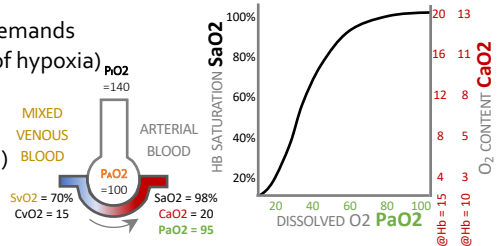


HYPOXIA & HYPOXEMIA by Nick Mark MD

DEFINITIONS:

Hypoxia – insufficient oxygen delivered to tissues to meet demands
Hypoxemia – low oxygen in the blood (most common type of hypoxia)

PiO₂ – atmospheric oxygen (how much O₂ is inspired)
P_AO₂ – alveolar oxygen (how much O₂ reaches the alveoli)
P_aO₂ – oxygen dissolved in arterial blood (measured on ABG)
SaO₂ – percent saturation of hemoglobin in arterial blood
CaO₂ – oxygen content of art. blood (dissolved & Hb bound)



OXYGEN DELIVERY:

Tissue hypoxia occurs when DELIVERY OF OXYGEN (DO₂) is inadequate to meet metabolic demands. DO₂ depends on CARDIAC OUTPUT (CO) & the OXYGEN CONTENT OF BLOOD (CaO₂)

$$DO_2 = (HR \times SV) \times [(1.34 \times Hb \times SaO_2) + (PaO_2 \times 0.003)]$$

CO O₂ bound to hemoglobin O₂ dissolved in blood

HYPOXEMIC HYPOXIA
 Insufficient oxygen in the blood (the most common type of hypoxia)
Low PaO₂

ISCHEMIC HYPOXIA
 Insufficient blood flow to tissues, also called stagnant hypoxia (e.g. low cardiac output)
Low SvO₂ → Low PaO₂

ANEMIC HYPOXIA
 Insufficient **O₂ carrying capacity** (e.g. severe blood loss) or abnormal hemoglobin (e.g. COHb, MetHb)
Low CaO₂ → Low SvO₂ → Low PaO₂

CYTOPATHIC HYPOXIA
 Cells cannot use oxygen (e.g. cyanide toxicity, maybe sepsis)
High PaO₂, High SvO₂

LOW INSPIRED OXYGEN (P_IO₂)

Fewer oxygen molecules enter the lungs with respiration (low P_AO₂)

- Normal Aa difference
- PaO₂ normalizes with supplemental oxygen

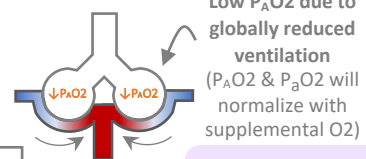
• **Causes:** low atmospheric pressure (e.g. high altitude), or low partial pressure of oxygen (FiO₂ < 0.21 e.g. confined space, low O₂ gas mixtures)

ALVEOLAR HYPOVENTILATION

Fewer O₂ molecules reach the alveoli due to decreased ventilation (low P_AO₂).

- Normal Aa difference
- PaO₂ normalizes with supplm. O₂
- Increased PaCO₂

• **Causes:** decreased respiratory drive (opioids, brainstem stroke, OHVS), neuromuscular weakness (GBS, ALS), chest wall problems (kyphoscoliosis, flail chest) or airflow obstruction (COPD, asthma)

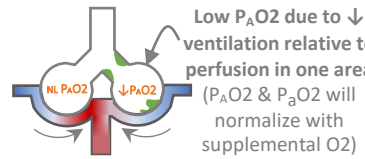


V/Q MISMATCH

Imbalance between regional lung ventilation and perfusion (low V/Q). Most common cause of hypoxemia.

- Increased Aa difference
- PaO₂ normalizes with suppl. O₂

• **Causes:** obstructive lung diseases (COPD), pulmonary vascular disease (PE), alveolar filling processes (pneumonia, pulmonary edema), interstitial disease & atelectasis

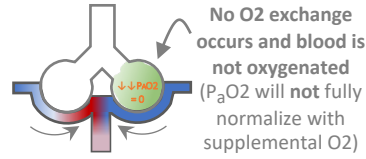


SHUNT

Blood passes from the right side of the heart to the left side without being oxygenated.

- Increased Aa difference
- PaO₂ does NOT normalize with supplemental oxygen

• **Causes:** anatomical (ASD, VSD, pulm AVMs) & physiological shunts (atelectasis, pneumonia, ARDS) where blood bypasses alveoli without effective gas exchange

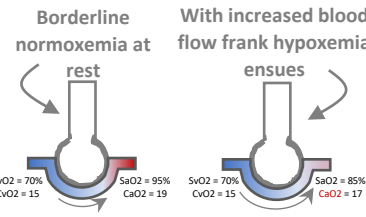


DIFFUSION LIMITATION

Impaired O₂ diffusion from alveoli to RBC, causing hypoxemia particularly in with increased cardiac output.

- Increased Aa difference
- PaO₂ normalizes with supplm. O₂

• **Causes:** pulmonary fibrosis, edema, & inflammation that impair gas exchange in the alveoli

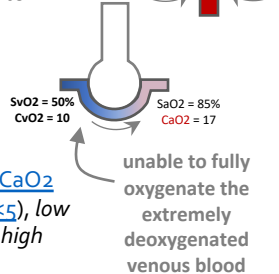


LOW MIXED VENOUS O₂ (SvO₂)

Venous blood returning to the lungs (SvO₂) has very low O₂ due to increased extraction.

- Normal Aa difference
- PaO₂ normalizes with supplemental oxygen

• **Causes:** severe anemia (low CaO₂ rarely a problem unless Hb < 5), low cardiac output, & extremely high oxygen consumption



Aa DIFFERENCE (aka Aa GRADIENT):
 The Aa DIFFERENCE is the ALVEOLAR OXYGEN TENSION (P_AO₂) minus the ARTERIAL OXYGEN TENSION (P_aO₂), reflecting the efficiency of oxygen exchange. It is used to identify the etiology of hypoxemic hypoxia: pulmonary causes have ↑ Aa difference whereas extra-pulmonary etiologies (↓ PiO₂, ↓ SvO₂, & alveolar hypoventilation) have nl Aa difference.

Normal Aa difference = $\frac{Age (yrs) + 10}{4}$
Aa difference = P_AO₂ - P_aO₂
P_AO₂ = (FiO₂ × [P_{atm} - P_{H2O}]) - $\left(\frac{PaCO_2}{Q}\right)$

Atmospheric pressure (760 mmHg @ sea level, 630 mmHg @ 1500m, 530 mmHg @ 3000m)
 H₂O vapor pressure (47 mmHg in the lungs)
 Alveolar CO₂ tension (assumed to be equal to arterial CO₂)
 Respiratory Quotient (normally ~0.8)