Meeting will begin at
14:00 Central Time

If you can see this and hear
music then you are ready. Music will begin
approximately 45 minutes to showtime.

We have muted all participants.
Please use the chat feature or
call 1-800-720-7287 for questions or help.

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Lung Protective Strategies

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Keith Varnes, RRT-ACCS, RRT-NPS, AE-C

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Learning Objectives

- Explain the pathogenesis of ventilator-induced lung injury
- Explain the rationale and implementation of strategies applied during mechanical ventilation to ensure gas transport, while minimizing ventilator-induced lung injury

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Lung Protective Strategies

- Rationale – Ventilate and oxygenate without ventilator-induced lung injury (VILI)

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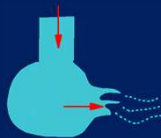
Ventilator-Induced Lung Injury

- VILI – injury to the lung caused by mechanical ventilation
  - Mechanical injury
    - Volutrauma, overdistending lung units, causing leaks



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Ventilator-Induced Lung Injury

- VILI – injury to the lung caused by mechanical ventilation
  - Mechanical injury
    - volutrauma, overdistending lung units, causing leaks
    - Atelectrauma – repetitive opening of "sticky" alveoli

- Hyperoxia – oxidant injury to the lung

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Ventilator-Induced Lung Injury

- VILI – injury to the lung caused by mechanical ventilation
  - Inflammation
    - biotrauma, due to release of mediators of inflammation
    - leads to multiple organ system failure

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Ventilator-Induced Lung Injury

- Targets
  - alveolar cells
  - alveolar capillaries
  - pulmonary fibrous network

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Ventilator-Induced Lung Injury

- Types of damage
  - Alveolar cells
    - Inflammation due to cytokine release
    - Abnormal surfactant production
  - Alveolar capillaries
    - Increased resistance to blood flow
    - Increased permeability - edema

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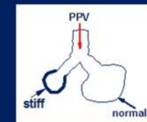
Ventilator-Induced Lung Injury

- Problem: Non-uniform pathology in ALI/ARDS
- High pressure to inflate stiff units stretches normal units



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Ventilator-Induced Lung Injury

- Specific causes
  - Excessive tidal volume – stretch
  - Deficient end-expiratory pressure atelectrauma
  - Hyperoxia
  - Excessive rate
  - Excessive inspiratory flow

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Ventilator-Induced Lung Injury

- In patients with ARDS, inflammatory response may occur after 2 hours of excessive tidal volume with hyperoxia

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Ventilator-Induced Lung Injury

- Lung protective strategies should address all of these:
  - Excessive tidal volume
  - End-expiratory pressure atelectrauma
  - Hyperoxia
  - Excessive rate
  - Inspiratory flow

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Lung Protective Strategies

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Lung Protective Strategies

- Open the lung and keep it open, with minimal stress
- Avoid de-recruitment (alveolar collapse)
- Ventilate at greatest compliance

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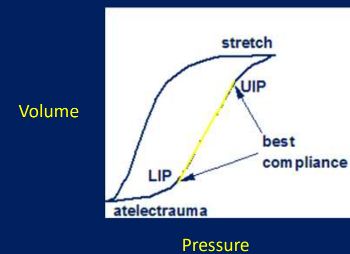
Best Compliance Zone

Volume



Pressure

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Open Lung Concept

- Tidal Volume < 7 mL/kg IBW or PBW
  - PBW Male = 50 kg + (2.3 kg per inch above 60)
  - PBW Female = 45.5 kg + (2.3 kg per inch above 60)
- Optimal PEEP
  - Recruits alveoli
  - Prevents de-recruitment
  - Moves edema from airways
- Recruitment maneuvers (RM)

Link to predicted body weight chart

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Open Lung Concept

- Optimal PEEP level with greatest:
  - Static lung compliance (Cst)
  - Mixed venous PO_2, SO_2

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Open Lung Concept

- Methods for optimal PEEP:
  - LIP on VP curve plus 2-3 cmH_2O
  - Incremental PEEP with compliance measurement
  - Decremental PEEP with compliance measurement
  - Alternate method (Mercat et al)

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Open Lung Concept

- Alternate method for PEEP:
  - T_V = 6 mL/kg IBW
  - PEEP increased to Ppt = 28-30 cmH_20
  - Alternate method (Mercat et al)

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Open Lung Concept

- Recruitment maneuver - high level of CPAP
- Rationale - recruit and re-recruit alveoli PRN
- CPAP 30-40 cmH_2O for 30-90 seconds

Next is a video of recruitment (1:02 min)

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Open Lung Concept

- Recruitment maneuver
  - Indications
    - Early in ALI, ARDS
    - After ventilator disconnections
    - Desaturation

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Open Lung Concept

- Recruitment maneuver
  - Procedure
    - FiO_2 100%
    - CPAP 30 cmH_2O for 30-90 seconds
    - If first RM tolerated, after 15-20 minutes repeat at 35-40 cmH_2O
    - May repeat, if tolerated

