Review of One Lung Ventilation

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Goal of One Lung Ventilation
• Provide adequate ventilation and oxygenation while providing a stable lung field for surgical manipulation.

Indications for One Lung Ventilation
• Lung Resection
  • Central or Peripheral Lung Cancer Lesions
  • Surgery remains an appropriate form of treatment of early stage lung cancer
  • Stage I or II small cell lung cancer
• Pneumonectomy
  • Lesions involving left or right mainstem bronchus
• Wedge Resection
  • Small Peripheral Lesions

Indications for One Lung Ventilation
• Single Lung Transplant
  • Idiopathic Pulmonary Fibrosis
  • Primary Pulmonary HTN
  • Cystic Fibrosis
  • Pediatrics
• Anesthetic Considerations in the Post Lung Transplant Patient
  • Extracellular Lung Fluid less easily removed
  • Denervation – loss of cough reflex
  • Aspiration and infection
  • Immunosuppressive Therapy
  • Cyclosporine - nephrotoxic

Objectives
• Identify surgical procedures that require one lung ventilation.
• Describe pre-operative testing for procedures that involve one lung ventilation
• Discuss airway devices (DLT & Bronchial blockers) utilized to achieve one lung ventilation
• Discuss physiology related to one lung ventilation
• Analyze ventilator settings utilized during single lung ventilation
• Identify anesthetic complications related to one lung ventilation

Indications for One Lung Ventilation
• Esophageal Surgery
• Thoracic Aneurysm Repair
• Mediastinal Procedures
• Anterior Approach to Thoracic Spine Procedures
• Dual Chamber Pacemaker insertion
• Confinement of Bleeding or Infection to one lung
Preoperative Testing

• Patients present with multiple co-morbidities
  • (ASA 3 or 4)
• Pulmonary Function Tests
  • Can provide insight into potential for ventilation problems in the perioperative period

Preoperative Testing - Lung Volumes

• Total Lung Capacity (TLC):
  • Sum of all Volumes
  • 5-6 Liters
• Tidal Volume (TV):
  • Volume inspired/expired during normal quiet inspiration
  • 6-8mL/Kg

Preoperative Testing - Lung Volumes

• Inspiratory Reserve Volume (IRV):
  • Volume inspired above a normal TV
• Expiratory Reserve Volume (ERV):
  • Volume of air that can be forcibly expired after a normal tidal volume breath

Preoperative Testing - Lung Volumes

• Vital Capacity (VC):
  • Inspiratory (IRV), and Expiratory (ERV) Reserve Volume, Tidal Volume (TV)
  • Approximately 60mL/kg

Preoperative Testing - Lung Volumes

• Functional Residual Capacity (FRC):
  • Expiratory Reserve Volume (ERV)
  • Residual Volume (RV)
    • Air Remaining in Lungs
    • 1000-1200mL
    • Body Plethysmography
    • Nitrogen Washout test
    • Helium Dilution

Pulmonary Function Testing

• Forced Vital Capacity (FVC)
  • Volume of air that can be exhaled after a maximal inspiration
  • Time: 4-6 seconds
  • Normal Volume: 4 Liters
Pulmonary Function Testing

- Forced Expiratory Volume in one second (FEV1)
  - Volume of air exhaled during a forced expiratory maneuver
  - Normal: 0.8 (80%)

- Forced Expiratory Flow (FEF 25-75)
  - aka Maximum Midexpiratory Flow (MMEF)
  - Middle half of FVC
  - Indicative of flow in medium sized airways
  - Approximate Normal Value 4.7 L/sec (70kg Adult)
  - Decreased in Obstructive Disease
  - Normal in Restrictive Disease

- FEV1 / FVC Ratio
  - Distinguish between Restrictive and Obstructive diseases
  - Normal: 0.8 (80%)

