Hypoxemia

Troy Schaffernocker, MD

### Decreased Partial Pressure of Oxygen

- Occurs at altitude
- Barometric pressure and altitude have a dramatic effect on oxygen tension
- Oxygen tension of inspired air:
  - Sea level = 150 mm Hg
  - Denver = 130 mm Hg
  - Mt. Everest = 43 mm Hg

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- Occurs at altitude
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  - Denver = 130 mm Hg
  - Mt. Everest = 43 mm Hg

### Hypoxemic Respiratory Failure

- Mechanisms of hypoxemia:
  - Decreased partial pressure of oxygen
  - Impaired diffusion
  - Ventilation/perfusion mismatch
  - Shunt
  - Hypoventilation

### Effect of Barometric Pressure and Altitude on Oxygen
Impaired Diffusion

- Interstitial lung disease
  - Thickened interstitium impedes diffusion of oxygen from the alveolus to the capillary
- Early in course of ILD, hypoxemia usually not significant except during states of increased oxygen demand (exercise)
- Combination of impaired diffusion and increased transit time of blood through alveolar capillaries (due to increased cardiac output from exercise) results in hypoxemia

Clinical Situation of Low V/Q (Shunt)

- V/Q = 0 is represented by true right to left shunting (intracardiac defect) with venous admixture of blood.
  - Alveoli completely bypassed
- Any situation where alveoli are filled (not ventilated):
  - Blood, pus, water
  - Alveolar hemorrhage, pneumonia, CHF, ARDS
- Atelectasis of lung

Ventilation/Perfusion

- The adequacy of gas exchange in the lungs is determined by the balance between pulmonary ventilation and capillary blood flow.
- Expressed as the ventilation-perfusion (V/Q) ratio.

Clinical Situations of High V/Q (Increase Deadspace)

- Pulmonary embolism
- Physiologic dead space as seen in COPD
  - Normal response is to increase minute ventilation
**Hypoventilation**

- Results in hypoxemia that is always associated with hypercapnia (by definition)
- Normal physiologic response to ↑ PaCO₂ is to increase minute ventilation and thus alveolar ventilation

**Hypoxemia: Diagnosis and Monitoring**

- Arterial Blood Gas (ABG)
- Alveolar Oxygen Tension
- Alveolar-arterial (A-a) Oxygen Gradient
- Oxygen Content and Delivery
- Pulse Oximetry

**Normal Arterial Blood Gases**

<table>
<thead>
<tr>
<th>AGE (Years)</th>
<th>PaO₂ (mmHg)</th>
<th>PaCO₂ (mmHg)</th>
<th>A – a PO₂ (mm Hg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>84-95</td>
<td>34-47</td>
<td>4-17</td>
</tr>
<tr>
<td>30</td>
<td>81-92</td>
<td>34-47</td>
<td>7-21</td>
</tr>
<tr>
<td>40</td>
<td>78-90</td>
<td>34-47</td>
<td>10-24</td>
</tr>
<tr>
<td>50</td>
<td>75-87</td>
<td>34-47</td>
<td>14-27</td>
</tr>
<tr>
<td>60</td>
<td>72-84</td>
<td>34-47</td>
<td>17-31</td>
</tr>
<tr>
<td>70</td>
<td>70-81</td>
<td>34-47</td>
<td>21-34</td>
</tr>
<tr>
<td>80</td>
<td>67-79</td>
<td>34-47</td>
<td>25-38</td>
</tr>
</tbody>
</table>

All values related to FiO₂ = 21% at sea level
Adapted from Intermountain Thoracic Society Manual, 1984 44-45

**Variation in ABGs**

<table>
<thead>
<tr>
<th>Variation</th>
<th>PaO₂ (mm Hg)</th>
<th>PaCO₂ (mmHg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>13</td>
<td>2.5</td>
</tr>
<tr>
<td>95th Percentile</td>
<td>+/- 18</td>
<td>+/- 4</td>
</tr>
<tr>
<td>Range</td>
<td>2 – 37</td>
<td>0 - 12</td>
</tr>
</tbody>
</table>

Represents variation over a 1-hour period in 26 clinically stable ventilator dependent patients
From Hess D, Agarwal NN. J Clin Monitor 1992
### Alveolar Oxygen Tension

- Determined by the alveolar gas equation:
- \((\text{Barometric pressure} - \text{H}_2\text{O vapor pressure})\) \(\text{FiO}_2 - \text{PaCO}_2/\text{Respiratory quotient}
- \((\text{BP} - \text{WVP})\text{FiO}_2 - \text{PaCO}_2/0.8
- \((760 - 47)0.21 - 40/0.8 = \)
- \(150 - 50 = 100 \text{ mm Hg}\)

