Oxygen Therapy

CRC 330
Cardiorespiratory Care
University of South Alabama
Overview of Therapeutic Topics

- Indications
- Therapeutic objectives
- Contraindications, hazards, precautions
- Assessment of outcome
- Equipment
- Procedures
- Laboratory exercises
- Clinical practice
Production of Oxygen: Fractional Distillation of Air

- Air is dried and filtered
- Compressed to 200 atm (this heats it)
- Compressed air is cooled to room temp
- Quickly expanded to 5 atm, where it liquifies
- The liquid air is transferred to a distillation column
- Allowed to warm, so gases can boil-off
  - N\textsubscript{2} boils off at -320.4 F
  - O\textsubscript{2} boils off at -297.3 F
- Process is repeated until oxygen purity exceeds 99%
Fractional Distillation

(Courtesy Nellcor Puritan Bennett, Pleasanton, Calif.)

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Indications for oxygen therapy

**Documented hypoxemia** defined as:

- Adults, children, and infants older than 28 days, \( \text{PaO}_2 < 60 \text{ mm Hg} \)
- Arterial saturation (\( \text{SaO}_2 \)) < 90% in subjects breathing room air
- \( \text{PaO}_2 \) or \( \text{SaO}_2 \) below desirable range for specific clinical situation
- In neonates, \( \text{PaO}_2 < 50 \text{ mm Hg} \) and/or \( \text{SaO}_2 < 88 \text{ mm Hg} \) or capillary \( \text{P}_02 < 40 \text{mm Hg} \)
Causes of Hypoxemia

- Hypoventilation
- Low ventilation/perfusion (V/Q)
- Diffusion defect
- Shunt
- Increased deadspace
Hypoventilation

- A relatively normal $V_E$ is necessary for adequate alveolar ventilation
- Best therapy is to restore ventilation, but supplement $O_2$ until ventilation is restored
Low Ventilation/perfusion

- Decreased ventilation in relation to perfusion ratio, as in COPD, pneumonia, due to narrowing and clogging of the airways.

- Oxygen therapy increases the PAO₂ to those alveoli that are being ventilated, resulting in an increase in PaO₂.
**Diffusion Defect**

- Increased thickness of the A-C membrane, caused by pulmonary alveolar or interstitial edema, fibrosis
- High FiO$_2$ needed, therapy is to reduce lung water
Shunt

- Massive alveolar collapse or consolidation, such that >25% of the Qt is not being exposed to ventilated alveolar epithelium
- Requires high FiO₂ and increased pressure
Increased Deadspace

- Massive tissue loss from emphysema results in perfusion of poorly ventilated alveoli or bullae (a form of decreased V/Q)
- Pulmonary emboli reduce perfusion of ventilated alveoli
**Indication:** An acute care situation in which hypoxemia is suspected

- Hypoxemia needs to be documented thereafter
- Signs/symptoms
  - tachycardia: pulse > 100 in adults
  - increased BP > 150/90 mm Hg in adults
  - Cyanosis
  - shortness of breath/tachypnea
  - SpO₂ < 90%
  - mental confusion
Other Indications

- Severe trauma: head injury, chest crush, traumatic amputation, severe blood loss
- Acute myocardial infarction
  - tachycardia/arrhythmias
  - SOB
  - Cyanosis
  - reduces myocardial work and oxygen consumption
- Short-term therapy
  - post-anesthesia recovery
  - Hypoventilation
  - anesthetic gas washout
Therapeutic Objectives of Oxygen Therapy

- Treat or prevent the symptoms and manifestations of hypoxia
  - Oxygen is most effective to treat hypoxemia caused by hypoventilation, decreased V/Q, and diffusion defects
  - shunts are less effectively treated
  - positive pressure
Therapeutic Objectives of Oxygen Therapy

- Minimize cardiopulmonary workload
  - compensatory response to hypoxemia is increased ventilation and cardiac output
  - hypoxemia and hypercapnia stimulate ventilation, increasing the WOB
  - hypoxemia causes an increase in CO, stressing the heart
Problems related to an increased PAO$_2$

