Adverse Effects and Complications of Mechanical Ventilation

Ibrahim Al-Sanouri, MD, FCCP, FAAAAAI
4 major concepts

- Know thy patient
- Know thy ventilator
- Put the ventilator between you and the patient
- Alive ventilated patients
- The illness caused the need for mechanical ventilation
MV complications

- Mechanicals Biophysical
- Inflammatory Cytokines Biochemical
- Disease
- Modes
- Medication
<table>
<thead>
<tr>
<th>Complication</th>
<th>OPP</th>
<th>GBS</th>
<th>Pneum</th>
<th>ARDS/ALI</th>
<th>PE</th>
<th>COPD</th>
<th>BA</th>
<th>Pleural disease</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barotrauma/Pneumothorax</td>
<td></td>
<td></td>
<td></td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Nosocomial pneumonia</td>
<td>14</td>
<td>4</td>
<td>6</td>
<td>3</td>
<td></td>
<td>2</td>
<td></td>
<td></td>
<td>29</td>
</tr>
<tr>
<td>Cardiovascular complications</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td>8</td>
</tr>
<tr>
<td>Airway complications</td>
<td>4</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td></td>
<td>1</td>
<td></td>
<td>10</td>
</tr>
<tr>
<td>Failure of closure of tracheostomy stoma</td>
<td></td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>GI haemorrhage</td>
<td>2</td>
<td></td>
<td>5</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>11</td>
</tr>
<tr>
<td>Equipment failure</td>
<td>2</td>
<td></td>
<td>2</td>
<td>2</td>
<td></td>
<td>1</td>
<td></td>
<td></td>
<td>7</td>
</tr>
</tbody>
</table>

OPP – Organophosphorous and carbamate poisoning; GBS – Guillain Barré Syndrome; Pneum – Complicated pneumonias; ARDS/ALI – Adult respiratory distress syndrome/Acute lung injury; PE – Cardiogenic pulmonary oedema; COPD – Acute exacerbation of chronic obstructive airway diseases; BA – Acute exacerbation of bronchial asthma.
Unable to Open Mouth
• Trismus
• Small mouth
• Peri-oral scarring
• Fascial swelling

Unable to insert laryngoscope
• Short neck
• Large chest
• Prominent upper incisors
• Small mandible
• Edema

Unable to see glottis
• Fixed position of the head
• Small jaw
• Anterior larynx
• Obstructed by blood or vomit

Unable to pass tube into trachea
• Fixed Unrecognizable glottis
• Too small glottis or sub-glottic diameter

Environment
• No skilled help
• No specialized equipments
• Missing of defective equipment
• Poor positioning

• Trauma
• Endobronchial intubation
• Esophageal intubation
• Severe hypoxia
• Severe hypotension
• Death

Mechanical
Injuries to Face, Lips and Oropharynx

- Trauma to the lip and checks from the tube tie
- Peri-oral herpes
- Injuries to the tongue particularly when entrapped between the endotracheal tube and the lower teeth
- Pressure ulcers to the palate and oropharynx are very uncommon
Maxillary Sinus and Middle Ear Effusion

- Maxillary effusion
  - 20% in patients intubated for > 7 days and oral intubation or oral gastric tubes
  - 47% when the gastric tube is placed nasally
  - 95%

- Secondarily infected maxillary effusion (45-71% of effusions)

- Middle ear effusion (29%) with 22% of them become infected

- Hearing impairment that may contribute to the confusion and delirium in elderly population
Pharyngo-laryngeal Dysfunction

- Post-extubation discomfort (40% regardless of the duration)
- Hoarsness
  - 52% in short-term intubation
  - 70% in patients with prolonged intubation
- Slowing of the reflex swallowing mechanism and risk of aspiration
  - 15.8% of patients who were intubated more than 4 days did not have a gag reflex
- Silent aspiration:
  - 20% in young population
  - 36% in older population
Laryngeal Injuries

- Some degree of glottic injury is seen in 94% of patients intubated for 4 days or longer
- Erosive ulcers of vocal cords (posterior commisure)
- Swelling and edema of the vocal cords
- Granulomas (7% in patients intubated for 4 days or more)
Tracheal Injuries

