About the Speaker

• Undergraduate
  – BS in Business Administration
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  – MBA with emphasis in consultancy

• Medical School
  – Sanford School of Medicine (University of South Dakota)

• Residency
  – University of New Mexico (Internal Medicine)

• Fellowship
  – University of New Mexico (Pulmonary/Critical Care)

• Relevant Work Experience
  – Executive Director, Residential Care Facility for the Chronically Ill
  – Public Health (Primary/Specialty Medical Care Indigent)
  – Hospitalist (Acute and Critical Care)
  – Pulmonologist/Intensivist
Disclosures

• I have no financial disclosures
Goals and Objectives

- Understand the risk factors for ARDS
- Define ARDS and the impact of the Berlin Criteria
- Discuss the role of mechanical ventilation in profound hypoxemia
- Understand the role of neuromuscular blockade in the management of ARDS
- Discuss the role of prone positioning in the treatment of ARDS
- Define how timing of tracheostomy effects outcomes
- List ineffective or harmful therapies in ARDS
Grading of Recommendations

• 1 = Strong Recommendation
• 2 = Weak Recommendation

• A = Good evidence from randomized trials
• B = Moderate strength evidence from small randomized trial(s) or upgraded observational trials
• C = Low strength evidence, well-done observational trials with control randomized controlled trials
• D = Very low strength evidence, downgraded controlled studies or expert opinion
INTRODUCTION
Introduction

• Distinct type of hypoxemic respiratory failure
  – Abnormality of both lungs

• Acute, diffuse, inflammatory lung injury
  – Increased pulmonary vascular permeability
  – Increased lung weight
  – Loss of aerated tissue

• Pathology
  – Diffuse alveolar damage
    • Alveolar edema with or without focal hemorrhage, acute inflammation of the alveolar walls, and hyaline membranes
Microscopy of ARDS

Normal Alveoli
Microscopy of ARDS

Case 39: Adult respiratory distress syndrome

intra-alveolar oedema
Microscopy of ARDS

Case 39: Adult respiratory distress syndrome

- brightly eosinophilic hyaline membranes
- regenerative hyperplasia of Type 2 pneumocytes (examples)
Common Causes of ARDS

• DIRECT
  – Aspiration of gastric contents
  – Infectious pneumonia
  – Inhalation of toxic gas or aerosol
  – Lung contusion
  – Near-drowning
  – Fat emboli

• INDIRECT
  – Bacterial sepsis
    • Especially gram-negative
  – Trauma of a non-thoracic origin
    • Multiple fractures
  – Multiple blood transfusions
  – Pancreatitis
  – Opiate and other drug overdose
    • Heroin, methadone, barbiturates, salicylates
  – Disseminated intravascular coagulation
  – Other infectious causes
  – Snake bite
  – Cardiopulmonary bypass
Introduction

- Case-fatality rate decreased during the 1990’s
  - Still exceeds 30%

- No drug has proven beneficial in the prevention or management of ARDS

- Mainstay of therapy
  - Supportive
    - Improving gas exchange
    - Preventing complications
Introduction

• Diagnosis of ARDS
  – Chest X-ray
    • Accuracy of portable chest radiograph to detect ARDS is limited
  – CT Scan
    • High PPV and moderate NPV
      – Upper-lobe-predominant ground-glass attenuation (95.2%/47.5%)
      – Central-predominant ground-glass attenuation (92.3%/51.4%)
      – Central airspace consolidation (92.0%/50.0%)
Mortality Prediction and the Berlin Criteria

INTRODUCTION
Definition of ARDS

- 1994 to 2012
  - American-European Consensus Conference (AECC)

- Criteria
  - Acute onset of hypoxemia defined by partial pressure of arterial oxygen/fraction of inspired oxygen (PaO$_2$/FiO$_2$, or P/F) ratio of > 200, with
  - New bilateral infiltrates
  - Not attributable to heart failure as defined by pulmonary capillary wedge pressure (PCWP) (as measured by a Swan-Ganz catheter) of not more than 18 mmHg (or absence of suspected left atrial hypertension/cardiogenic pulmonary edema if PCWP was not available)
Definition of ARDS

2012
- European Society of Intensive Care Medicine
  - Expert panel to improve the reliability and validity of the ARDS definition → Berlin Criteria

