Hypoxemia

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- **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)

	A-a PO2 gradient	PvO2
Hypoventilation	Normal	Normal
V/Q mismatch	Inc	Normal
DO2/VO2 imbalance	Inc	Dec

Definitions and equations

- **A-a oxygen gradient** = PAO2 - PaO2
  - **PAO2** = (FiO2 x [Patm - PH2O]) - (PaCO2 ÷ R)
    - **A**lveolar oxygen amount
    - FiO2 = usually 0.21 at RA
    - Patm = 760 mmHg at sea level
    - PH20 = 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**
    - **a**rterial 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)

        - 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**
        - Tx
            - **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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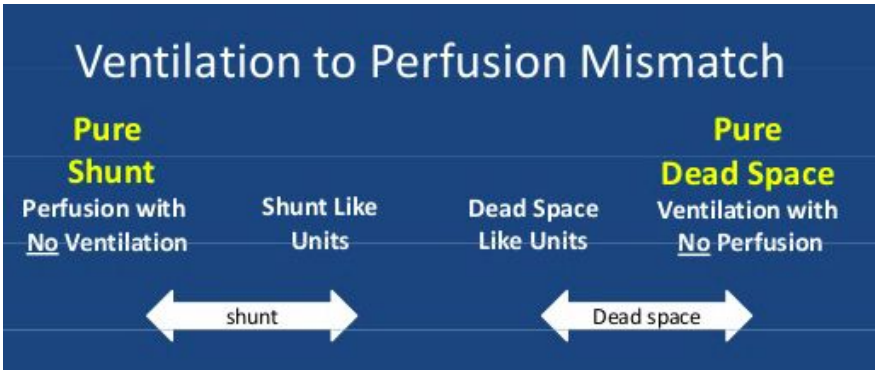

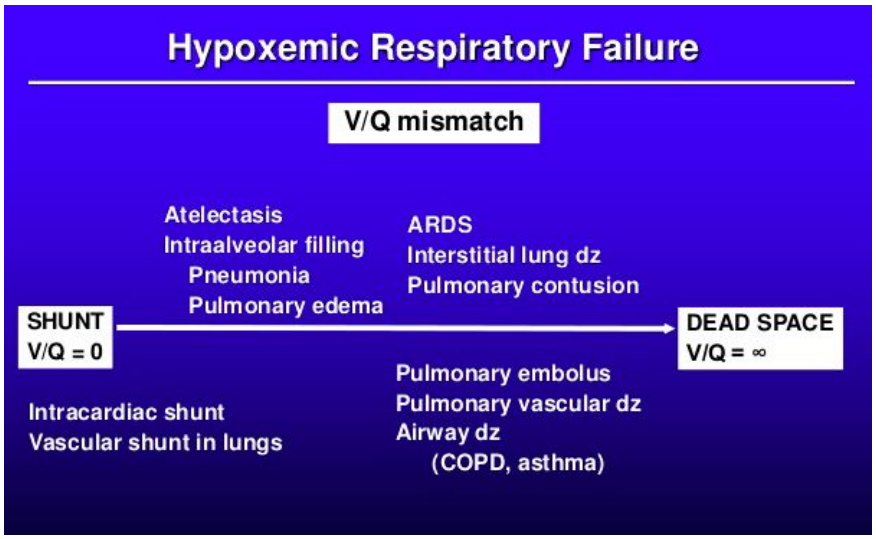

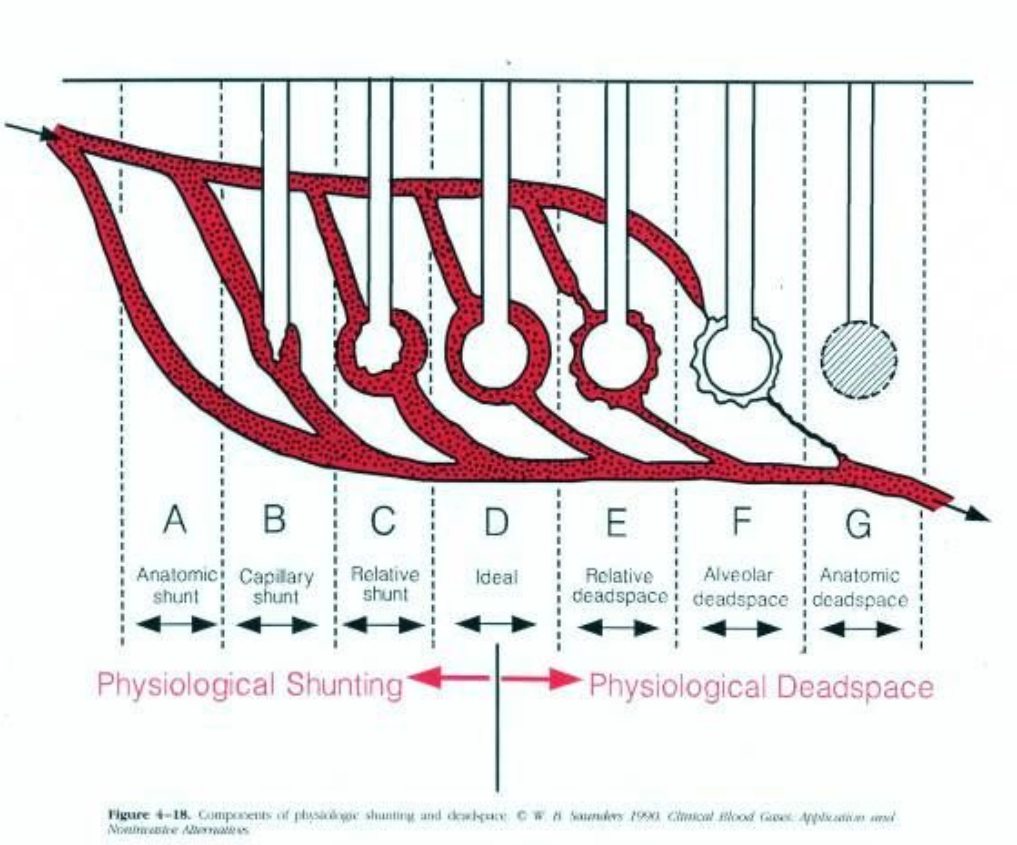

Figure 4–18. Components of physiologic shunting and deadspace. © W. B. Saunders 1990. *Clinical Blood Gases: Application and Noninvasive Alternatives.*

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Sources:

- **Good** (stating V/Q mismatch consists of two opposing forms: dead space and shunt)
  - Marino's ICU Book
  - http://www.uptodate.com/contents/physiologic-and-pathophysiologic-consequences-of-mechanical-ventilation
  - 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=pRIkwjlFRgo
- **Hella confusing**, read with caution
  - https://www.uptodate.com/contents/oxygenation-and-mechanisms-of-hypoxemia