Obstructive vs. Restrictive

- Airways obstructed
  - COPD
  - Asthma
  - Chronic Bronchitis
- FVC = Low
  - Air trapping
  - FEV1 = Low
  - FEV1/FVC Ratio: <0.7
- Example:
  - FEV1 1.2
  - FVC 3.0
  - Ratio = 0.40
  - Restrictive expansion of lung/chest wall
  - Pulmonary Fibrosis
  - Neuromuscular Disease
  - Pregnancy

- FVC = Normal
  - FEV1 = Low
  - FEV1/FVC Ratio >0.8
- Example:
  - FEV1 2.8
  - FVC 3.2
  - Ratio = 0.85

Preoperative Testing

- Pneumonectomy Criteria
- Arterial Blood Gas (Room Air)
  - PaCO2 < 45
  - PaO2 >50
  - FEV1 > 0.8 (800mL)
    - Low predicted FEV1 (less than 0.8) & high PaCO2
    - Pneumonectomy – contraindicated.
Preoperative Testing

- Split Lung Function Tests
- Regional Perfusion Test
  - Xenon Injection – Insoluble radioactive isotope to determine perfusion of lung fields
- Regional Ventilation Test
  - Inhaled Radioactive Gas to determine ventilation of lung fields.

Preoperative Testing

- History & Physical Exam
- Labs: CBC, BMP, Coagulation Profile, ABG (baseline)
- EXG
  - Right Atrial & Ventricular Changes
  - Radiographic Films (CT, CXR)
- Location of Lesions:
  - Central vs. peripheral
  - Structures to be involved during a procedure

Anatomy Review

- Left Main Bronchus: 45-55 degree angle, 4-5 cm
- Right Main Bronchus: 25 degree angle, 2.5 cm
- Right Upper Lobe Bronchus - 90 degree angle off of Right Mainstem
VIDEO Page

- Two Lung Ventilation
  - http://www.youtube.com/watch?v=YbwXAurQr30
- Right Lung Ventilation
  - http://www.youtube.com/user/SchCnty#p/a/u/1/BOV/n3Rb0bQo
- Left Lung Ventilation
  - http://www.youtube.com/watch?v=mWdpZ7JNvM8

Airway Devices

- One Lung Ventilation
  - 25

Double Lumen ETT

- Robertshaw Design
- Sizes 26 - 41 Fr
  - Adult Female: 26-37 Fr
    - Average depth 27 cm
  - Adult Male: 39-41 Fr
    - Average depth 29 cm
- Size selection – largest that can be safely inserted.
- Sources cite Macintosh Blade provides better visualization
- Decrease chance of balloon rupture on kidney
- Placement MUST be confirmed with fiberoptic bronchoscopy
- Movement of DLT of 1 cm can cause serious ventilation/oxygenation problems

Right vs Left Double Lumen ETT Placement

- Teaching has focused on Left Sided DLT placement for most thoracic procedures
  - Potential to block ventilation of Right upper lobe
  - Potential to migrate across carina
- A challenge to conventional wisdom: placement of Bronchole (distal) Lumen into the non-operative lung
  - Right DLT for Left lung surgery
  - Left DLT for Right lung surgery

- Opposite Sided DLT Placement Advantages
  - No interference or stapling of DLT into bronchus during lobectomy or pneumonectomy
  - Allows the trachea lumen to be clamped
  - Bronchoscopy through trachea lumen to assess distal balloon – not interrupt ventilation
  - Tracheal (Proximal) cuff damage during intubation
  - One Lung Ventilation can still be achieved by the functional bronchial (distal) balloon
Right vs Left Double Lumen ETT Placement

- Bronchial cuff passed through cords & turned 90 degrees as tracheal cuff passes cords.
- Tracheal Cuff inflated – placement confirmed
- Bronchial Cuff inflated – fiberoptic confirmation

Double Lumen ETT Placement

- Bronchial Cuff can be passed deeper into bronchus to facilitate placement
  - Easier to withdraw DLT when it becomes warm & malleable
  - Position re-confirmed after patient position change
    - Supine to Lateral
    - Fiberoptic Bronchoscopy

Achievement of One Lung Ventilation

- Achievement of One Lung Ventilation
  - Operative Lung clamped on Adaptor to Vent Circuit
  - Port on Operative lung opened and allowed to deflate

