Pulmonary Function Testing Part II

Arthur Jones, EdD, RRT

Specialized testing regimens

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

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.

Diffusing Capacity Testing

Learning Objectives:

- 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.

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

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.

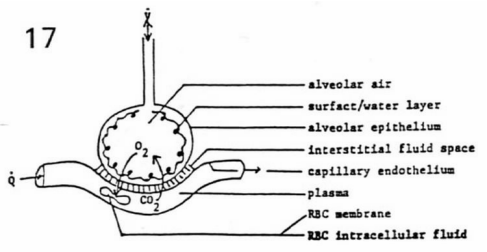
Anatomic diffusion pathway

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

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

Anatomic diffusion pathway



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_{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 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

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 (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

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

$$DLCOsb = \frac{VA\ (STPD) \times 60}{(PB - PH2O)\ (T)} \times Ln\ \frac{FCOI}{FCOF}$$

DLCOsb 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 acceptability criteria

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

DLCOsb procedure

- patient performs FVC maneuver
- inspires to TLC
- holds breath for 9 - 11 sec.
- exhales
- alveolar sample collected between 750 - 1000 mL

DLCO predicted value

- Normal DLCO = 25 ml/min/mmHg $\pm$ 20%
- Predicted based on:
  - BSA
  - Hb - 1 mg/dL ==> 7% change in DLCO
  - 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

Prognostic value of DL_{CO}

- Determines when COPD develops into emphysema
- Predicts complications after surgical resection of lung
- Predicts mortality in pulmonary arterial hypertension

Conditions with increased DL_{CO}

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

Bronchodilator Benefit & Bronchial Challenge Testing

Conditions with decreased DL_{CO}

- Decreased surface area
  - emphysema
  - lung resection
- Increased wall thickness
  - hypersensitivity pneumonitis
  - fibrosis
  - sarcoidosis
- Decreased carrying capacity - anemia

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

- 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

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

Bronchodilator benefit testing

- Significant improvements
  - > 12% and 200 mL increase in FEV_1 or FVC
  - >30% increase in sGaw

Bronchodilator benefit testing

- Pretests - may include:
  - spirometry; e.g., FEV_1
  - sGaw measurement
  - lung volumes
  - diffusing capacity

Bronchodilator benefit testing

- 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

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

Example: Pre = 1.2L; Post = 1.7L

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

Bronchial challenge testing

- 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

- Purposes
  - detect airway hyperreactivity
  - isolate cause of hyperreactivity
  - quantify severity of bronchospasm
  - assess changes in bronchoreactivity

Bronchial challenge testing

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

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

- Side effects
  - Methacholine
    - headache
    - itching
    - signs and symptoms of severe allergic reaction
  - Histamine
    - same as for methacholine
    - flushing

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
  - 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
    - standardizes dose by volume
    - most precise
    - requires dosimeter
  - 2 minute tidal breathing
    - standardizes dose by time
    - requires only small volume nebulizer

Methacholine challenge testing

- Procedure - 5 breath dosimeter
  - 5 breaths methacholine - 0.0625 to 16 mg/mL
  - wait 3 minutes
  - repeat, until:
    - FEV1 $\leq$ 80% control
    - methacholine concentration = 16 mg/mL

Methacholine challenge testing

- 5 breath dosimeter

Methacholine challenge testing

- Procedure - 2 min. tidal breathing
  - administer NSS control dose
  - posttest, 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:
    - FEV1 $\leq$ 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 and next-to-last dosages
  - sGAW decrease of 35% ==> positive response

Exercise challenge testing

- Preconditions
  - withhold activity and medications, as for methacholine challenge
  - pretest ECG
  - pretest FEV1 $\geq$ 65% predicted
  - room temperature < 25 C^o
  - relative humidity $\leq$ 50%

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

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

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

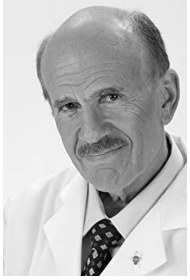
- Procedure
  - low level exercise for 1-2 min.
  - vigorous exercise
    - 85% HRmax - maximum heart rate = (220 - age)
    - 6-8 minutes
  - posttest mechanics

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 and sGAW to increase (improve)

Nitric oxide (NO) physiology

- Louis Ignarro, MD, PhD
  - Nobel Prize winner, 1998
  - Research on NO



Exhaled Nitric Oxide Analysis

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

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

Nitric oxide (NO) physiology

- 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

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

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

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

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

NIOX MINO™ FENO analyzer

Image courtesy of Aerocrine

FENO analysis

Bedmont FeNO analyzer

Solgroup Geanox FeNO analyzer

Preoperative testing:

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

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:

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

Preoperative Testing

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 VTG for pulmonary resection for emphysema
- Spirometry with maximal bronchodilation
- Perfusion, V/Q scans, contrast MRI - can be used to estimate post- operative FEV_1 for lung resections
- Measurement of FEV_1 on first day post-op is good predictor of morbidity

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

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

Pause for a Cause

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

Testing for disability

- Disability - the inability to perform tasks required for employment, due to impairments:
  - mental
  - physical
  - political
  - religion

