Lung Clearance & Expansion Techniques

Arthur Jones, EdD, RRT

Learning Objectives:

- Describe the causes and complications of impaired pulmonary mucous transport.
- Outline patient assessment techniques for mucokinetic and lung expansion therapy.
- Discuss the actions, effects, administration and evidence for effectiveness of mucokinetic agents.
- Discuss the techniques, effects and evidence for effectiveness of manual and mechanical techniques for mucokinesis.
- Discuss the types, etiologies, risk factors and complications of atelectasis.
- Discuss the techniques, effects and evidence for effectiveness of manual and mechanical techniques for preventing and treating atelectasis.

Mucociliary Transport

Respiratory Romance Poem

When you're kissing your honey,
and her nose gets runny;
don't think it's funny;
it's not

Functions of Mucus

- Traps foreign particles for removal
- Humidifies inspired air
- Prevents infection
- Dilutes toxins
- Neutralizes toxic gases
- Buffers pH

Mucus

- Composition
  - H_2O 95%
  - mucins
    - complex glycoproteins
    - two primary types: MUC5AC; MUC5B
    - bind bacteria - decrease infections

Mucus

- Composition
  - carbohydrate, SO4
  - proteins- IgE, IgM, IgA, lysozyme
  - oxidants, antioxidants
  - surfactant

Sources of Mucus

- Normal production = 10-20 ml/day
- Goblet cells
- Submucosal glands
- Clara cells - defensive secretions
- Serous cells - defensive secretions
- Type II pneumocytes- surfactant
- Epithelial cells- transport Cl & Na; H2O follows

Mucus- control of secretion

- Parasympathetic
  - muscarinic receptors in submucosal glands
  - stimulation increases secretion
  - blocking decreases secretion; e.g., anticholinergic agents (atropine)

Mucus- control of secretion

- Sympathetic (adrenergic)
  - there is no adrenergic innervation of secretory structures
  - adrenergic influence is through circulating catecholamines
  - catecholamines increase secretion
- Inflammatory mediators- increase secretion

Mucus- control of secretion

- Non-adrenergic, non-cholinergic (NANC)
  - neurotransmitters
    - vasoactive intestinal peptide
    - tachykinin
  - stimulate secretion

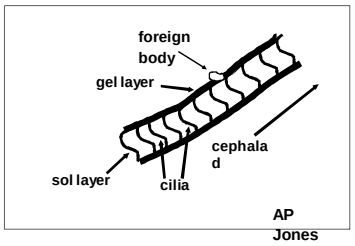
Control of transport

- Mucociliary clearance
- Tidal expiratory flow
- Forced expiratory flow (cough)

Pulmonary clearance mechanisms

- Cilia
  - line epithelium to terminal bronchi
  - beat in metachronal wave @ 10-20 Hz

Mucociliary escalator



Click to view metachronal wave
https://www.youtube.com/watch?v=j3CuqRDGPmU

Factors affecting ciliary motility

- Increase ciliary motility
  - adrenergic agents
  - cholinergic agents
- Decrease ciliary motility
  - alcohol
  - hereditary dx - ciliary dyskinesia
  - increased mucus viscosity
  - smoke
  - infection

Transport abnormalities

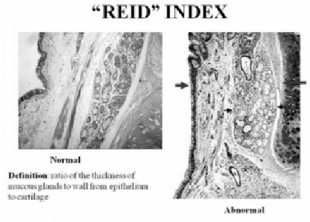
- Abnormal mucus
  - Chronic bronchitis
  - Asthma
  - Cystic fibrosis
- Ciliary dyskinesia - immotile cilia
- Drying
- Cough impairment

Transport abnormalities

- Chronic bronchitis
  - increased mucus glands at expense of other cells (increased Reid index)
  - increased depth of mucus layer
  - decreased mucociliary clearance
  - worsened with continued smoking

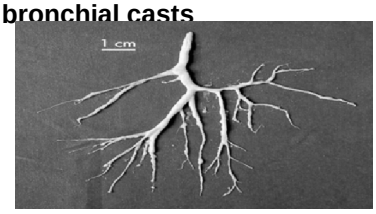
Transport abnormalities

- Chronic bronchitis
  - increased mucus glands at expense of other cells (increased Reid index)



