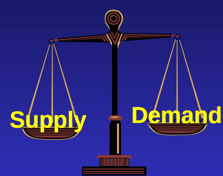
# OXYGEN TRANSPORT CALCULATIONS

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## IN REVIEW…

- There are four primary monitoring questions
  - Is intravascular volume or "preload" adequate?
  - Is blood flow adequate?
  - Is vascular resistance appropriate?
  - Is oxygen transport balance appropriate?
- Volumetric assessment of preload status is superior to pressure-based measurements
- Continuous hemodynamic monitoring provides an improved understanding of patient illness and response to therapy

## OXYGEN TRANSPORT BALANCE

- The foremost question in critical care is not:
  a) What is the perfect PAOP or EDVI?
  b) What cardiac output ensures patient survival?
  c) What systemic vascular resistance is optimal?
- The ultimate question is:
  d) Is tissue oxygen delivery sufficient to meet cellular oxygen demand?

## OXYGEN TRANSPORT BALANCE

- Failure to provide sufficient oxygen to meet cellular demands leads to
  - Cellular ischemia
  - Bacterial translocation
  - Sepsis
  - Worsening shock
  - Organ dysfunction
  - Multiple system organ failure
  - Death

## DEFINITIONS

- Oxygen delivery ($DO_2$)
  - The amount of oxygen pumped to the tissues by the heart
- Oxygen consumption ($VO_2$)
  - The amount of oxygen consumed by the tissues
- Oxygen demand
  - The amount of oxygen required by the tissues to function aerobically
  - May exceed both oxygen delivery and consumption during critical illness

## ASSESSING OXYGEN TRANSPORT

- To assess the adequacy of a patient's oxygen transport balance, four more questions must be considered
  - Does oxygen delivery meet the patient's needs?
  - Is cardiac output adequate for consumption?
  - Is oxygen consumption adequate for demand?
  - Is the patient's hypoxemia due to a pulmonary problem or to a low flow state?

## OXYGEN TRANSPORT BALANCE

- If oxygen delivery and oxygen consumption are balanced
  - "Supply" equals "demand"
  - The cellular requirements of the body are met
  - Normal metabolic processes proceed uninhibited
  - Anaerobic metabolism is minimized

"A Happy Pea Monster"

The well-known fable of the "Pea Monster" will be used to illustrate the key concepts of oxygen transport balance

## OXYGEN TRANSPORT BALANCE

- If oxygen demand exceeds delivery, shock is present
  - Cellular oxygen is deficient
  - Energy is produced via anaerobic metabolism with lactic acid (lactate) as a byproduct
    - ➢ Lactate cannot be reutilized and accumulates leading to:
      - Metabolic acidosis
      - Cellular injury
      - Cellular death

"A Sick Pea Monster"

## OXYGEN TRANSPORT BALANCE

- Oxygen consumption may just meet oxygen demand
  - Requires a high extraction of oxygen from blood
  - Places patient at risk for rapid decompensation
    - ➢ Little physiologic reserve is present
    - ➢ Organs with high baseline oxygen extraction, such as the heart, are at high risk for ischemia

"An Unhappy Pea Monster"

## OXYGEN TRANSPORT BALANCE

- Patient survival is improved by optimizing oxygen delivery to ensure that…

1) Oxygen demand is met at baseline

AND

2) There is an adequate physiologic oxygen reserve to cope with acute increases in oxygen demand

## OXYGEN CALCULATIONS

- Knowledge of the oxygen transport equations is essential to understanding the pathophysiology and appropriate treatment for the various shock states
- Pulmonary artery and central venous oximetry catheters provide the ability to monitor oxygen transport balance at the bedside
  - Continuous mixed venous oximetry ($SvO_2$)
  - Continuous central venous oximetry ($ScvO_2$)
  - Intermittent calculation of oxygen delivery ($DO_2I$) and oxygen consumption ($VO_2I$)

