Abnormal Ventilation, Abnormal Gas Exchange

Ventilation and Gas Exchange

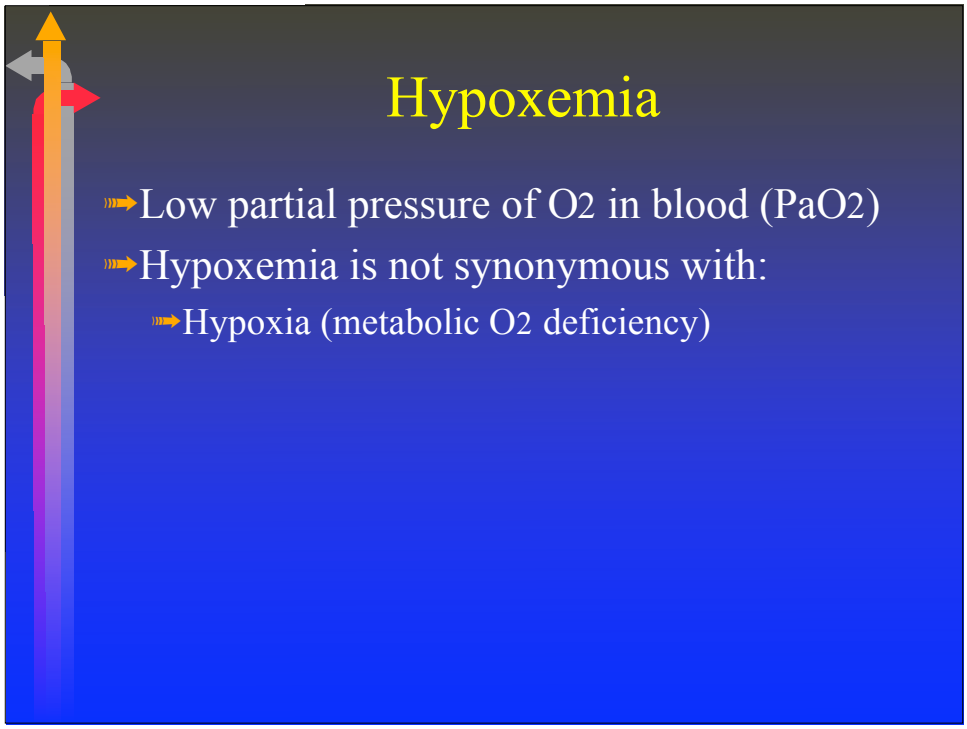
- Objective: to achieve adequate tissue oxygenation and remove metabolically produced CO2.
- Ventilation: concerned with delivery of fresh volume of air to gas exchanging units, and the removal of a sufficient volume of mixed gas out
- Gas Exchange: the ability to move gas across the alveolar-capillary membrane

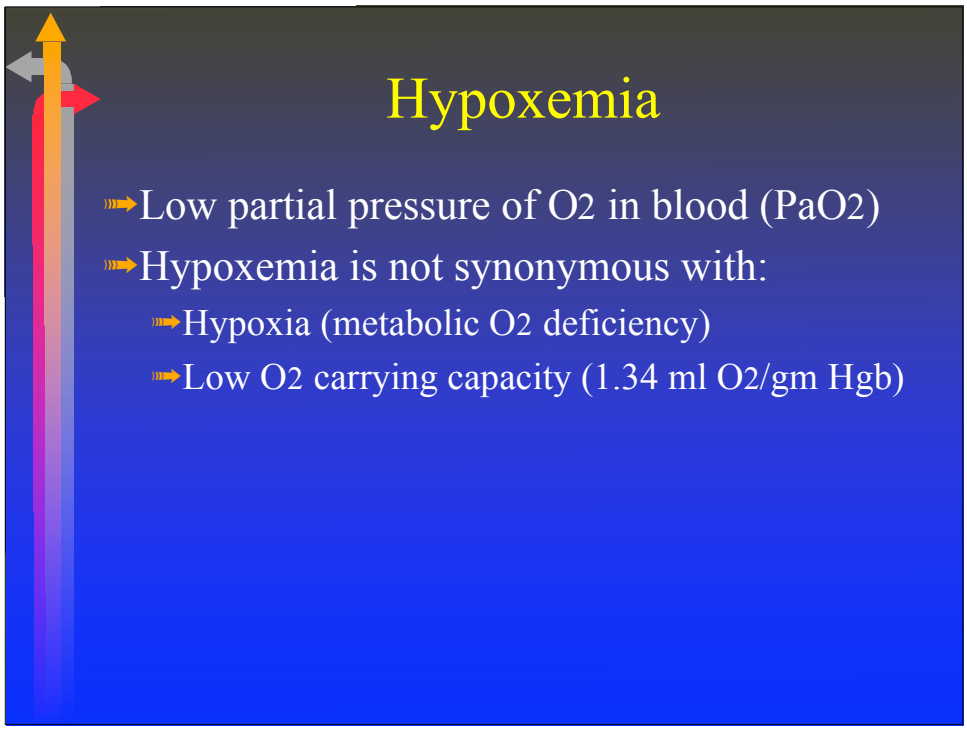
Ventilation and Gas Exchange

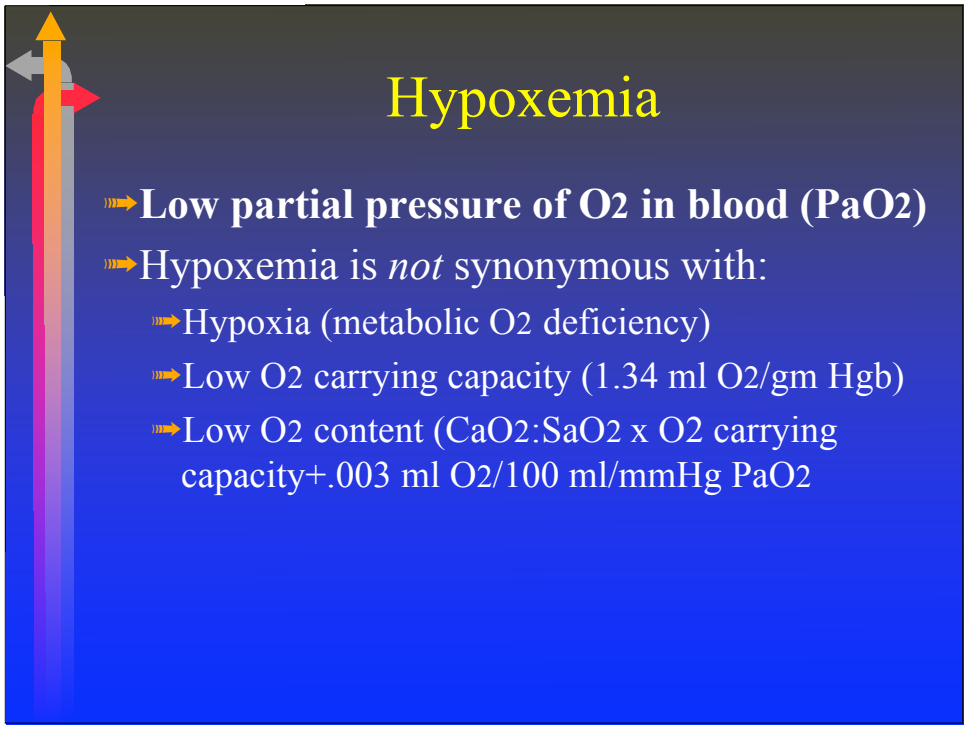
- The failure of either or both results in impaired arterial blood gases and ultimately *respiratory failure.*
- Ventilatory failure: *Hypercapnic respiratory failure*
- Gas exchange failure: *Hypoxemic respiratory failure*
- *Hypoxemia is the inevitable result of both*