Transport abnormalities

- Asthma
  - mucous plugging with eosinophilic sputum
  - bronchial casts



Transport abnormalities

- Cystic fibrosis- hereditary defect of secretory glands
  - defective gene encodes cystic fibrosis transmembrane regulator (CFTR)
  - CFTR affects ion transport across airway epithelium - exact physiologic action is controversial
  - airway surface liquids are decreased, increasing mucus viscosity & adhesiveness

Transport abnormalities

- Cystic fibrosis
  - chronic airway obstruction with mucus ==> infection
  - neutrophils release proteases ==> inflammation & airway remodeling (bronchiectasis)
    - worsens mucus clearance
    - loads mucus with DNA

Transport abnormalities

- Cystic fibrosis
  - colonization with pseudomonas produces biofilm that increases resistance of organisms to antimicrobials

Transport abnormalities

- Hereditary ciliary dyskinesia (Kartagener's syndrome)Autosomal
  - Rare condition
  - Autosomal recessive trait
  - immotile cilia ==> impaired mucus clearance ==> recurrent infection ==> bronchiectasis

Click for a different view of wave (1 min)
https://www.youtube.com/watch?v=rudgK8joOC0&feature=emb_logo

Transport abnormalities

- Drying of mucus ==> increased viscosity
  - inadequate humidification of inspired air, especially with bypassed airways
  - ventilation increased above capabilities of airways to humidify
    - exercise
    - noninvasive ventilation - humidify BiPAP

Transport abnormalities

- Cough impairment
  - artificial airways
  - neuromuscular weakness
  - pain

Consequences of impaired transport

- Mucus plugging - atelectasis
- Infection
  - pneumonia
  - recurrent pneumonia - bronchiectasis

Patient Assessment For Mucokinetic & Lung Expansion Therapy

Symptoms

- Shortness of breath
- Cough
- Mucus production
- Wheezes

Physical signs

- Fever - NOT for atelectasis
- Thick mucus and/or plugs
- Tachypnea
- Accessory muscle work
- Asymmetric chest motion (severe)
- Tracheal shift (severe)

Physical signs

- Breath sounds
  - diminished or absent
  - rhonchi
  - wheezes
  - crackles (atelectasis, pneumonia)
  - bronchial (tubular) sounds
- Cyanosis (severe)
- Increased peak inspiratory pressure

Spirometry

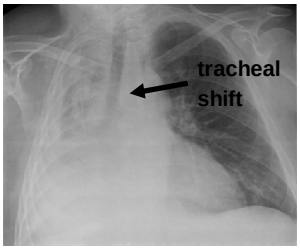
- Decreased FVC, IC
- Decreased PEF, FEV_1

Blood gases

- Hypoxemia - V/Q mismatch
- Hypercapnia
  - when superimposed on COPD
  - severe tachypnea ==> increased dead space

Radiologic signs

- Atelectasis - especially with plugging
- Pneumonia



Pharmacological Mucokinesis

Issues with mucokinetic agents

- Different condition ==> different mucus characteristics
- Viscosity
  - excessive viscosity impairs cilia
  - decreased viscosity may impair clearance
  - cilia may not mobilize very thin secretions (swimming in air)
  - thin secretions flow to dependent lung

Issues with mucokinetic agents

- Adhesiveness impairs clearance - secretions 'stick' to airways

Beta adrenergic agents

- Bronchodilation may enable secretion mobilization - enlarged airways loosen plugs
- Mucociliary effects
  - increase ciliary motility
  - increase mucus production

Beta adrenergic agents

- Clinical outcomes
  - short-acting beta-adrenergics - no benefits on clearance
  - long-acting beta-adrenergics; e.g., salmeterol - modest benefits

Mucokinetic agents

- Expectorants - increase mucus production
- Mucolytics - reduce mucus viscosity
- Surfactants - reduce mucus adhesiveness
- Hypertonic saline
- Bland aerosols
  - no benefits
  - may harm - bronchospasm, etc.
  - no further discussion

Expectorants

- Potassium iodide (SSKI) - acts directly on mucus glands
- indirect-acting expectorants - irritate gastric mucosa, stimulating cholinergic receptors to stimulate secretion
  - Guaifenesin (Mucinex)
  - Elixir terpin hydrate (AKA GI gin)

OTC cold medications

- Does this make sense - combining an agent to increase mucus secretion with another agent to suppress cough?