## MEASURED PARAMETERS

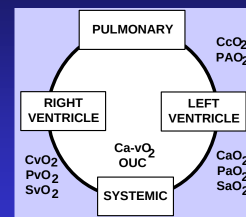
- Arterial oxygen tension ($PaO_2$)
- Arterial carbon dioxide tension ($PaCO_2$)
- Arterial oxygen saturation ($SaO_2$ or $SpO_2$)
- Mixed venous oxygen saturation ($SvO_2$)
- Central venous oxygen saturation ($ScvO_2$)
- Venous oxygen tension ($PvO_2$)
- Hemoglobin (Hgb)
- Cardiac output (CO)

## CALCULATED PARAMETERS

- Cardiac index (CI)
- Pulmonary capillary oxygen content ($CcO_2$)
- Arterial oxygen content ($CaO_2$)
- Venous oxygen content ($CvO_2$)
- Arterial-venous oxygen content difference ($Ca\text{-}vO_2$)
- Oxygen utilization coefficient (OUC)
- Oxygen delivery index ($DO_2I$)
- Oxygen consumption index ($VO_2I$)
- Intrapulmonary shunt (Qsp/Qt)

## VASCULAR CIRCUIT

- Central to any assessment of oxygen transport is the ability to calculate the amount of oxygen in the blood at any point in the body
- Such calculations are dependent upon both the measured oxygen tension and oxygen saturation at each point




## CALCULATING OXYGEN CONTENT

- To calculate the oxygen content of blood, one must recognize that:
  1. Oxygen can be either "bound" or "unbound"
  2. Each gram of Hgb can carry up to 1.34 mL of oxygen
     - This number varies from species to species
  3. The solubility of oxygen in blood is 0.0031 mL/dL
  4. The amount of oxygen carried by Hgb depends upon its saturation
     - This varies depending upon the patient's inspired oxygen fraction ($FiO_2$) and the presence of any mixed, unoxygenated blood
       - Also known as "intrapulmonary shunt"

## OXYGEN CONTENT

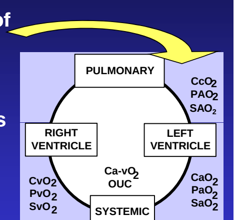
- Oxygen content
  = oxygen bound to Hgb + oxygen dissolved in plasma
- Oxygen bound
  = Hgb conc x oxygen Hgb can carry x Hgb saturation
- Oxygen dissolved
  = oxygen tension x solubility coefficient of oxygen

$$C■O_2 = (1.34 \times Hgb \times S■O_2) + (P■O_2 \times 0.0031)$$

where "■" signifies the location of the blood
("c" for end-capillary, "a" for arterial, or "v" for venous)

## CALCULATING OXYGEN CONTENT

- To calculate the oxygen content of blood as it leaves the alveolus ($C_cO_2$), remember that:
  1. Hgb should be fully saturated (i.e., $S_AO_2$=1.0 if $F_iO_2$ > 0.21) as it leaves the alveolus
  2. The alveolar oxygen tension ($P_AO_2$) must be determined using the Universal Gas Law




$$P_B = P_AO_2 + P_ACO_2 + P_AN_2 + P_{H2O}$$

## ALVEOLAR OXYGEN TENSION ($P_AO_2$)

- Assuming an $F_iO_2$ of > 0.30 (i.e., $S_AO_2$=1.0)

$$P_AO_2 = F_iO_2 \times [(P_B - P_{H20}) - (P_aCO_2/RQ)]$$

*where $P_B$ = barometric pressure, $P_{H2O}$ = water vapor pressure, RQ = respiratory quotient*

$P_AO_2$ = 0.30 x [(760 torr - 47 torr) - (40 torr / 0.8)]
*(assuming normal values)*

$P_AO_2$ = 0.30 x 663 torr = 199 torr

*$P_AO_2$ can also be approximated rapidly at the bedside as 700 torr x $FiO_2$ - 50 torr*

## PULMONARY END-CAPILLARY OXYGEN CONTENT ($CcO_2$)

- The oxygen content of pulmonary end-capillary blood as it leaves the alveolus

$C_cO_2$ = (1.34 x Hgb x 1.0) + ($P_AO_2$ x 0.0031)
*(oxygen bound)* *(oxygen dissolved)*