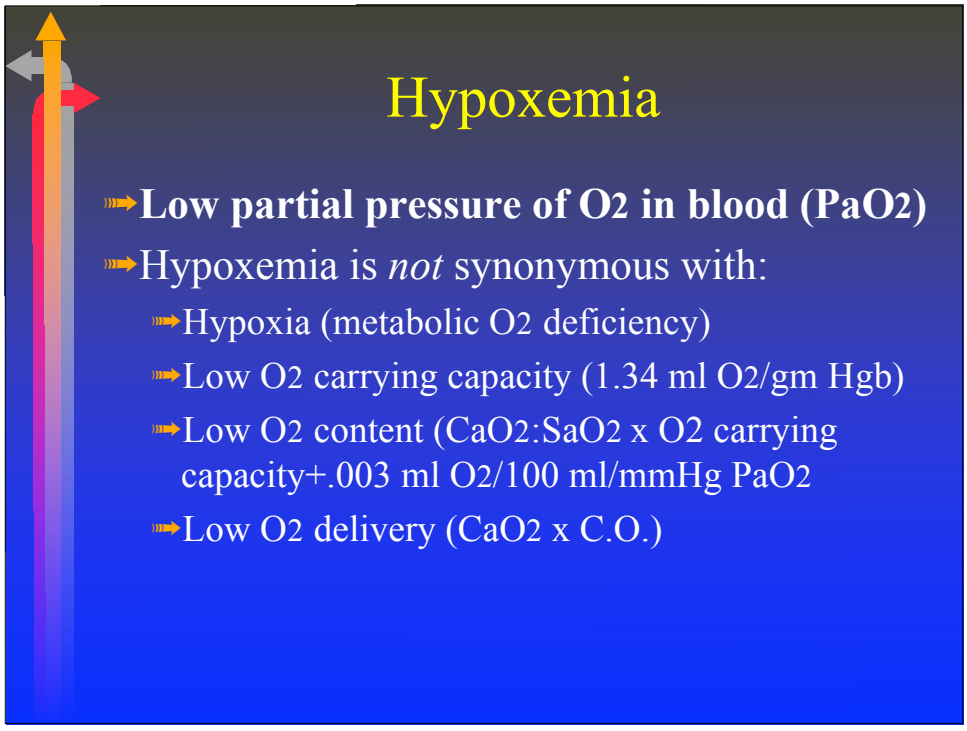
Hypoxemia

- Low partial pressure of O_2 in blood (PaO_2)
- Hypoxemia is not synonymous with:


Hypoxemia
Low partial pressure of O2 in blood (PaO2)
Hypoxemia is not synonymous with:
Hypoxia (metabolic O2 deficiency)


Hypoxemia
Low partial pressure of O2 in blood (PaO2)
Hypoxemia is not synonymous with:
Hypoxia (metabolic O2 deficiency)
Low O2 carrying capacity (1.34 ml O2/gm Hgb)


Hypoxemia
Low partial pressure of O2 in blood (PaO2)
Hypoxemia is not synonymous with:
Hypoxia (metabolic O2 deficiency)
Low O2 carrying capacity (1.34 ml O2/gm Hgb)
Low O2 content (CaO2:SaO2 x O2 carrying capacity+.003 ml O2/100 ml/mmHg PaO2


Hypoxemia
Low partial pressure of O2 in blood (PaO2)
Hypoxemia is not synonymous with:
Hypoxia (metabolic O2 deficiency)
Low O2 carrying capacity (1.34 ml O2/gm Hgb)
Low O2 content (CaO2:SaO2 x O2 carrying capacity+.003 ml O2/100 ml/mmHg PaO2
Low O2 delivery (CaO2 x C.O.)

Physiologic Causes of Hypoxemia

Alveolar Hypoventilation

Decreased PIO_2

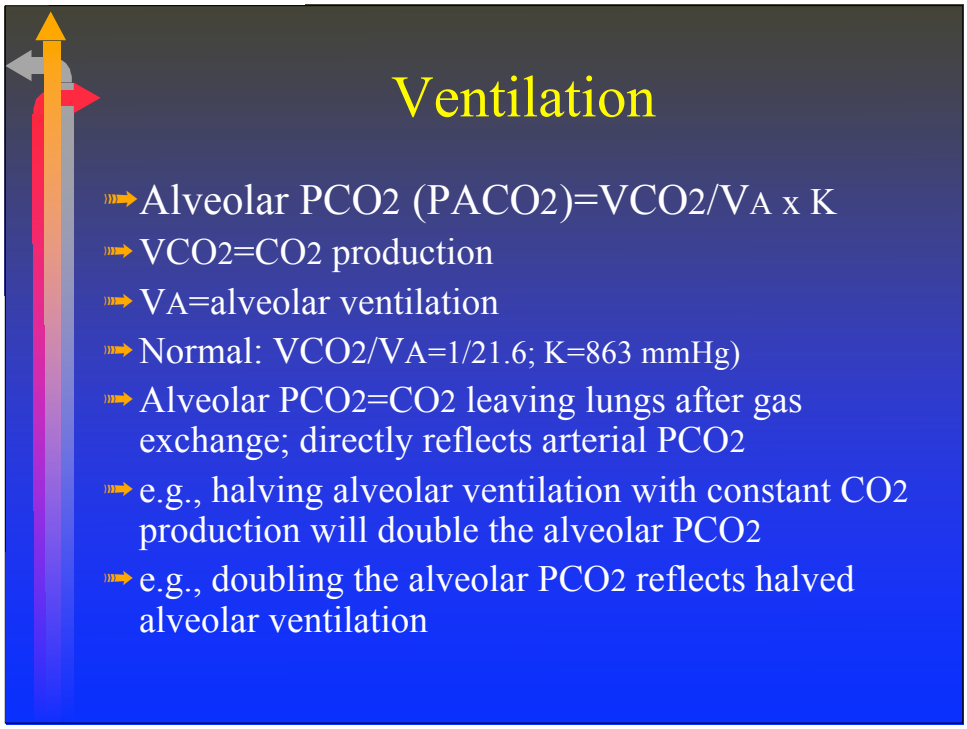
Diffusion Abnormality

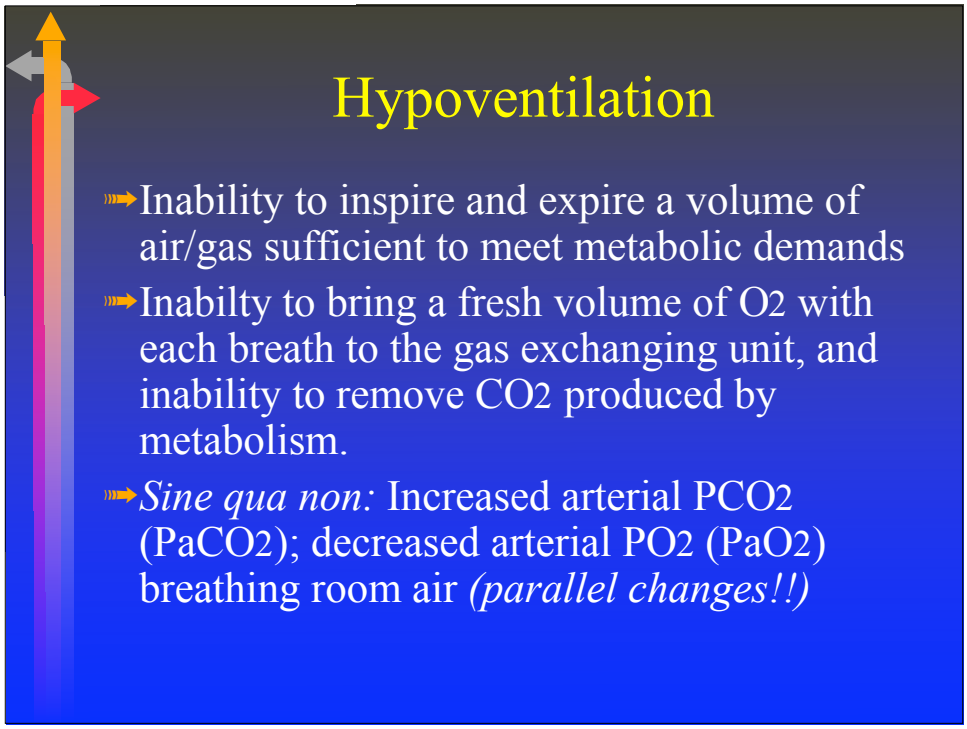
V/Q mismatch

Shunt

Ventilation

- Minute Ventilation (V_E)=tidal volume (V_T) x respiratory frequency
- Alveolar ventilation (V_A)=that part of minute ventilation which participates in gas exchange
- Alveolar ventilation=alveolar volume (tidal volume-dead space volume) x respiratory frequency


