OXYGEN DELIVERY DEVICES

MD SEMINAR
Dr Hemanth C
Internal Medicine
INTRODUCTION

• Tissue oxygenation
• Assessment of tissue hypoxia
• Indications for oxygen therapy
• Techniques of oxygen administration
  - Oxygen delivery devices
TISSUE OXYGENATION

• Depends on oxygen delivery and utilization by tissue
• Oxygen delivery – integrated function of pulmonary, CVS and hematological systems

\[ \text{DO}_2 = \text{CO} \times \text{CaO}_2 \times 10 \]

• \( \text{DO}_2 \) – oxygen delivery, ml/min
• \( \text{CO} \) – cardiac output, L/min
• \( \text{CaO}_2 \) – \( \text{O}_2 \) content of arterial blood, ml/dl

*Fishman’s Pulmonary Diseases and disorders*
CaO₂ = ([Hgb] x 1.34 x SaO₂) + (PaO₂ x 0.0031)

- [Hgb] = Hemoglobin concentration, g/dl
- 1.34 = oxygen carrying capacity of Hb, ml/g
- SaO₂ = %O₂ saturation of Hb
- 0.0031 = solubility coefficient for oxygen

*Fishman’s Pulmonary Diseases and disorders*
• DO$_2$ – oxygen delivery
• VO$_2$ – oxygen utilization
TISSUE HYPOXIA

• Arterial hypoxemia (low PaO\textsubscript{2})
  - decreased oxygen intake
  - ventilation – perfusion imbalance
  - diffusion defect
  - alveolar hypoventilation
  - shunt (does not improve)

  \begin{itemize}
  \item PaO\textsubscript{2} improves with supplemental oxygen
  \end{itemize}

• Reduced oxygen delivery (normal PaO\textsubscript{2})
  - circulatory hypoxia (low cardiac output/ hypovolemia)
  - abnormal blood oxygen transport (anemia/ hemoglobinopathies / CO poisoning)

• Excessive or dysfunctional tissue utilization
  - inhibition of intracellular enzymes (cyanide – cytochrome oxidase)
TISSUE HYPOXIA

RECOGNITION AND ASSESSMENT

- Combination of clinical and laboratory parameters
- Clinical manifestations are highly variable and nonspecific
## Clinical manifestations

<table>
<thead>
<tr>
<th>SYSTEM</th>
<th>SIGNS AND SYMPTOMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>RESPIRATORY</td>
<td>Tachypnea, dyspnea, cyanosis</td>
</tr>
<tr>
<td>CVS</td>
<td>Palpitations</td>
</tr>
<tr>
<td></td>
<td>Increased CO, tachycardia, arrhythmias</td>
</tr>
<tr>
<td></td>
<td>Hypotension, angina, diaphoresis, shock</td>
</tr>
<tr>
<td>CNS</td>
<td>Headache, confusion, euphoria</td>
</tr>
<tr>
<td></td>
<td>Delirium, papilledema, seizures</td>
</tr>
<tr>
<td></td>
<td>Obtundation and coma</td>
</tr>
<tr>
<td>METABOLIC</td>
<td>Lactic acidosis, Na and water retention</td>
</tr>
<tr>
<td>NEUROMUSCULAR</td>
<td>Weakness, tremors, asterixis, incoordination, hyper-reflexia</td>
</tr>
</tbody>
</table>
Laboratory assessment

• $vO_2$ – (mixed venous PO$_2$) an approximation of mean tissue PO$_2$ (<30mm Hg tissue hypoxia)
  - requires pulmonary artery catherization (ICU)
• Surrogate markers of tissue hypoxia
  - PaO$_2$
  - Arterial hemoglobin oxygen saturation
  - Serum lactate levels
INDICATIONS FOR O$_2$ THERAPY

- **ACUTE OXYGEN THERAPY**
  - Acute hypoxemia (PaO$_2$ < 60mm Hg; SpO$_2$ <90%)
  - Cardiac and respiratory arrest
  - Hypotension (SBP < 100 mm Hg)
  - Low cardiac output + metabolic acidosis (HCO$_3^-$ < 18 mmol/L)
  - Respiratory distress (RR > 24/min)