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Pressure Control Inverse Ratio Ventilation (PCIRV)

- PCV limits volutrauma, because small T_V is delivered
- Inverse I:E prolongs time for recruitment, limiting time for de-recruitment
- Early application in ALI/ARDS permits decreasing FiO_2 and improves patient outcomes

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Pressure Control Inverse Ratio Ventilation (PCIRV)

- History
  - Initially used for neonates (1972), using Bennett PR-2 ventilators
  - Subsequent application for neonates resulted in VILI

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Pressure Control Inverse Ratio Ventilation (PCIRV)

- History
  - Initially used for neonates (1972), using Bennett PR-2 ventilators
  - Subsequent application for neonates resulted in VILI
  - Applied to adults in 1980s, using Siemens 900C
  - Subsequent application for adults resulted in VILI
  - Flow pattern made the difference

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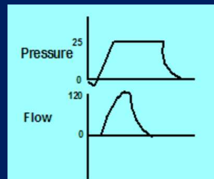
Pressure Control Inverse Ratio Ventilation (PCIRV)

- Square pressure wave form
- Decelerating flow wave form



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Pressure Control Inverse Ratio Ventilation (PCIRV)

- Indications: ARDS, ALI
- Advantages
  - Minimal volutrauma
  - Maximal time for alveolar recruitment
  - Minimal time for alveolar de-recruitment

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Pressure Control Inverse Ratio Ventilation (PCIRV)

- Disadvantages
  - Patient asynchrony, discomfort
  - Requires sedation, paralysis
  - Hemodynamic compromise, usually manageable with fluid administration
- IRV with pressure-controlled, volume guarantee may be equally effective, depending on inspiratory flow pattern

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Dual Level CPAP

- Not a new mode - studied by Downes, (1987)
- Two levels of CPAP, with time-triggered, time-cycled pressure release and spontaneous breathing
- May be perfect mode for ARDS/ALI in spontaneously breathing patients

See below for FYI link to article on APRV

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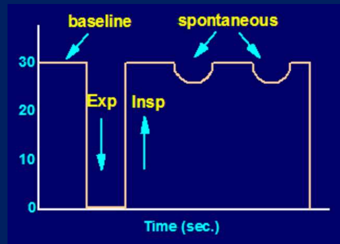
Dual Level CPAP



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Dual Level CPAP

- Indication - acute lung injury
- Advantages
  - Lower peak, plateau pressures
  - Spontaneous breathing
  - Recruitment, with limited opportunity for de-recruitment
  - Improved V/Q matching
  - Limited adverse circulatory effects

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Dual Level CPAP

- Disadvantages
  - Asynchrony with spontaneous breaths (probably unimportant)
  - Unfamiliarity of staff with technique
  - Limited research

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Dual Level CPAP

- Ventilator settings
  - Pressure High below UIP (20-30 cmH_2O)
  - Pressure Low above LIP (0-5 cmH_2O)
  - Time High 4-6 seconds
  - Time Low 0.2-0.8 seconds

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Dual Level CPAP

- Availability
  - Drager ventilators
  - Siemens Servo-i
  - Hamilton ventilators
  - Puritan-Bennett 840
  - GE Engstrom Carestation

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Permissive Hypercapnea

- PCO_2 permitted to rise rather than increase ventilator settings
  - Prevents volutrauma
  - Elevated CO_2 may inhibit inflammation

Link to article on CO_2 and acute lung injury

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Permissive Hypercapnea

- Precautions
  - Superimposed metabolic acidema
  - Cerebral edema
  - Hypovolemia
  - Beta blockade

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Permissive Hypercapnea

- Acidema may be reversed with tromethamine (THAM)
  - Proton acceptor
  - Does not depend on CO_2 excretion to increase pH

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Permissive Hypoxemia

- Rationale - to avert VILI, and/or pulmonary oxygen toxicity
- Considerations
  - Fetal PO2 - UA 12-18 mmHg, UV 26-32 mmHg
  - Lowest reported PaO_2 in adult human - 19 mmHg (Mt. Everest climber)
  - Hyperoxemia is associated with increased mortality

Link to an article about permissive hypoxemia

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Permissive Hypoxemia

- Compensations
  - Cardiac output augmentation
  - Hypercapnea - increases O_2 release to tissues
  - Erythrocytosis - increases content
  - Decreased muscular activity decreases O2 requirements - hibernation?

Link to 2nd article about permissive hypoxemia

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Permissive Hypoxemia

- Monitoring
  - PaO_2, SpO_2
  - Noninvasive cardiac output
  - Blood lactate
  - Acid-base status
- Contraindications
  - Brain injury
  - Limited cardiac output
  - Anemia
  - Pulmonary hypertension

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Tracheal Gas Insufflation (TGI)

- Continuous flow of gas in trachea to wash out CO2
- Safety issues are concerns
- Equipment issues (circuits) are concerns
- Interactions with ventilator trigger, etc.