Mucolytics

- N-acetylcysteine (Mucomyst)
- dornase alfa (Pulmozyme)
- sodium bicarbonate
  - no benefits
  - may harm

N-acetylcysteine (Mucomyst)

- Oral administration (200 mg TID)
  - may improve pulmonary function
  - may reduce risk of hospitalization
  - reduced exacerbations
  - reduced days of illness
  - reduced days of antibiotic use
  - effects may be due to antioxidant activity
- There is no evidence to support aerosol administration

Dornase alfa (Pulmozyme)

- Reduces viscosity of purulent secretions
- May contribute to increased longevity in CF patients
- Not recommended for COPD or bronchiectasis
- Several cases reporting direct instillation for mucus plugging with resolution of atelectasis

Hypertonic saline aerosol

- Action - hyperosmolarity causes airway cells to secrete H2O
- Nebulized 3% - 7% saline QID
- Increases mucus clearance
- May improve pulmonary function
- Effective for sputum induction
- Need trials comparing hypertonic saline with alfa dornase - saline is much less costly

Surfactant

- Theoretically, decreases adhesion of mucus to airways
- Surfactant abnormality may play a role in generation of COPD
- One trial (1997) - aerosol surfactant improved pulmonary function and mucus clearance for chronic bronchitics.
- Need more research

Potential mucokinetics

- mannitol dry powder - mucokinesis
- tyloxapol (formerly Alevaire) - antioxidant, detergent
- nacystelyn - antioxidant, mucokinetic
- heparin - mucokinesis for CF
- denufosol tetrasodium - hydrates mucus, improves clearance for CF patients

Summary

- Long-acting beta-agonists may increase mucus clearance
- Bland aerosols and NaHCO3 - no confirmed mucokinetic effects
- Oral mucokinetics; e.g., acetylcysteine - benefits in chronic bronchitis (antioxidant)
- Aerosolized alfa dornase - effective for cystic fibrosis
- Aerosolized hypertonic saline - effective for cystic fibrosis

Nonpharmacologic Mucokinesis

Bronchial hygiene physical therapy

- Components
  - percussion
  - postural drainage
  - vibration
  - shaking

Bronchial hygiene physical therapy

- Application as routine for COPD, bronchiectasis and chronic bronchitis
  - research has been low-quality
  - increases sputum production
  - no effects on pulmonary function
  - no evidence either way
- application for exacerbations of COPD and chronic bronchitis - no evidence

Bronchial hygiene physical therapy

- Application as routine for cystic fibrosis
  - some form of BHPT is an accepted standard
  - trials with subjects getting no mucokinetic support would be unethical
  - research with CF involves comparison of methods
  - mechanical percussion is as effective as manual percussion

Cough

- For patients with compromised mucociliary transport, cough is the most effective and important mucokinetic method.
- Cough is compromised by:
  - neuromuscular weakness
  - obstructive disease - forced expiration collapses airways (dynamic compression)

Directed cough

- Directed cough - a deliberate cough maneuver that is taught, supervised, and monitored.
- Examples - forced expiratory technique (FET, or huff cough) and manually assisted cough

Directed cough

- Forced expiratory technique (FET)
  - slow diaphragmatic breaths followed by glottis-open huffs at low-to-mid lung volumes
  - produce higher flow than maximum forced expiration
  - especially useful for patients with obstructive disease

Directed cough

- Active cycle of breathing - breathing control exercises with FET
  - relaxed, normal breathing
  - four deep breaths
  - relaxed, normal breathing
  - deep breaths
  - relaxed normal breathing
  - low lung volume huffs
  - high lung volume huffs

Autogenic drainage

- Controlled breathing at increasing lung volumes
  - slow, nasal breathing
  - 10-20 low volume breaths with 3 sec. hold
  - 10-20 high volume breaths with 3 sec. hold
  - huff coughs

Autogenic drainage

- especially applicable to CF patients
- at least as effective as BHPT, active cycle of breathing, PEP
- difficult to learn