*Fishman’s Pulmonary Diseases and disorders*
LONG TERM OXYGEN THERAPY

• CONTINUOUS OXYGEN

1. Resting $\text{PaO}_2 < 55$ mm Hg / $\text{SpO}_2 < 88\%$

2. Resting $\text{PaO}_2$ of 56-59 mm Hg / $\text{SpO}_2$ of 89% in the presence of cor pulmonale
   A. Dependent edema (CHF)
   B. P pulmonale on ECG
   C. Polycythemia (Hematocrit $> 56\%$)

*Fishman’s Pulmonary Diseases and disorders*
LONG TERM OXYGEN THERAPY

• NON-CONTINUOUS OXYGEN
  (not recommended now a days)
  1. During exercise: \( \text{PaO}_2 < 55 \text{ mm Hg} \) or \( \text{SpO}_2 < 88 \% \) with low level of exertion
  2. During sleep: \( \text{PaO}_2 < 55 \text{ mm Hg} \) or \( \text{SpO}_2 < 88 \% \) with associated complications
     - pulmonary hypertension
     - daytime somnolence
     - cardiac arrhythmias

Fishman’s Pulmonary Diseases and disorders
TECHNIQUES OF OXYGEN ADMINISTRATION
“Oxygen delivery system is a device which is used to administer, regulate and supplement oxygen to a subject to increase the arterial oxygenation”
Oxygen delivery systems

- Normobaric
  - Low dependency
    - Variable performance
  - Medium dependency
  - High dependency
    - Fixed performance

- Hyperbaric

*Ward’s textbook of anaesthetic equipment 6th Edn*
<table>
<thead>
<tr>
<th>Type of Normobaric Oxygen delivery device</th>
<th>Definition</th>
<th>Respiratory pattern</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOW DEPENDENCY</td>
<td>Supplemental oxygen alone is sufficient to correct hypoxia</td>
<td>Spontaneous breathing present</td>
</tr>
<tr>
<td>MEDIUM DEPENDENCY</td>
<td>Supplemental oxygen and a degree of respiratory assistance is required</td>
<td>Spontaneous breathing present but requires additional support. Example: CPAP</td>
</tr>
<tr>
<td>HIGH DEPENDENCY</td>
<td>Supplemental oxygen and full respiratory support is required</td>
<td>Absent spontaneous respiration. Requires NIPPV or IPPV</td>
</tr>
</tbody>
</table>
Low dependency system

• Variable performance devices / low flow devices
• Fixed performance devices / high flow devices
• Choice of **delivery system** is based upon:
  1. Degree of hypoxemia
  2. Requirement for precision of delivery
  3. Patient comfort
  4. Cost
## Low dependency Oxygen Delivery Systems

<table>
<thead>
<tr>
<th>LOW FLOW OXYGEN DEVICES</th>
<th>HIGH FLOW OXYGEN DEVICES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cannot deliver constant $\text{FiO}_2$</td>
<td>Maintain constant $\text{FiO}_2$</td>
</tr>
<tr>
<td>Flow 6 - 8 L/min</td>
<td>Delivering $O_2$ at very high flow</td>
</tr>
<tr>
<td>Mixture of oxygen + room air</td>
<td>Flow usually 4 times the actual Minute volume</td>
</tr>
<tr>
<td>$\text{FiO}_2$ varies with tidal volume</td>
<td>Used in – treatment of hypoxic patients who depend on hypoxic drive to breathe and require controlled increments in $\text{FiO}_2$</td>
</tr>
<tr>
<td>- Shallow breathing = less entrainment of room air (high $\text{FiO}_2$)</td>
<td>- Young and vigorous patients with hypoxemia, with ventilatory requirement exceeding the capability of low flow systems</td>
</tr>
<tr>
<td>- deep, hyperpneic breathing = more entrainment of room air (less $\text{FiO}_2$)</td>
<td></td>
</tr>
<tr>
<td>Eg : Nasal cannulae, oxygen masks, mask with reservoir bags etc</td>
<td>Eg : jet-mixing venturi masks, reservoir nebuliser, oxygen blender</td>
</tr>
</tbody>
</table>
Variation of FiO2 in low flow

