Tissue Oxygenation

Critical Care Monitoring

Tissue Oxygenation

Assessing the Adequacy of Tissue Oxygenation

Tissue oxygenation is the end-product of many complex steps

Tissue Oxygenation - Step 1

- Oxygen must be made available to alveoli
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  - 
  -
Tissue Oxygenation - Step 2

- Oxygen must cross the alveolar-capillary membrane

Tissue Oxygenation - Step 3

- Oxygen must load into blood and be transported

Tissue Oxygenation - Step 4

- Tissues must uptake oxygen
Tissue Oxygenation

Tissue Oxygenation - Step 5

• Tissue utilize oxygen

Tissue Oxygenation

• Problem in assessment
  – Tissue oxygenation cannot be directly measured
  – Use indirect assessment techniques
    • Vo, shunt calculations (distribution of ventilation)
    • AaDO2, a/A (ability to cross AC membrane)
    • PaO2, CaO2, Qr (transport)
    • C(a-v)O2 (O2 extraction by tissues)

Tissue Oxygenation

• Clinical assessment
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**V/Q Relationships**

- Purpose of ventilation
  - 
  -
- Ideal for ventilation to match perfusion

**V/Q Relationships**

- V/Q match is not the case
- Matching does not occur causing variations that affect tissue’s ability to
  - Receive adequate O₂
  - Remove CO₂

**V/Q Relationships**

- V/Q mismatch is any condition that ↑↓ ventilation
  or
  ↑↓ blood flow through the lungs
Tissue Oxygenation

V/Q Relationships

Abnormal V/Q Relationships

- Deadspace ventilation ($V_D$)
- Deadspace effect
- Intrapulmonary shunt ($Q_S/Q_T$)
- Shunt effect (Venous admixture)

Deadspace Ventilation

Equals the portion of inspired volume that does not participate in gas exchange

$V_D = V_{D,anat} + V_{D,alv}$

(total = anatomical + alveolar)
Tissue Oxygenation

V/Q Relationships
Anatomical Deadspace

- Normal =

- Ventilation in conducting airways (down to respiratory bronchioles)

V/Q Relationships
Anatomical Deadspace ↑

V/Q Relationships
Anatomical Deadspace ↓
Tissue Oxygenation

V/Q Relationships

Alveolar Deadspace

- Theoretically doesn't exist except in disease
- Defined as the volume of gas in the alveoli that are ventilated but not perfused

Alveolar Deadspace

The classic deadspace-producing disease =

V/Q Relationships

Deadspace Effect

V/Q mismatch when ventilation is in excess of perfusion

Ventilation > Perfusion
Tissue Oxygenation

V/Q Relationships

Deadspace Effect ↑

•

•

i.e., anything that ↑ ventilation and/or ↓ lung perfusion

Assessing Deadspace

• Measured in 2 ways:

\[ V_{D_{phys}} = \frac{(PaCO_2 - P_{ECO2}) \cdot VT}{PaCO_2} \]

\[ \frac{V_D}{VT} = \frac{(PaCO_2 - P_{ECO2})}{PaCO_2} \]

Assessing Deadspace

• Normal \( V_D/VT = \)

  – Spontaneous breathing:

  – On vent: 
Tissue Oxygenation

V/Q Relationships

Intrapulmonary Shunt

Defined as the portion of the cardiac output that returns to the left heart without being oxygenated

Perfusion w/o Ventilation

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V/Q Relationships

Intrapulmonary Shunt

**total = anatomic + capillary**

(physiologic)

Normal =

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V/Q Relationships

Anatomic Shunt

- Is the major portion of total shunt
- 2 - 5% of cardiac output
- Normal blood flow through:
  -
  -
  -
Tissue Oxygenation

V/Q Relationships

Anatomic Shunt

- Increased in:
  - 
  - 
  - 

Capillary Shunt

- True shunt
- Small amount is normal
- Perfusion of non-ventilated alveoli

Causes of ↑ capillary shunt:
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- 
- 
- 
- 

Tissue Oxygenation
Capillary Shunt

- Capillary shunt is refractory to oxygen therapy
  - Alveoli are unable to ventilate
  - Blood passing by good alveoli cannot carry more O₂ once it is fully saturated

- Treatment is

Shunt Effect (Venous Admixture)

V/Q mismatch when perfusion is in excess of ventilation

Perfusion > Ventilation

- Responsive to O₂ therapy
- Caused by:
  - 
  - 
  - 

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Tissue Oxygenation

V/Q Relationships
Shunt Effect
(Venous Admixture)

i.e., anything that ↓ ventilation
and/or
↑ perfusion

Assessing Shunt

Classic Shunt Equation

\[ \frac{Q_s}{Q_T} = \frac{CcO_2 - CaO_2}{CcO_2 - CvO_2} \]

Clinical Shunt Equation

\[ \frac{Q_s}{Q_T} = \frac{AaDO_2 \times 0.03}{(CaO_2 - CvO_2) + (AaDO_2 \times 0.03)} \]
V/Q Relationships

Assessing Shunt

- Shunt equation is useful tool:
  - To evaluate effectiveness of O₂ therapy
  - To differentiate shunt or V/Q imbalance as cause of hypoxemia

Crossing AC Membrane

AaDO₂

- = P_AO₂-PaO₂ = P_(A-a)O₂
- Normal
  - Room air
  - 100% O₂
- Normal lungs readily transfer O₂
- Transfer hindered in pulmonary disease

Diffusion across AC membrane is dependant on:

-
Tissue Oxygenation

Crossing AC Membrane
Causes of ↑ AaDO₂
• ↓ Surface area of AC membrane
  –
  –
  –
  –
  –
  –

Crossing AC Membrane
Causes of ↑ AaDO₂
• ↑ thickness of AC membrane
  –
  –
  –

Crossing AC Membrane
Causes of ↑ AaDO₂
• Normal
  –
  –
Tissue Oxygenation

Crossing AC Membrane

Remember!!