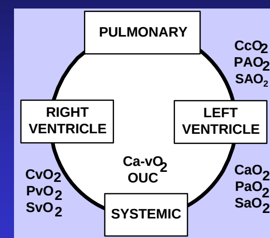
= (1.34 mL $O_2$/gm x 15 gm x 1.0)+(199 torr x 0.0031)

= 20.1 ml $O_2$/dl blood + 0.6 ml $O_2$/dl blood

= 20.7 ml $O_2$/dl blood

- Note again that alveolar ($P_AO_2$) and not arterial ($P_aO_2$) oxygen tension is used in this equation

## PULMONARY END-CAPILLARY OXYGEN CONTENT ($CcO_2$)




20.7 mL/dL
199 torr
1.0

## ARTERIAL OXYGEN CONTENT ($CaO_2$)

- Oxygen content of arterial blood leaving the heart
  - 98% of arterial oxygen is bound to Hgb
  - 2% of arterial oxygen is dissolved in plasma

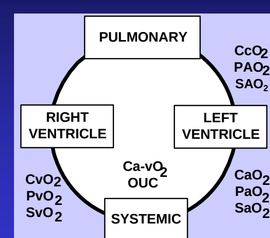
$C_aO_2$ = (1.34 x Hgb x $S_aO_2$) + ($P_aO_2$ x 0.0031)

= (1.34 x 15 gm x 1.0) + (100 torr x 0.0031)

= 20.1 ml $O_2$/dl blood + 0.31 ml $O_2$/dl blood

= 20.4 ml $O_2$/dl blood

## ARTERIAL OXYGEN CONTENT ($CaO_2$)




20.7 mL/dL
199 torr
1.0

20.4 mL/dL
100 torr
1.0

## $CcO_2$ vs. $CaO_2$

- Question:
  - So if the $CcO_2$ was 20.7 mL, in this example, and the $CaO_2$ is now 20.4 mL, where did the other 0.3 mL of oxygen go??? The blood hasn't even made it out of the heart yet???
- Answer:
  - A small amount of oxygen is used by the lung and heart before being pumped to the body
  - This deoxygenated blood is returned to the left heart and contributes to intra-pulmonary shunt (stay tuned!)

## VENOUS OXYGEN CONTENT ($CvO_2$)

- Oxygen content of blood returning to the heart
  - >99% of arterial oxygen is bound to Hgb
  - <1% of venous oxygen is dissolved in plasma

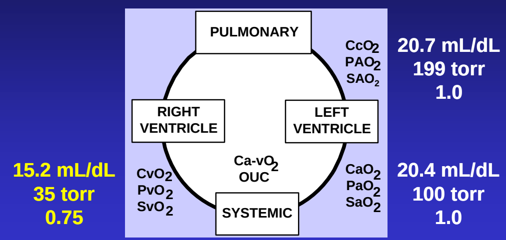
$C_vO2$ = (1.34 x Hgb x $S_vO_2$) + ($P_vO_2$ x 0.0031)
$PvO_2$ can be measured with a venous blood gas, or estimated as 35 torr with high accuracy

= (1.34 x 15 gm x 0.75) + (35 torr x 0.0031)

= 15.1 ml $O_2$/dl blood + 0.11 ml $O_2$/dl blood

= 15.2 ml $O_2$/dl blood

## VENOUS OXYGEN CONTENT ($C_vO_2$)




## ARTERIAL-VENOUS OXYGEN CONTENT DIFFERENCE (Ca-vO2)

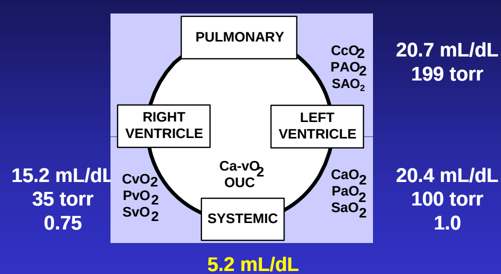
- The difference in oxygen content between arterial and venous blood
  - Represents the amount of oxygen used during one pass of blood through the body
  - Can be used as an estimate of the patient's physiologic oxygen reserve

$C_{a\text{-}v}O_2 = C_aO_2 - C_vO_2$

$= 20.4$ ml $O_2$/dl blood – 15.2 ml $O_2$/dl blood

$= 5.2$ ml $O_2$/dl blood

## ARTERIAL-VENOUS OXYGEN CONTENT DIFFERENCE (Ca-vO2)




So you now have the ability to measure or calculate the oxygen content and tension at any point in the body!