Criteria
- Defining three categories of ARDs severity on the basis of P/F ratio
  - ≤ 300 and >200 “mild” ARDS (previously acute lung injury)
  - 100-200 “moderate” ARDS
  - <100 “severe” ARDS
- Defining “acute” onset of bilateral infiltrates as within 7 days of exposure to an ARDS risk factor or worsening respiratory symptoms
- More definitive chest radiograph criteria were provided
  - Bilateral infiltrates consistent with pulmonary edema and not fully explained by effusion, lobar/lung collapse, or nodules
  - Use of CT scan allowable
- Use of the PCWP for defining cardiogenic pulmonary edema was removed
- If a risk factor for ARDS is not identified
  - Some objective criteria of cardiac function
- Minimum use of PEEP of at least 5 cm H₂O on mechanical ventilation (or delivered by NIV only in the mild ARDS category) → assessing the severity of oxygenation impairment using the P/F ratio
Implications of Berlin Criteria

• Derived and validated
  – Variable which did not improve severity prediction were excluded
    • Lung compliance, radiographic severity, levels of PEEP, and exhaled minute ventilation

• Categorizing severity directed attention to most afflicted group

• Allowed for mortality prediction
  – Mild 27%
  – Moderate 32%
  – Severe 47%
MANAGEMENT OF HYPOXEMIA
Management of Hypoxemia

- Options for improving arterial oxygen saturations
  - Use of high fractions of inspired oxygen (FiO₂)
  - Decrease oxygen consumption
  - Improve oxygen delivery
  - Manipulate mechanical ventilator support

- Risk of high fractions of FiO₂
  - Absorptive atelectasis
    - Three gasses hold alveoli open (nitrogen, carbon dioxide and oxygen)
    - At ≥ 50% FiO₂ with small tidal volumes
    - Nitrogen is washed out (into venous system and released)
    - When oxygen is absorbed, little other gas to keep alveoli open
  - Oxygen toxicity
    - Oxygen damage from toxic oxygen species (free radicals) occurs within hours
      - Destroys type I alveolar cells
      - Proliferate type II alveolar cells → exudative stage → increase edema
        » Fluid build up increased V/Q mismatch → shunt
    - Goal is 50-60% range as soon as possible
Early versus Late Intubation

- Large multi-ICU prospective cohort study 2006-2011

- 457 patients with ARDS
  - 106 (23%) not intubated at time of diagnosis
  - Non-intubated patients had lower morbidity and severity of illness
  - However, mortality at 60 days was the same (36%) in both groups
  - Of 106 non-intubated patients
    - 56% required intubation within 3 days
  - Late intubation group had significantly higher 60-day mortality (56%) when compared to the early intubation group (36%; \( p < 0.03 \)) and patients never requiring intubation (26%; \( p = 0.002 \))
  - Increased mortality in the late intubation group persisted at 2-year-follow-up
  - Adjustments for baseline clinical and demographic differences did not change the results
MECHANICAL VENTILATION
Low Tidal Volume Ventilation

MECHANICAL VENTILATION
ARDS Net (Low Tidal Volume Ventilation)

- **ARMA Trial**
  - Compared 12 ml/kg (ideal body weight) and 6 ml/kg
  - Significant reduction in mortality with low tidal volume ventilation
    - 38% to 31%

- **Meta-analysis of six randomized trials (2009)**
  - Low tidal volume ventilation had significantly improved 28 day mortality (27.4 versus 37%) and hospital mortality (34.5 versus 43.2 percent) when compared to conventional mechanical ventilation
Low Tidal Volume Ventilation (LTVV)

• More recent studies have applied low tidal volume ventilation to at risk patients
  – Surgical patients

• A trial of intraoperative low-tidal-volume ventilation in abdominal surgery, NEJM (2013)
  – “Prophylactic“ protective ventilation
  – Improved clinical outcomes in intermediate- and high-risk patients undergoing abdominal surgery
Concerns for LTVV

- Low tidal volume ventilation is well tolerated and not associated with any clinically important adverse outcomes

- Concerns
  - Auto-PEEP
    - Theory → Higher RR used to maintain minute ventilation during LTVV may create auto-PEEP
      - Subgroup analysis reveals negligible quantities of auto-PEEP between two ventilation groups
  - Sedation
    - Work of breathing and asynchrony may increase need for sedation
      - Post-hoc analysis showed no significant differences in the percentage of days patients received sedatives, opioids, or neuromuscular blockage between the two ventilation groups
Potential Mechanisms of Protection

- **Barotrauma**
  - High pressures to lungs resulting in injury

- **Volutrauma**
  - High tidal volumes inducing lung stretch resulting in injury