<table>
<thead>
<tr>
<th>Ventilatory minute volume (Respiratory rate x tidal volume)</th>
<th>30 l/min (40 breaths/min x 750 ml/breath)</th>
<th>5 l/min (10 breaths/min x 500 ml/breath)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Oxygen flow rate</strong></td>
<td>2 l/min</td>
<td>2 l/min</td>
</tr>
<tr>
<td>Calculation of inspired oxygen concentration (FiO2)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 l/min of 100% oxygen + 28 l/min of air drawn into the mask (21% oxygen) = 30 l/min minute volume</td>
<td></td>
<td>2 l/min of 100% oxygen + 3 l/min of air drawn into the mask (21% oxygen) = 5 l/min minute volume</td>
</tr>
<tr>
<td><strong>Thus</strong> FiO2 = [\frac{(1.0 \times 2) + (0.21 \times 28)}{30}] = 0.26 (26%)</td>
<td></td>
<td><strong>Thus</strong> FiO2 = [\frac{(1.0 \times 2) + (0.21 \times 3)}{5}] = 0.53 (53%)</td>
</tr>
</tbody>
</table>
Common Low flow devices

• Nasal cannula (prongs or spectacles)
• Nasal catheters
• Transtracheal catheter
• Face mask
• Partial rebreathing mask
• Non rebreathing mask
• Tracheostomy mask
NASAL CANNULA

- Right nasal prong
- Left nasal prong
- Delivery tube
- Restraining band
NASAL CANNULA

- Consists of 2 soft prongs attached to O₂ supply tubing
- A flow rate of 2–4 L/min delivers an FiO₂ of 0.28–0.36 respectively
- FiO₂ = 20% + (4 × oxygen litre flow)
- No increase in FiO₂ if flow is more than 6L/min
- Nasopharynx acts as a reservoir
- If patient breaths through mouth, air flow produces a Venturi effect in the posterior pharynx entraining oxygen from the nose
- Available in different sizes and different prong shapes
NASAL CANNULA

- **Curved prongs:** Improved anatomical fit
- **Flared prongs:** Slows down the flow of oxygen
- **Curved / Flared prongs:** Combines the benefits of both the above designs
- **Straight prongs**
- **Curved prongs with ear guards:** Improved anatomical fit and patient comfort
NASAL CANNULA

Advantages:
• Ideal for patients on long-term oxygen therapy
• Light weight and comfortable
• The patient is able to speak, eat and drink
• Humidification not required
• Low cost (Rs.70)

Disadvantages:
• Can not provide high flow O₂
• Irritation and can not be used in nasal obstruction
• FiO₂ varies with respiratory efforts
• High flow rates are uncomfortable
NASAL CATHETER
NASAL CATHETER

Uvula

Catheter tip placed behind uvula
NASAL CATHETER

- Single lumen catheter, which is lodged into the anterior naris by a foam collar, inserted to just above the uvula
- Oxygen flows of 2–3 L/min can be used. FiO₂ 35-40%
- It should not be used when a nasal mucosal tear is suspected because of the risk of surgical emphysema.
- Deep insertion can cause air swallowing and gastric distension
- Must be repositioned every 8 hours to prevent breakdown
- No advantages over nasal cannula
SIMPLE FACE MASK