### (A-a) Gradient

- Normal if hypoxemia is due to hypoventilation (e.g. narcotic overdose) or low atmospheric O2 (e.g. high altitude).
- High if hypoxemia is due to V/Q mismatch (e.g. Pulmonary Embolus), Impaired Diffusion (e.g. ILD), or Shunt (e.g. ASD)

### (A-a) Gradient

- Partial pressure of oxygen in the alveolus minus partial pressure of oxygen in an artery.
  - \([\text{FiO}_2 \times (\text{Barometric pressure} - \text{water vapor}) - (1.25 \times \text{PCO}_2)] - \text{PaO}_2\)
- At Room Air
  - \([150 - (1.2 \times \text{PCO}_2)] - \text{PaO}_2 = \text{A-a Gradient}\)
    - Normal = 8 - 12 mmHg
    - Increases with age - Age/4 + 4

### Oxygen Saturation & Oxygen Delivery

- Remember oxygen content (\(\text{CaO}_2\)) is a more important management measure than \(\text{PaO}_2\)
  - \([^\text{[Hb]} \times \%\text{Sat} \times 1.34 \text{ ml/g}] + (\text{PaO}_2 \times 0.003)]\)
- Oxygen delivery the key parameter
  - \(\text{CaO}_2 \times \text{Cardiac output (CO)}\)
**Pulse Oximetry**

- Uses the differential absorbance of light by oxyhemoglobin and deoxyhemoglobin to estimate the oxygen saturation
- Caveats:
  - Detection of Acute Hypoxemia may be slow
  - Does not measure ventilation
  - Ambient light
  - Electromagnetic Radiation
  - Severe Anemia
  - Hypoperfusion
  - Hypothermia
  - Venous Congestion
  - Nail Polish

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**Nasal Cannula**

<table>
<thead>
<tr>
<th>Flow Rate</th>
<th>Oxygen Delivery (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 LPM</td>
<td>24%</td>
</tr>
<tr>
<td>2 LPM</td>
<td>28%</td>
</tr>
<tr>
<td>3 LPM</td>
<td>32%</td>
</tr>
<tr>
<td>4 LPM</td>
<td>36%</td>
</tr>
<tr>
<td>5 LPM</td>
<td>40%</td>
</tr>
<tr>
<td>6 LPM</td>
<td>44%</td>
</tr>
</tbody>
</table>

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**Advantages and Disadvantages of the Nasal Cannula**

**Advantages:**
- Comfortable
- Able to communicate
- Patient can eat and take oral medications.
- Easy to use at home.

**Disadvantages:**
- Nasal obstruction may impede gas flow.
- May cause nasal mucosal drying (can be humidified with sterile water)

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**Oxygen Delivery Devices**
**Simple Mask**

LOW FLOW Device

5-8 LPM

* 5-6L=40%
* 6-7L=50%
* 7-8L=60%

- Flow should be set at 5 L/min or more in order to avoid rebreathing exhaled carbon dioxide (CO₂)
- Least used mask due to unpredictable FiO₂ percentage (easier to use Venti Mask)

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**Non-Rebreather Mask**

LOW FLOW Device

15 LPM

Bag should remain 1/3-1/2 full after the patient takes a deep breath

Delivers 90%-100% oxygen

- Must have all 3 valves

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**Partial Rebreather Mask**

15 LPM

Bag should remain 1/3-1/2 full after the patient takes a deep breath

Delivers 60%-80% oxygen

- Must have all values removed to be considered a Partial Rebreather Mask

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**Face Tent**

Advantages:
- Designed for patients with facial trauma or surgery that cannot wear a regular mask or nasal cannula.

Disadvantages:
- Clumsy and uncomfortable
- Variable FiO₂ due poor mask seal
**Low-Flow Oxygen Delivery**

<table>
<thead>
<tr>
<th>Device</th>
<th>Reservoir Capacity (mL)</th>
<th>Oxygen Flow (L/min)</th>
<th>Approximate FIO2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nasal Cannula</td>
<td>50</td>
<td>1</td>
<td>0.31 - 0.34</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>0.24 - 0.28</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>0.26 - 0.34</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4</td>
<td>0.34 - 0.38</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5</td>
<td>0.38 - 0.42</td>
</tr>
<tr>
<td>Simple Face mask</td>
<td>150 - 250</td>
<td>5-15</td>
<td>0.40 - 0.50</td>
</tr>
<tr>
<td>Mask - reservoir bag</td>
<td>750 - 1250</td>
<td>5-7</td>
<td>0.35 - 0.75</td>
</tr>
<tr>
<td>Partial Rebreather</td>
<td></td>
<td>5-10</td>
<td>0.40 - 1.0</td>
</tr>
<tr>
<td>Nonrebreather</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Estimated based on tidal volume of 500 mL, RR of 20 and I:E of 1:2
From Shapiro BA, et al 1991