## OXYGEN DELIVERY INDEX ($DO_2I$)

- Volume of gaseous oxygen pumped from the left ventricle per minute per meter squared BSA

$DO_2I = CI \times C_aO_2 \times 10$ dL/L

*The 10 dL/L corrects for the fact that CI is measured in L/min/m² and oxygen content is measured in ml/dl*

$= 4.0$ L/min-m² x 20.4 ml $O_2$/dl blood x 10 dL/L

$= \sim 800$ ml $O_2$/min-m²

- This is a very important resuscitation endpoint for ensuring adequate oxygen delivery to the tissues

## OXYGEN CONSUMPTION INDEX ($VO_2I$)

- Volume of gaseous $O_2$ returned to the right atrium per minute per meter squared BSA

$VO_2I = CI \times C_{a\text{-}v}O_2 \times 10$ dL/L

*The 10 dL/L corrects for the fact that CI is measured in L/min/m² and oxygen content is measured in ml/dl*

$= 4.0$ L/min-m² x 5.2 ml $O_2$/dl blood x 10 dL/L

$= \sim 200$ ml $O_2$/min-m²

## OXYGEN UTILIZATION COEFFICIENT (OUC)

- Percentage of delivered oxygen which is consumed by the body
  - Also known as the oxygen extraction ratio ($O_2ER$)

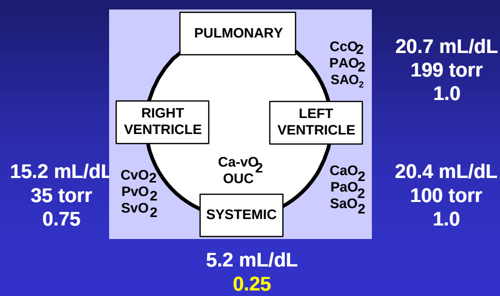
$OUC = VO_2I / DO_2I$

$= 200$ ml $O_2$/min-m² / 800 ml $O_2$/min-m²

$= \sim 0.25$

- If $SaO_2$ is maintained at > 0.92, OUC can be approximated as 1- $SvO_2$

## OXYGEN UTILIZATION COEFFICIENT (OUC)




## MIXED VENOUS OXYGEN SATURATION ($SvO_2$)

- Provides a continuous "online" indication of the relative balance between $VO_2I$ and $DO_2I$
- It is the "flow-weighted average" of the venous saturations from all perfused vascular beds
  - Does not reflect oxygen transport adequacy of non-perfused vascular beds
  - A "normal" $SvO_2$ therefore does not mean that all tissues are adequately oxygenated
  - Does not yield information about the adequacy of perfusion of any individual vascular bed

## MIXED VENOUS OXYGEN SATURATION ($SvO_2$)

- Can be used…
  - As an "early warning signal" to detect the onset of oxygen transport imbalance before clinical deterioration occurs
  - To evaluate the efficacy of therapeutic interventions such that physiologic end-points are reached more quickly
  - To identify potentially detrimental consequences of "patient care" (suctioning, positioning, etc.) that might otherwise go unnoticed

## MIXED VENOUS OXYGEN SATURATION ($SvO_2$)

- If $S_vO_2$ decreases…
  - Consumption ($VO_2I$) is increasing OR
  - Delivery ($DO_2I$) is decreasing
- If $S_vO_2$ increases…
  - Consumption ($VO_2I$) is decreasing OR
  - Delivery ($DO_2I$) is increasing OR
  - Blood is being shunted without releasing its oxygen OR
  - Oxygen uptake by the tissues is decreasing