Cough assistance

- manual cough assistance - tussive squeeze, abdominal thrust
- in/exsufflator - indicated for MEP < 60 cm H2O
  - positive pressure for inflation
  - negative pressure for increased expiratory (cough) flow
  - usual pressures 40 to -40 cm H2O
  - may reverse atelectasis
  - improves symptoms and SPO2

In/exsufflator - cough assistance

Image Courtesy of Philips Respironics

Positive expiratory pressure (PEP)

- PEP - CPAP with mouthpiece or mask
- Can administer with small-volume nebulizer treatment
- Effective for cystic fibrosis; not for COPD
- Patients prefer over BHPT

Positive expiratory pressure (PEP)

- PEP - CPAP with mouthpiece or mask
- Thera PEP

Vibratory PEP

- Oscillations in airways produce by passive exhalation, with positive end-expiratory pressure
- Devices - equivalent performance
  - Flutter(TM) - gravity-dependent
  - Acapella(TM) - not gravity-dependent
- Effective for mucus clearance
- May be effective for atelectasis

Click to see video of Flutter device (1 min.)
http://www.youtube.com/watch?v=AWK36ayTT4Q

Vibratory PEP

- Two models - > 15 L/min, <15 L/min
- Can administer via:
  - mouthpiece
  - mask
  - manual resuscitator
- Can administer with small-volume nebulizer treatment
- Adjustable, but no measure of PEP level

Vibratory PEP

- Recommended regimen
  - 10-20 breaths/cycle
  - followed by directed coughs to raise mucus
  - repeat cycles for 10-20 min. up to QID

Vibratory PEP

- Relative contraindications
  - ICP>20mmHg
  - recent facial, oral, or skull surgery
  - esophageal surgery
  - middle ear pathology
  - untreated pneumothorax

High-frequency oscillation/percussion

- Approaches
  - internal airway oscillation/percussion
  - external chest oscillation/percussion

Intrapulmonary percussive devices

- Vortran PercussiveNeb(TM)

Intrapulmonary percussive devices)

- Percussionaire devices
  - IPV 1C(TM) - institutional
  - Impulsator(TM) - institutional &

Intrapulmonary percussive devices

- Operation - short inspiratory flow pulses to airways that may work by:
  - causing radial displacement of airways, pulsing gas to distal side of secretions
  - generating high-frequency 'mini-coughs' - expiratory oscillations
  - mucolysis, due to resonating frequency response
  - increased ciliary activity

External oscillation/percussion

- High-frequency chest wall oscillation/compression (HFCWO)
  - The Vest(TM) - home and institutional models
  - SmartVest(TM) - programmable

Click to see video of The SmartVest(TM) system (2.25 min
https://www.youtube.com/watch?v=03dwITbNNnY

Vest device operation

- vest on chest inflated/deflated at adjustable pressure and frequency
  - 5-20 cm H2O
  - 2-25 Hz
- oscillates chest
  - 'mini-coughs'
  - resonating frequency may cause mucolysis

High-frequency chest wall oscillation

- Hayek RTX(TM)
  - also operates in physiological frequency ranges as a cuirass ventilator (see neuromuscular conditions lesson)

Hayek RTX(TM)

- biphasic - inspiratory & expiratory pressures
  - frequency up to 17 Hz
  - pressures -70 cm H2O to +70 cm H2O
- oscillations for secretion mode
  - vibration phase - high f, low P
  - cough phase - low f, higher P

Click to see video of Hayek ventilator (1 min)
https://www.youtube.com/watch?v=G2_eVGgx1zE&feature=emb_logo

Evidence for effectiveness

- Trials are mostly small, crossover trials - quality of evidence?
- These techniques seem to be at least as good as conventional BHPT (depends on who's doing the BHPT)
- Clinical trial (McIlwayne, 2013)
  - Compared HFCWO vs. PEP
  - Results favor PEP over HFCWO

Evidence for effectiveness

- Considerations
  - costs - capital, personnel & training
  - portability - home use
  - patient capability - self-administration
  - patient tolerance
  - patient preference ==> adherence

Dymedso Frequencer(TM)

- Acoustic/mechanical device
- Invented by cystic fibrosis patient

Image courtesy of Dymedso

Dymedso Frequencer(TM)

