Abnormal Ventilation, Abnormal Gas Exchange

Ventilation and Gas Exchange

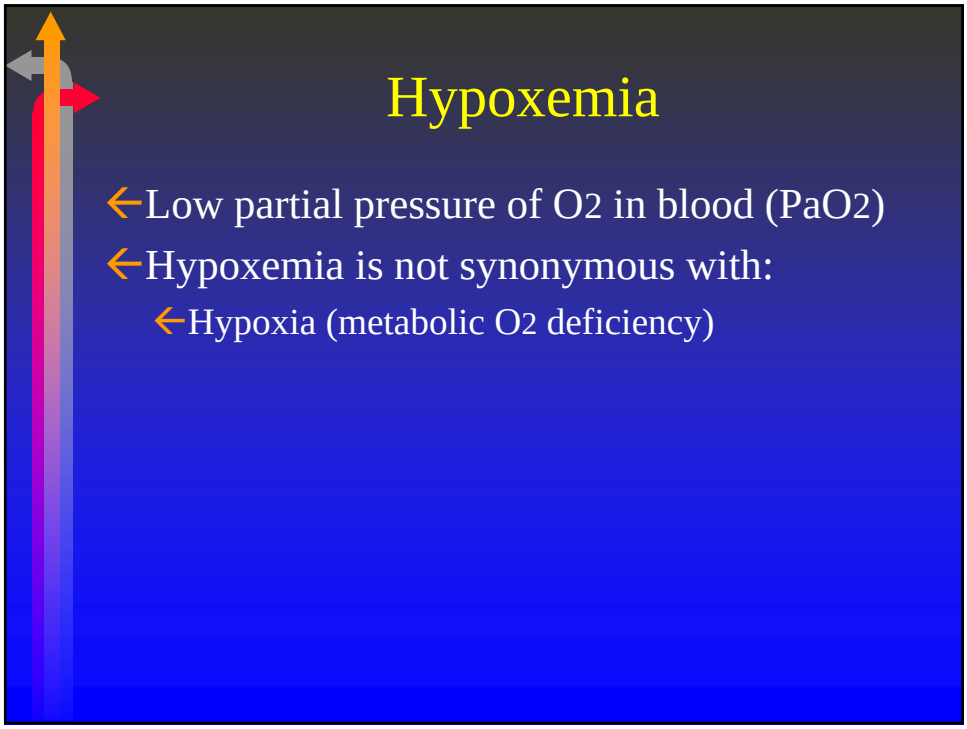
- Objective: to achieve adequate tissue oxygenation and remove metabolically produced CO_2.
- Ventilation: concerned with delivery of fresh volume of air to gas exchanging units, and the removal of a sufficient volume of mixed gas out
- Gas Exchange: the ability to move gas across the alveolar-capillary membrane