Ventilation
Alveolar PCO2 (PACO2)=VCO2/VA x K
VCO2=CO2 production
VA=alveolar ventilation
Normal: VCO2/VA=1/21.6; K=863 mmHg)
Alveolar PCO2=CO2 leaving lungs after gas exchange; directly reflects arterial PCO2
e.g., halving alveolar ventilation with constant CO2 production will double the alveolar PCO2
e.g., doubling the alveolar PCO2 reflects halved alveolar ventilation


Hypoventilation
Inability to inspire and expire a volume of air/gas sufficient to meet metabolic demands
Inabilty to bring a fresh volume of O2 with each breath to the gas exchanging unit, and inability to remove CO2 produced by metabolism.
Sine qua non: Increased arterial PCO2 (PaCO2); decreased arterial PO2 (PaO2) breathing room air (parallel changes!!)

Hypoventilation/ Alveolar hypoventilation

- All hypoventilation concerns either :
- increased dead space/tidal volume (anatomic or physiologic), or
- Decreased MINUTE ventilation (decreased tidal volume, and/or decreased respiratory rate)
- Each is considered alveolar hypoventilation if PaCO2 is elevated.

Alveolar Hypoventilation: 2 Clinical Pearls

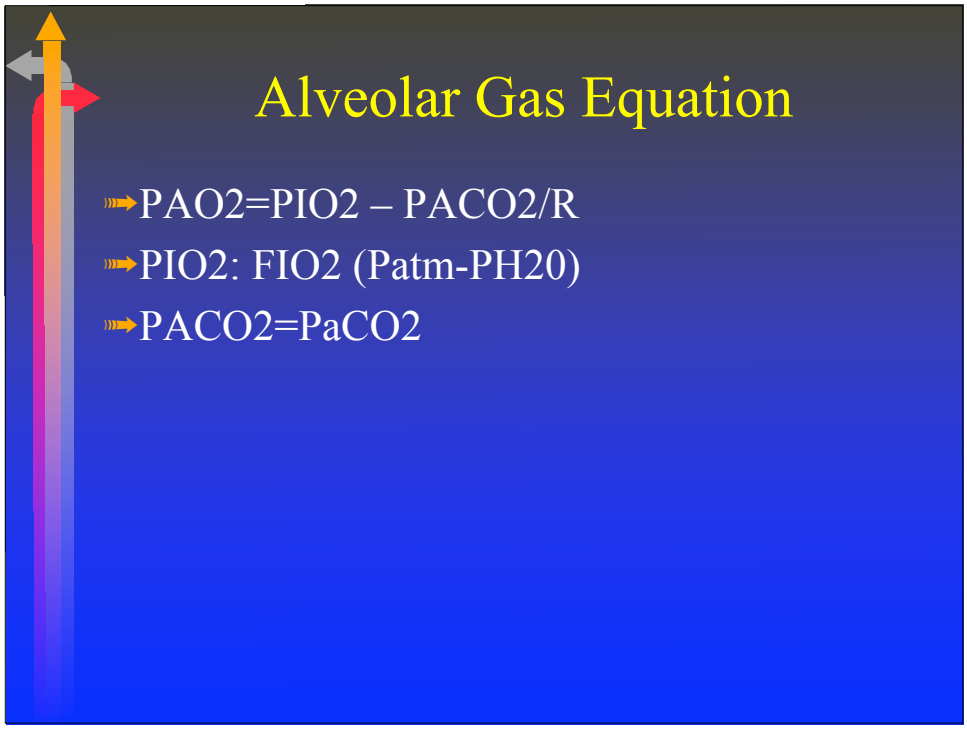
- Does not widen the $AaDO_2$
- The hypoxemia may be readily ameliorated with supplemental O_2

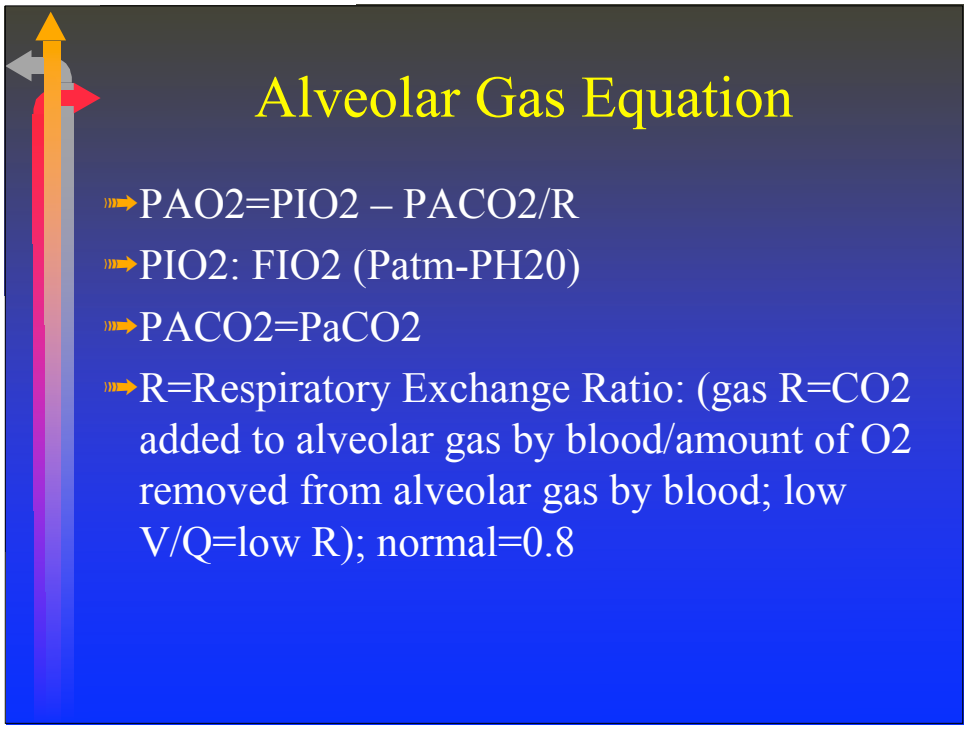
Alveolar Gas Equation

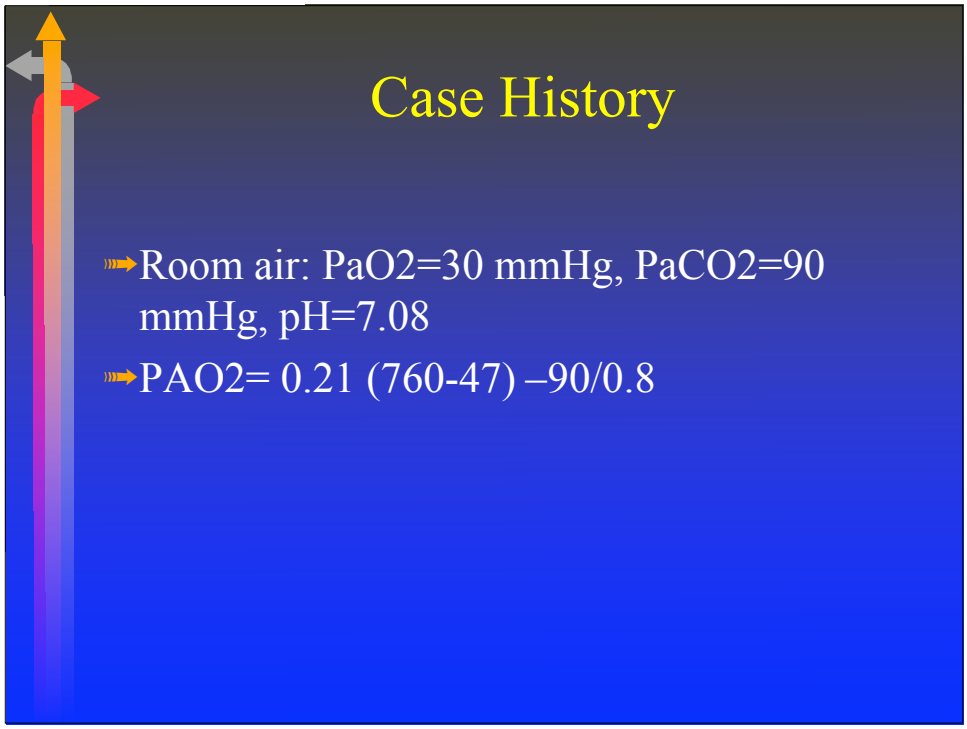
- PAO2=PIO2 – PACO2/R
  - PAO2=PIO2 – PACO2/R + [PCO2 x FIO2 x 1-R/R]