- Operation - mechanical and acoustical stimulation over chest at 30-70 Hz
- Agitation by mechanical and acoustical waves causes mucolysis
- Controls adjusted by patient sensation:
  - frequency
  - volume

Dymedso Frequencer(TM)

- Evidence for effectiveness
  - One clinical trial
    - 22 CF patients
    - nonrandomized
    - outcome measure - sputum weight
    - more sputum with Frequencer

Kinetic bed therapy

- Intensive care beds with additional capabilities
  - rotation
  - postural drainage
  - percussion
- Rationale - mobilize secretions to prevent ventilator-associated pneumonia and atelectasis

Kinetic bed therapy

- Evidence of effectiveness for kinetic beds for mechanically ventilated patients
  - may compromise hemodynamics - some patients do not tolerate
  - clinical trials found mixed results
  - meta-analysis concluded:
    - possible reduction in pneumonia
    - no effect on mortality
    - no effect on duration of ventilation
    - no effect on hospital stay

Fiberoptic bronchoscopy

- Advantage - direct visualization
- Disadvantages:
  - expense
  - invasiveness
- Not indicated for generalized secretion removal
- Indicated for lobar or segmental atelectasis due to mucus plug or foreign body (kids)

Ventilation patterns

- Ventilator settings influence mucokinesis
  - increased inspiratory flow moves mucus deeper
  - increased expiratory flow moves mucus cephalad
  - increased expiratory time moves mucus cephalad
  - auto-PEEP can work either way
- Authors do not advocate clinical application of findings

Summary & Review

- Bronchial hygiene physical therapy
  - standard for CF, bronchiectasis
  - no support for routine application to COPD
- Cough
  - becomes primary mucokinetic with impaired mucociliary clearance
  - compromised by neuromuscular ds, COPD

Summary & Review

- Directed cough - taught, supervised cough
  - FET
  - Active cycle of breathing
- Autogenic drainage - esp. for CF
- Cough assistance - manual and mechanical
- PEP
- Vibratory PEP

Summary & Review

- Intrapulmonary percussive devices
  - Pulses to airways & mini-coughs
  - Devices
    - Vortran PercussiveNeb(TM)
    - IPV; Impulsator(TM) (Forrest Bird)
- External oscillators/ percussors
  - The Vest(TM)
  - SmartVest(TM)
  - Hayek RTX(TM) cuirass

Summary & Review

- Frequencer(TM) - acoustic/mechanical vibrations
- Kinetic bed therapy
- Fiberoptic bronchoscopy
- Ventilation patterns

Therapy for Atelectasis

Atelectasis primary types

- Obstructive atelectasis- AKA absorption atelectasis
  - most common
  - mechanism - airway obstructed and distal gas is absorbed
  - obstructions
    - mucus plugs
    - foreign body - aspiration
    - tumor - intraluminal or extraluminal

Atelectasis primary types

- Obstructive atelectasis
  - worsened by high FIO2 - O2 is absorbed
  - lessened by collateral ventilation - augmented by end-expiratory pressure

Atelectasis types & causes

- Non-obstructive
  - Passive atelectasis
    - pleural separation - pleural effusion
    - shallow breathing - healthy persons develop atelectasis with shallow breathing, as with TV watching
  - Compression atelectasis
    - volume occupying lesions
    - abdominal distension

Atelectasis types & causes

- Non-obstructive
  - Adhesive atelectasis
    - surfactant deficiency; e.g., RDS, ARDS
    - shallow breathing
    - inhalation injury; e.g., smoke
    - cardiopulmonary bypass
  - Gravity-dependent atelectasis - due to gravity-dependent volume changes in alveoli

Risk factors

- Patient factors
  - Current smoking
  - COPD
  - Ischemic heart disease
  - Obesity - high risk & persistence
  - Hx of stroke
  - Shallow breathing
  - Watching television - decreases sigh rates (sad movies??)