**Cool Aerosol Mask**

- High Flow Oxygen Delivery with High Particulate Humidity
  - Hydration of airways for tenacious secretions
  - Treatment of Airway Edema
  - Accommodate High Liter Flow of High Flow Systems

**Venturi Mask (Venti Mask)**

- 3-15 LPM
- 24%-50% (set on base of mask)
- Set Flo2 with percentage markings on the base of mask and adjust the oxygen flowmeter to the appropriate LPM

**Venturi Mask and Bernoulli’s Principle**

- Bernoulli’s Principle: Pressure is least where the velocity of flow is the greatest.
- As FIO2 and entrained room air combine and flow through the constricted opening of the Venturi device the flow velocity to the patient increases greatly.
- By changing the opening size and oxygen flow the Flo2 can be varied.
HFNC (High Flow Nasal Cannula)

- Principle: In the past O2 Delivery by nasal route was limited by the ability to humidify and warm the inspired gas.
- Provides adequately warmed and humidified gas
- Provides more “wash out” of the nasopharyngeal deadspace,
- Greater flow matches the patient’s natural inspiratory flow.
- High flow can be titrated to potentially provide positive distending pressure for lung recruitment.

Roca et al Respiratory Care 2010
Dewan et al Chest 1994

O2 Delivery

HFNC

- CONTRAINDICATIONS
  - Unable to protect their airway
  - Inability to adequately ventilate
  - Facial trauma
  - Significant epistaxis (Nose bleed) or patients with nasal complications

- COMPLICATIONS/ PRECAUTIONS
  - Nasal dryness, edema or bleeding
  - Drying mucous, mucous plugging or airway inflammation
  - Sinusitis
  - Inappropriate or interrupted oxygen flow may cause hypoxemia and or hypercapnia

Non-invasive Ventilation

- CPAP
  - Continuous Positive Airway Pressure
- BiPAP/Bilevel
  - Bilevel Positive Airway Pressure
- Best Evidence
  - COPD Exacerbations
  - CHF (Congestive Heart Failure) with Pulmonary Edema

Wettstein et al Respiratory Care 2005


**Non-invasive Ventilation**

- Supportive Evidence
  - Facilitation of weaning and extubation in COPD
  - Immunosuppressed Patients
  - Extubation Failure in COPD or CHF
  - Prevention of Respiratory Failure in Asthma
  - Palliative

**BiPAP/Bilevel**

- Bilevel positive airway pressure (BiPAP) is a mode that delivers an inspiratory positive airway pressure (IPAP) and expiratory positive airway pressure (EPAP)
- The magnitude of the difference between IPAP and EPAP is directly proportional to the amount of tidal volume augmentation and the alveolar ventilation.
- If using a ventilator
  - Pressure Support + PEEP = IPAP
  - PEEP = EPAP

**CPAP vs BiPAP/Bilevel**

- A trial of BiPAP may be worthwhile in patients who do not tolerate CPAP. This is particularly true for patients who seem likely to benefit from a low expiratory pressure:
  - patients with discomfort caused by exhaling against the CPAP
  - patients with mouth leaks despite optimization of the interface
  - and patients with musculoskeletal chest pain due to breathing at a higher functional residual capacity

**Nasal vs Full Face Mask**

- Nasal
  - Smaller
  - Easy to fit
  - Can have significant leak through mouth
- Full Face
  - Bulkier
  - Aspiration Risk
  - Claustrophobia
Non-invasive Ventilation

- Contraindications
  - Respiratory Arrest
  - Anatomically unable to fit mask
  - Inability to protect airway
  - Inability to manage secretions
  - Inability to cooperate with therapy – poor mental status, agitation, etc
  - Aspiration Risk
  - Recent upper airway or upper GI surgery

Mechanical Ventilation

- #1 Indication “If you think about it”
- Elective intubation is much safer than emergent intubation
- Airway control in an unstable patient is better for the patient
- Being on the ventilator does not create ventilator dependence – Severe illness creates ventilator dependence

Hypoxemia

Outpatient Use of supplemental oxygen
Ruthann Kennedy, RN

Indications for Oxygen

- Resting room air saturation ≤ 88%
- PaO₂ ≤ 55 mmHg
- Desaturation SaO₂ ≤ 88% with exertion
- During sleep: desaturation PaO₂ ≤ 55 mmHg or SaO₂ ≤ 88%
- PaO₂ ≤ 59 mmHg or SaO₂ ≤ 89% in the presence of cor pulmonale, right heart failure, hematocrit > 55%.
# Ordering Oxygen