- **Hemodynamics**
  - Less over distention improving venous return

- **Atelectrauma**
  - Lack of maintenance of open lung units has the potential to exacerbate lung injury from opening and closing of lung units
  - Studies show higher PEEP in moderate ARDS improved outcomes

- **Biotrauma**
  - Activation of cellular signaling cascades resulting in lung inflammation from stretching lung unit
Implementation

- Goal plateau airway pressure checked q4 hours and after every PEEP or tidal volume change
- Goal plateau airway pressure is 30 cm H₂O (ARMA Trial)
  - Goal plateau airway pressure in practice is < 28 cm H₂O
    - Decreases alveolar over distension and makes it unlikely to induce lung strain
- Goal for PaO₂ is between 55 and 80 mmHg
  - SpO₂ between 88-95%
- Permissive hypercapnia allowed

- 2016 multicenter international prospective cohort study (3,022 patients)
  - ARDS recognized in 60% patients
  - < 66% received a tidal volume of 8 mL/kg PBW
Spontaneous Breathing in ARDS

- Complete inactivity of the diaphragm results in disuse atrophy and muscle weakness
  - Ventilator-induced diaphragmatic dysfunction (VIDD)
  - Occurs in as little as 18-24 hours of MV
  - Can contribute to difficulty weaning and poorer prognosis

- Experimental studies → Assist-control ventilation or pressure support ventilation can reduce VIDD
  - Timing of allowing spontaneous breathing has been debated

- Experimental lung injury models in ARDS
  - Reduced markers of lung inflammation and epithelial cell damage
  - Improved tidal ventilation gas exchange and oxygen delivery
  - Increased systemic blood flow
Spontaneous Breathing in ARDS

• 2005 Study by Neumann et al.
  – Partial ventilator support with airway pressure release ventilation (APRV) compared to standard ventilation
    • Promoted alveolar recruitment in distal peri-diaphragmatic areas
    • Improved ventilation/perfusion matching and gas exchange
    • Increased oxygen delivery
  – Limited to those with mild to moderate ARDS

• 2013 Study by Yoshida and co-workers
  – Spontaneous breathing in a model of severe lung injury caused
    • High transpulmonary pressure
    • Worsened oxygenation and lung damage
    • Caused local injury by internal redistribution of volume
Considerations in Spontaneous Breathing

• Real transpulmonary pressures becomes the sum of the pressure generated by the ventilator and by the patient's respiratory muscles
  – Pressure targeted modes
    • Pressure assist/control ventilation and pressure support ventilation
    • True driving pressure is higher than the airway pressure (Paw)
  – Volume controlled ventilation
    • Transpulmonary pressure and tidal volumes are kept constant irrespective of muscular pressure

• Currently ongoing large multicenter randomized controlled study
  – Early Spontaneous Breathing in Acute Respiratory Distress Syndrome (BiRDS)
Not Standards of Care

- Proportional assist ventilation
- Neurally adjusted ventilator assist
- Noisy pressure support ventilation
PEEP in ARDS

- ARDS characterized by a major loss in lung volume
  - Alveolar flooding
  - Atelectasis
  - Consolidation
- PEEP is used to reverse hypoxemia and atelectasis
- Goal of PEEP is to recruit (or maintain recruitment of) atelectatic or flooded lung

- Three large multicenter randomized trials have tested higher versus lower PEEP while limiting tidal volumes in all patients
  - ALVEOLI Trial (Assessment of Low tidal Volume and elevated End-expiratory volume to Obviate Lung Injury)
  - ExPress Trial (Expiratory Pressure)
  - LOVS Trial (Lung Open Ventilation Study)
PEEP in ARDS Trial Results

- No significant improvement in mortality
- Express trial found an improvement in ventilator-free days

- Meta-analysis of the trials
  - Modest reduction in mortality for patients with moderate and severe ARDS in the higher PEEP arms
Physiological Consequences of PEEP

• Increase end-expiratory lung volume (EELV)
  – Highly recruitable patient
    • Substantial part of increased EELV due to reopening of previously collapsed lung tissue (recruitment)
  – Poorly recruitable patient
    • Most of the increase is generated by inflation of previously open lung tissue
      – Leads to overdistention \( \rightarrow \) risk of volutrauma
    – Effectiveness of PEEP based on patient characteristics

• Clinical trials suggest applying PEEP without assessment of recruitability may affect improving survival
  – This may explain the small effects of the previous trials
Techniques to Determine Proper PEEP