- Absorption atelectasis
- Oxygen toxicity
- Bronchopulmonary dysplasia
Absorption atelectasis

- Normal $O_2$ diffusion gradient of 60 mm Hg maintained by 79% $N_2$ in alveoli
- 100% $O_2$ is administered, the PAO$_2$ rises to 668 mmHg, = very large diffusion gradient
- Oxygen in alveoli rapidly diffuses into the blood, causing alveolar collapse, and an increase in shunt
- Compounded when patients have a lower than normal Vt
- Give only the amount of oxygen needed to raise the PaO$_2$ above 60!
Absorption Atelectasis

A

\[
\begin{align*}
\text{O}_2 & : 55 \\
\text{CO}_2 & : 45 \\
\text{H}_2\text{O} & : 47 \\
\text{Total} & : 147
\end{align*}
\]

\[
\begin{align*}
\text{O}_2 & : 668 \\
\text{CO}_2 & : 45 \\
\text{H}_2\text{O} & : 47 \\
\text{Total} & : 760
\end{align*}
\]

B

\[
\begin{align*}
\text{O}_2 & : 40 \\
\text{CO}_2 & : 45 \\
\text{N}_2 & : 573 \\
\text{H}_2\text{O} & : 47 \\
\text{Total} & : 705
\end{align*}
\]

\[
\begin{align*}
\text{O}_2 & : 100 \\
\text{CO}_2 & : 40 \\
\text{N}_2 & : 573 \\
\text{H}_2\text{O} & : 47 \\
\text{Total} & : 760
\end{align*}
\]

Pure O\textsubscript{2} Air
Oxygen Toxicity

- Increased permeability of the A-C membrane, due to its exposure to high concentrations of oxygen for a prolonged period of time.

- Time and concentration vary by individual; exposure to 100% oxygen for more than 24 hours leads to symptoms:
  - tremors, twitching, substernal burning
  - pulmonary edema
  - reduction in VC, RV and CL
  - reduced clearance of pulmonary secretions due to decreased ciliary motility
Biochemistry of O₂ Toxicity

- As oxygen takes place in biochemical functions, free radicals of oxygen are produced:
  - hydroxyl (OH), perhydroxyl (HO₂), and superoxide O₂
- Normally, free radicals are rapidly detoxified by superoxide dismutase.
- Type II cells do not produce enough SOD to detoxify the increased number of free radicals.
- Free radicals damage the A-C membrane, increasing type I cell interspaces, and poisoning the surfactant production mechanism; allows fluid exudate and decreased compliance.
Bronchopulmonary dysplasia

- Fibrotic disorder of the neonatal lung
- Caused by exposure to high ventilatory pressures and high FiO$_2$
- Clinical implications
  - Ventilate with lowest possible pressures
  - Use the lowest possible FiO$_2$ to maintain oxygenation
Precautions, hazards, and complications of oxygen therapy

- Problems related to an increase in PaO$_2$
  - Oxygen induced hypoventilation
  - Oxygen induced pulmonary vasodilation and decreased V/Q
  - Retinopathy of prematurity
  - Closure of the ductus arteriosus
Oxygen induced hypoventilation

- Normal drive to breathe is hypercapnia
- Oxygen administration to patients with chronic hypoxemia/hypercapnia may cause worsening hypoventilation
- These patients have a “blunted” hypercapnic drive, because they are chronically hypercapnic
- They rely on hypoxemia to stimulate breathing; when their hypoxemia is relieved, they hypoventilate
Oxygen induced pulmonary vasodilation

- When oxygen is administered, pulmonary vasoconstriction is relieved, increasing perfusion to areas with poor ventilation.
- This decreases the V/Q ratio, without a decrease in VE.
- PaCO₂ increases.
- Regardless, administer oxygen cautiously to patients with chronic hypercapnia, to maintain PaO₂ in the 60s.
  - use high flow systems in unstable patients.
  - monitor SpO₂.
Retinopathy of Prematurity

