Critical Oxygen Delivery
Oxygen is Good and Blood Goes Round and Round
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Objectives

- Review oxygen transport basics
- Review flow independent and dependent states
- Review implications of critical oxygen delivery and shock
- Understand the principles of Oxygen Debt and its Implications
- Discuss options for detecting and monitoring these states

Oxygen Delivery

\[
\text{CaO}_2 = (1.34 \times \text{Hb} \times \text{SaO}_2) + (0.0031 \times \text{PaO}_2)
\]

Oxygen Transport

Venous Oxygen Delivery

\[
\text{DO}_{2} = \text{VO}_{2} + \text{CO}_2
\]

The Carbon Dioxide Equivalent

\[
\text{VCO}_2 = \text{PetCO}_2
\]

Central Venous Oxygen Saturation

\[
\text{SVO}_2 = \text{DO}_{2} - \text{VO}_{2}
\]
Oxygen Debt = Shock
The Magnitude (Degree and Time) that VO2 is Below Critical DO2
Magnitude of Total Body Ischemia?

Baseline
- Amount of hemoglobin
- Amount of oxygen (hemoglobin saturation)
- Amount of flow
- Metabolic requirement of particular organ

Hemorrhage
- Loosing blood (hemoglobin)
- Hemoglobin saturation maintained.
- Blood moving slower through tissue
- More time for cells to extract oxygen presented to it.

Additional Layer of Complexity

Shock Mortality and Morbidity
- There is only one variable which consistently predicts both mortality and incidence of multiple organ failure following traumatic shock:

OXYGEN DEBT
VO2 pattern after 4 minutes of Exercise

Figure 9A-2. Rate of oxygen uptake by the lungs during maximal exercise for 4 minutes and then for almost 1 hour after the exercise is over. This figure demonstrates the principle of oxygen debt.

Level of Oxygen Debt Directly Linked To Inflammatory Response and Immune Dysfunction

Animal paying back debt and lactate normalizing

Animal reaccumulating debt with lactate going up

Animal partially paying back debt and lactate normalizing

DO2 /MAP Relationship: What Relationship?
What to Monitor

- Whole Body Indices
  - Lactate
  - Hemoglobin
  - Blood Pressure, Heart Rate
  - Central Venous Hgb Oxygen Saturation (ScvO2)
- Tissue Specific Indices
  - Tissue Hgb Oxygen Saturation
  - Tissue PO2 and PCO2
  - Video Microscopy

How to Monitor Oxygen Debt: Lactate and Time
Lactate is the Troponin of the Whole Body

Venous Hemoglobin Oxygen Saturation

- What is Normal?
- Total SvO2 may appear normal
- Regional SvO2 can be low
- A low SvO2 is always bad!
- What is Accessible?
- What is Sensitive?
  - What changes earliest
  - What normalizes latest
- Shoot for Target Values?
- Keep Tissue saturation above level associated with DO2crit.
  - Allowing for closed loop resuscitation?

Principles of Tissue Monitoring

- Distribution of blood volume within tissue
  - 70% venules
  - 20% capillaries
  - 10% arterioles
- Post-extraction compartment monitoring
  - Oxygen extraction
  - CO2 production
- Indicates adequacy of DO2
- More Valuable than Cardiac output, BP

The Potential
Tissue CO2 Technologies

VO2
PetCO2
*CO2
VCO2
PetCO2
Delivery Independent

VO2
Delivery Dependent

Things to Consider

- If lactate normal, how close to critical DO2 is the patient?
- Is oxygen extraction high and if so how high?
- How long can patient tolerate?
- Is increase in DO2 planned?
  - Activity
  - Ventilator Weaning

Things to Consider
Balancing Supply and Demand

- Is there a way to increase DO2 without transfusion?
  - Increase cardiac output
    - Give more preload
    - Decrease afterload
  - Increase tissue DO2 through vasodilation?
    - Futuristic
  - Is there a way to decrease VO2?
    - Decrease temperature
    - Decrease pain
    - Decrease activity

Conclusions to Oxygen is Good
Blood Goes Round and Round

- Essential for Rationale Management
  - Diagnostic and treatment endpoints
  - Avoiding and decreasing oxygen debt
  - Prevent Under and Over Resuscitation
  - Essential for Rational Transfusion Trigger
- Monitoring is Harder than it sounds
  - At least use lactate and its resolution
  - Will need robust, easy to use technologies to use pre-oxygen debt parameters

Conclusions Continued

- Can a single signal do it or do we need multiple signals?
  - How do they reflect oxygen debt?
- Advice to those thinking they have the answer:
  - Don't quit your day jobs!
- If We Find It: New Treatment Paradigms:
  - Closed Loop Resuscitation
  - Targeted vasodilation
  - Rationale hypotension
  - Eliminating blood shortage