## MIXED VENOUS OXYGEN SATURATION ($SvO_2$)

- As a general rule…

  A "low" $S_vO_2$ is always bad

  A "normal" $S_vO_2$ is not necessarily good

  A "high" $S_vO_2$ is usually bad

## MIXED VENOUS OXYGEN SATURATION ($SvO_2$)

- The four determinants of $SvO_2$
  - Hemoglobin (Hgb)
  - Cardiac output / index (CO / CI)
  - Arterial oxygen saturation ($Sao_2$)
  - Oxygen consumption index ($VO_2I$)
- The four main causes of low $SvO_2$
  - Anemia
  - Low cardiac output
  - Arterial desaturation
  - Increased $VO_2I$

## MIXED VENOUS OXYGEN SATURATION ($SvO_2$)

- Two common sources of error in $SvO_2$
  - Inadequate calibration
    - Perform in-vitro calibration prior to catheter insertion
    - Perform in-vivo calibration via mixed venous blood gas
  - Catheter malposition
    - If the catheter tip is against the wall of the pulmonary artery, the light reflected back to the catheter will be amplified artificially increasing the $SvO_2$ measurement

## MIXED VENOUS OXYGEN SATURATION ($SvO_2$)

- A sensitive "online" monitor of the adequacy of balance between oxygen delivery and oxygen consumption
- Not a specific indicator of the cause for oxygen transport compromise
- Accurately predicts potentially detrimental changes in patient status before they become clinically apparent
  - Allows appropriate therapeutic interventions to be initiated prior to development of severe changes in cardiorespiratory status

## FOUR PRIMARY QUESTIONS

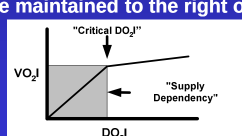
- Is $DO_2I$ adequate to meet the patient's needs?
- Is CI adequate to support $VO_2I$?
- Is $VO_2I$ appropriate for oxygen demand?
- Is the patient's hypoxemia due to a pulmonary problem or to a low flow state?

## FUNDAMENTAL QUESTIONS

- Question #1
  - Is $DO_2I$ adequate to meet the patient's needs?
    - $DO_2I$ should be at least 500 ml $O_2$/min-m$^2$
      - Higher levels do not change outcome
    - If lower, check the $SvO_2$
      - < 0.65 suggests that oxygen supply is barely meeting oxygen demand
    - Ensure that the patient's Hgb is appropriate
      - Consider transfusion of packed red blood cells if $DO_2I$ is inadequate
        - » Hgb level has the greatest impact on $DO_2I$

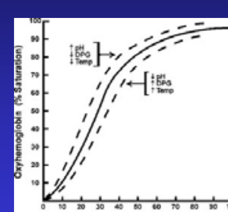
## OXYGEN SUPPLY DEPENDENCY

- When $DO_2I$ exceeds oxygen demand, $VO_2I$ will "plateau" and no longer rise in response to $DO_2I$
  - The goal in oxygen transport resuscitation
- When $DO_2I$ no longer meets oxygen demand, $VO_2I$ becomes "supply dependent"
  - So called "critical $DO_2$"
  - Patients should be maintained to the right of "critical $DO_2I$"




## OXYGEN UNLOADING

- The optimal Hgb concentration is unknown
- Judicious amounts of acidemia, hypercarbia, and fever all produce a right shift in the oxyhemoglobin association curve and may improve tissue unloading of oxygen
- These factors should be kept in mind when attempting to improve oxygen delivery to the tissues



## FUNDAMENTAL QUESTIONS

- Question #2
  - Is CI adequate to support $VO_2I$?
    - Check the Ca-$vO_2$
    - Check the heart rate and stroke volume

## FUNDAMENTAL QUESTIONS

- Question #2
  - Is CI adequate to support $VO_2I$?
    - Check the Ca-$vO_2$
      - If < 5 ml $O_2$/dl blood, CI is sufficient to meet the body's demands for oxygen
        - » A large percentage of blood returned to the heart is still oxygenated
      - If > 5 ml $O_2$/dl blood, an abnormally high percentage of oxygen is being extracted from the blood
        - » Attempts to increase CI and $DO_2I$ should be undertaken