- An increase in PaO₂ above normal in the neonatal period may cause retinal vasoconstriction and necrosis, leading to fibrosis behind the lens, leading to blindness
- Maintain the infant’s PaO₂ below 80 mm Hg
Closure of the ductus arteriosus in Infants With ductus-dependent Heart Lesions

- Transposition of the aorta and pulmonary artery
- Duct joining the aorta and pulmonary artery
- Needs to be maintained in some congenital defects, but may close if a normal PaO₂ is maintained (these kids are normally cyanotic)
Other hazards related to oxygen therapy and equipment

- Oxygen supports combustion
  - always post no smoking signs, educate the patient and associates; NO SMOKING!
  - keep spark-generating toys away from aerosol tents/hoods
  - keep FiO₂ low in patients having intratracheal laser procedures

- Bacterial contamination of associated humidifiers/nebulizers
Assessment of Outcome

- Relief from hypoxemia
- Stable cardiac status
- Stable perfusion status
- Normal ventilatory status
- Normal work of breathing
Equipment for Oxygen Therapy

- Low-flow or variable performance
  - Total flow is up to 15 L/min
  - $\text{FiO}_2$ depends upon
    - Minute volume
    - Ventilatory pattern
    - Reservoir size
    - Oxygen flow rate
- Low flow does not imply low concentration
Differences Between Oxygen Delivery Systems

A = Low flow device
B = High flow device
C = Reservoir device

Flow

Exp

Insp

= Patient's flow

= Device's flow

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Low-flow Oxygen Therapy

**Equipment**

- Nasal cannula
  - Plastic cannulae, one in each nostril, elastic or lariat to keep in place
  - Easy, light, cheap, disposable
  - Easily dislodged, high flow can cause frontal sinus pain, nose must be patent
  - Nasopharynx as a reservoir
  - 1-6 L/min, to deliver approx. 24-44% O₂
  - Use a bubble humidifier if flow exceeds 4 L/min
Low-flow Oxygen Therapy Equipment

- Oxygen-sparing/storing devices
  - reservoir-type cannulas, generally used in the home
  - Largely replaced by TTOT
Low-flow Oxygen Therapy

- Transtracheal catheter (TTOT)
  - Surgically-placed catheter for long term oxygen therapy
  - Deadspace is minimized, $\text{FiO}_2$ is maintained at a lower flow than with a cannula
  - Hidden by clothing

- $\text{FiO}_2$ may be calculated, but most practitioners titrate liter flow to the desired $\text{PaO}_2$, $\text{SaO}_2$, or clinical finding
Low-flow Oxygen Therapy

Equipment: Masks

- Provide a higher FiO₂ for a given oxygen input, because of the reservoir
- FiO₂ depends on flow, reservoir size, and air leakage
  - used when moderate to high concentrations of oxygen are needed for up to several hours
  - since a tight seal is necessary, they may be uncomfortable and cause a pressure sore; are hot; may cause aspiration if patient vomits
Low-flow Oxygen Therapy

**Equipment: Masks**

- **Simple mask**
  - clear plastic mask, kept in place by elastic
  - patient inhales from the reservoir of the mask and room air through side holes
  - 5-10 L/min to provide 35-50% oxygen
  - do not run at < 5L/min, as CO₂ may accumulate in the mask
  - post-op, interim therapy
Low-flow Oxygen Therapy

Equipment: Masks

- Partial rebreather mask
  - clear plastic mask with a reservoir bag attached
  - patient inhales from the mask and reservoir bag
  - first 1/3 of exhalation goes into the bag (anatomic DS)
  - oxygen flow is adjusted so bag never deflates more than 2/3 during inspiration
  - run at 6-10 L/min to provide 35-60% oxygen (CPG says > 50%)
Low-flow Oxygen Therapy

Equipment: Masks

- Nonrebreather mask
  - clear plastic mask with a reservoir bag, and one-way valves to prevent rebreathing into the bag
  - gas fills the bag, the patient’s inspiratory effort opens the valve, and inspiration continues
  - may deliver 100% source gas, but a study showed only 57-70%
  - used to deliver therapeutic gases (He and CO\textsubscript{2} mixtures), useful for CO poisoning
High Flow Oxygen Therapy Equipment

