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Quick Review: Oxygen Transport

T Fujii, B Phillips

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Abstract

This is a brief review on Oxygen Transport.

“The first concern in any life-threatening illness is to maintain an adequate supply of oxygen to sustain oxidative metabolism”

...Marino

OXYGEN TRANSPORT

The Oxygen Transport Variables:

Oxygen Content [CaO_2] Oxygen Delivery [DO_2] Oxygen Consumption [VO_2] Extraction Ratio [ER]

OXYGEN CONTENT

The oxygen in the blood is either bound to hemoglobin or dissolved in plasma

The sum of these two fractions is called the Oxygen Content

CaO_2 = the Content of Oxygen in Arterial Blood Hb = Hemoglobin (14 g/dl) SaO2 = Arterial Saturation (98%) PaO2 = Arterial PO2 (100 mmHg)

Figure 1

$$CaO_2 = \underbrace{(1.3 \times Hb \times SaO_2)}_{\text{amount carried by Hb}} + \underbrace{(0.003 \times PaO_2)}_{\text{amount dissolved in plasma}}$$

$CaO_2 = (1.3 \times 14 \times 0.98) + (0.003 \times 100)$ $CaO_2 = 18.1$ ml/dl (ml/dl = vol %; 18.1 vol %)

* at 100% Saturation, 1 g of Hb binds 1.3 ml of Oxygen !
* at 100% Saturation, 0.003 ml/mmHg of Oxygen is Dissolved in Plasma !

The PaO_2 should be reserved for evaluating the efficiency of pulmonary gas exchange

Figure 6

Example # 1: 35 yr old male s/p GSW to Chest

Pulse 126 - BP 164 / 72 - RR 26 Hb = 12 Hct = 36 ABG's: pH 7.38 / PaO_2 100 / $PaCO_2$ 32 / 96 % Sat

Question # 1: What is this Patient's Oxygen Content ?

OXYGEN DELIVERY

DO_2: the Rate of Oxygen Tranport in the Arterial Blood * it is the product of Cardiac Output & Arterial Oxygen Content

$DO_2 = Q \times CaO_2$

Cardiac Ouput (Q) can be "indexed" to body surface area Normal C.I. : 2.5 - 3.5 L/min-m^2 By using a factor of 10, we can convert vol % to ml/s

$DO_2 = Q \times CaO_2$ $DO_2 = 3 \times (1.3 \times Hb \times SaO_2) \times 10$ $DO_2 = 3 \times (1.3 \times 14 \times .98) \times 10$ $DO_2 = 540$ ml/min-m^2

Normal Range: 520 - 720 ml/min-m^2

Figure 5

O_2ER = VO2 / DO2 x 100
O_2ER = 130 / 540 x 100
O_2ER = 24 %

Normal Extraction
22 - 32 %

Example # 2: 35 yr old male s/p GSW to Chest

Pulse 126 - BP 164 / 72 - RR 26

Hb = 12 / Hct = 36 ABG's: pH 7.38 / PaO_2 100 / $PaCO_2$ 32 / 96 % Sat C.I. = 2.86

Question # 2: What is this Patient's Oxygen Delivery ?

Oxygen Consumption

Oxygen uptake is the final step in the oxygen transport pathway and it represents the oxygen supply for tissue metabolism

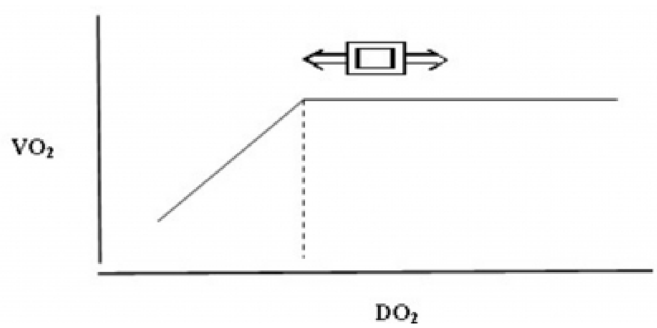
The Fick Equation: Oxygen Uptake is the Product of Cardiac Ouput and the Arteriovenous Difference in Oxygen Content