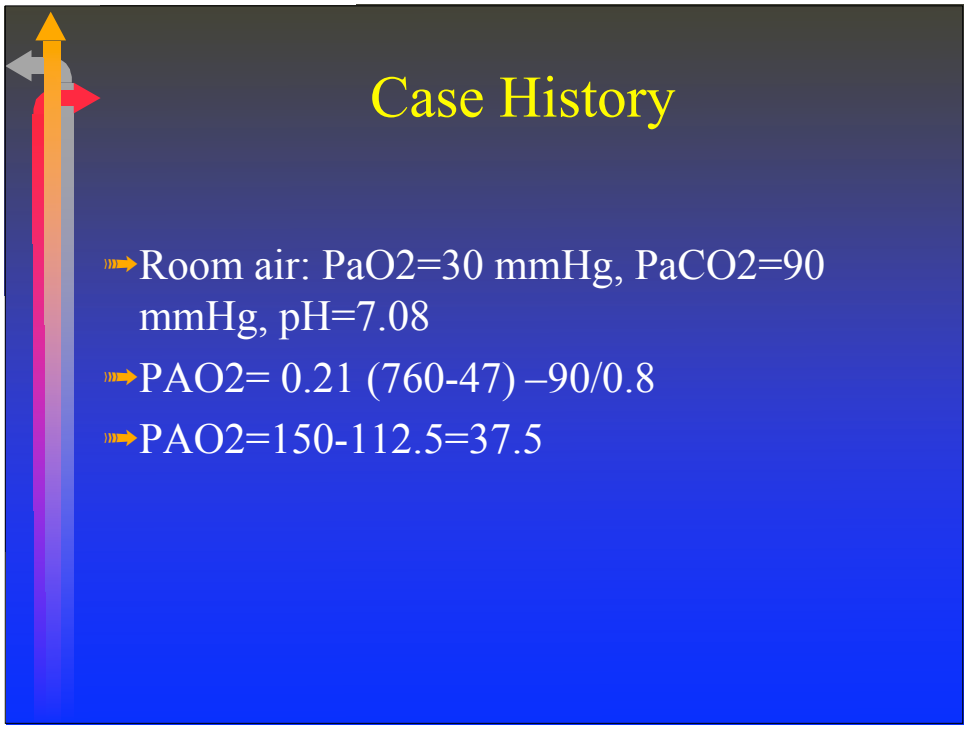
Alveolar Gas Equation

- PAO2=PIO2 – PACO2/R
- PIO2: FIO2 (Patm-PH20)


Alveolar Gas Equation
PAO2=PIO2 – PACO2/R
PIO2: FIO2 (Patm-PH20)
PACO2=PaCO2


Alveolar Gas Equation
PAO2=PIO2 – PACO2/R
PIO2: FIO2 (Patm-PH20)
PACO2=PaCO2
R=Respiratory Exchange Ratio: (gas R=CO2 added to alveolar gas by blood/amount of O2 removed from alveolar gas by blood; low V/Q=low R); normal=0.8


Case History
Room air: PaO2=30 mmHg, PaCO2=90 mmHg, pH=7.08
PAO2= 0.21 (760-47) –90/0.8

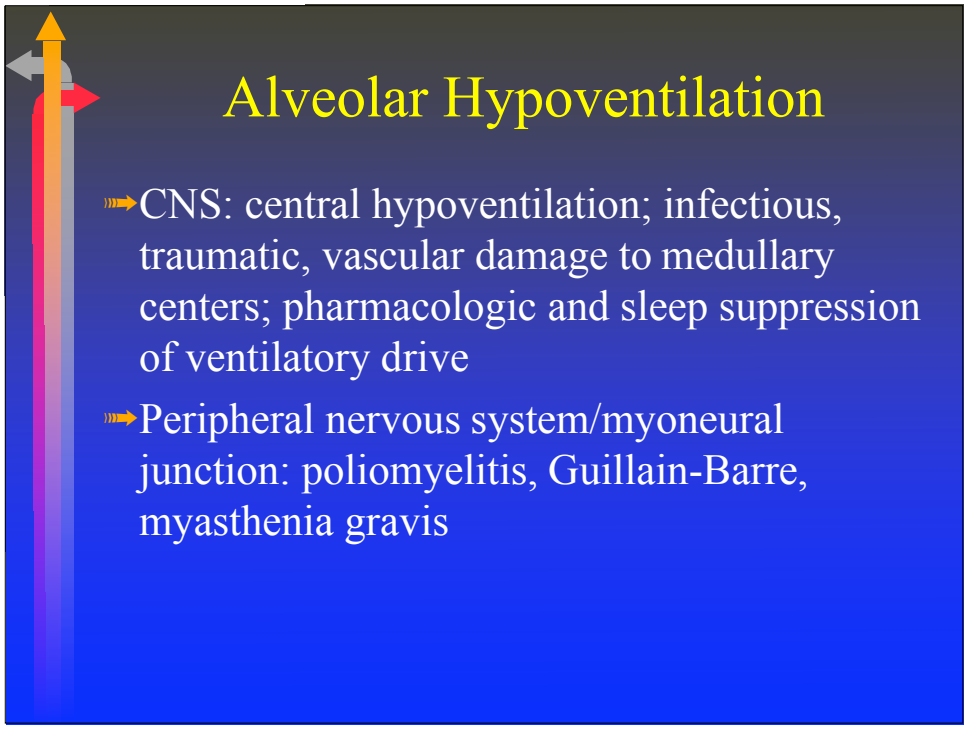

Case History
Room air: PaO2=30 mmHg, PaCO2=90 mmHg, pH=7.08
PAO2= 0.21 (760-47) –90/0.8
PAO2=150-112.5=37.5