## FUNDAMENTAL QUESTIONS

- Question #2
  - Is CI adequate to support $VO_2I$?
    - Check the heart rate and stroke volume
      - CI = SVI x HR
      - High heart rates may reduce diastolic filling time impairing stroke volume
      - Patients with tachycardia may benefit from
        - » Fluid resuscitation
        - » Judicious beta-blockade
        - » Correction of abnormal rhythms

## FUNDAMENTAL QUESTIONS

- Question #3
  - Is consumption appropriate for demand?
    - Check a lactic acid level
      - If > 2.0 mmol/L, anaerobic metabolism is present
        - » CI and $DO_2I$ should be optimized
        - » If $SvO_2$ is normal, lactic acid is probably due to prior anaerobic metabolism
        - » If $SvO_2$ is low, anaerobic metabolism is likely still occurring

## FUNDAMENTAL QUESTIONS

- Question #4
  - Is the patient's hypoxemia due to a pulmonary problem (i.e., increased intrapulmonary shunt) OR to a low flow state (i.e., low Ca-$vO_2$)?
    - Calculate the patient's intrapulmonary shunt ($Q_{sp}/Q_t$)

## INTRAPULMONARY SHUNT (Qsp/Qt)

- Also known as "venous admixture"
- Blood which does not pass through ventilated portions of the lung and leaves the lung desaturated
- Normal intrapulmonary shunt is 2-5%
- May exceed 50% in patients with severe acute respiratory distress syndrome (ARDS)
- Commonly estimated using $P_AO_2$-$P_aO_2$
  - The "alveolar-arterial" or "A-a gradient"

## NORMAL INTRAPULMONARY SHUNT

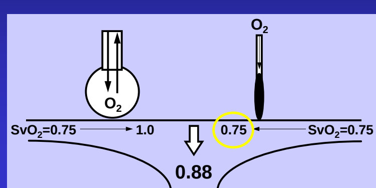
- There are three primary sources of normal Qsp/Qt (i.e., deoxygenated blood leaving the left heart)
  - Bronchial artery blood which enters the pulmonary veins after giving up some of its oxygen to the bronchi
  - Desaturated blood which enters the left ventricle via the Thebesian veins after perfusing the myocardium
  - Normal alveolar collapse in the apices of the lungs (West's Zone I lung)

## ABNORMAL INTRAPULMONARY SHUNT

- There are a number of sources of Qsp/Qt in the critically ill
  - Atelectasis
  - Lobar pneumonia
  - Inhalation injury
  - Drowning
  - Acute Respiratory Distress Syndrome (ARDS)
  - Abdominal Compartment Syndrome (ACS)

## INTRAPULMONARY SHUNT

- Represents an "oxygen refractory" hypoxemia
  - Shunted blood is not exposed to ventilated alveoli
  - Cannot be improved with supplemental oxygen <u>regardless</u> of the oxygen fraction administered




## INTRAPULMONARY SHUNT EQUATION

- Knowing how Qsp/Qt is calculated is important
- Definitions
  - Qt = total cardiac output
  - Qs = shunted portion of cardiac output
  - Qns = normal pulmonary end-capillary blood flow that is not shunted past abnormal alveoli
- Therefore,

$$Qt = Qs + Qns$$

*Total blood flow = shunted + non-shunted blood*

## INTRAPULMONARY SHUNT EQUATION

- Further definitions
  - $Qt * CaO_2$ = total oxygen delivered to the body
    - ➢ *The equation for oxygen delivery ($DO_2$)*
  - $Qs * CvO_2$ = total oxygen within shunted blood
    - ➢ *No oxygen is added; content remains $CvO_2$*
  - $Qns * CcO_2$ = total oxygen within end-capillary blood
- Therefore,

$$Qt\,(CaO_2) = Qs\,(CvO_2) + Qns\,(CcO_2)$$

*Total oxygen delivered = sum of the oxygen within shunted and non-shunted blood*