- Cuff pressure tracheal damage: tracheal ulceration, edema and submucosal hemmorrhage
- Tracheal dilatation
- Tracheal stenosis:
  - At the site of the cuff (50%)
  - At the site of the tracheostomy (35%)
  - Unclear (15%)
Cardiovascular Effects of Mechanical Ventilation
Decreased pressure Gradient for venous return and decrease RV preload

PPV
Decreased CO due to decreased RV filling Volume due to decreased venous return
Effect of Positive Pressure Ventilation on Right Atrial Distension

PPV
Decreased CO due to decreased RV filling
Volume due to decrease RA compliance
Spontaneous Ventilation
Spontaneous Ventilation
Hypotension following MV

Following Intubation

- Vasodilatory Effects of Hypnotic Agents
  - Unmask relative and absolute hypovolemia
  - Loss of compensatory mechanisms: Vasodilation

- Application of Positive Pressure ventilation
  - Increased Intrathoracic Pressure
  - Reduced Venous Return: Reduced Preload Reduced Cardiac Output

HYPOTENSION
Cyclic BP effects is related to Volume status

Ventilation on sick individual
PPV could increase CO and BP

- Ventricular interdependence: decrease CO during spontaneous breathing due to: increase RV filling volume with shifting the intraventricular septum causing mechanic impedance for LV decreasing its compliance causing decrease CO and BP

- In this situation PEEP will be beneficial

- Increase in transmural pressure of the great arteries in the thorax, Transmural pressure represent how easy the blood vessels could distend once accommodating for the stroke volume to enter
Cyclic changes in Gas exchange and partial pressures
Hemodynamic effects of mechanical insufflations

- End of inspiration: Maximum of SBP, PP, Aortic velocity
- End of inspiration: Minimum of SBP, PP, Aortic velocity

Diagram:
- Inc. LV ejection
- Dec. LV ejection
- RV preload
- RV ejection
- RV afterload
- Blood pulmonary transit time
- LV preload
- LV afterload
- LV preload
- Pleural pressure
- Transpulmonary pressure
Effect of Mechanical Ventilation on Pulmonary Vascular Resistance
Effect of Changing Lung Volume on Pulmonary Vascular Resistance

- Total pulmonary vascular resistance
- Intra-alveolar vaso-compression
- Hypoxic vasoconstriction
Effect of Lung Volume on RV afterload

- No effect in Normal individual with PEEP less than 10 cmH2O.
- Major effect in patients with dynamic hyperinflation such as asthmatic and COPD, and in pre-existing pulmonary hypertension.
- Small changes in PVR can cause considerable hemodynamic compromise secondary to acute increase in PVR.
- Avoid gas trapping in these patients.

Know the patient, Know.
Alveolar pressure and Gas exchange
Effects of PPV on hemodynamic

- Pleural pressure
- Venous Return
- V/Q Matching
- LV afterload
- Work of Breathing

- Fully Spontaneous
- Partial Ventilator support
- Fully Controlled
Bradycardia and intra-arteriolar vasodilatation
Biochemical effect of Mechanical Ventilation
Inflammatory cytokines
Inflammatory Biochemical injury

Local and systemic Inflammation cascade
Micro vascular, Alveolar Fracture

Hotchkiss et al.
Critical care Med, 2002

Prot for Gas and Bacteria
Biochemical effect of MV

Pro-Inflammatory Cytokines during PPV
Oxygen Toxicity
- Tracheobronchitis
- Absorpetive atelctasis
- Hypercarbia
- Diffuse alveolar damage
Intrinsic PEEP, Auto PEEP

Air Trapping

Flow (L/min)

Inspiration

Expiration

Time (sec)

