1

Mechanical Ventilation

Tissue Oxygenation

2

Assessing the Adequacy of Tissue Oxygenation

Tissue oxygenation is the end-product of many complex steps

3

Tissue Oxygenation - Step 1

- Oxygen must be made available to alveoli
  –
  –

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
  -

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Tissue Oxygenation - Step 5

- Tissue utilize oxygen
  –

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Tissue Oxygenation

- Problem in assessment
  – Tissue oxygenation cannot be directly measured
  – Use indirect assessment techniques
    - V_D, shunt calculations (distribution of ventilation)
    - $AaDO_2$, a/A (ability to cross AC membrane)
    - PaO_2, CaO_2, Q_T (transport)
    - $C(a\text{-}v)O_2$ (O_2 extraction by tissues)

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Tissue Oxygenation

- Clinical assessment
  –
  –
  –
  –
  –

Step 1

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 O_2
  - Remove CO_2

V/Q Relationships

V/Q mismatch is any condition that ↑□ ventilation

or

↑□ blood flow through the lungs

V/Q Relationships

Abnormal V/Q Relationships

- Deadspace ventilation (V_D)
- Deadspace effect

- Intrapulmonary shunt (Q_S/Q_T)
- Shunt effect (Venous admixture)

V/Q Relationships

Deadspace Ventilation

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

V/Q Relationships

Deadspace Ventilation

$$V_D = V_{Danat} + V_{Dalv}$$

(total = anatomical + alveolar)

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V/Q Relationships

Anatomical Deadspace

- Normal =
- Ventilation in conducting airways (down to respiratory bronchioles)

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V/Q Relationships

Anatomical Deadspace ↑

-
-
-
-
-

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V/Q Relationships

Anatomical Deadspace □

-
-
-
-
-

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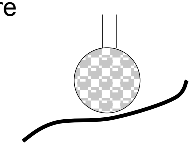
V/Q Relationships

Alveolar Deadspace

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



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V/Q Relationships

Alveolar Deadspace

The classic deadspace-producing disease =

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V/Q Relationships

Deadspace Effect

V/Q mismatch when ventilation is in excess of perfusion

Ventilation > Perfusion

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V/Q Relationships

Deadspace Effect ↑

•

•

i.e., anything that ↑ ventilation

and/or

[?] lung perfusion

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V/Q Relationships

Assessing Deadspace

- Measured in 2 ways:

$$V_{D_{phys}} = \frac{(P_aCO_2 \,[?]\, P_{\bar{E}}CO_2)\, V_T}{P_aCO_2}$$

$$V_D/V_T = \frac{(P_aCO_2 \,[?]\, P_{\bar{E}}CO_2)}{P_aCO_2}$$

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V/Q Relationships

Assessing Deadspace

- Normal V_D/V_T =
  - *Spontaneous breathing:*
  - *On vent:*

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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:
  –
  –
  –

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V/Q Relationships

Anatomic Shunt

- Increased in:
  –
  –
  –

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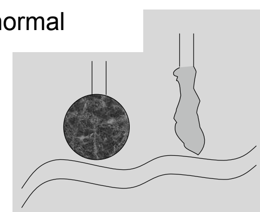
V/Q Relationships

Capillary Shunt

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



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V/Q Relationships

Capillary Shunt

- Causes of ↑ capillary shunt:
  –
  –
  –
  –
  –

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V/Q Relationships

Capillary Shunt

- Capillary shunt is refractory to oxygen therapy
  - Alveoli are unable to ventilate
  - Blood passing by good alveoli cannot carry more O_2 once it is fully saturated
- Treatment is

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V/Q Relationships

Shunt Effect (Venous Admixture)

V/Q mismatch when perfusion is in excess of ventilation

Perfusion > Ventilation

Section 2b Tissue Oxygenation 33

V/Q Relationships

Shunt Effect (Venous Admixture)

- Responsive to O_2 therapy
- Caused by:
  -
  -
  -

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V/Q Relationships

Shunt Effect (Venous Admixture)

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

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V/Q Relationships

Assessing Shunt

Classic Shunt Equation

$$\dot{Q}_S / \dot{Q}_T = \frac{CcO_2 - CaO_2}{CcO_2 - C\bar{v}O_2}$$

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V/Q Relationships

Assessing Shunt

- Clinical Shunt Equation

$$\dot{Q}_S / \dot{Q}_T = \frac{AaDO_2 \times .003}{(CaO_2 - C\bar{v}O_2) + (AaDO_2 \times .003)}$$

V/Q Relationships

Assessing Shunt

- Shunt equation is useful tool:
  - To evaluate effectiveness of O_2 therapy
  - To differentiate shunt or V/Q imbalance as cause of hypoxemia

Step 2

Crossing AC Membrane AaDO2

- = P_AO_2-PaO_2 = $P_{(A-a)}O_2$
- Normal
  - Room air
  - 100% O_2
- Normal lungs readily transfer O_2
- Transfer hindered in pulmonary disease

