vomiting
  - Chest pain, SOB
  - SpO_2 drop > 5%
  - Dysrhythmias: frequent PVCs, etc.
  - PSYS > 250 mm Hg
  - Equipment failure

Exercise Tolerance Testing

- Post-test cool down period
  - Minimal exercise
  - Final measurements

Up next: Videos of cardiac stress testing & VO_2 max test

Indicators of Maximal Effort

VO_2 max ≥ 85% pred

VE max ≥ 70% MVV

HR max > 90% pred

Blood lactate ≥ 4 mM/L

Data Reported

- VE, TV, f
- $VO_2 = (FiO_2 \times VI) - (FEO_2 \times VE)$
- METS = VO_2 max/3.5 ml/min x BW
- CO_2 production = $(FECO_2 - FiCO_2)$ VE
- O_2 pulse = $VO_2 \times 1000/HR$
- $Vd/Vt = (PaCO_2 - PetCO_2)/PaCO_2$
- $R = VO_2/VCO_2$

Normal Responses

- VO_2 max ≥ 95% pred
- VE max ≥ 70% MVV
- PaO_2, SpO_2 WNL
- Vd/Vt values decreases
- HR max ≥ 90% pred
- O_2 pulse increases

Interpretation of Abnormal Results

Parameters at Maximal Exercise	Poor Conditioning
VO2max	Low
MET S	Low
VEmax/MVV	Low
SpO2 SaO2	Normal
Vd/Vt	Normal
HRmax/workload	High
O2 pulse	Normal

Interpretation of Abnormal Results

Parameters at Maximal Exercise	Poor Conditioning	Pulmonary disorders
VO2max	Low	Low
METS	Low	Low
VEmax/MVV	Low	High (low MVV)
SpO2 SaO2	Normal	Low (if diffusion limited)
Vd/Vt	Normal	Normal- High (high if VDA)
HRmax/workload	High	Normal
O2 pulse	Normal	Normal

Interpretation of Abnormal Results

Parameters at Maximal Exercise	Poor Conditioning	Pulmonary disorders	Cardiovascular disorders
VO_2max	Low	Low	Low
METS	Low	Low	Low
VEmax/MVV	Low	High	Low
SpO_2 SaO_2	Normal	Low	Normal
Vd/Vt	Normal	Normal- High	Normal
HRmax/workload	High	Normal	High
O_2 pulse	Normal	Normal	Low

Metabolic Testing

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 & 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 & 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 CO_2 production

FYI see links below for article on calorimetry & weaning

Methods for Nutritiional 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 VO_2, VCO_2, VE to calculate energy expenditure
  - Closed circuit method
  - Open circuit method

FYI see links below for AARC CPG on indirect calorimetry during mechanical ventilation

Closed Circuit Method

- Subject rebreathes in closed system
- CO_2 is absorbed
- O_2 measured volumetrically with spirometer → $VI - VE = VO_2$
- Not compatible with current ventilators

Open Circuit Method

- Hood or canopy for spontaneously breathing patients
- Ventilator - attaches at airway
- Measured parameters
  - FiO_2 & FEO_2
  - $FiCO_2$ & $FECO_2$
  - VE

See links below to view open circuit calorimetry with hood

Open Circuit Method

- Calorimeters

See links below to view

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)
  - VO_2
  - VCO_2
  - UN (urinary N_2) - 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
  - $DL_{CO}sb$ - most common
  - Normal $DL_{CO}sb$ = 25 mL/min/mm Hg
  - Increased with obesity, asthma
  - Decreased with emphysema, fibrosis

Summary & Review

- Bronchodilator benefit: before & after bronchodilator tests
  - Indications
  - Preconditions
  - Procedure
  - Significant improvement
    - 12% FEV_1 increase & 200 mL FEV_1 or FVC increase
    - 30% sGAW increase

Summary & Review

- Bronchial challenge testing: detects & 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 & ≤ 25 ppb for children
  - Increased → eosinophilic inflammation
  - Decreased trend → effective steroid therapy

Summary & Review

- Preoperative testing: for risk, postoperative function, & care planning
  - Indications, e.g. smoking history
  - Tests, e.g. spirometry, DL_{CO}, 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 & measure physical impairment
  - Battery: Hx & Px, spirometry, DL_{CO}, 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: VO_2 max, METS, O_2 pulse, HR max

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 SpO_2

Summary & Review

- Cardiopulmonary exercise testing
  - Stress testing: treadmill or bicycle ergometer exercise to exhaustion
  - Monitors
    - Expired O_2 & CO_2
    - SpO_2
    - TV, f, VE
    - HR, BP, ECG
    - Lactate (optional)

Summary & Review

- Cardiopulmonary exercise testing
  - Indicators of maximal effort, e.g. HR max > 90% pred.
  - Normal responses: oxygenation stable or improved, O_2 pulse increases

Summary & Review

- Cardiopulmonary exercise testing
  - Indicators of maximal effort, e.g. HR max > 90% pred.
  - Normal responses: oxygenation stable or improved, O_2 pulse increases
  - Interpretation
    - Poor conditioning: normal pulmonary parameters & O_2 pulse
    - Pulmonary disease: low pulmonary parameters
    - Cardiac disease: low O_2 pulse

Summary & Review

- Metabolic testing: to measure nutritional requirements & determine metabolic contributions
  - Indications, e.g. prolonged mechanical ventilation
  - Calorimetry methods
    - Direct vs. indirect
    - Indirect: closed vs. open circuits

Summary & Review

- Metabolic testing
  - Calorimeter attached to airway & measures
    - FiO_2, FEO_2
    - $FiCO_2$, $FECO_2$
    - VE
  - Calculated values
    - Resting energy expenditure (REE)
    - Caloric equivalents
    - Respiratory quotient (RQ)

Summary & Review

- Results may detect
  - Measurement error
  - Starvation or ketosis
  - Contributions from carbohydrates, lipids, proteins
  - Underfeeding
  - Overfeeding

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