• Definitions
  ○ Hypoxemia
    ■ Definition
      ● Low partial pressure of oxygen (PaO2) in the blood (low level of oxygen in the blood)
      ● It does not always cause tissue hypoxia
    ■ Causes
      ● Hypoventilation
      ● V/Q mismatch
        ○ Primarily dead space defect **(often called V/Q mismatch)**
        ○ Primarily shunt defect
      ● Diffusion limitation
      ● Reduced inspired O2 tension
  ○ Hypoxia
    ■ Definition
      ● Insufficient oxygen to meet a tissue’s metabolic demand (low level of oxygen in a tissue or organ)
      ● Hypoxemia can lead to tissue hypoxia, but not always
  ○ Oxygenation
    ■ Definition
      ● Process of oxygen diffusing from alveolus to pulmonary capillary to bind to hemoglobin or dissolve in plasma
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Causes of hypoxemia (initial workup)

<table>
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<th>A-a PO2 gradient</th>
<th>PvO2</th>
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<td>Hypoventilation</td>
<td>Normal</td>
<td>Normal</td>
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<tr>
<td>V/Q mismatch</td>
<td>Inc</td>
<td>Normal</td>
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<tr>
<td>DO2/VO2 imbalance</td>
<td>Inc</td>
<td>Dec</td>
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Definitions and equations

- **A-a oxygen gradient** = PAO2 - PaO2
  - **PAO2** = (FiO2 x [Patm - PH2O]) - (PaCO2 + R)
    - Alveolar oxygen amount
    - FiO2 = usually 0.21 at RA
    - Patm = 760 mmHg at sea level
    - PH2O = partial pressure of water = 47 mmHg (at 37ºC)
    - PaCO2 = arterial carbon dioxide tension = (normally 40 mmHg)
    - R = respiratory quotient = usually 0.8 (but varies to use of carb, protein, fat)
    - (remember to compare it to A-a gradient appropriate for age = age/4+4)
  - **PaO2**
    - arterial oxygen amount
    - (measure with an ABG)
  - **High A-a gradient**
    - Oxygen transfer/gas exchange problems
      - V/Q mismatch, alveolar membrane diseases or ILD
  - **Normal A-a gradient**
    - With hypoxemia implies hypoventilation (displacement of O2 with CO2 or other gas)

- **PvO2** = k*(DO2/VO2)
  - mixed venous PO2
  - (measured using indwelling pulmonary artery catheter; if none, can measure the PO2 in the SVC)
  - A dec in PvO2 implies a DO2/VO2 imbalance
  - **DO2**
    - systemic O2 delivery
      - (low CO, anemia, etc = dec DO2)
  - **VO2**
    - rate of O2 uptake
      - (hypermetabolic state = inc VO2)
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- **Hypoventilation**
  - **Mechanism**
    - Lung alveolus is a space of 100% gas → if the partial pressure of one gas increase the partial pressure of another gas must decrease
    - In hypoventilation there is decrease air movement → alveolar increase of carbon dioxide (PACO2) → oxygen (PAO2) in alveoli must decrease
    - A-a gradient is normal
  - **Causes**
    - CNS depression (drug overdose, opiates, CNS lesions)
    - Obesity hypoventilation (Pickwickian) syndrome
    - Impaired neural conduction (ALS, GB)
    - Muscular weakness (myasthenia gravis, hypothyroidism, critical illness myopathy)
    - Poor chest wall mechanics (kyphoscoliosis)
  - **Tx**
    - Responds to supplemental oxygen