Bronchial Blocker Tubes

- Univent:

Bronchial Blocker Tubes

- Single Lumen Tube with an Endobronchial Blocker device to isolate a Right or Left Mainstem Bronchus
- Indicated in patients with difficult airway anatomy
- Thoracic Trauma Situations
- Pediatric Patients
- Does not need to be exchanged
  - Mediastinoscopy followed by Thoracotomy
  - Bilateral Lung Transplantation
  - Post-op ventilator management
Bronchial Blocker Insertion

- Regular intubation technique
- Rotation towards operative lung
- Trachea cuff is inflated
- Fiberoptic assisted placement of Blocker into operative lung
- Collapse of operative lung
  - Exhalation via distal opening in Blocker

Bronchial Blocker Tubes

- Univent Tube
  - Bronchial Block in a small channel bored into the tube
  - Silastic Construction
  - Disadvantages:
    - May be difficult to place blocker
    - Prolonged collapse of operative lung
    - May become dislodged with surgical manipulation

- Arndt Endobronchial Blocker
  - Regular Endotracheal Tube
  - Adaptor placed on ETT
  - Blocker is guided by a snare attached to a fiberoptic bronchoscope
  - Aerosol Lubricant
  - Disadvantages:
    - Difficult positioning into operative bronchus
    - Can be caught on Murphy’s Eye or Carina during insertion

Positioning:

- Supine
  - Sternotomy or Anterior Thoracotomy
- Lateral
  - Lateral or Posterior Lateral Thoracotomy

Physiology

- Lateral Decubitis Positioning for Thoracic Procedures
  - Presents additional challenges to OLV
  - Dependent lung has pressure of medistinal structures
  - Relaxed diaphragm will increase intrathoracic pressure from abdominal contents moving cephalad

- Ventilation and perfusion are greatest in the dependent lung field
  - Minute Ventilation = 4 liters/min
  - Cardiac Output = 5 liters/min
  - Normal V/Q Ratio = 0.8
  - Determines Shunt State vs. Dead Space
West Lung Zones

- **Zone 1 – Alveolar Deadspace**
  - Upper Lung Field
  - $P_A > P_a > P_v$
- **Zone 2 – Waterfall Region**
  - Falls into pulmonary venous system
  - $P_a > P_A > P_v$
- **Zone 3 – Dependent Lung Field**
  - $P_a > P_v > P_A$
  - Continuous Blood Flow

SHUNT

- Shunt – perfusion no ventilation
- $V/Q = 0$
- Normal Physiologic Shunt 2-5%
- Causes:
  - Airway Obstruction
  - Alveolar Collapse
  - Alveolar Obstruction (Pneumonia / Edema)

DEADSPACE

- Deadspace – ventilation no perfusion
- $V/Q = \infty$
- Normal Anatomic Deadspace 2mL/kg
- Causes:
  - Clots
  - PE
  - Fat Embolism

Physiology of Shunt

- Ventilation/Perfusion Mismatch
- While one lung is being ventilated – both lungs are still receiving deoxygenated blood from the heart
- Creates the situation of pulmonary shunt
- Blood enters the arterial system WITHOUT being oxygenated

V/Q Shunt & Deadspace

- Perfusion, No Ventilation
  - $V/Q < 0.8$
  - Alveolar Collapse
  - Alveolar Block
- Ventilation, No Perfusion
  - $V/Q > 0.8$
  - Clots
  - PE

Physiology: Lateral Decubitus Positioning

<table>
<thead>
<tr>
<th>Lung Field</th>
<th>Awake Respiration</th>
<th>Anesthetized</th>
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<tbody>
<tr>
<td></td>
<td>Ventilation</td>
<td>Perfusion</td>
</tr>
<tr>
<td>Non-dependent Lung (Up Lung)</td>
<td>↓</td>
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<tr>
<td>Dependent Lung (Down Lung)</td>
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Calculation of Alveolar Oxygen Level