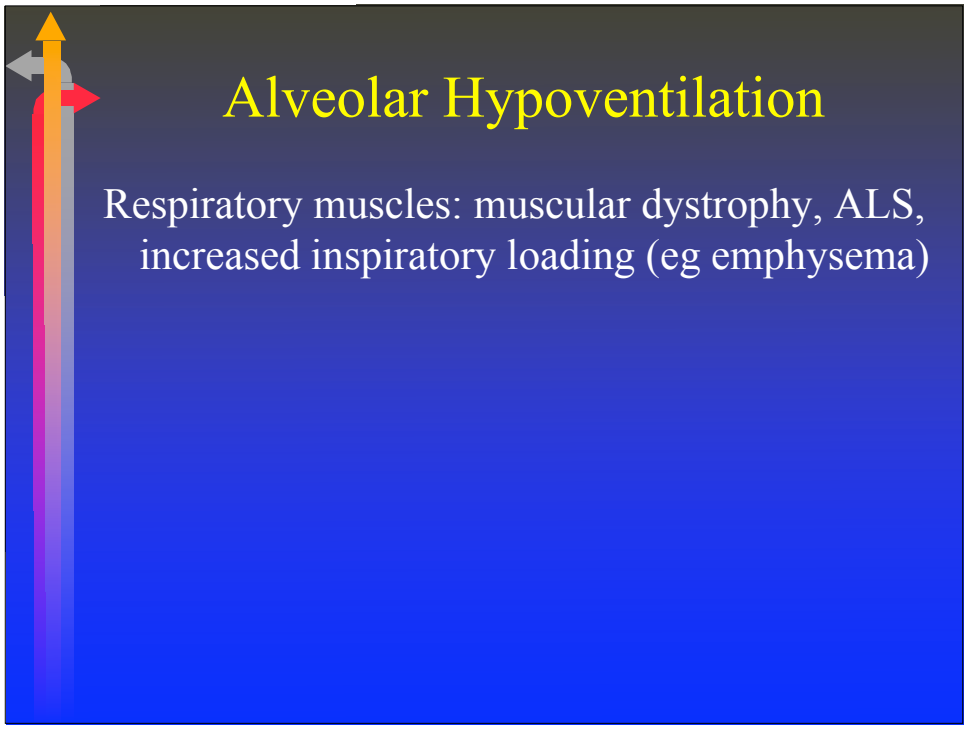
Case History

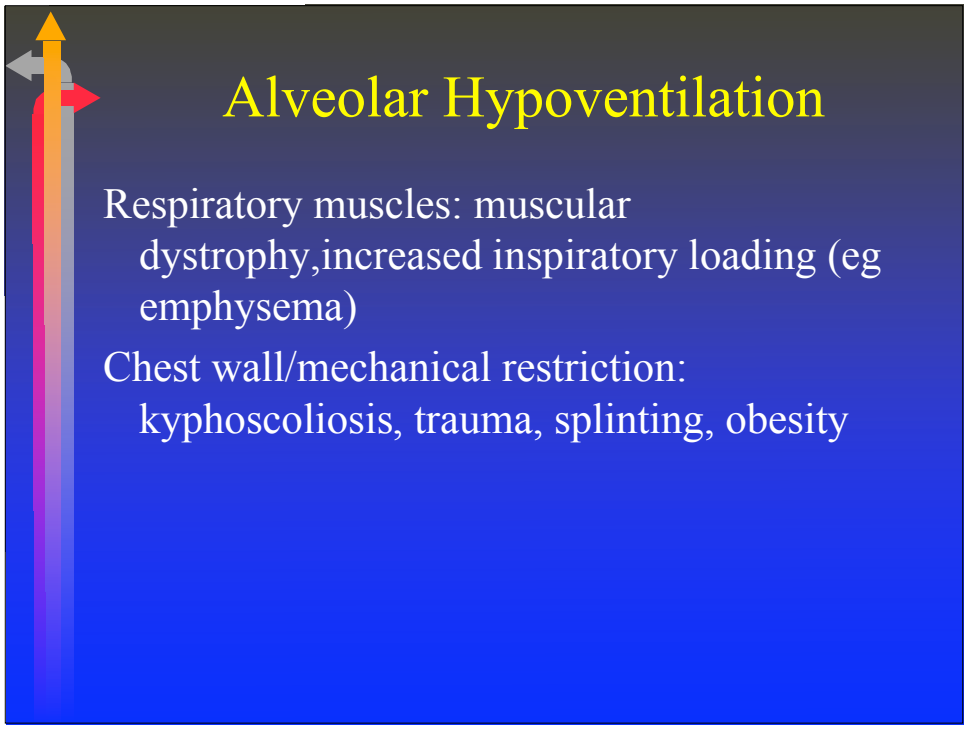
- PaO2=30 mmHg, PaCO2=90 mmHg, pH=7.08
- PAO2= 0.21 (760-47) –90/0.8
- PAO2=150-112.5=37.5
- AaDO2=7.5 mmHg

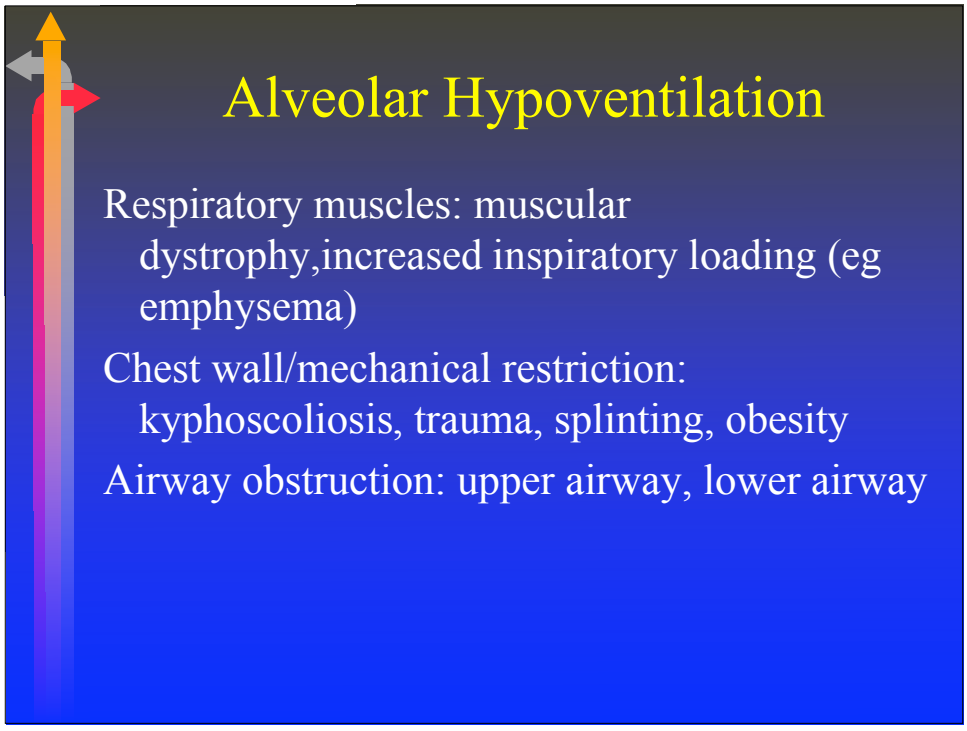
Alveolar Hypoventilation

- CNS: central hypoventilation; infectious, traumatic, vascular damage to medullary centers; pharmacologic and sleep suppression of ventilatory drive


Alveolar Hypoventilation
CNS: central hypoventilation; infectious, traumatic, vascular damage to medullary centers; pharmacologic and sleep suppression of ventilatory drive
Peripheral nervous system/myoneural junction: poliomyelitis, Guillain-Barre, myasthenia gravis


Alveolar Hypoventilation
Respiratory muscles: muscular dystrophy, ALS, increased inspiratory loading (eg emphysema)


Alveolar Hypoventilation
Respiratory muscles: muscular dystrophy,increased inspiratory loading (eg emphysema)
Chest wall/mechanical restriction: kyphoscoliosis, trauma, splinting, obesity


Alveolar Hypoventilation
Respiratory muscles: muscular dystrophy,increased inspiratory loading (eg emphysema)
Chest wall/mechanical restriction: kyphoscoliosis, trauma, splinting, obesity
Airway obstruction: upper airway, lower airway

Alveolar Hypoventilation

Respiratory muscles: muscular dystrophy,increased inspiratory loading (eg emphysema)

Chest wall/mechanical restriction: kyphoscoliosis, trauma, splinting, obesity

Airway obstruction: upper airway, lower airway

Increased dead space ventilation: pulmonary embolism; COPD

Hypercapnic Respiratory Failure

- Primary deficit=hypoventilation without gas exchange abnormality, until late
- Hypoxemia MUST result