$VO_2 = Q \times [(CaO_2 - CvO_2)]$

$VO_2 = Q \times (CaO_2 - CvO_2)$ $VO_2 = Q \times [\ (1.3 \times Hb) \times (SaO_2 - SvO_2) \times 10\ ]$ $VO_2 = 3 \times [\ (1.3 \times 14) \times (.98 - .73) \times 10\ ]$ $VO_2 = 3 \times [\ 46\ ]$ $VO_2 = 138$ ml/min-m^2

Normal VO2: 110 - 160 ml/min-m^2

Figure 7



Example # 3: 35 yr old male s/p GSW to Chest

Pulse 126 - BP 164 / 72 - RR 26 Hb = 12 / Hct = 36 ABG's: pH 7.38 / PaO_2 100 / $PaCO_2$ 32 / 96 % Sat C.I. = 2.86 SvO_2 71 %

Question # 3: What is this Patient's Oxygen Consumption ?

EXTRACTION RATIO

ER = the fractional uptake of oxygen from the capillary bed O_2ER: derived as the Ratio of Oxygen Uptake to Oxygen Delivery

Figure 8

	Normal Range
Content [CaO_2]	16 - 19 vol %
Delivery [DO_2]	520 - 720 ml/min-m^2
Consumption [VO_2]	110 - 160 ml/min-m^2
Extraction Ratio [ER]	22 - 32 %
Mixed Venous PO_2	33 - 53 mmHg
Mixed Venous SO_2	68 - 77 %

Questions:

ER = 18 %, what does this imply ?
ER = 40 %, what does this imply ?

{image:6}

Example # 4: 35 yr old male s/p GSW to Chest

Pulse 126 - BP 164 / 72 - RR 26 Hb = 12 / Hct = 36 ABG's: pH 7.38 / PaO_2 100 / $PaCO_2$ 32 / 96 % Sat C.I. = 2.86 SvO_2 71 %

Question # 4: What is this Patient's Extraction Ratio ?

The uptake of oxygen from the microcirculation is a set point that is maintained by adjusting the Extraction Ratio to match changes in oxygen delivery

The ability to adjust O_2 Extraction can be impaired in serious illness

The Normal Response to a Decrease in Blood Flow is an Increase in O_2 Extraction sufficient enough to keep VO_2 in the normal range

VO_2 = Q x Hb x 13 x (SaO2 - SvO2) Q = 3; VO_2 = 3 x 14 x 13 x (.97 - .73) = 110 ml/min-m^2 Q = 1; VO_2 = 1 x 14 x 13 x (.97 - .37) = 109 ml/min-m^2

THE DO-VO CURVE

{image:7}

MIXED VENOUS OXYGEN

By rearranging the Fick Equation, the determinants of Venous Oxygen are:

VO2 = Q x Hb x 13 x (SaO_2 - SvO_2)

SvO_2 = SaO_2 - (VO_2/Q x Hb x 13)

* the most prominent factor in determining SvO2 is VO_2/Q

Causes of a Low SvO_2:

Hypoxemia
Increased Metabolic Rate
Low Cardiac Output
Anemia

ANOTHER POINT: OXIMETRY

Arterial Oxygen Saturation can be estimated but Venous Oxygen Saturation MUST be Measured !

* Remember the shape of the Oxyhemoglobin Curve * The SaO_2 falls on the flat portion & can be safely estimated, while the Venous % Sat (68 - 77 % falls on the Steep Portion and can vary significantly even with small errors in estimation !

In Critically-ill patients, augmenting the extraction ratio (in response to a change in oxygen delivery) may not be possible! In these patients, the Venous Oxygen Levels may change little in response to changes in Cardiac Output ! Thus, the Relationship between CO(Q) and Mixed Venous Oxygen must be determined before using SvO_2 or PvO_2 to monitor changes in DO_2 or VO_2

The Transport Variables:

{image:8}

** DO_2 & VO_2 are indexed to body surface area

References

Author Information

Tisha K. Fujii, DO
Dept. of Trauma & Critical Care, Boston University School of Medicine , Boston Medical Center

Bradley J. Phillips, MD
Dept. of Trauma & Critical Care, Boston University School of Medicine , Boston Medical Center