Air Trapping Auto-PEEP

Normal

Patient
Gastrointestinal Effects of Mechanical Ventilation
GI Effects of MV

<table>
<thead>
<tr>
<th>GI Complications Seen in Patients Receiving MV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Complications</td>
</tr>
<tr>
<td>Erosive esophagitis</td>
</tr>
<tr>
<td>SRMD</td>
</tr>
<tr>
<td>Asymptomatic, endoscopically evident damage</td>
</tr>
<tr>
<td>Clinically evident bleeding</td>
</tr>
<tr>
<td>Clinically significant bleeding</td>
</tr>
<tr>
<td>Diarrhea</td>
</tr>
<tr>
<td>Decreased bowel sounds</td>
</tr>
<tr>
<td>High gastric residuals</td>
</tr>
<tr>
<td>Constipation</td>
</tr>
<tr>
<td>Ileus</td>
</tr>
<tr>
<td>AAC</td>
</tr>
</tbody>
</table>
Esophagus, Stomach and Small Intestine

- **Erosive esophagitis** (30-50% of patients ventilated >48 hours)
  - NG tube
  - Poor lower esophageal sphincter tone and reflux
  - Opiates and adrenergic agonists
  - Duodenogastroesophageal reflux through the action of trypsin

- **Upper gastrointestinal hemorrhage:**
  - Stress
  - Decreased gastric mucosal protection secondary to a fall in splanchnic blood flow

- **Decreased motility of stomach and small intestine**
Liver and Gallbladder

- Reduction in portal venous flow secondary to the fall in cardiac output
- Increased hepatic arterial flow “hepatic arterial buffer response”
- Normal total hepatic perfusion
- Hepatic engorgement
- Venous ischemia and elevation of serum transaminases and hyperbilirubinemia
- Reduction in drug clearance secondary to reduction of hepatic blood flow
Large Bowel

- Constipation
- Abdominal distension
GI Effects of PPV

Mechanical Ventilation
- Sympathetic system activation
  - Increased catecholamines
    - Activated Renin-Angiotensin-Aldosterone
- +Medications (e.g., opiates)
- High PEEP
- +Hypovolemia
- "Injurious" ventilatory strategies
  - Pro-Inflammatory cytokine release (e.g., IL-1, TNFα)

Splanchnic Hypoperfusion
- Decreased cardiac output
  - +Medications (vasopressors)

GI Mucosal Injury
- Reperfusion injury
  - Disruption of cell function
  - Disruption of cell junctions
  - Impaired intestinal immune function
  - Decreased mucus production
  - Loss of gut barrier function/increased permeability
  - Malnutrition
  - Translocation of bacteria and toxins
  - SIRS/MODS

Altered GI Motility
- Direct effects of cytokines
  - Altered intestinal microflora
  - Bacterial overgrowth
  - Luminal toxins
Renal Functions during Mechanical Ventilation
Renal Effects of MV

- The usual renal response to reduction of cardiac output and mean arterial pressure
- Reduction in urine output secondary to a fall in the transmural pressure of the right atrium that results in reduction of the secretion of atrial naturitic peptide and the activation of renin-angiotensin-aldosterone system and pituitary vasopressin secretion
Neurological Functions during Mechanical Ventilation
Acute Effects

- Vasoconstriction secondary to hypercapnia
- Decreased intra-cerebral blood volume and intracranial pressure
- PEEP reduces cerebral perfusion pressure by decreasing venous return and increasing intracranial pressure
  - 20-25% of is transmitted to the central venous pressure in a normal compliant lung
  - >20% is transmitted in patients with decreased lung compliance
Normal Sleep Pattern

- Stage 1
- Stage 3
- REM
- Stage 2
- Stage 4
Hyponogram for a Patient on Mechanical Ventilation
Mechanisms by which mechanical Ventilation Disrupt Sleep

- **Noise disruption**
  - Ventilator alarm:
    - inappropriate threshold
    - Delayed alarm inactivation
  - Humidifier alarms
- **Disruption by nursing interventions**
  - Airway suction
  - Nebulizer delivery
- **Ventilation-related pharmacological disruption**
  - Benzodiazepines (↓REM, ↓deep NREM)
  - Opioids (↓REM, ↓deep NREM)
  - Neuromuscular blocking drugs
- **Ventilator mode**
  - Pressure support ventilation
Asynchrony with the patient
Asynchrony with the ventilator

- Fighting the ventilators
- Inconsistent tidal volume
- Increase work of breathing
- Barotraumas and thoracic air leak
- Insufficient gas exchange
- Disturbances in the cerebral blood flow
Ventilation complications
Mode specific

What About New Modes?