Physiologic Causes of Hypoxemia

Alveolar Hypoventilation

Decreased PIO2

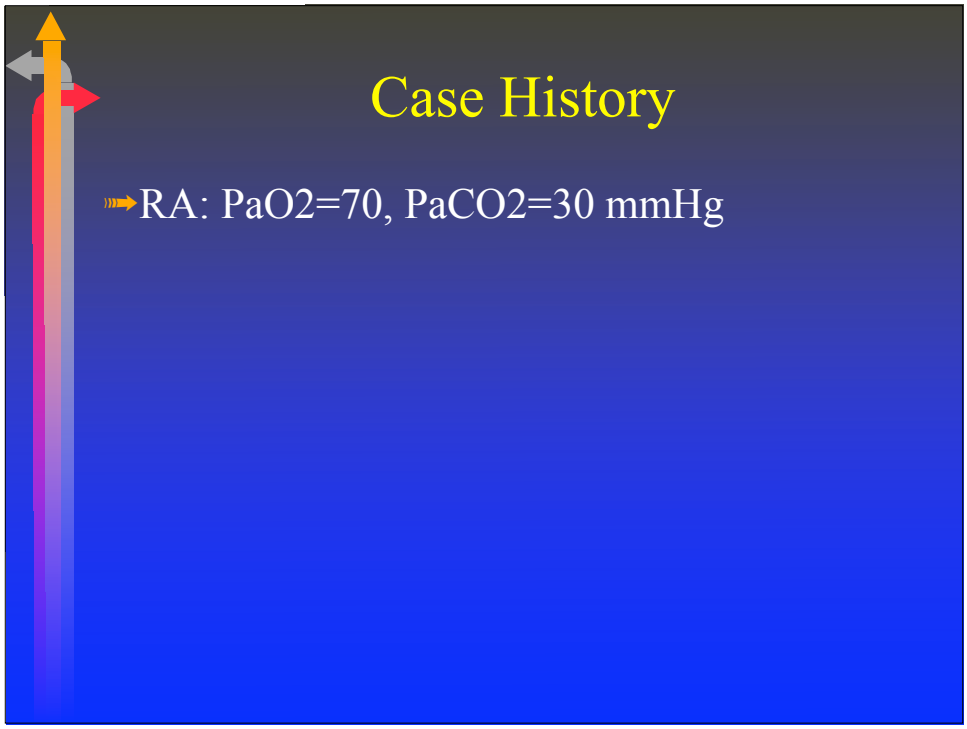
Diffusion Abnormality

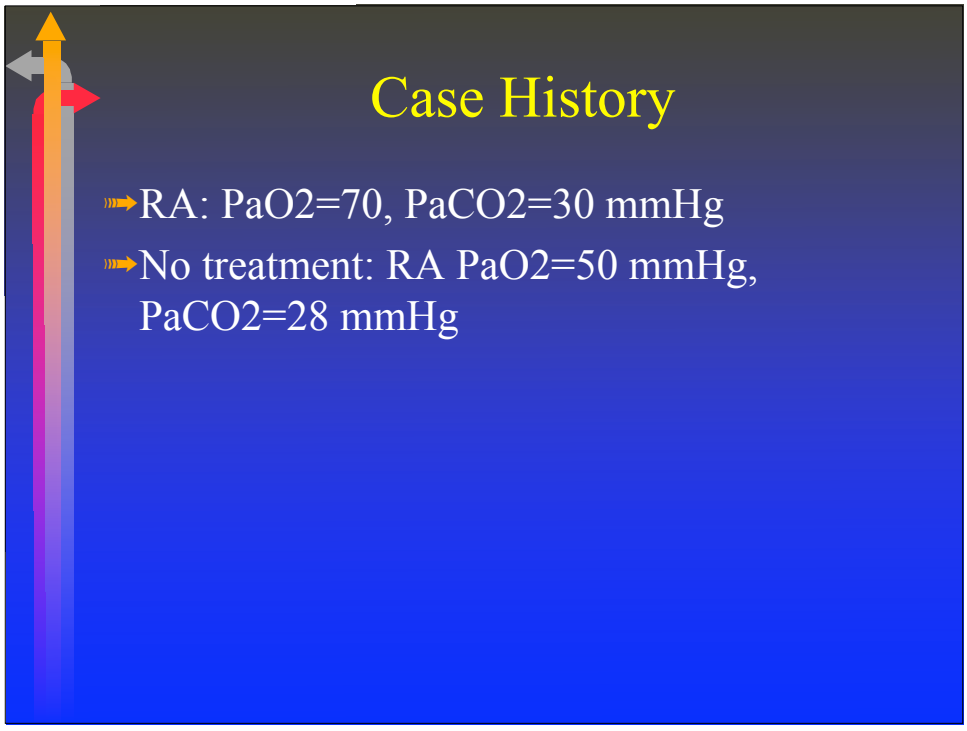
V/Q mismatch

Shunt

Climbing Everest (Decreased PIO2)

- P atm= 250 mmHg
- PaCO2=18 mmHg; R=1
- PAO2=PIO2-PCO2/R
- PAO2=.21 (250-47)-18/1=24.6


Case History
RA: PaO2=70, PaCO2=30 mmHg

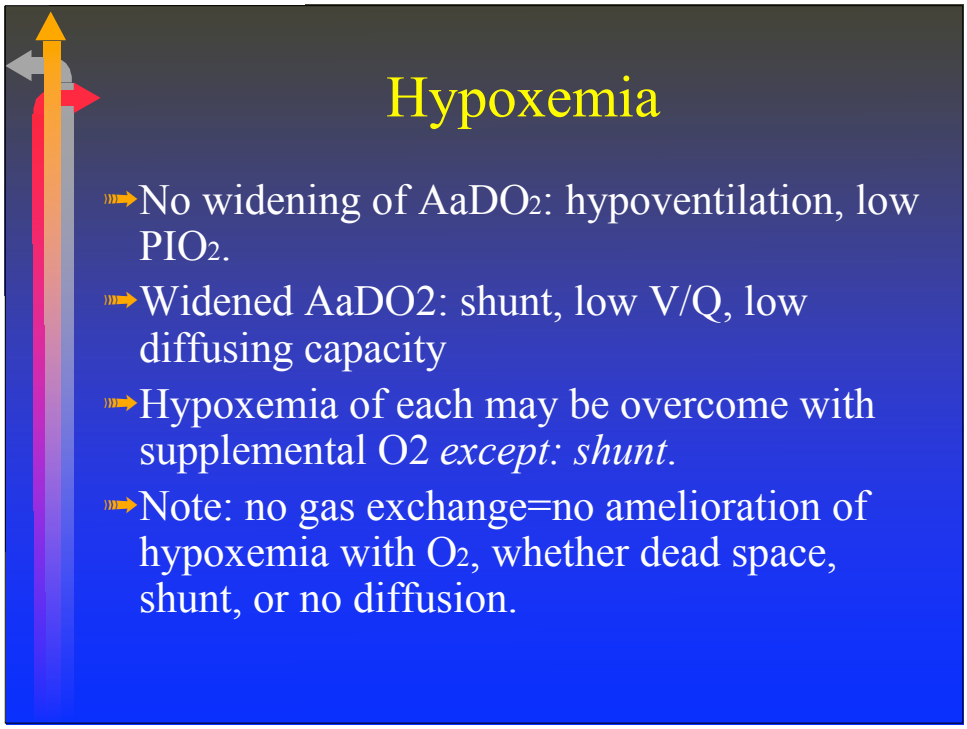

Case History
RA: PaO2=70, PaCO2=30 mmHg
No treatment: RA PaO2=50 mmHg, PaCO2=28 mmHg