**Hypoxemia** caused by:

- 
- 
- 
- 
- 
- 

Estimate Shunt

Rough estimate of % shunt from AaDO$_2$:

**Every 20 mmHg AaDO$_2$ = 1% shunt**

(at FiO$_2$ 1.0)

Example:
Tissue Oxygenation

Crossing AC Membrane

AaDO\textsubscript{2} Summary

- Use AaDO\textsubscript{2} to:
  - 
  - 
  - 

Crossing AC Membrane

\textit{a/A Ratio}

- \(= \text{PaO}_2 + \text{PAO}_2\)
- \(= \%\) of alveolar \(O_2\) \(\rightarrow\) arterial blood
- Normals
  - 
  - 
- Also assesses diffusion across AC membrane

Better assessment than AaDO\textsubscript{2} since AaDO\textsubscript{2}
changes with different FiO\textsubscript{2}’s
Oxygen Transport

• Oxygen carried in the blood 2 ways:
  –
  –

Uptake by the Blood

• Dissolved (per 100 ml blood)
Oxygen Transport

Uptake by the Blood

• Combined with hemoglobin (per 100 ml blood)

• Total amount carried in arterial blood
  (per 100 ml blood or vol%) =

\[(1.34 \times \text{Hgb} \times \text{SaO}_2) + (\text{PaO}_2 \times .003)\]

Oxyhemoglobin Dissociation Curve

Cardiopulmonary Anatomy & Physiology
Des Jardins
pp. 216-228
### Transport by the Blood

- Heart must pump oxygenated blood to the tissues
- Normal cardiac function is essential for adequate cardiac output
- $Q_T$ is the amount of blood pumped by the ventricles in 1 minute
- $Q_T = \text{stroke volume} \times \text{heart rate}$

### Fick Equation

\[ Q_T = \frac{\text{VO}_2}{C(a-v)\Delta O_2 \times 10} \]
Tissue Oxygenation

Oxygen Transport
Transport by the Blood
• Cardiac output varies according to
  – Tissue oxygen demand
  – Amount of oxygen carried in the blood

• Effect of ↑O₂ demand on QT
  – As VO₂ ↑ - QT must ↑
  – ↑ QT is accompanied by
    •
    •
  – Causes of ↑ demand
    •
    •

• Effect of ↓CaO₂ on QT
  – with normal O₂ demand, a ↓ in CaO₂ →
    Duh! hypoxia →
  – Causes of ↓ CaO₂
    •
    •
    •
Tissue Oxygenation

Oxygen Transport
Transport by the Blood
- Total O$_2$ delivery to tissues (DO$_2$)

\[ \text{DO}_2 = \dot{Q}T \times \text{CaO}_2 \times 10 \]

Tissue Oxygenation

Oxygen Transport
Transport by the Blood
- Total O$_2$ delivery ↓
  -
  -
  •
  •

Tissue Oxygenation

Oxygen Transport
Tissue O$_2$ Uptake
- \( \dot{V}O_2 = O_2 \) extraction
- Normal = 200-350 ml/min (200-350)
- Difference between CaO$_2$ and CvO$_2$ = O$_2$ extracted but only by that organ drained so must use CvO$_2$
Tissue Oxygenation

Oxygen Transport

Tissue O2 Uptake

• Total O2 extracted by body tissues
  (per 100 ml blood)

\[ \text{CaO}_2 - \text{CvO}_2 = \text{C(a-v)O}_2 \]

• Normal =

\[ \text{Fick Equation} \]

\[ \dot{\text{VO}}_2 = \text{C(a-v)O}_2 \times \dot{Q} \times 10 \]
Tissue Oxygenation

Oxygen Transport
Tissue O2 Uptake
• From Fick Equation can see that with a steady VO2, the Qt and C(a–v)O2 are inversely proportional, i.e.

\[
\text{as } \dot{Q}_t \downarrow \rightarrow C(a-v)O_2 \uparrow \]

Tissue Oxygenation
Oxygen Transport
Tissue O2 Uptake
• Essential relationship

\[
\dot{Q}_t \downarrow \rightarrow O_2 \text{ extraction } \uparrow \rightarrow \quad P\tilde{V}O_2 \downarrow \rightarrow S\tilde{V}O_2 \downarrow \rightarrow \quad C\tilde{V}O_2 \downarrow \rightarrow C(a-\tilde{V})O_2 \uparrow \]

Tissue Oxygenation
Oxygen Transport
Tissue O2 Utilization
• Hindered by
  – Cyanide poisoning
  – Amobarbital (Amytal) overdose
  
• =

Step 5