Risk factors

- Nosocomial factors
  - Anesthesia
  - High FIO2 - O2 absorbed
  - Cardiopulmonary bypass

Complications

- Atelectasis after upper abdominal and thoracic surgery is common.
- Postoperative atelectasis does not commonly cause significant morbidity
- Hypoxemia - most common
- Pneumonia - rarely a result of postoperative atelectasis
- Fever - NOT

Prevention of atelectasis - NOT

- Interventions that do NOT prevent postoperative atelectasis
  - Incentive spirometry
  - Bronchial hygiene physical therapy
  - Kinetic beds
- Routine application of these measures to prevent postoperative complications is not justified by research findings

Prevention of atelectasis

- Interventions that may help prevent postoperative atelectasis:
  - avoiding high FIO2 during and after surgery - increasing FIO2 to extubate increases risk for postoperative atelectasis
  - PEEP during surgery, especially for obese patients
  - ambulation

Prevention of atelectasis

- Interventions that may help prevent postoperative atelectasis:
  - PEP, CPAP after surgery - good evidence in support
    - thoracoabdominal aneurysm surgery - continuous NCPAP @ 10 cm H2O for 12 - 24H
    - PEP or CPAP via face mask 30 breaths Q1H x 3D (pressure??)
    - meta-analysis supports

Prevention of atelectasis

- Interventions that may help prevent postoperative atelectasis:
  - deep breathing exercises? NOT
    - 2005 study - deep breathing was with 10 cm PEP
  - cough assistance - patients with impaired cough
  - vibratory PEP?

Treatment of atelectasis

- Obstructive atelectasis
  - bronchial hygiene physical therapy - first choice for acute atelectasis
  - bronchoscopy
    - foreign body aspiration
    - acute, extensive atelectasis
  - alfa dornase (Pulmozyme) nebulized and instilled - for non-CF pediatric patients
  - cough assistance?

Treatment of atelectasis

- Non-obstructive atelectasis
  - intrapulmonary percussive ventilation
    - 15 min BID via face mask- pediatric patients
    - superimposed on CMV for obese patients
  - vibratory PEP?
  - ambulation

Treatment of atelectasis

- Non-obstructive atelectasis
  - CPAP, PEP
  - Noninvasive pressure support (BiPAP) - face mask
    - may be better than CPAP
    - PEEP 5 cm H2O
    - PS for TV = 8-10 mL/kg
    - 30 min. QID
    - improved radiological atelectasis score over CPAP

Bottom line (my opinion)

- In most instances, atelectasis happens (like the bumper sticker)
- For most patients, ambulation is all that's needed to prevent and treat atelectasis
- Incentive spirometry is a waste of time, money and environmental resources (plastic, dump space)

Bottom line (my opinion)

- Patients at risk may benefit from preventative measures
  - morbidly obese
  - excessive, tenacious secretions
  - prolonged procedures, esp. on CP bypass
  - compromised cough
    - peak cough flow < 160 L/min (adults)
    - MEP < 45 cm H2O

Bottom line (my opinion)

- Preventative measures
  - Cough assistance for weak cough
  - CPAP, BiPAP, vibratory PEP
  - most patients need mask therapy
  - end-expiratory pressure should be measured - ≥10 cm H2O
  - duration and frequency must be adequate??
    - continuous nCPAP or BiPAP
    - 30 breaths Q1H

Bottom line (my opinion)

- Atelectasis is common - only treat for acute, complicated cases:
  - clinical signs of respiratory distress
  - moderate-severe hypoxemia
  - segmental, lobar involvement

Bottom line (my opinion)

- Treatment measures
  - CPAP, PEP, BiPAP, vibratory PEP - by mask
  - bronchial hygiene physical therapy
  - cough assistance
    - manual
    - mechanical - CoughAssist(TM)
  - intrapulmonary percussive ventilation - mask or with ventilator
  - fiberoptic bronchoscopy - lobar, from plugs

Summary & Review

- Atelectasis
  - types
    - obstructive
    - non-obstructive - adhesive, passive, etc.
  - risk factors - patient and nosocomial
  - complications
    - hypoxemia
    - pneumonia - rare
    - fever - NOT

Summary & Review

- Prevention of atelectasis
  - NOT:
    - BHPT
    - incentive spirometry
  - maybe:
    - PEP, CPAP, vibratory PEP
    - cough assistance

Summary & Review

- Treatment of atelectasis
  - obstructive
    - BHPT
    - bronchoscopy
  - non-obstructive
    - intermittent percussive ventilation
    - PEP, CPAP, vibratory PEP
    - BiPAP

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