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Prone Positioning

- Effects
  - Improved V/Q equality
  - May increase FRC
  - Increased secretion drainage - may be the primary benefit
  - Increased effects of RMs
  - May decrease VILI

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Prone Positioning

- Precautions
  - Tracheostomies
  - Chest tubes
  - Obesity, abdominal distension
  - Pregnancy
  - Ventral surface lesions
  - Pelvic or spinal lesions

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Prone Positioning

- Precautions
  - Physically difficult to achieve with many patients
  - Pronation reduces chest wall compliance - patients on PCV will need increased PIP
  - Pronation may cause secretion drainage from mouth and ETT - be prepared for it

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Prone Positioning

- Disadvantages/adversity
  - Pressure injury to face
  - Misadventures
  - Personnel resources - time

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Prone Positioning

- Status of research findings
  - Short term improvement in oxygenation
  - No improved outcomes for adults or children
  - Pronation must be applied early and be prolonged (≥ 16 hours/day) to be effective

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High Frequency Ventilation

- Ventilation at high rates, low tidal volumes, high MAP
- Types
  - HFJV – $T_V > VD_{AN}$
  - HFOV – $T_V < VD_{AN}$

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High Frequency Ventilation

- Advantages
  - Minimal TV prevents volutrauma and stretch
  - Ventilate in presence of large leaks
- Disadvantages
  - Expense – equipment, training

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High Frequency Ventilation

- Research findings
  - As good as conventional ventilation
  - No improvement in outcomes, compared to conventional ventilation
- Additional research needed:
  - Appropriate conditions?
  - Appropriate patient population?
  - Appropriate method - jet, oscillator?

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Nitric Oxide

- Action – dilates pulmonary vessels for ventilated alveoli, improving V/Q matching
- FDA approved only for persistent pulmonary hypertension (PPHN) of the newborn

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Nitric Oxide

- Action – dilates pulmonary vessels for ventilated alveoli, improving V/Q matching
- FDA approved only for persistent pulmonary hypertension (PPHN) of the newborn
- Use for other conditions off-label and may not be paid for
- Very expensive:
  - Equipment, NO gas
- Training

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Nitric Oxide

- Status of research
  - Temporary improvement of oxygenation
  - No improvement in outcomes
- Inhaled prostacyclin is as effective and less expensive

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Additional Strategies

- Surfactant
  - Reduced mortality among children with ARDS
  - Adults
    - Volume required - expensive
    - Inconsistent research results

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Additional Strategies
- Partial liquid ventilation - very expensive
- Anti-inflammatory nutrition - borage oil
- Antioxidant therapy - n-acetylcysteine

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Partial Liquid Ventilation
- Lungs filled to FRC with perflubron (LiquiVent), with these properties
  - High density - flows to dependant areas of the lung
  - Low surface tension - increases compliance
  - High solubility for O_2 and CO_2 - transports gases
  - High volatility - quickly excreted

Next see a video of a mouse swimming in perflubron (includes strong language)

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Partial Liquid Ventilation
- Physiologic effects
  - Increased lung compliance, due to:
    - Decreased surface tension
    - Alveolar recruitment
  - Decreased VILI due to increased compliance
  - Decreased shunt due to alveolar recruitment & diffusion across perflubron

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Partial Liquid Ventilation
- Potential applications
  - RDS - neonates
  - Meconium aspiration - not effective for adults
  - ALI/ARDS

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Partial Liquid Ventilation
- Procedure
  - Proflubron instilled to FRC
  - Re-installation required, due to evaporation

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Partial Liquid Ventilation
- Research Findings
  - Neonates - non-responders to surfactant survived (n=10)
  - A trial in 2006 found negative for PLV
  - Earlier trials did not compare PLV with lung protective ventilation

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Partial Liquid Ventilation

- Barriers to adoption
  - Expense
    - Perflubron
    - Time - dosing, re-dosing
  - Lack of positive research findings
- Opinion - PLV will not become a widely-used technique, at least for adults

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Summary & Review

- VILI mechanisms
  - Atelectrauma
  - Volutrauma
  - Inflammation
- Lung protection
  - Alveolar recruitment
  - Avoid stretch

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Summary & Review

- Lung Protective Strategies
  - Low T_V, optimal PEEP, RMs
  - Pressure-controlled inverse ratio ventilation
  - Dual level CPAP (APRV)
  - Tracheal gas insufflation
  - Prone positioning
  - High-frequency ventilation
  - Nitric oxide

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The End

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Evaluations & Certificates

- Please go back to Lesson 2 on our website and click Mark Complete.
- Then go to lesson 3, fill out the evaluation, click Submit, then Mark Complete.
- Certificates will be available immediately.
- We will turn off the evals in 1 hour.

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