- Gas flow is sufficient to meet the patient's inspiratory flow needs
  - by entraining air
  - by mixing gases and storing the mix in a nonrebreathing system
- Provide a constant FiO₂
High Flow Oxygen Therapy
Equipment: Air Entrainment Mask

- Principle of constant pressure jet mixing
  - a rapid velocity of gas through a restricted orifice creates viscous shearing forces that entrain air into the main stream
  - orifice size determines amount of air entrainment
  - the smaller the orifice, the greater the shearing force, and more air is entrained, resulting in a higher flow and lower FiO2
  - FiO2 is independent of gas flow, varies with manufacturer
Air Entrainment Mask

High Flow Oxygen Therapy

Equipment: Air Entrainment Mask

- Used to provide 24-60% $O_2$
- Normal resting $Vi$ is about 30 L/min, but this may double or triple in distress
- Use the mask to provide at least 40 L/min
- Formula to determine air entrainment ratio:

\[
\text{liters air entrained} = (100 - \%O_2) \times \left( \frac{\%O_2}{21} \right)
\]

liters of source $O_2$
High Flow Oxygen Therapy

Equipment: Air Entrainment Mask

- Air:oxygen entrainment ratios

<table>
<thead>
<tr>
<th>FiO₂</th>
<th>ratio</th>
</tr>
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<tbody>
<tr>
<td>.24</td>
<td>25:1</td>
</tr>
<tr>
<td>.28</td>
<td>10:1</td>
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<td>8:1</td>
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<td>1.7:1</td>
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<tr>
<td>.60</td>
<td>1:1</td>
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</tbody>
</table>
High Flow Oxygen Therapy

Equipment: Air Entrainment Mask

- Some mfrs vary the oxygen orifice size, others vary the air entrainment orifice size.
- Downstream resistance will decrease entrainment and total flow, while the FiO\(_2\) will rise.
- Generally used when a precise FiO\(_2\) is desired, such as in an exacerbation of COPD.
- Mask must be removed to eat, so substitute a NC.
- An aerosol entrainment collar is provided if humidification is necessary.
- Bubble humidifier is not used.
High flow oxygen therapy equipment: air entrainment nebulizers

- Most nebulizers have variable air entrainment ports to provide 28-100% oxygen
- Also provide humidification and heat
- Allows a wide variety of patient interfaces
- Use with a water trap to prevent water bolus
- Most will run at 12-15 L/min, provide up to 40-50% without dropping flow
- High-flow, high FiO₂ nebulizers available
Air Entrainment Nebulizers
High flow oxygen therapy equipment: Oxygen blender systems

- Use an oxygen blender to provide the desired $\text{FiO}_2$
- 75 L/min flowmeter controls gas flow to a heated humidifier
- Gas goes to the patient through large-bore tubing
- A more “true” high-flow system; provides a high $\text{FiO}_2$ at a high flow
- Risk of oxygen toxicity increases; consider positive pressure therapy (shunt)
Oxygen Blenders

- Combined precision metering device and means of equalizing inlet pressures
- Alarm system that provides an audible alert to a drop in gas pressure
- Crossover allows continued flow if one gas fails
- May deliver 2-100 L/min, at 21-100% O2
- Knob sets the desired FiO2
- Used to provide high flow oxygen therapy and to power ventilators
- Analyze O2 periodically, replace if inaccurate
High Flow Oxygen Therapy Equipment

- **Oxyhood**
  - plexiglass container fitting over infant’s head
  - should be supplied by an oxygen blender system to reduce noise; a heated humidifier is preferred
High Flow Oxygen Therapy

- **Incubator:** 40% oxygen, varies with opening
- **Aerosol mist tent**
  - a large plastic enclosure
  - powered by oxygen, can provide a stable concentration
  - hard to keep a tight seal, therefore $\text{FiO}_2$ varies
Indications for High Flow Oxygen