Exhalation ports

Oxygen inlet
SIMPLE FACE MASK

• Transparent mask provided with side holes
• Reservoir capacity **100–250 ml**
• Different oxygen flow rates result in a highly variable and unpredictable \( \text{FiO}_2 \)
• **Rebreathing of \( \text{CO}_2 \)** can occur with \( \text{O}_2 \) flow rates of less than 2 L \( \text{O}_2 \) l/min or if minute ventilation is very high
• **4 L/min of oxygen** flow delivers an \( \text{FiO}_2 \) of about **0.35–0.4** providing there is a normal respiratory pattern
• Flow rates greater than 8L/min do not increase \( \text{FiO}_2 \)
SIMPLE FACE MASK

**Advantage:**
- Less expensive (Rs 80/-)
- Can be used in mouth breathers

**Disadvantage:**
- Uncomfortable
- Require tight seal
- Do not deliver high FiO$_2$
- FiO$_2$ varies with breathing efforts
- Interfere with eating, drinking, communication
- Difficult to keep in position for long
- Chances of rebreathing are high
PARTIAL REBREATHING MASK

• Mask with reservoir bag of capacity 1lit
• Oxygen flows directly into the reservoir bag, which fills during exhalation
• Designed in such a way that it captures exhaled gases from initial part of expiration from the dead spaces.
• Useful in situations where supplies are limited
PARTIAL REBREATHTING

- Expired Gas
- Inspired Gas
- 100% Oxygen
- Mixed Inspired and Expired Gas

Reservoir Bag
PARTIAL REBREATHEING MASK

• Deliver an FiO\textsubscript{2} between 0.6 and 0.8

• A minimum of 8L/min should enter the mask to remove exhaled CO\textsubscript{2} and to refill oxygen reservoir

• Flow rate must be sufficient to keep bag 1/3 to 1/2 inflated at all times
PARTIAL REBREATHE MASK

Advantage:

• Inspired gas not mixed with room air
• Patient can breathe room air through exhalation ports if oxygen supply gets interrupted

Disadvantage

• More oxygen flow does not increase $\text{FiO}_2$
• Interfere with eating and drinking
NON REBREATTHING MASK

• Provided with one way valves between mask and bag, exhalation ports
• \( \text{FiO}_2 \) of 95\% can be achieved with an oxygen flow rates of 10 to 15 L/min
• Ideally NRM should not allow entrainment of air, but because of safety concerns one of the two exhalation ports is not provided with valve
NONREBREATHER

Expired Gas
One Way Valve

Inspired Gas
One Way Valve

100% Oxygen

Reservoir Bag
NON REBREATHTING MASK

• Higher oxygen supply rates are required
• Desirable in cases where rebreathing of CO$_2$ would be detrimental, for example after head injury
• Best results will be achieved by adequate flow rates such that the reservoir bag empties by no more than a third during inspiration and by best seal possible between the mask and the face
NON REBREATHING MASK

Advantage:
• Highest possible FiO₂ without intubation
• Suitable for spontaneously breathing patients with severe hypoxia

Disadvantage
• Expensive
• Require tight seal, Uncomfortable
• Interfere with eating and drinking
• Not suitable for long term use
• Malfunction can cause CO₂ buildup, suffocation
<table>
<thead>
<tr>
<th>FLOW RATE (L/min)</th>
<th>FiO$_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nasal cannula 1-6</td>
<td>0.24-0.44</td>
</tr>
<tr>
<td>Trans tracheal catheter 0.5-4</td>
<td>0.24-0.4</td>
</tr>
<tr>
<td>Oxygen mask 5-6 6-7 7-8</td>
<td>0.4 0.5 0.6</td>
</tr>
<tr>
<td>Mask with reservoir bag 6-10</td>
<td>0.6-0.9</td>
</tr>
<tr>
<td>Non rebreathing 4-10</td>
<td>0.6-1.0</td>
</tr>
<tr>
<td>Venturi mask (HIGH FLOW) 3-15</td>
<td>0.24-0.5</td>
</tr>
</tbody>
</table>
HIGH FLOW / FIXED PERFORMANCE

• Based on Venturi modification of Bernoulli principle
• Gas flow is sufficient to meet the demands of patient
• Not synonymous with high concentration of O$_2$
• The plastic body of the mask with holes on both sides
• The proximal end of the mask consists of a Venturi device. The Venturi devices are color-coded and marked with the recommended oxygen flow rate to provide the desired oxygen concentration.