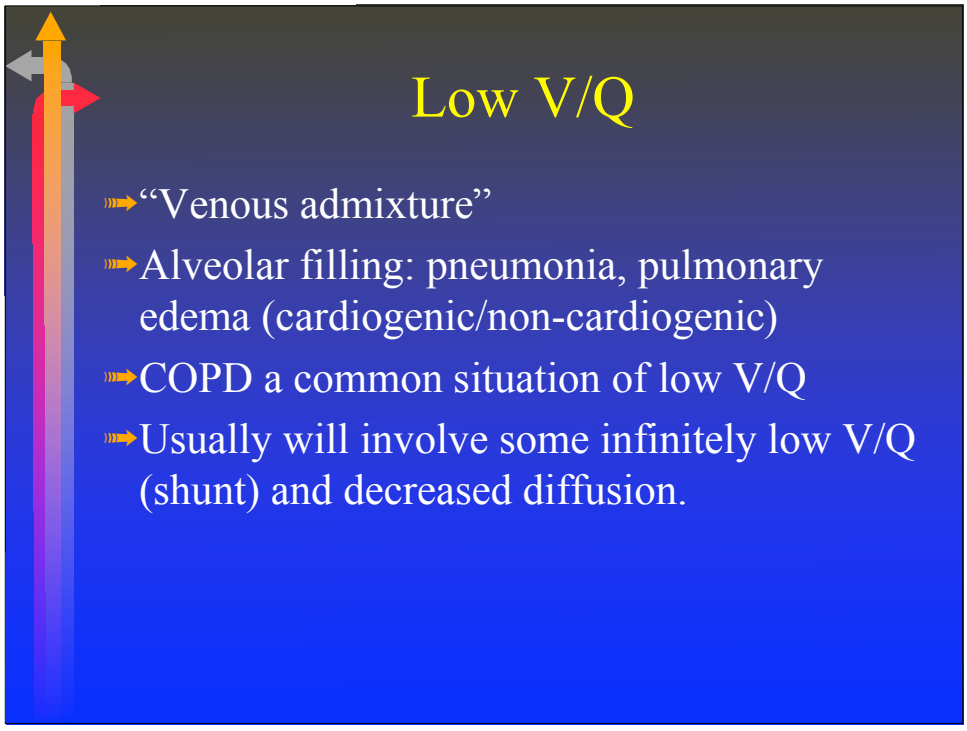
What happened?

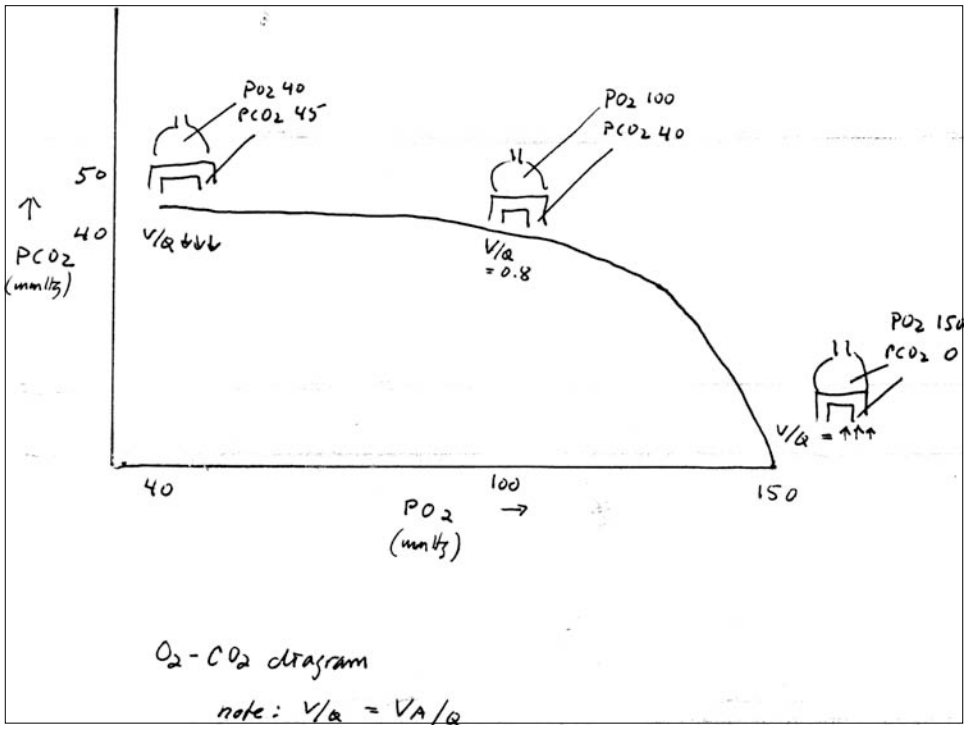
- $PAO_2=PIO_2 - PACO_2/R$
- 0.21 FIO2, PaO2=50 mmHg, PaCO2=28 mmHg
- PAO2=0.21(713)-28/0.8=150-35= 115 mmHg
- AaDO2=115-50= 65 mmHg

AaDO2 and Hypoxemia

- Widened in diffusion disorder, V/Q mismatch, and shunt
- Not widened in alveolar hypoventilation and decreased PIO2
- Normal 10-15 mmHg in young adult

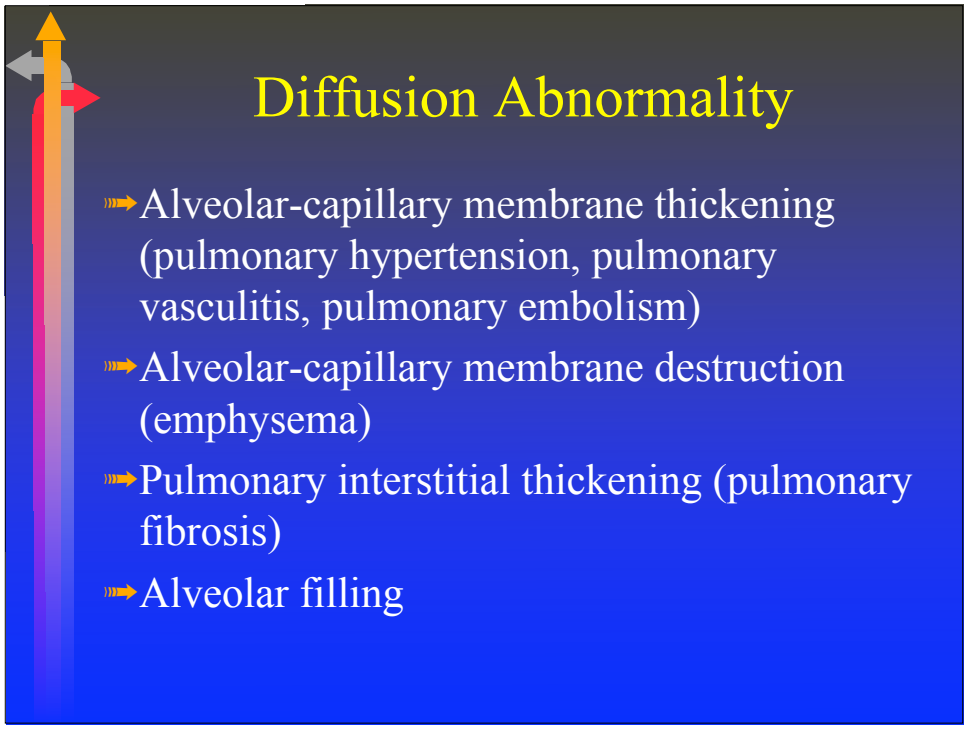

Hypoxemia
No widening of AaDO2: hypoventilation, low PIO2.
Widened AaDO2: shunt, low V/Q, low diffusing capacity
Hypoxemia of each may be overcome with supplemental O2 except: shunt.
Note: no gas exchange=no amelioration of hypoxemia with O2, whether dead space, shunt, or no diffusion.