Ventilation and Gas Exchange

- The failure of either or both results in impaired arterial blood gases and ultimately to *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: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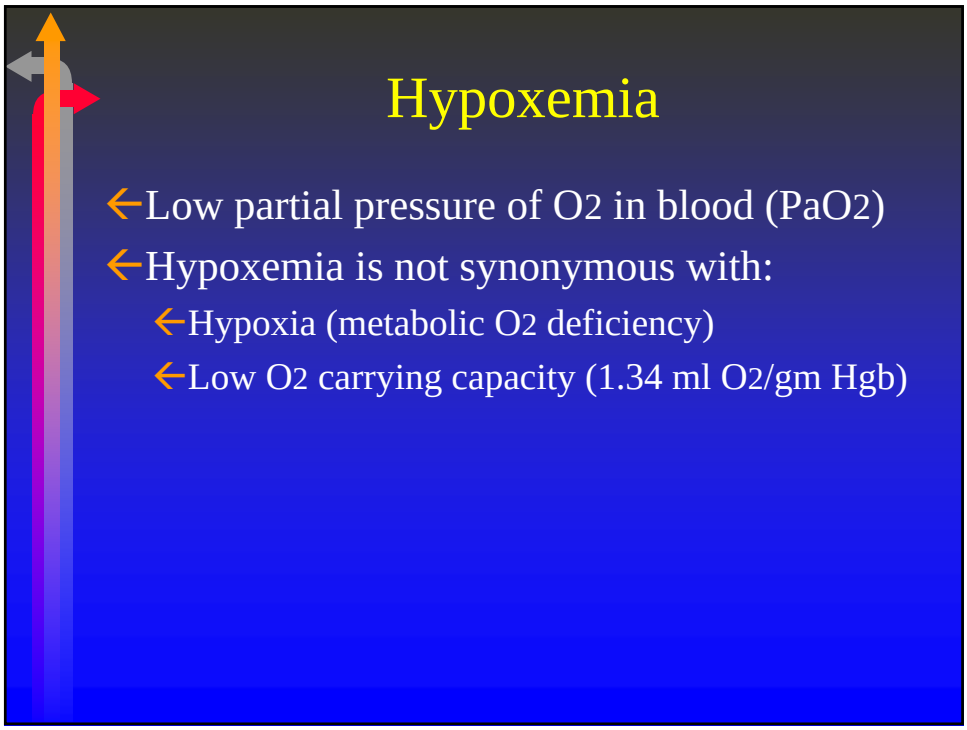