• Alternatively, a calibrated adjustable venturi device can be used to deliver the desired FiO₂.
• Bernoulli’s principle:

• Venturi principle:
Adjustable venturi valve
Jet-mixing Venturi Mask/ Air Entrainment Mask (AEM)
Venturi mask (AEM)

• Delivers fixed concentration of oxygen
• The size of the constriction determines the final concentration of oxygen for a given gas flow
• As forward flow of inspired gas increases, the lateral pressure adjacent and perpendicular to the vector of flow decreases, resulting in entrainment of gas
• The smaller the orifice is, the greater the negative pressure generated, so the more ambient air entrained, the lower the FiO$_2$
• FiO$_2$ can be 0.24, 0.28, 0.31, 0.35, 0.4 or 0.6
• Because of the high fresh gas flow rate, the exhaled gases are rapidly flushed from the mask, via its holes. Therefore there is no rebreathing and no increase in dead space.

• These masks are recommended when a fixed oxygen concentration is desired in patients whose ventilation is dependent on the hypoxic drive.
<table>
<thead>
<tr>
<th>$F_{O_2}$ BY VENTURI VALVE</th>
<th>NOZZLE COLOUR</th>
<th>OXYGEN FLOW RATE TO VENTURI VALVE (l min$^{-1}$)</th>
<th>AMOUNT OF AIR ENTRAINED (l min$^{-1}$)</th>
<th>TOTAL FLOW TO PATIENT (l min$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.24</td>
<td></td>
<td>2</td>
<td>51</td>
<td>53</td>
</tr>
<tr>
<td>0.28</td>
<td></td>
<td>4</td>
<td>41</td>
<td>45</td>
</tr>
<tr>
<td>0.31</td>
<td></td>
<td>6</td>
<td>41</td>
<td>47</td>
</tr>
<tr>
<td>0.35</td>
<td></td>
<td>8</td>
<td>37</td>
<td>45</td>
</tr>
<tr>
<td>0.40</td>
<td></td>
<td>10</td>
<td>32</td>
<td>42</td>
</tr>
<tr>
<td>0.60</td>
<td></td>
<td>15</td>
<td>15</td>
<td>30</td>
</tr>
</tbody>
</table>
The Venturi attachments, with a reservoir tubing, can be attached to a tracheal tube or a supra glottic airway device as part of a T-piece breathing system.
DEVICE FLOW RATE

• The air:O₂ ratio for an air entrainment mask at FiO₂ 40%?

Air:oxygen = \frac{100 - \text{FiO₂}}{\text{FiO₂} - 21} = \frac{100 - 40}{40 - 21} = \frac{60}{19} = 3.2

• Ratio for 40% is (3.2 : 1)
• If the O₂ Flow meter is set at 10 L/min
• Then the entrained air will be 10 \times 3.2 = 32 L/min
• Total flow = (air + O₂) = (10 + 32) = 42 L/min
VENTURI MASK

**Advantage**
- Fine control of FiO$_2$ at fixed flow
- Fixed, reliable, and precise FiO$_2$
- High flow comes from the air, saving the oxygen cost
- Can be used for low FiO$_2$ also
- Helps in deciding whether the oxygen requirement is increasing or decreasing

**Disadvantage**
- Uncomfortable
- Expensive (400-600)
- Cannot deliver high FiO$_2$
- Interfere with eating and drinking
HIGH FLOW NASAL CANNULA

• Delivers heated and humidified oxygen via special devices (eg, Vapotherm®).

• Rates up to 8 L/min in infants and up to 40 L/min in children and adults.

• In patients with respiratory distress or failure, oxygen by humidified high-flow nasal cannula may be better tolerated than by face mask.