Crossing AC Membrane AaDO2

- Diffusion across AC membrane is dependant on:
  -
  -

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Crossing AC Membrane

Causes of ↑ $AaDO_2$

- ￼ Surface area of AC membrane
  - –
  - –
  - –
  - –
  - –
  - –

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Crossing AC Membrane

Causes of ↑ $AaDO_2$

- ↑ thickness of AC membrane
  - –
  - –
  - –

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Crossing AC Membrane

Causes of ↑ $AaDO_2$

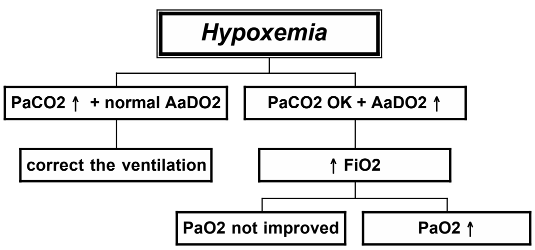
- Normal
  - –
  - –

Crossing AC Membrane

Remember!!

Hypoxemia caused by:

-
-
-
-
  -
  -



Crossing AC Membrane

Estimate Shunt

Rough estimate of % shunt from $AaDO_2$:

Every 20 mmHg $AaDO_2$ = 1% shunt

(at FiO2 1.0)

Example:

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Crossing AC Membrane

AaDO2 Summary

- Use $AaDO_2$ to:
  - –
  - –
  - –

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Crossing AC Membrane a/A Ratio

- = $PaO_2 \div PAO_2$
- = % of alveolar O_2 arterial blood
- Normals
  - –
  - –
- Also assesses diffusion across AC membrane

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Crossing AC Membrane a/A Ratio

Better assessment than $AaDO_2$ since $AaDO_2$ changes with different FiO_2's

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Step 3

Oxygen Transport

- O_2 has crossed alveolar-capillary membrane and must be:
  -
  -

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Oxygen Transport

Uptake by the Blood

- Oxygen carried in the blood 2 ways:
  -
  -

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Oxygen Transport

Uptake by the Blood

- Dissolved (per 100 ml blood)

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Oxygen Transport

Uptake by the Blood

- Combined with hemoglobin (per 100 ml blood)

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Oxygen Transport

Uptake by the Blood

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

$(1.34 \times Hgb \times SaO_2) + (PaO_2 \times .003)$

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Oxyhemoglobin Dissociation Curve

Cardiopulmonary Anatomy & Physiology
Des Jardins
pp. 216-228

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Oxygen Transport

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 =

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Oxygen Transport

Transport by the Blood

Q_T = stroke volume x heart rate

(Q_T = SV x HR)

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Oxygen Transport

Transport by the Blood

- Fick Equation

$$\dot{Q}_T = \frac{\dot{V}O_2}{C(a-\bar{v})O_2 \times 10}$$

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Oxygen Transport

Transport by the Blood

- Cardiac output varies according to
  - Tissue oxygen demand
  - Amount of oxygen carried in the blood

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Oxygen Transport

Transport by the Blood

- Effect of ↑O_2 demand on Q_T
  - As VO_2 ↑ - Q_T must ↑
  - ↑ Q_T is accompanied by
    -
    -
  - Causes of ↑ demand
    -
    -
    -

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Oxygen Transport

Transport by the Blood

- Effect of □ CaO_2 on Q_T
  - with normal O_2 demand, a □ in CaO_2 □
  - Duh! hypoxia □
  - Causes of □ CaO_2
    -
    -
    -
    -

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Oxygen Transport

Transport by the Blood

- Total O_2 delivery to tissues (DO_2)

$$DO_2 = Q_T \times CaO_2 \times 10$$

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Oxygen Transport

Transport by the Blood

- Total O_2 delivery
  -
  -
    -
    -
    -

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Step 4

Oxygen Transport

Tissue O_2 Uptake

- = VO_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 $C\bar{v}O_2$

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Oxygen Transport

Tissue O_2 Uptake

- Total O_2 extracted by body tissues (per 100 ml blood)

$$CaO_2 - C\bar{v}O_2 =$$

$$C(a-\bar{v})O_2$$

- Normal =

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Oxygen Transport

Tissue O_2 Uptake

- Total O_2 extracted by body tissues (VO_2)

$$C(a-\bar{v})O_2 \times Q_T \times 10$$

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Oxygen Transport

Tissue O_2 Uptake

- Fick Equation

$$\dot{V}O_2 = C(a-\bar{v})O_2 \times \dot{Q}_T \times 10$$

Oxygen Transport

Tissue O_2 Uptake

- From Fick Equation can see that with a steady VO_2, the Q_T and $C(a-\bar{v})O_2$ are inversely proportional, i.e.

as Q_T □ □ $C(a-\bar{v})O_2$ ↑

Oxygen Transport

Tissue O_2 Uptake

- Essential relationship

Q_T □ □ O_2 extraction ↑ □
$P\bar{v}O_2$ □ □ $S\bar{v}O_2$ □ □
$C\bar{v}O_2$ □ □ $C(a-\bar{v})O_2$ ↑

Step 5

Oxygen Transport

Tissue O_2 Utilization

- Hindered by
  - Cyanide poisoning
  - Amobarbital (Amytal) overdose

- =