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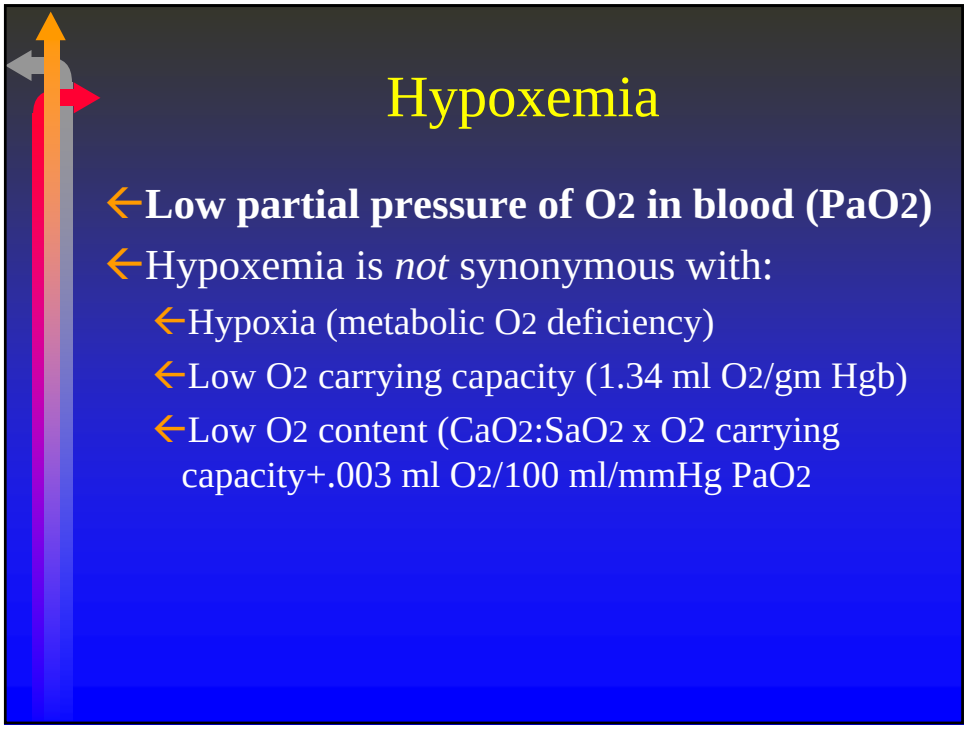
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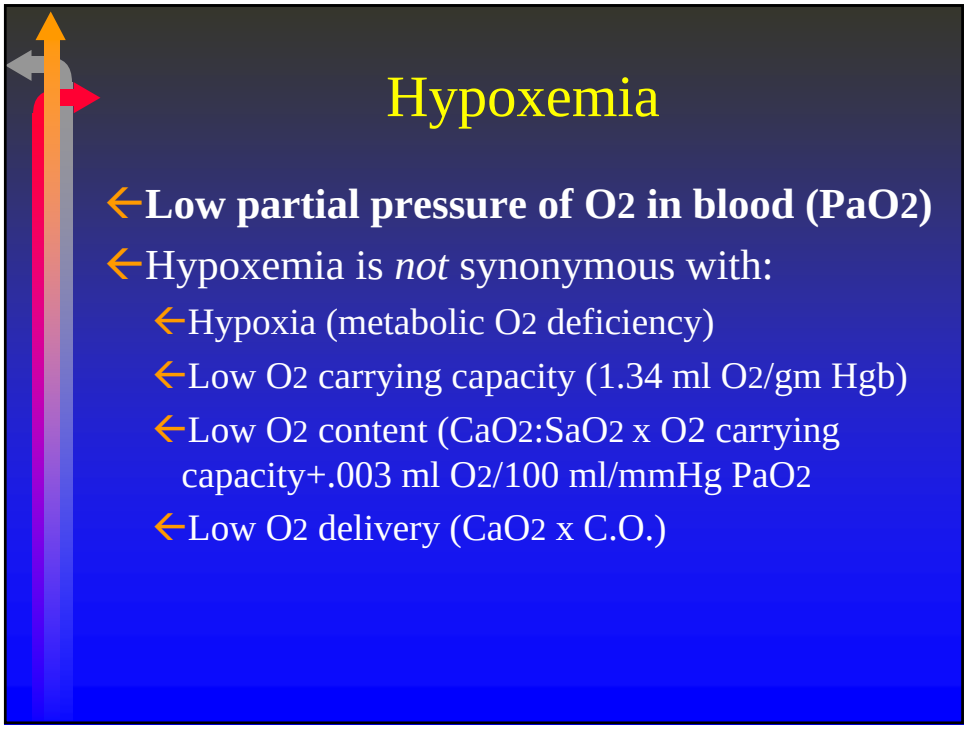
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Low O2 delivery (CaO2 x C.O.)