- Multiple pressure-volume curves
- Measurement of lung volume
- Use of $P_{oes}$ and transpulmonary pressure
- Lung ultrasound
- Physiological tests based on oxygenation
Techniques to Determine Proper PEEP

- **Multiple pressure-volume curves**
  - Plotting several pressure-volume curves at different PEEP levels on the same volume axis
  - Measuring or estimating the volume above functional residual capacity
- Measurement of lung volume
- Use of $P_{oes}$ and transpulmonary pressure
- Lung ultrasound
- Physiological tests based on oxygenation
Techniques to Determine Proper PEEP

- **Multiple pressure-volume curves**
- **Measurement of lung volume**
  - Nitrogen washout/wash-in technique
    - Good correlation with helium dilution or CT scans
  - Direct measurement of lung volume
  - FRC and/or EELV at each PEEP level and calculation of the strain
- Use of Poes and transpulmonary pressure
- Lung ultrasound
- Physiological tests based on oxygenation
Techniques to Determine Proper PEEP

- Multiple pressure-volume curves
- Measurement of lung volume
- **Use of $P_{oes}$ and transpulmonary pressure**
  - Estimate pleural pressure and then estimating transpulmonary pressure at end-inspiration and expiration from the difference between $P_{plat}$ or PEEP and esophageal pressures
    - Transpulmonary pressure = $P_{aw} - P_{oes}$
  - **EPVent Study** (Esophageal Pressure directed Ventilation)
    - ARDS → reduced chest wall compliance, edema or abdominal distension
      - Transpulmonary pressure can be negative at end-expiration
      - Indicates closed or compressed airways or atelectatic lung
    - PEEP can be increased until transpulmonary pressure becomes positive at end-expiration to keep airways open (positive values do not assure open alveoli in the zones distal to the sampling catheter)
    - Single center randomized controlled trial
      - $P_{oes}$ guided (experimental) versus ARDSNetwork (control)
      - Positive end-expiratory TPP experience higher $\text{PaO}_2/\text{FiO}_2$, better respiratory system compliance and trend toward reduced 28-day mortality
- **Goals titration of PEEP**
  - End-expiratory transpulmonary pressure between 0 and 10 cmH$_2$O (reduce cyclic alveolar collapse)
  - Maintaining end-inspiratory transpulmonary pressure ≤ 25 mc H$_2$O (reduce alveolar over distension)
- Lung ultrasound
- Physiological tests based on oxygenation
Techniques to Determine Proper PEEP

- Multiple pressure-volume curves
- Measurement of lung volume
- Use of Poes and transpulmonary pressure
- **Lung ultrasound**
  - Lung scoring based on the repeated examination of six lung regions in each lung before and after increasing PEEP
  - Equivalent to the pressure-volume curve methods
- Physiological tests based on oxygenation
Techniques to Determine Proper PEEP

- Multiple pressure-volume curves
- Measurement of lung volume
- Use of Poes and transpulmonary pressure
- Lung ultrasound
- **Physiological tests based on oxygenation**
High-Frequency Oscillatory Ventilation (HFOV)

- Theoretically ideal for lung protection in ARDS

- Effective in improving oxygenation in adults when started early

- Adults with moderate-to-severe ARDS
  - Instituted early versus LTVV
  - May increase in-hospital mortality
OSCILLATE Trial

- Multicenter, prospective, non-blinded, randomized trial
  - HFOV versus control (LTVV)
- 548 intubated pts with early moderate-severe ARDS
- Primary outcome of in-hospital mortality
  - 47% versus 35%
- Secondary outcomes
  - ICU mortality 45% vs 31%
  - 28 day mortality 40% vs 29%
  - MV in survivors 11 days vs 10 days
  - Hospital days survivors 30 days vs 25 days
- Multiple criticisms
BETA-2 AGONISTS
Beta-2 Agonists in ARDS

- Several studies shown improved physiological outcomes
  - Randomized control trial
    - IV albuterol (15 mcg/kg/hr) versus placebo
    - Less lung water (9 vs 13 mL/kg)
    - Lower plateau airway pressure (24 vs 30 cmH₂O)
  - Randomized control trial
    - Aerosolized albuterol (5 mg) or placebo q4 hours for up to 10 days
    - No differences in ventilator-free days or hospital mortality
  - Beta-agonist Lung Injury Trial (BALTI-2)
    - IV salbutamol vs placebo
    - Terminated early due to increased mortality in the salbutamol group