*J intensive Care Med 2009:24:323*
HIGH FLOW NASAL CANNULA
HIGH FLOW NASAL CANNULA

• High flow washes out carbon dioxide in anatomical dead space.
• Creates positive nasopharyngeal pressure.
• \( \text{FiO}_2 \) remains relatively constant.
• Because gas is generally warmed to 37°C and completely humidified, mucociliary functions remain good and little discomfort is reported.

HIGH FLOW NASAL CANNULA
BLENDING SYSTEMS

- When high $O_2$ conc / flow is required
- Inlet – separate pressurized air, $O_2$ source
- Gases are mixed inside either manually or with blender
- Output – mixture of air and $O_2$ with precise FiO$_2$ and flow
- Ideal for spontaneously breathing patients requiring high FiO$_2$
$O_2$ blending device
Long term O$_2$ delivery systems

• Gas supplies
  - Oxygen concentrators (stationary)
  - Compressed gas
  - Liquid oxygen

• Delivery devices for LTOT include most of the low flow devices

• Designed to “conserve” home oxygen by improving efficiency of oxygen delivery
LTOT delivery devices:

- Nasal cannulae
- Reservoir nasal cannulae
- Electronic conserving devices
  - Pulse devices (fixed volume/breath)
  - Demand devices (variable volume – length)
- Transtracheal catheters
Reservoir nasal cannula

FIGURE 38-8  Reservoir cannula.
TRANSTRACHEAL CATHETER
TRANSTRACHEAL CATHETER

• Advantages
  - Reduce total oxygen usage of 50 – 75%
  - Lack of nasal/facial irritation due to flow
  - Infrequency of catheter displacement in sleep

• Disadvantages
  - Infection
  - Mucus balls – potentially fatal
  - Catheter breakage
SELECTION OF DEVICE

3 P’s

• Purpose
• Patient
• Performance

- Goal is to match the performance characteristics of the equipment to both the objectives of therapy (purpose) and the patient’s special needs
• **Purpose** – improve arterial hypoxemia
• **Patient** factors in selection -
  ✓ Severity and cause of hypoxemia
  ✓ Patient age group (infant, child, adult)
  ✓ Degree of consciousness and alertness
  ✓ Presence or absence of tracheal airway
  ✓ Stability of minute ventilation
  ✓ Mouth breathing vs. nose breathing patient
### Device based on performance

<table>
<thead>
<tr>
<th>DESIRED $\text{FiO}_2$ LEVEL</th>
<th>DESIRED $\text{FiO}_2$ STABILITY</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>FIXED</td>
</tr>
<tr>
<td>LOW (&lt; 35%)</td>
<td>A E M (Air entrainment mask) / venturi mask</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>MEDIUM (35%-60%)</td>
<td>A E M (Air entrainment mask) / venturi mask</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>HIGH (&gt;60%)</td>
<td>Blending system</td>
</tr>
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<td></td>
<td></td>
</tr>
</tbody>
</table>
SCENARIO 1

Emergencies with suspected tissue hypoxia

• Cardiac/respiratory failure, shock, trauma, CO poisoning
• Highest possible FiO$_2$ – ideally 100%
• CO/ cyanide poisoning – hyperbaric system
• True high flow / closed reservoir system
SCENARIO 2

Critically ill adult patient with moderate to severe hypoxemia

- Goal – $\text{PaO}_2 > 60 \text{ mm Hg} / \text{SpO}_2 > 90 \%$
- Reservoir / high flow system ($>60\% \text{FiO}_2$)
SCENARIO 3

Critically ill adult patient with mild to moderate hypoxemia

• Immediate post op phase, recovering from MI
• Stability of FiO$_2$ is not critical
• System with low to moderate FiO$_2$
• Nasal cannula / simple mask
SCENARIO 4

Adult patient with COPD with acute-on-chronic hypoxemia

• Goal – adequate arterial oxygenation without depressing ventilation
• Adequate-(SpO$_2$ of 85%-92%)(PaO$_2$ 50-70mm Hg)
• Low concentration AEM(venturi mask 0.24-0.28) or low flow nasal cannula
Thank you