**Lung Protective Strategies**

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**Learning Objectives:**
- Outline the pathogenesis and pathophysiology of ventilator-induced lung injury.
- Examine the mechanisms by which lung protective strategies can prevent ventilator-induced lung injury.
- Discuss the effects, procedures, advantages, disadvantages and evidence for effectiveness pertaining to the following lung protective strategies:
  - open lung concept
  - pressure-controlled inverse ratio ventilation
  - dual level continuous positive airway pressure
  - permissive hypercapnea
  - tracheal gas insufflation
  - prone positioning
  - high-frequency ventilation
  - nitric oxide
  - partial liquid ventilation

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**Lung protective strategies**

- Rationale: ventilate & 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
  - atelectrauma: repetitive opening of ‘sticky’ alveoli
  - hyperoxia: oxidant injury to 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
Ventilator-induced lung injury

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

- Types of damage
  - alveolar cells
    - inflammation, due to cytokine release
    - abnormal surfactant production
  - alveolar capillaries
    - increased resistance to blood flow
    - increased permeability - edema

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

- Specific causes
  - excessive tidal volume - stretch
  - deficient end-expiratory pressure - atelectrauma
  - hyperoxia
  - excessive rate
  - excessive inspiratory flow

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

- Lung protective strategies should address all of these
  - tidal volume
  - end-expiratory pressure
  - hyperoxia
  - rate
  - inspiratory flow
Lung Protective Strategies

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

Best Compliance Zone

- Tidal volume <7 mL/kg IBW
- Optimal PEEP
  - recruits alveoli
  - prevents de-recruitment
  - moves edema from airways
- Recruitment maneuvers (RM)

Open Lung Concept

Optimal PEEP level with greatest:
- Static lung compliance (Cst)
- Mixed venous PO2, SO2

Methods for optimal PEEP
- LIP on VP curve- plus 2-3 cm H2O
- incremental PEEP with compliance measurement
- decremental PEEP with compliance measurement
- alternate method (Mercat et al)

FYI - Link to predicted body weight chart
http://www.ardsnet.org/system/files/pbwtables_2005-02-02_0.pdf
Open Lung Concept
- Alternate method for PEEP
  - TV = 6 mL/kg IBW
  - PEEP increased to Ppt = 28-30 cm H2O

Open Lung Concept
- Recruitment maneuver - high level CPAP
  - Rationale - recruit and re-recruit alveoli PRN
  - CPAP 30-40 cm H2O for 30-90 sec

Click to see video of lung recruitment
http://www.youtube.com/watch?v=oKH7CtsEgHw

Open Lung Concept
- Recruitment maneuver
  - Indications
    - early in ALI, ARDS
    - after ventilator disconnections
    - desaturation

Open Lung Concept
- Recruitment maneuver
  - Procedure
    - FIO2 100%
    - CPAP 30 cm for 30-40 sec
    - if first RM tolerated, after 15-20 min. repeat at 35-40 cm
    - may repeat, if tolerated

Pressure controlled inverse ratio ventilation (PCIRV)
- PCV limits volutrauma, because small TV is delivered
- inverse I:E prolongs time for recruitment, limiting time for de-recruitment
- early application in ALI/ARDS permits decreasing FIO2 and improves patient outcomes

PCIRV
- History
  - Initially used for neonates (1972), using Bennett PR-2 ventilators
  - Subsequent application for neonates resulted in VILI
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 applications for adults resulted in VILI
  - Flow pattern made the difference

- **Indication**
  - ARDS, ALI

- **Advantages:**
  - Minimal volutrauma
  - Maximal time for alveolar recruitment
  - Minimal time for alveolar derecruitment

- **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.

PCIRV

- **Flow pattern**:
  - Square pressure waveform
  - Decelerating flow wave

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 ALI/ARDS in spontaneously breathing patients.

FYI - Link to article on APRV
http://www.thoracicmedicine.org/article.asp?pii=1071-2225;year=2007;volume=2;issue=4;spage=176;epage=179;aulast=Daoud

Dual level CPAP

- Baseline
- Spontaneous
- Time (sec.)
**Indication** - acute lung injury

**Advantages**
- Lower peak, plateau pressures
- Spontaneous breathing
- Recruitment, with limited opportunity for de-recruitment
- Improved V/Q matching
- Minimal adverse circulatory effects

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

**Ventilator settings**
- Pressure High below UIP (20-30 cm H2O)
- Pressure Low above LIP (0-5 cm H2O)
- Time High 4-6 sec.
- Time Low 0.2-0.8 sec.