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 PCO_2 ($PACO_2$)=VCO_2/V_A x K
- VCO_2=CO_2 production
- V_A=alveolar ventilation
- Normal: VCO_2/V_A=1/21.6; K=863 mmHg)
- Alveolar PCO_2=CO_2 leaving lungs after gas exchange; directly reflects arterial PCO_2
- e.g., halving alveolar ventilation with constant CO_2 production will double the alveolar PCO_2
- e.g., doubling the alveolar PCO_2 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 O_2 with each breath to the gas exchanging unit, and inability to remove CO_2 produced by metabolism.
- *Sine qua non:* Increased arterial PCO_2 ($PaCO_2$); decreased arterial PO_2 (PaO_2) breathing room air *(parallel changes!!)*

Hypoventilation/ Alveolar hypoventilation

- All hypoventilation concerns either increased dead space/tidal volume (anatomic or physiologic) : ALVEOLAR HYPOVENTILATION; or
- Decreased MINUTE ventilation (decreased tidal volume, decreased respiratory rate)
- Increased minute ventilation *may* make up for impaired alveolar ventilation; opposite not true…

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
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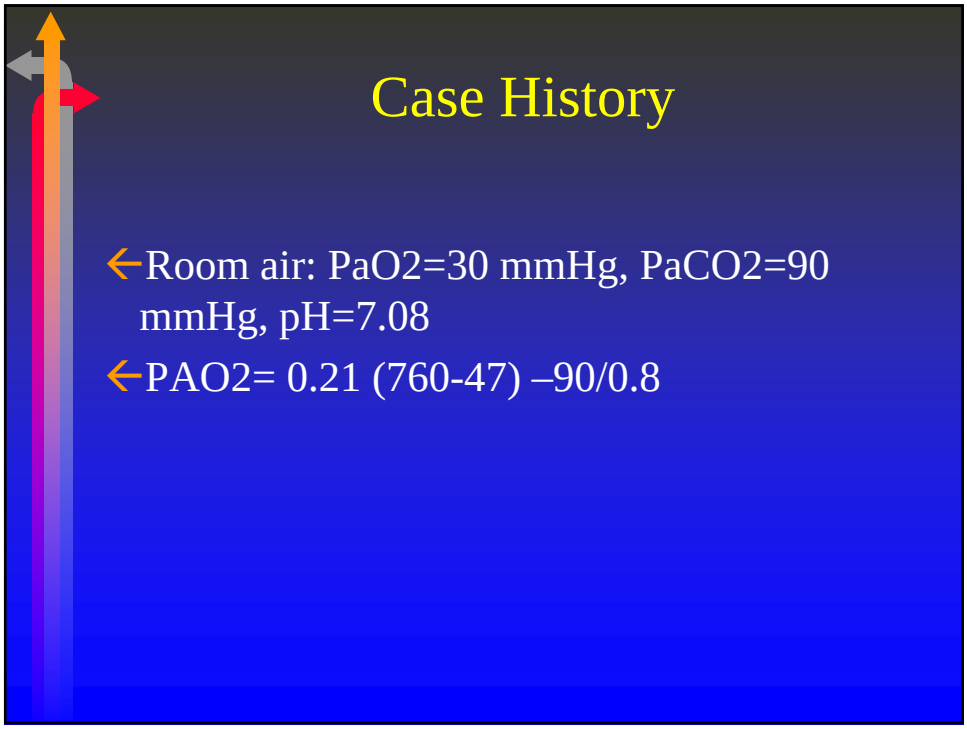
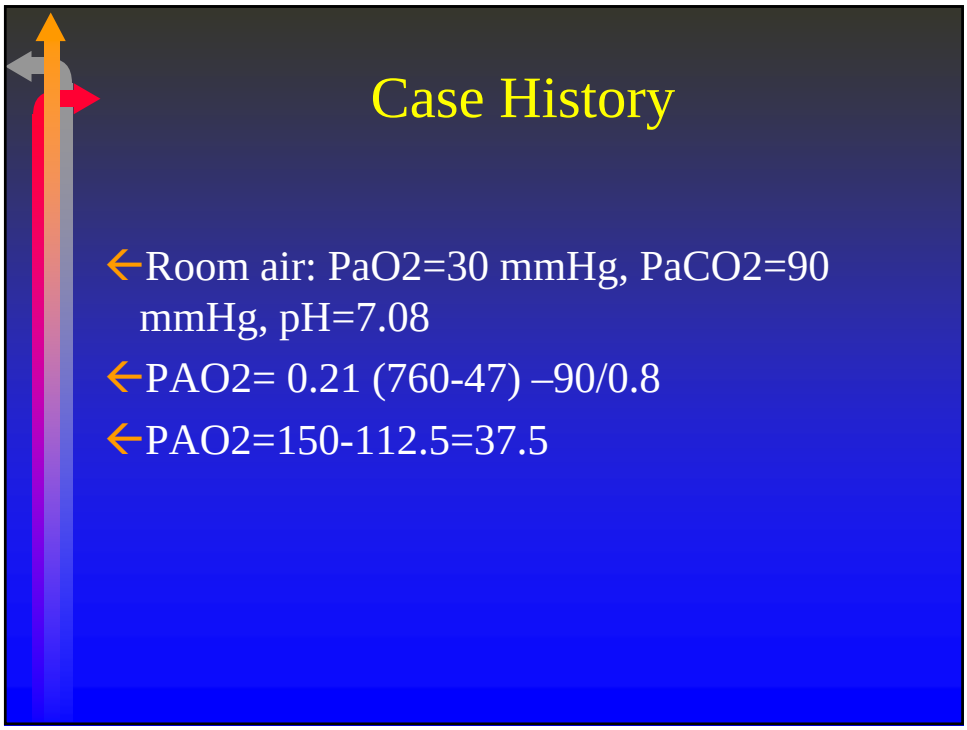
- PACO2=PaCO2

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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- 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)

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Alveolar Hypoventilation

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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