- Determination of Hypoxemia
  - $V/Q$ Mismatch
  - Hypoventilation
- Alveolar:arterial Gradient ($A:a$ Gradient)
  - Calculation to determine the effectiveness of gas exchange at the Alveolar level
  - $PAO_2 - PaO_2$
  - Normal 5-15 mmHG (Room Air)
    - Normal Physiologic $V/Q$ Mismatch
    - Hypoxia + Normal $A:a$ Gradient = Hypoventilation
    - Hypoxia + Elevated $A:a$ Gradient = $V/Q$ Mismatch
Calculation of Alveolar Oxygen Level

- **Alveolar Oxygen Calculation (PAO\(_2\))**
  \[ PAO_2 = \text{FiO}_2 \times (PB - PH_2O) - PaCO_2/RQ \]

- Respiratory Quotient (RQ) = 0.8
- 250 mL of Oxygen diffuses from alveoli to pulmonary circulation
- 200 mL of Carbon Dioxide moves from pulmonary circulation to alveoli
- Oxygen 250mL/Carbon Dioxide 200mL = 0.8

Example:
ABG on Room Air (FiO\(_2\) = 0.21)
- \( PaO_2 \) 90
- \( PaCO_2 \) 40

\[ PAO_2 = \text{FiO}_2 \times (PB - PH_2O) - PaCO_2/RQ \]
\[ PAO_2 = 0.21 \times (760 - 47) - 40/0.8 \]
\[ PAO_2 = 149.7 - 50 = 99.7 \]
\[ PAO_2 - PaO_2 = 9.7 \]

Physiology: Hypoxic Pulmonary Vasoconstriction

- Mechanism of Pulmonary Vasoconstriction not completely understood
- Redox theory – possible explanation
  - Alveolar hypoxemia reduces the activated oxygen species
  - Leads to inhibition of voltage gated Potassium channel
  - Inflow of extracellular calcium
  - Results in localized vasoconstriction
- HPV is reported to decrease Cardiac Output to non-ventilated lung 20-25%

Factors that effect of efficiency of HPV
- High Cardiac Output / Hypervolemia
  - Recruit constricted vasculature
- Hypovolemia
  - Vasculature constriction of well ventilated lung fields
- Excessive Tidal Volume or high PEEP
- Hypocapnia
- Hypothermia
- Infection

Medications that effect of efficiency of HPV
- Inhalational Gases > 1 to 1.5 MAC
  - All volatile anesthetics inhibit HPV
- Calcium Channel blockers
  - Verapamil, Nifedipine, Nicardipine
- Direct acting vasodilators
  - Nitroglycerin, Nitroprusside, Hydralazine
- Beta Agonists - Dobutamine
- Vasoactive Medications
  - Potential to vasoconstrict blood flow to oxygenated area
  - Epinephrine, Dopamine & Phentylephrine
Physiology: Hypoxic Pulmonary Vasoconstriction

- Potentiation of perfusion to well oxygenated lung fields
- Nitric Oxide
  - Endothelial smooth muscle vasodilator
  - Selective vasodilation of ventilated lung fields
  - Studies found little effect on improving oxygenation
- Almitrine (Duxil)
  - Has effects on peripheral chemoreceptors in Carotid Bodies
  - Respiratory stimulate to improve oxygenation in patients with COPD
  - Studies utilizing Nitric and Almitrine – found an increase in oxygenation
  - Approved in Europe for short term therapy
  - Neuro toxic effects on myelinated fibers

Ventilator Techniques

- Maintain two lung ventilation as long as possible.
- Inspired Flow of 100% Oxygen
  - Bleomycin – cause oxygen toxicity
    - Adjust FiO2 as necessary
- Keep peak airway pressure < 30mmHG
  - Pressure Control Ventilation preferred
  - Study in PCV vs. VCV – no significant difference in PaO2
- PaCO2 30-40 mmHG
  - Prevent Hyperventilation
  - Hypopcapnia in the ventilate lung field with increase vascular resistance – inhibit HPV