## INTRAPULMONARY SHUNT EQUATION

$$Qt\,(CaO_2) = Qs\,(CvO_2) + (Qt - Qs)(CcO_2)$$

*Substituting (Qt - Qs) for Qns…*

$$Qt\,(CaO_2) = Qs\,(CvO_2) + Qt\,(CcO_2) - Qs\,(CcO_2)$$

*Rearranging…*

$$Qs\,(CcO_2 - CvO_2) = Qt\,(CcO_2 - CaO_2)$$

*Further rearranging…*

$$\frac{Qs}{Qt} = \frac{(CcO_2 - CaO_2)}{(CcO_2 - CvO_2)}$$

The "Shunt Equation"

## OXYGEN TRANSPORT BALANCE

- For those of you who are still awake, you will no doubt remember the following fable from your preschool days…

## The Pea Monster

### A Fable of pea eating monsters and oxygen transport

Once upon a time, there was a pea eating monster who lived near a pea factory. A train delivered the peas to the monster day and night. As long as the villagers delivered enough peas to the monster, he remained happy and didn't terrorize the countryside.

## NORMAL PEA DELIVERY

- The train made 5 trips between the pea factory and the monster every minute. Each train consisted of 5 cars with each car holding 40 peas.
- Therefore…
  - 5 trips per minute
  - 5 cars per train
  - 40 peas per car
  - 200 peas per train
  - 1000 peas per minute

## NORMAL PEA CONSUMPTION

- The pea monster ate 10 peas from each car as it passed
- Therefore, he consumed…
  - 10 peas per car
  - 50 peas per train
  - 5 trains per minute
  - 250 peas per minute

## NORMAL PEA UTILIZATION

- The villagers created the "pea utilization ratio" and the "train car pea saturation" to monitor the monster

$$\text{Pea Utilization Ratio} = \frac{\text{Pea Consumption}}{\text{Pea Delivery}} = \frac{\text{250 peas per min}}{\text{1000 peas per min}} = 0.25$$

$$\text{Train car pea saturation} = \frac{\text{Delivery - Consumption}}{\text{Delivery}} = \frac{\text{(1000–750) peas per min}}{\text{1000 peas per min}} = 0.75$$

## NORMAL PEA RETURN

- Peas delivered = 200 peas per train
- Peas returned = 150 peas per train
- Peas consumed = 50 peas per train

## POTENTIAL PROBLEMS

- If the Pea Monster gets hungry and eats more peas, fewer peas are returned and the factory may not be able to fully load the train cars before the train leaves the factory again
- As a result, there will be fewer peas to deliver to the monster during the next trip

## POTENTIAL PROBLEMS

- The monster has short arms that limit how many peas he can reach. The first 10 peas (25%) are scooped off easily.

## POTENTIAL PROBLEMS

- The second 10 peas (50%) can be plucked out, but with some difficulty.

## POTENTIAL PROBLEMS

- The monster's arms are too short to reach the bottom of the car and he cannot remove the bottom 20 peas!

## PEA DELIVERY

- May be augmented by:
  - Increasing the number of
    - Peas per car
      - Up to a point that the cars are full
    - Cars per train
      - More cars can be added to the train
    - Trains per minute
      - The train can travel faster
  - Improving the ease of pea removal
  - Increasing the rapidity of pea loading

## WHEN THE MONSTER'S NEEDS ARE MET…

## WHEN THE MONSTER'S NEEDS ARE NOT MET…


## CAUSES OF AN UNHAPPY MONSTER

- Hungry monster
- Too few cars
- Train too slow
- Cars not full of peas
- Too few peas
- Wrong peas
- Peas missing cars
- Train missing loader

## HUNGRY MONSTER

- 5 cars per train
- 5 trains per minute
- ~~10~~ 20 peas eaten per car
- ~~50~~ 100 peas eaten per train
- ~~250~~ 500 peas eaten per minute
- 1000 peas delivered per minute

Pea utilization = $\frac{500 \text{ peas}}{1000 \text{ peas}}$ = 0.50

## TOO FEW CARS

- 5 trips per minute
- ~~5~~ 4 cars per train
- ~~10~~ 12.5 peas eaten per car
- 50 peas eaten per train
- ~~200~~ 160 peas delivered per train
- ~~1000~~ 800 peas delivered per minute