- **V/Q mismatch**
  - **Definition**
    - Imbalance of ventilation and perfusion
    - A-a gradient is almost always elevated
  - **Causes** (two opposing forms; per Marino and UpToDate: Mechanical ventilation article)
    - **Primarily dead space defect**
      - COPD, asthma, PE
    - **Primarily shunt defect**
      - PNA, pulm edema, ARDS
  - **Normal lung**
    - A normal lung has V/Q mismatch: V/Q ratio is higher in the apices and lower at the bases
      (higher ventilation in the apices, more perfusion in the bases)
  - **Dead space**
    - **Definition**
      - Ventilation is excessive to perfusion (V/Q >1)
      - Ventilated lung but no blood flow → no gas exchange
      - ***when the pathology has mostly dead space defects = people call this a V/Q mismatch***
      - **Memory cue:** When I see DEAD, I think NO BLOOD = DEAD LUNG. There is SPACE, because alveoli are ventilated and open.
    - **Anatomic dead space**
      - Large conducting airways have no contact with capillary blood
      - Pharynx, trachea
      - Using a snorkel :)
    - **Physiologic dead space**
      - Poor perfusion
      - PE
      - Reduced blood flow (low CO)
      - COPD (emphysema destroys alveolar septae and pulm capillary bed → limited blood flow to a fairly well oxygenated lung)
      - Positive pressure ventilation (can inc ventilation to alveoli that do not have corresponding inc in perfusion → worsens dead space)
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- **Tx**
  - **Responds to supplemental oxygen**
  - **Intrapulmonary shunt**
    - **Definition**
      - Ventilation is inadequate to perfusion (V/Q <1)
      - When blood passes from the right to the left side of the heart without being oxygenated
    - **Anatomic shunts**
      - When blood bypasses alveoli
      - Can cause extreme V/Q mismatch (V/Q=0)
      - **Intracardiac shunts** (ASD, VSD, AVMs)
    - **Physiologic shunts**
      - When non-ventilated alveoli are perfused
      - Atelectasis
      - Disease with alveolar filling (PNA, pulm edema, ARDS)
      - Obesity
  - ** DOES NOT respond to supplemental oxygen**
    - Blood is not in contact with an alveolar membrane that can exchange oxygen → so breathing 100% will not correct hypoxemia
  - **ICU**
    - Particularly in the ICU: for ARDS, a shunt is created where lungs are perfused but ventilation is limited due to alveoli filling → thus, increasing FiO2 has limited benefit → thus, you can decrease FiO2 without causing more hypoxia
    - Positive pressure ventilation, esp with PEEP, can tx dead space caused by atelectasis, by opening more alveoli

- **Diffusion limitation**
  - **Definition**
    - Impaired movement of oxygen from the alveolus to the pulmonary capillary due to problem with diffusion through the alveolar membrane
    - Exercise induced-hypoxemia
    - A-a gradient is elevated
  - **Mechanism**
    - During rest, oxygen diffuses slowly, allowing even impaired diffusion to oxygenate sufficiently
    - During exercise, there is less time for oxygenation → oxygenation is impaired
  - **Causes**
    - **ILD, pulmonary fibrosis**
  - **Tx**
    - Responds to supplemental oxygen

- **Reduced inspired O2 tension**
  - **Definition**
    - Decreased FiO2 or atmospheric pressure will decrease PiO2
    - PiO2 = FiO2 x (Patm - PH2O)
    - A-a gradient is normal
  - **Mechanism**
    - Body naturally hyperventilates → PaO2 inc but PCO2 dec
  - **Causes**
    - **High altitude**
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Ventilation to Perfusion Mismatch

Pure Shunt
Perfusion with No Ventilation
Shunt Like Units
Pure Dead Space
Ventilation with No Perfusion

shunt
Dead space

Hypoxemic Respiratory Failure

V/Q mismatch

Atelectasis
Intraalveolar filling
Pneumonia
Pulmonary edema

ARDS
Interstitial lung dz
Pulmonary contusion

SHUNT
V/Q = 0
Intracardiac shunt
Vascular shunt in lungs

DEAD SPACE
V/Q = ∞
Pulmonary embolus
Pulmonary vascular dz
Airway dz
(COPD, asthma)

Physiological Shunting

Physiological Deadspace
Sources:

- **Good** (stating V/Q mismatch consists of two opposing forms: dead space and shunt)
  - Marino’s ICU Book
  - [https://www.openanesthesia.org/pulmonary_physiology_and_respiratory_failure/](https://www.openanesthesia.org/pulmonary_physiology_and_respiratory_failure/)

- **Okay** (really good explanations, but doesn’t show how dead space and shunts are part of V/Q mismatch)
  - [https://www.youtube.com/watch?v=RJ-H8_0-8wk](https://www.youtube.com/watch?v=RJ-H8_0-8wk)
  - [https://www.youtube.com/watch?v=pRlkwlFRgo](https://www.youtube.com/watch?v=pRlkwlFRgo)

- **Hella confusing, read with caution**