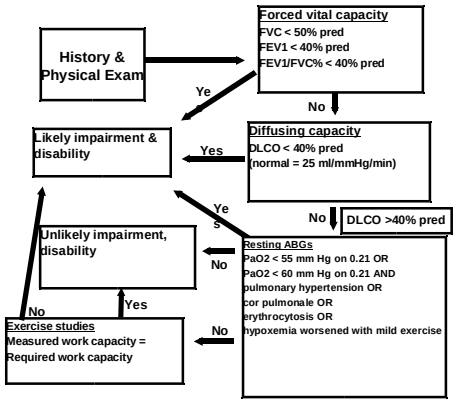
Testing for disability

- History
- Physical examination
- Imaging studies
- PFTs
  - spirometry
  - diffusing capacity
  - arterial blood gases
  - exercise testing

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

Algorithm for disability



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

Disability evaluation

- Obstruction (COPD) - FEV_1
- Restriction - FVC
- Asthma
  - FEV_1
  - episode frequency

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

- 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

Contraindications for exercise testing

- Limiting neurologic, neuromuscular or orthopedic conditions
- Pulmonary contraindications:
  - FEV_1 < 30%
  - room air PaO2 < 40 mm Hg
  - PaCO2 > 70 mm Hg
  - severe pulmonary hypertension

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

Contraindications for exercise testing

- Cardiovascular conditions:
  - acute pericarditis
  - CHF
  - recent MI
  - heart block - 2nd or 3rd degree

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

Metabolic changes with exercise

- METS = $\frac{VO2_{MAX}}{3.5 \text{ ml /min x BW}}$
- Normal METS (sedentary) = 7
- Normal $VO2_{MAX}$ = (7 x 3.5) = 24.5 ml/min/kg

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 pulse = VO2/HR
  - index of stroke volume

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

- O2 consumption
  - Normal VO2 = 250 ml/min (3.5 ml/kg BW)
  - $VO2_{MAX}$ = greatest O2 consumption a person can reach
  - Normal $VO2_{MAX}$ = 7 times resting value
  - METS - unit relating $VO2_{MAX}$ to resting value

Metabolic changes with exercise

- CO2 production increases proportional to VO2, up to anaerobic threshold, then increases 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.

Testing for general fitness

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

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

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

General types of tests

- Tests to evaluate fitness
- Tests to evaluate effects of exercise on oxygenation
- Tests to evaluate exercise tolerance

(stress tests)

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

Testing to evaluate desaturation

- Subject exercises on treadmill or ergometer for 6 min.
  - Parameters monitored:
    - Pre-exercise SaO2, SpO2- correlate values
    - Exercise SpO2
    - ECG
    - Blood pressure

Exercise testing equipment

- Treadmill
  - Advantages
    - familiar exercise
    - typical activity (ADL)

Testing to evaluate desaturation

- 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

Exercise testing equipment

- Treadmill
  - Disadvantages
    - subject weight is a factor
    - large, heavy, noisy
    - expensive
    - safety issues

FYI - click to see treadmill misadventures (2 min)
http://www.youtube.com/watch?v=u7SOOg-5LBg

Types of exercise tolerance tests

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

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

Exercise tolerance testing

- Preliminary assessment
  - Hx & Px
  - 12 lead ECG
  - PFTs
    - Spirometry
    - MVV
    - DLCO

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

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

- 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

- 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 video of exercise testing (2 min.)
https://www.youtube.com/watch?v=xx83GohD5u4&t=8s

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
  - Death

Data reported

- VE, TV, f
- VO2 = (FIO2 x VI) - (FEO2 x VE)
- METS = $VO2_{MAX}$/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

Exercise tolerance testing

- Posttest cool down period
  - minimal exercise
  - final measurements

Click to see cardiac stress testing (2.5 min.)
http://www.youtube.com/watch?v=x_Z0GF6AuTw

Normal responses

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

Indicators of maximal effort

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

Interpretation of abnormal results

Parameters at Maximal Exercise	Poor Conditioning
VO2max	Low
METS	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

Purposes of metabolic testing:

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

Interpretation of abnormal results

Parameters at Maximal Exercise	Poor Conditioning	Pulmonary disorders	Cardiovascular disorders
VO2max	Low	Low	Low
METS	Low	Low	Low
VEmax/MVV	Low	High	Low
SpO2 SaO2	Normal	Low	Normal
Vd/Vt	Normal	Normal- High	Normal
HRmax/workload	High	Normal	High
O2 pulse	Normal	Normal	Low

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)

Metabolic Testing

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

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

Complications of malnourishment

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

Closed circuit method

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

Methods for nutritional assessment

- Anthropometric
  - skin fold thickness
  - arm circumference
- Laboratory assessment - serum proteins
- Calorimetry

Open circuit method

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

Open circuit method

- Hood or canopy for spontaneously breathing patients

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

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

Summary & Review

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

Calculated parameters

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

Summary & Review

- Bronchodilator benefit - before and after bronchodilator tests
  - indications
  - preconditions
  - procedure
  - significant improvement -
    - 12% FEV_1 increase and 200 mL FEV_1 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

- 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 - PaO2, comorbidities; e.g., pulmonary hypertension

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 = $\leq$ 35 ppb for adults and $\leq$ 25 ppb for children
  - increased ==> eosinophilic inflammation
  - decreased trend ==> effective steroid therapy

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

- 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 $\leq$ 50% pred.
  - significant risk; e.g., FVC $\leq$ 1.5 L

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)

Summary & Review

- 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

Summary & Review

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

Summary & Review

- Metabolic testing
  - calorimeter attached to airway and measures:
    - FIO2, FEO2
    - FICO2, FECO2
    - VE
  - calculated values:
    - resting energy expenditure (REE)
    - caloric equivalents
    - respiratory quotient (RQ)

Summary & Review

- 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

Summary & Review

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

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