1. Qualification of oxygen need
2. Select DME
3. Written prescription
   - Flow rate, instructions & length of therapy
   - Example: Oxygen 2L/m with rest, and 4L/m with exertion and sleep, length of therapy -lifetime. Provide home and portable equipment

## Medicare Requirements

1. Resting, Room Air Saturation ≥88%
2. Desaturation ≤ 88% with exertion or sleep
3. Improved saturation with the addition of supplemental oxygen

## Documentation requirements

- The desaturation must be obtained within 2 days of hospital discharge or within 30 days of outpatient testing
- Oxygen saturation ≤88%
  - AT REST on room air
  - Requires no further testing

## Example

- 56 year old patient with interstitial lung disease presents with an initial room air \( \text{SaO}_2 = 90\% \). While walking in the hall, the saturation drops to 84%. With the addition of supplemental oxygen at 2 L/m, the saturation increases to 95%.
**Pulse Oximetry**

- Standard of care for the assessment of oxygen saturation
- “Fifth” vital sign
- Easily accessible
- Available from DME for patient use

**Limitations of Pulse Oximetry**

- Digital injury, especially in conjunction with vasopressors
- Delay in the detection of acute hypoxemia
- Does not assess ventilation
- A significant drop in the PaO$_2$ must occur before the saturation decreases (oxygen hemoglobin dissociation curve)

**Oxygen-Hgb Dissociation Curve**

**Standard Oxygen Concentrator**

- Non-portable, compressed air (gas)
- Oxygen delivery customarily up to 5L/m
- Special concentrators can deliver 10L/m
- Requires electricity
### Compact Oxygen Concentrator

- Compressed air
- Eclipse

Weight is approximately 18 pounds
- 4 hour battery life or AC capable
- Continuous 0.5 – 3.0 L/m
- Pulse 0.5 – 6.0 L/m

### E cylinder

### E tank

*(Compressed Oxygen)*

- Tank Duration 5.7 hours with flow rate of 2L/m continuous.
- Commonly used in conjunction with wheeled cart
- “Portable” but not necessarily convenient for transportation
- Tank itself weighs 4-5 lbs and is 25 inches tall

### Conserving Device

- Reservoir Cannulas – Partial rebreather devices that store oxygen from exhalation
  - Oximizer
  - Oximizer Pendant
- Transtracheal oxygen
- Pulsed Delivery
**Oximizer**

- Advantage: comfort and easy to use
- Disadvantage: cosmetic
- Extends larger than a nasal cannula and is clearly visible

**Oximizer Pendant**

- Appears like a standard nasal cannula
- There is a pendant that sits on the upper chest

**Transtracheal Oxygen**

- Advantages:
  - Increased mobility and exercise
  - Lower oxygen flow requirements
- Disadvantages
  - Invasive
  - Dislodgement
  - Infection
Transtracheal Oxygen

Liquid Oxygen

- LOX – liquid oxygen
- Reservoir – Home unit
  ✓ Weighs 100-160 pounds when filled
- Portable unit
  ✓ Examples: Helios, Escort, Spirit, Sprint

Advantages of Liquid Oxygen

- Reservoir holds 8-10 day supply of oxygen with continuous flow rate at 2L/m
- Does not require electricity resulting in an average monthly savings of $70.
- Delivery of high flow – up to 15L/m
- Portable unit weighs 3.5 lbs with a duration time of 8 hours at 2L/m
Inflight Oxygen

- HAHST: High Altitude Hypoxia Stimulation Test
- ABG drawn on 15% oxygen
- $PO_2 < 50$ mmHg indicative of need for supplemental $O_2$ in flight

Helios

Disadvantages of Liquid Oxygen

- Requires hand and arm strength
- Requires hand eye coordination to fill portable tanks
- Connections can freeze. The actual temperature is negative 297°F.
- Reservoir has to be refilled by DME source
**SmartDose™**

- Automatically adjusting O₂ flow rate in continuous or pulse dosing.
- Available for use in conjunction with:
  - ✓ Compressed O₂
  - ✓ Liquid O₂

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**Product Comparison**

<table>
<thead>
<tr>
<th>Standard conserver</th>
<th>SmartDose™</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increased WOB</td>
<td>Decreased WOB</td>
</tr>
<tr>
<td>Lower dose size &amp; flow rate with activity</td>
<td>Increased dose size &amp; flow rate with activity</td>
</tr>
<tr>
<td>Triggered manually</td>
<td>Auto-adjusts before pt develops symptoms</td>
</tr>
<tr>
<td>Limits activity resulting in deconditioning</td>
<td>Promotes activity</td>
</tr>
<tr>
<td>Forces pt to focus on the device &amp; disease</td>
<td>Allows pt to focus on living</td>
</tr>
</tbody>
</table>

No additional cost