Ventilator Techniques

- Tidal Volume (TV) Strategies:
  - High Tidal Volume No PEEP
  - Low Tidal Volume with PEEP
    - TV of 8-15 mL/kg are reported to have minimal effect on HPV
    - TV of less than 6 mL/kg has been implicated with atelectasis in the dependent lung

Ventilator Techniques

- Higher Tidal Volumes (10-15 mL/kg)
  - Larger TV were recommended to prevent atelectasis in the dependent lung field
  - Volutrauma
    - Overdistention of Lung Segments
  - Increased pulmonary resistance
  - Shunt blood towards the non ventilated
  - Implicated with inflammatory mediators
  - Fibrin Deposits
  - Acute Lung Injury

Ventilator Techniques

- Physiologic Tidal Volume
  - 6-8 mL/kg TV (cited by numerous sources)
    - Avoid acute lung injury
  - Small Amount of PEEP
    - Higher settings of PEEP can constrict alveolar circulation and increase shunt.
  - Debate over PEEP
    - Replenish FRC
    - Shunt blood away from ventilated lung fields
    - Hemodynamic compromise

Ventilator Techniques

- Termination of OLV
  - Manual Ventilation of 20-30 cmH2O
  - Recruitment maneuver to re-expand atelectatic lung tissue
  - Surgical assessment of lung tissue / hemorrhage
Ventilator Techniques

- Extubation or Exchange
- Type of Procedure
  - Complex Lung Resection, Esophagogastrectomy, Thoracic Aortic Aneurysm repair
- Need for post-op ventilation
- Unexpected fluid shifts/blood loss
- Airway edema
- Facial edema
- Sustained neuromuscular blockade

Hypoxemia – One Lung Ventilation

- Reported to occur in 5-10% of OLV Procedure
- Improve Alveolar Ventilation & Pulmonary Perfusion
- Assessment of DLT or Bronchial Blocker Device placement
  - Fiberoptic Bronchoscopy
  - High Peak Airway Pressures
  - Pneumonecmy – early compression/clamping of the surgical side pulmonary artery
  - Divert blood flow to ventilated lung field

Hypoxemia

- Application of PEEP to ventilated lung
- Continuous Insufflation of oxygen into operative lung
- Changing TV & respiratory rate

Hypoxemia

- Periodic inflation of the collapsed lung with oxygen
- CPAP to Nondependent/Nonventilated lung
  - 5-10 cmH2O to non-ventilated lung
  - Can interfere with surgical exposure
    - Closed chest procedure (Thoracoscopy)
  - RE-EXPANSION of Collapsed Lung until Oxygen Saturation Stabilized
    - Communication with Surgeon

Complications

- Displacement of Airway Device during positioning
- Inability to place airway device
- Lesion involving mainstem bronchus
- Airway Fire
  - Application of CPAP or continuous oxygen to the non-ventilated/surgical side lung field can increase the risk of fire
  - Suturing of Airway Device into a mainstem bronchus

CPAP to Non Ventilated Lung
Complications

- Pneumothorax of dependent/ventilated lung
- Tracheal Injury from airway device
- Laryngeal Edema
- Bilateral Vocal Cord Paralysis
  - Recurrent Laryngeal nerve injury
- Acute Lung Injury
- Re-expansion Pulmonary Edema
  - Rare not well understood phenomena
  - Similar to ARDS
  - Result from alveolar-capillary membrane disruption

Complications - Positioning

- Brachial Plexus Injuries
  - Overextension of Neck
  - Overextension of Arms
  - Rib retraction
  - Pneumonectomy - severe the long thoracic nerve
    - Serratus Anterior Muscle
- Ulnar Injuries
  - Improper padding of elbows (cubital tunnel)
- Dependent Eye Injury
  - Hypotension
  - Improper padding of head

Summary

- Thoracic procedures involving one lung ventilation provide a special challenge to the anesthesia team.
- Careful pre-operative evaluation can provide useful data on patient’s lung function prior to one lung ventilation.
- Double lumen and bronchial blocker airway devices can provide suitable means to conduct one lung ventilation.

Questions
References


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