**Availability**
- Drager ventilators
- Siemens Servoi
- Hamilton ventilators
- Puritan-Bennett 840
- GE Engstrom Carestation

**Permissive hypercapnea**
- PCO2 permitted to rise rather than increase ventilator settings
- Prevents volutrauma
- Elevated CO2 may inhibit inflammation

**Precautions**
- Superimposed metabolic acidemia
- Cerebral edema
- Hypovolemia
- Beta blockade

FYI - Link to article on CO2 and acute lung injury
http://erj.ersjournals.com/cgi/reprint/20/1/6
**Permissive hypercapnea**

- Acidemia may be reversed with tromethamine (THAM)
  - proton acceptor
  - does not depend on CO2 excretion to increase pH

FYI - Link to article on THAM and permissive hypercapnia
http://ajrccm.atsjournals.org/cgi/content/full/162/4/1361

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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 triggers, etc.

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**Prone positioning**

- Effects:
  - may increase FRC
  - increased secretion drainage - may be the primary benefit
  - improved VQ equality
  - increased effects of RMs
  - may decrease VILI

FYI - Link to article on pragmatics of pronation
http://ajrccm.atsjournals.org/cgi/content/full/165/10/1359

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**Precautions:**

- tracheostomies
- chest tubes
- obesity, abdominal distension
- pregnancy
- ventral surface lesions
- pelvic, spinal lesions

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**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.

FYI - Link to article on pragmatics of pronation
http://ajrccm.atsjournals.org/cgi/content/full/165/10/1359

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**Disadvantages/adversity**

- pressure injury to face
- misadventures
- personnel resources - time
**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 H) to be effective.

FYI - click for abstract of 2013 study on prolonged pronation for ARDS

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**High frequency ventilation**
- Ventilation at high rates, low tidal volume, high MAP
- Types:
  - HFJV- TV > VD<sub>AN</sub>
  - HFOV- TV < VD<sub>AN</sub>

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**High frequency ventilation**
- Advantages:
  - minimal TV prevents volutrauma and stretch
  - ventilate in presence of large leaks
- Disadvantage
  - expense- equipment, training

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**Nitric Oxide**
- Action- dilates pulmonary vessels for ventilated alveoli, improving VQ matching
- FDA approved only for persistent pulmonary hypertension in newborns

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**Nitric Oxide**
- Action- dilates pulmonary vessels for ventilated alveoli, improving VQ matching
- FDA approved only for persistent pulmonary hypertension in newborns
- Use for other conditions is off-label and may not be paid for
- Very expensive:
  - equipment, NO gas
  - training
Nitric Oxide

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

Additional strategies

- surfactant
  - reduced mortality among children with ARDS
  - adults
    - volume required - expense
    - inconsistent research results
    - aerosolized lucinactant under study

Additional strategies

- partial liquid ventilation - very expensive
- anti-inflammatory nutrition - borage oil
- antioxidant therapy - n-acetylcysteine

Partial liquid ventilation

- Lungs filled to FRC with perflubron (LiquiVent), with these properties:
  - high density - flows to dependent areas of lung
  - low surface tension - increases compliance
  - high solubility for O2 and CO2 - transports gases
  - high volatility - quickly excreted

Click to see video of mouse swimming in perfluorobutane (includes strong language)
http://www.youtube.com/watch?v=1NAU8Iz6aXE

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 perfluorobutane

Partial liquid ventilation

- Potential applications:
  - RDS - neonates
  - meconium aspiration - not effective for adults
  - ALI/ARDS
Partial liquid ventilation

- Procedure
  - perflubron instilled to FRC
  - re-instillation required, due to evaporation

Partial liquid ventilation

- Research findings
  - neonates - non-responders to surfactant survived (n = 10)
  - adults - most recent trial (2006) found negative for PLV
  - earlier trials did not compare PLV with lung protective ventilation

FYI - Click to download article on PLV for neonates with RDS
http://content.nejm.org/cgi/content/full/335/11/761
FYI - Click to download article on PLV for adults with ARDS
http://ajrccm.atsjournals.org/cgi/reprint/173/8/882

Partial liquid ventilation

- Barriers to adoption
  - expense
    - perflubron
    - time - dosing, redosing
  - lack of positive research findings

- Opinion - PLV will not become a widely-used technique, at least for adults

Summary & Review

- VILI mechanisms
  - atelectrauma
  - volutrauma
  - inflammation

- Lung protection
  - alveolar recruitment
  - avoid stretch

Summary & Review

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

References

References

- Thomas Dyhr, Jan Bonde and Anders Larsson. Lung recruitment manoeuvres are effective in regaining lung volume and oxygenation after open endotracheal suctioning in acute respiratory distress syndrome.