- Grade 1B
  - Recommend against use of beta-agonists for people with ARDS
NEUROMUSCULAR BLOCKADE
Neuromuscular Blockers (NMBs)

- Long history of use in the ICU
- Previously, no protocolized use of NMBs

- Multi-center trial in 2010
  - 340 intubated patients with severe ARDS (P/F ratio of < 150)
  - Randomized to cisatracurium besylate versus placebo for 48 hours
  - All patients received LTVV + minimum PEEP 5
  - Both groups received deep sedation
  - Adjusted 90-day in-hospital mortality rate was lower with NMB versus placebo
  - No increased neuromuscular weakness was observed
  - Increased number of ventilator-free days
Neuromuscular Blockers (NMBs)

- Possible pathways of benefit
  - Limiting lung injury arising from ventilator desynchrony
    - Increased pneumothorax seen in placebo group
  - Less biotrauma evidenced by less end-organ failure
    - Reduction in serum cytokines
  - Limits expiratory muscle function reducing respiratory system collapse and de-recruitment
    - Improved compliance
    - Improved VA matching
  - Recent studies support direct anti-inflammatory effects of blocking nicotinic acetylcholine receptor-alpha 1
PRONE POSITIONING
Prone Positioning

• Prior to 2013
  – Known that prone positioning improved oxygenation in ARDS
  – Failed to show improved mortality

• Fears and concerns over prone positioning
  – Facial edema
  – Skin breakdown (pressure necrosis)
  – Transient desaturations
  – Dislodgement of line, endotracheal tubes
  – Hemodynamic instability
Prone Positioning

- 2013 Study of Prone Positioning
  - 466 patients
  - Randomized patients to prone positioning for at least 16 hours/day versus standard positioning
  - Severe ARDS (PaO$_2$/FiO$_2$ < 150) and proned within 36 hours of intubation and after 12-24 hours of stabilization
  - LTVV and PEEP at least 5
  - 28-day mortality (32.8% versus 16% prone)
  - Benefit persisted until day 90
  - No significant difference in complications between groups
    - Except, increased rate of cardiac arrest in the supine group
  
  - Considerations
    - Study took place in center with experience in prone positioning
Prone Positioning

• Benefits
  – Improved lung ventilation perfusion matching
  – Improved right ventricular dysfunction
  – Recruitment of lower-lobe atelectatic lung units
  – Decreased intrapulmonary shunting
  – Improved maintenance of open lung units
    • Limiting ventilator–induced lung injury
  – Improved secretion clearance (gravitational)
FLUID MANAGEMENT
Fluid Management

- ARDS is an increased vascular permeability state
  - Hydrostatic versus oncotic pressures

- Study of 1000 patients (FACTT Trial)
  - Randomized to conservative or liberal fluid management strategy for 7 days
  - CVP < 4 mmHg versus CVP 10-14 mmHg
  - Cumulative fluid balance was -136 mL vs +6992 mL
  - Conservative group improved oxygenation index and lung injury score and increased ventilator-free days (15 vs 12) and ICU-free days (13 vs 11)
  - 60 day mortality was unchanged
  - Mean CVP remained above goal

- Grade 1C Recommendations are conservative fluid management with use of albumin and furosemide
NONINVASIVE VENTILATION & OXYGENATION
Invasive versus Noninvasive

• Majority use invasive MV for ARDS

• Who is appropriate for noninvasive ventilation
  – Hemodynamically stable
  – Easily oxygenation
  – Does not need immediate intubation
  – Intubation is not an option
  – No contraindications

• Conflicting data regarding benefits and harm
Studies on NIV

• Single-center trial of 83 patients
  – Patients requiring full face mask NIV for \( \geq 8 \) hours
    • Mild to moderate disease
    • Randomized face mask versus helmet
    • Reduced need for intubation (18% vs 62%)
    • Higher rate of ventilator-free days
    • Shorter ICU stay
    • Lower 90-day mortality without an increase in adverse effects
  – Study was stopped early so outcomes may have been exaggerated based on effect size
Studies on NIV

- Small randomized control trial of 40 patients
  - NIV versus high concentration supplemental oxygen
    - NIV arm better improvement of PaO$_2$/FiO$_2$
    - Less likely to require intubation (4.8% vs 36.8%)

- Limitations
  - Small study (size effect imprecise)
  - Selection bias by physicians based on preference for NIV
  - Caregivers were not blinded (may influence decision to intubate)
  - Exclusion criteria
    - Patients > 70 years old
    - Multiple organ failure
    - PaO$_2$/FiO$_2$ < 200
Studies on NIV

- Study of hypoxemic respiratory failure
  - NIV versus high flow nasal cannula
  - Increased mortality in association with NIV

- Etiology of potential harm
  - Higher than expected tidal volumes in NIV?