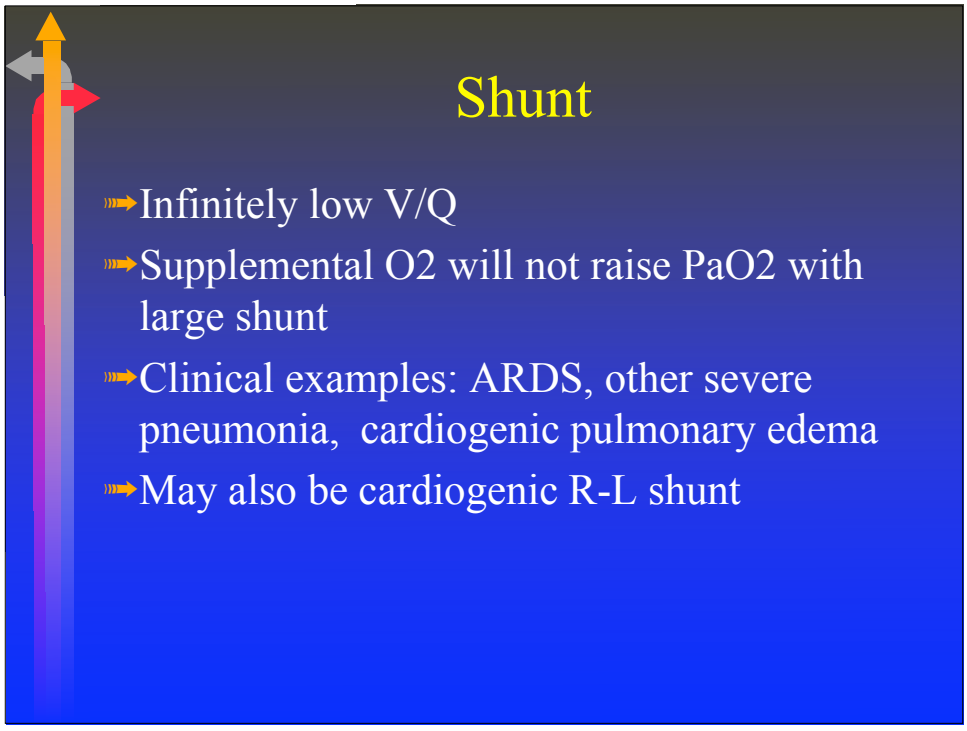

Low V/Q
"Venous admixture"
Alveolar filling: pneumonia, pulmonary edema (cardiogenic/non-cardiogenic)
COPD a common situation of low V/Q
Usually will involve some infinitely low V/Q (shunt) and decreased diffusion.

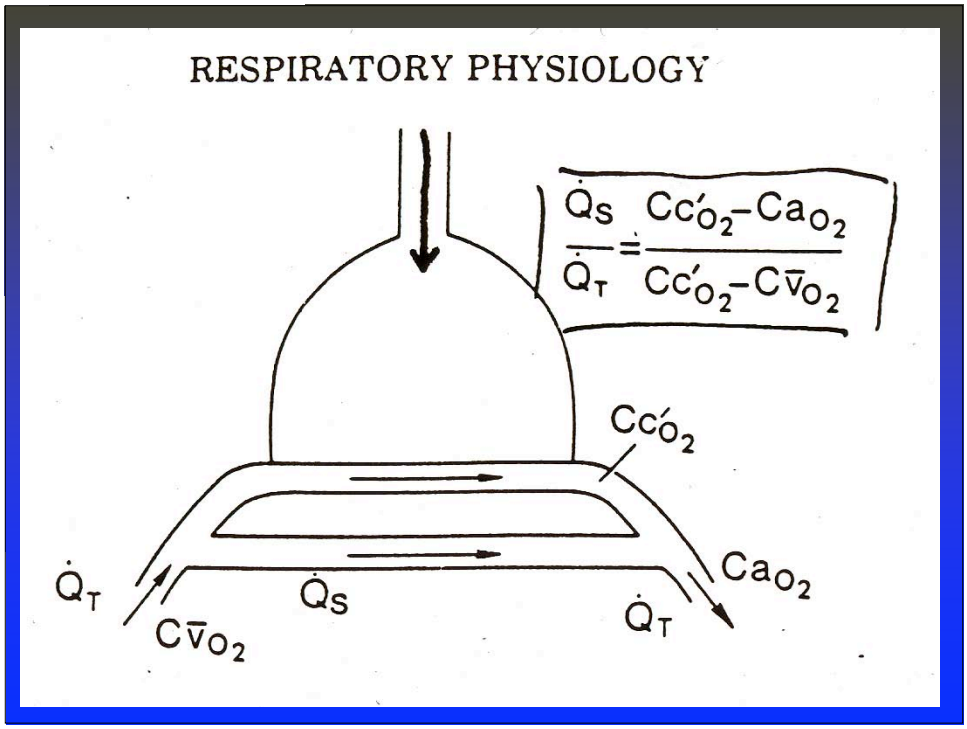


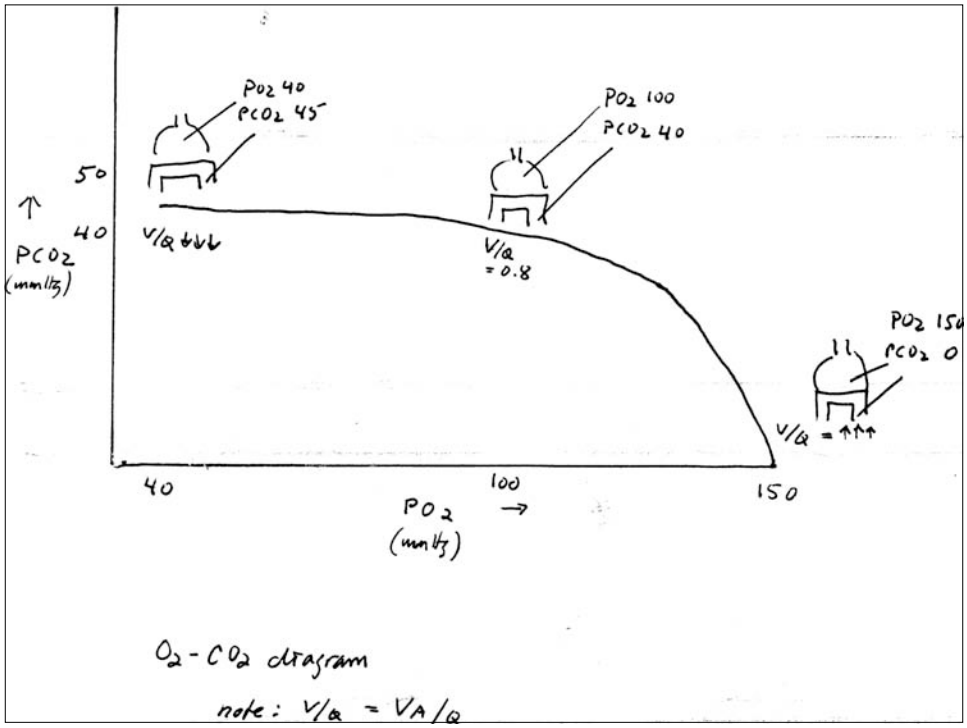
Low V/Q

- Low relationship of V to Q; NOT low ventilation
- Low V/Q is NOT hypoventilation (unless all units are the same low V/Q)


Diffusion Abnormality
Alveolar-capillary membrane thickening (pulmonary hypertension, pulmonary vasculitis, pulmonary embolism)
Alveolar-capillary membrane destruction (emphysema)
Pulmonary interstitial thickening (pulmonary fibrosis)
Alveolar filling


Shunt
Infinitely low V/Q
Supplemental O2 will not raise PaO2 with large shunt
Clinical examples: ARDS, other severe pneumonia, cardiogenic pulmonary edema
May also be cardiogenic R-L shunt


RESPIRATORY PHYSIOLOGY
$\frac{\dot{Q}_S}{\dot{Q}_T} = \frac{Cc'_{O_2} - Ca_{O_2}}{Cc'_{O_2} - C\bar{v}_{O_2}}$
Cc'_{O_2}
Ca_{O_2}
$\dot{Q}_T$
$\dot{Q}_S$
$\dot{Q}_T$
$C\bar{v}_{O_2}$


P_{O_2} 40
P_{CO_2} 45
P_{O_2} 100
P_{CO_2} 40
P_{O_2} 150
P_{CO_2} 0
50
40
P_{CO_2} (mmHg)
V/Q ∞
V/Q = 0.8
V/Q = ↑↑↑
40
100
150
P_{O_2} (mmHg)
O_2 - CO_2 diagram
note: V/Q = VA/Q

Hypoxemic Respiratory Failure

- Primary deficit=hypoxemia without hypoventilation, until late
- Gas exchange abnormality: shunt, low V/Q, low diffusing capacity, all…

SUMMARY

- Hypoventilation: High $PaCO_2$, Low PaO_2, no widening of $AaDO_2$
- Gas exchange abnormality: Low PaO_2, normal to low $PaCO_2$, widened $AaDO_2$
- Hypoxemia of all hypoventilation and gas exchange abnormalities may be sufficiently overcome by supplemental O_2 unless gas exchange abnormality is *absolute (eg shunt)*