- Hyperpnea
- Tachypnea: ventilatory rate > 30
- Irregular ventilatory pattern
- Precise FiO₂ desired
- Unknown etiology of hypoxemia
- Inability to achieve an acceptable SpO₂ with nasal cannula
- Mouth breathers; nasal obstruction
Selecting a Delivery Approach

- **Purpose**
  - Increase FiO₂ to correct hypoxemia

- **Patient**
  - Severity, age, LOC, airway, \( V_E \)

- **Equipment performance**
  - Low FiO₂: AEM or NC
  - Moderate: AEM or simple mask
  - High: blender or NRBM
Oxygen Therapy Protocol

- Initial order
- Therapist initiates therapy
- \( \text{SpO}_2 \) measured and flow/\( \text{FiO}_2 \) is titrated
- Periodic evaluation
- At minimal flow/\( \text{FiO}_2 \), room air trial
- D/C \( \text{O}_2 \) if oxygenation and physical examination are acceptable
Oxygen Analyzers: Galvanic

- Oxygen diffuses through a teflon membrane
- Electrolyte solution is CsOH or KOH
- PB and Au are the electrodes
- Oxygen diffuses proportionally to its partial pressure
- For each oxygen molecule that diffuses, 4 electrons are released at the cathode, this registers as a current on the meter, and is read as a concentration of oxygen
Oxygen Analyzers: Galvanic

- Current flow is maintained by the reaction itself
- Such analyzers have a fuel cell as the source of electrons
- Once the fuel cell is spent, it is replaced
  - Failure to calibrate
- No batteries, except for an alarm
- Slow response time
- Fuel cell shelf life 16 mo.
Oxygen Analyzers: Polarographic

- Same principle as the fuel cell analyzer
- Uses a battery to polarize the electrodes, which speeds response time
- Similar equations
- KCl electrolyte solution
- Electrodes don’t last as long as fuel cells, and must be recharged or replaced
  - Failure to calibrate
- Effected by water on the electrode - keep dry
- Positive pressure effects readings
Oxygen Analyzer Calibration

- Place electrode in room air, calibrate
- Place electrode in 100% oxygen, calibrate
- Return to room air; reading should return to within 2% of 21%
- If it does not calibrate
  - battery may be spent (polarographic only)
  - fuel cell is spent
  - teflon membrane is soiled
  - electrode needs recharging
Pulse oximetry: Theory

- Utilizes photospectrometry to measure the oxygen saturation of a capillary bed.
- Two light emitting diodes, one at 660 nm, the other at 900 nm.
- Red/infrared light passes through the capillary bed to a detector.
- Detector senses the resultant color.
- The darker the color, the lower the saturation.
Pulse oximetry: Indications

- Need to monitor adequacy of arterial oxyhemoglobin saturation
- Need to quantitate the effect of oxygen therapy or other therapeutic procedure on hemoglobin saturation
- Assessment of oxygenation, in compliance with third party payers for home oxygen therapy
Pulse oximetry: Limitations

- Motion artifact
- Abnormal hemoglobins (carboxy and met)
- Intravascular dyes (blue, green)
- Low perfusion
- Ambient light
- Skin pigmentation
- Nail polish when using a finger probe
- Cannot quantitate hyperoxia
- Hyperbilirubinemia does not affect readings
Outline of procedure

- Inform the patient
- Establish hypoxemia
  - ABG, oximetry, or clinical signs
- Consider patient factors
  - Severity/cause of hypoxemia
  - Age
  - Level of consciousness
  - Type of airway
  - Stability of minute ventilation
- Determine desired FiO₂ and patient stability
Outline of procedure

- General goals and patient categories
  - Emergent hypoxemia
    - High FiO2
  - Critically-ill
    - High FiO2 titrated to achieve desired SpO2
  - Stable, acutely-ill
    - Low-moderate FiO2, titrated to achieve desired SpO2
  - CO2 retainers
    - Low FiO2 titrated to SpO2 88-92%
Outline of Procedure

- Setup the appropriate equipment
- Check that it is working properly
  - Adequate flow
  - Humidifier pops-off, if applicable
- Reassure the patient
- Apply to the patient
- Assess adequacy of therapy
- Documentation