- Grade 2B NIV only in a select minority of patients with sepsis-induced ARDS
PULMONARY ARTERY CATHETERS
Swan-Ganz Catheters in ARDS

- The best available evidence strongly suggests that pulmonary artery catheters do not improve management of patients with ARDS, either with or without shock.

- Grade 1A Recommends against use of PA catheters as part of routine management of ARDS.
Trachestomy
Early vs Late Tracheostomy

- January 2015 Cochrane Review
  - All critically ill patients
  - Mortality in ≤ 10 days or > 10 days
  - 8 studies and 1977 patients
  - Early tracheostomy had lower risk of mortality
    - Did not have subgroup characteristics to determine best selection for either strategy
  - 11 early tracheostomy to prevent 1 death in late tracheostomy
  - Suggestion of benefit of time off mechanical ventilation in the early tracheostomy group
  - Higher discharge from the ICU at 28 days
  - No significant differences in pneumonia rates
LIQUID VENTILATION
Liquid Ventilation

- Oxygenation perfluorocarbon mixtures

- Types of Liquid Ventilation
  - Total Liquid Ventilation
    - Special ventilator
    - Lungs and circuit are liquid filled
  - Partial Liquid Ventilation
    - Liquid “PEEP”
    - Lungs filled with liquid, but ventilated with a gas tidal volume (conventional ventilator on top of a liquid FRC)

- Advantages
  - Improve compliance and gas distribution
  - Lower resistance to expansion (easier to distend the lung with liquid)
  - Easier to open and maintain alveolar volume with liquid than gas (less damage)
  - Alveoli are flushed of “debris” (decreases inflammation)
  - Perfluorocarbon decreases neutrophilic and macrophage chemotactic and phagocytic responses

- Experimental
INEFFECTIVE OR HARMFUL THERAPIES
Ineffective or Harmful Therapies

- N-acetylcysteine
- Procysteine
- Glutamine
- Antioxidants
  - Selenium, beta carotene, zinc, vitamin E and C
- Lisophylline
- Intravenous prostaglandin E1
- Neutrophil elastase inhibitors
- Ibuprofen
- Activated protein C (Xigris)
- Ketoconazole
- Statins
EXTRACORPOREAL MEMBRANE OXYGENATION
Introduction to ECMO

• Partial cardiopulmonary bypass
• First successful adult ECMO support was 1972
• Types of ECMO
  – Arteriovenous (AV)
    • Uses patients own blood pressure to move the blood through the circuit
  – Venovenous (VV)
    • Takes blood from a large vein and returns to a large vein
    • Does not support cardiac output
  – Venoarterial (VA)
    • Deoxygenated blood from a central vein and returns to the arterial system, usually the aorta
    • Partial cardiac output support
CESAR Trial

- Conventional ventilation versus ECMO for Severe Adults Respiratory failure
EXTRACORPORAEOAL CO₂ REMOVAL
Extracorporeal CO₂ Removal

- Veno-venous (or arterio-venous) extracorporeal device at low blood flow rates (300-1000 mL•min)
  - Traditional ECMO 3-5 L/min
  - Flow rates are similar to renal replacement therapy
  - Use smaller cannulas

- Adequate for substantial CO₂ removal but only minimal blood oxygenation

- Facilitate ultraprotective lung ventilation
  - Tidal volumes <= 4 mL•kg
Extracorporeal CO₂ Removal Studies

• Prospective cohort study [2009]
  – CO₂ removal device to reduce tidal volume to < 6 mL•kg
  – Observed improvement of morphological markers of lung protection

• Randomized control trial [2013]
  – Very low tidal volume (3 mL•kg) + arterio-venous CO₂ removal versus conventional protective ventilation
    • 79 patients
  – Safe, feasible and without physiologically relevant hypercapnia/acidosis
  – Significant reduction in analgesic and sedative use
  – Increased ratio of spontaneous breathing compared with controls
  – Serum levels of pro-inflammatory cytokine IL-6 significantly reduced
  – Overall did not reduce mechanical ventilation, ICU or hospital stay
    • Post hoc analysis indicated that in most hypoxemic patients (PaO₂/FiO₂ < 150)
    • Had significantly shorter ventilation period
Questions and Answers

THE END
References


References