Pea utilization = $\frac{250 \text{ peas}}{800 \text{ peas}}$ = 0.31

## TRAIN TOO SLOW

- ~~5~~ 4 trips per minute
- 5 cars per train
- ~~10~~ 12.5 peas eaten per car
- ~~50~~ 62.5 peas eaten per train
- 250 peas eaten per minute
- ~~1000~~ 800 peas delivered per minute

Pea utilization = $\frac{250 \text{ peas}}{800 \text{ peas}}$ = 0.31

## HUNGRY MONSTER & SLOW TRAIN

- ~~5~~ 4 trips per minute
- 5 cars per train
- ~~10~~ 20 peas eaten per car
- ~~50~~ 100 peas eaten per train
- ~~250~~ 400 peas eaten per minute
- ~~1000~~ 800 peas delivered per minute


Pea utilization = $\frac{400 \text{ peas}}{800 \text{ peas}}$ = 0.50

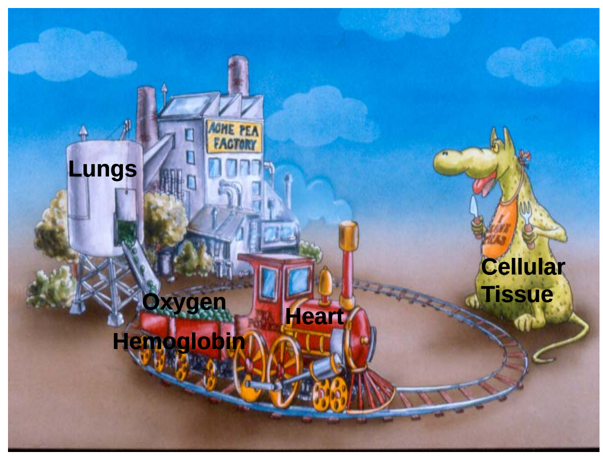
## HUNGRY MONSTER, SLOW TRAIN, TOO FEW CARS, CARS NOT FULL

- ~~5~~ 4 trips per minute
- ~~5~~ 4 cars per train
- ~~40~~ 30 peas per car
- ~~10~~ 15 peas eaten per car
- ~~250~~ 320 peas eaten per minute
- ~~1000~~ 480 peas delivered per minute

Pea utilization = $\frac{320 \text{ peas}}{480 \text{ peas}}$ = 0.66

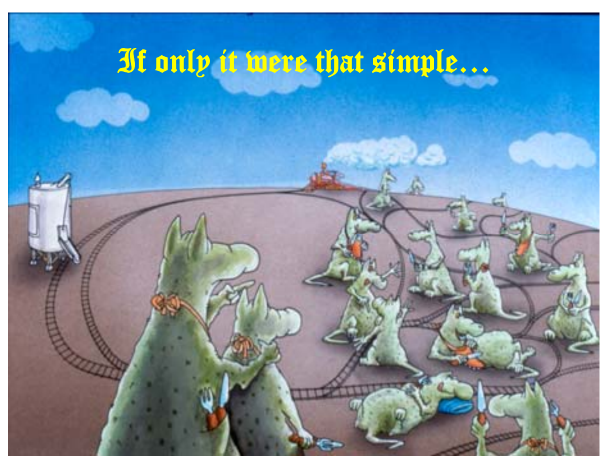
## THE MORAL OF THE FABLE…

- Never heard of the “Fable of the Pea Monster”???
  - Your preschool education was obviously deficient
- So what is the moral of the fable?


## THE MORAL OF THE FABLE…

| | |
|---|---|
| • Hungry monster | Increased consumption |
| • Too few cars | Low hemoglobin |
| • Train too slow | Low cardiac output |
| • Cars not full of peas | Low oxygen saturation |
| • Too few peas | Low $FiO_2$ |
| • Wrong peas | Carboxyhemoglobin |
| • Peas missing cars | V/Q mismatch |
| • Train missing loader | Intrapulmonary shunt |



## CONCLUSIONS

- Assessment of oxygen transport balance through calculation of oxygen delivery, consumption, and utilization is an essential part of patient resuscitation
- The oxygen transport parameters are useful resuscitation endpoints in titrating therapy to ensure adequate tissue perfusion and oxygenation