Physiologic Causes of Hypoxemia

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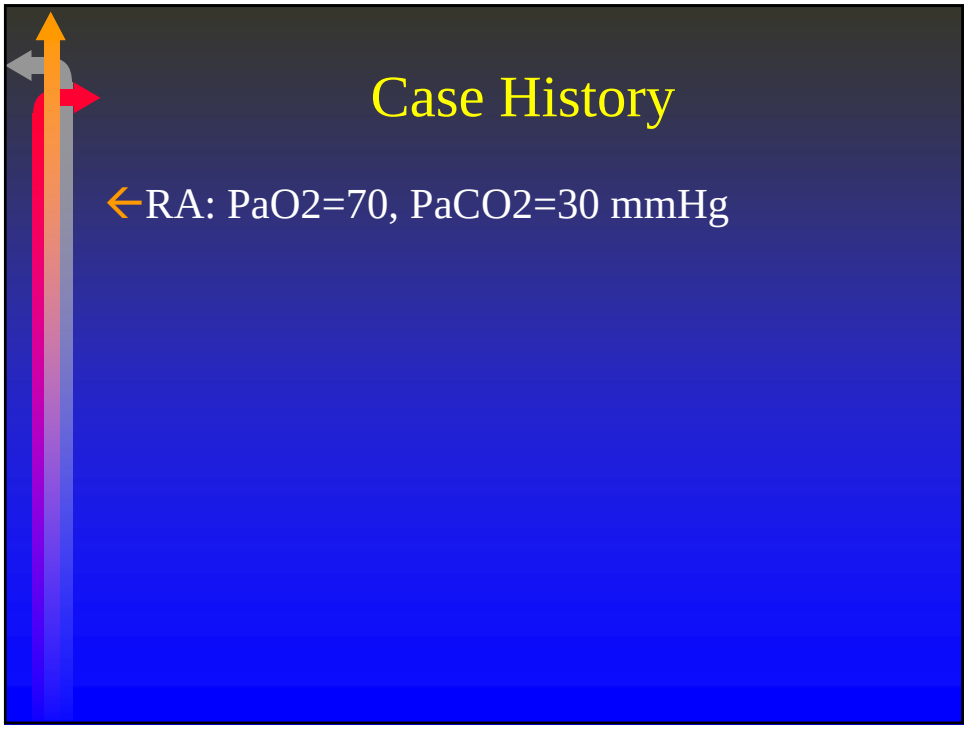
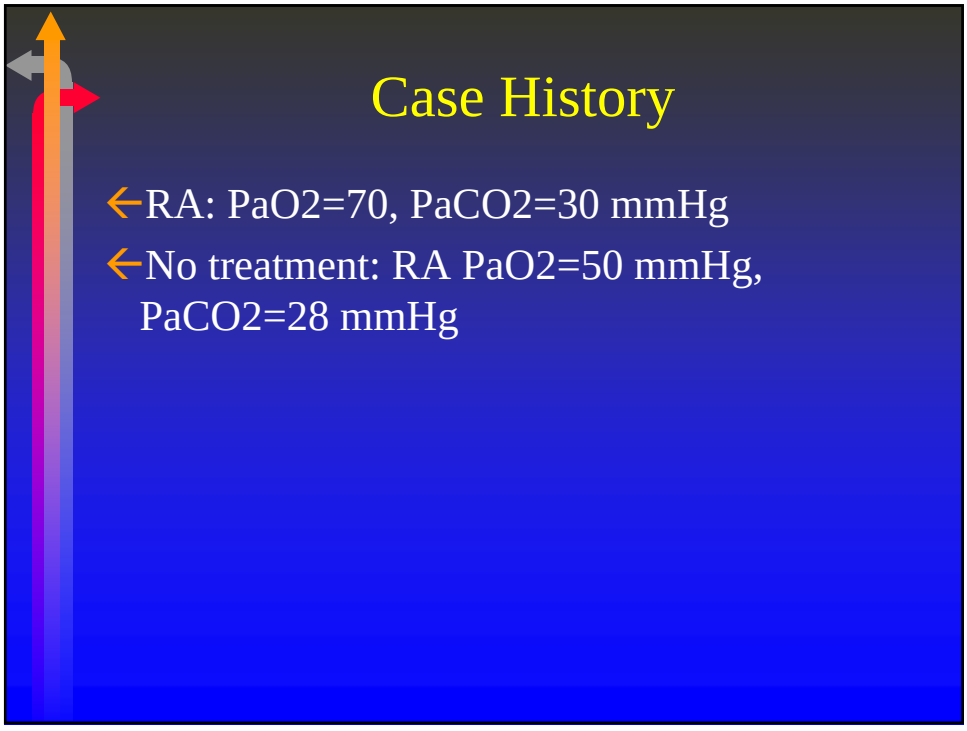
V/Q mismatch

Shunt

Climbing Everest

- 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

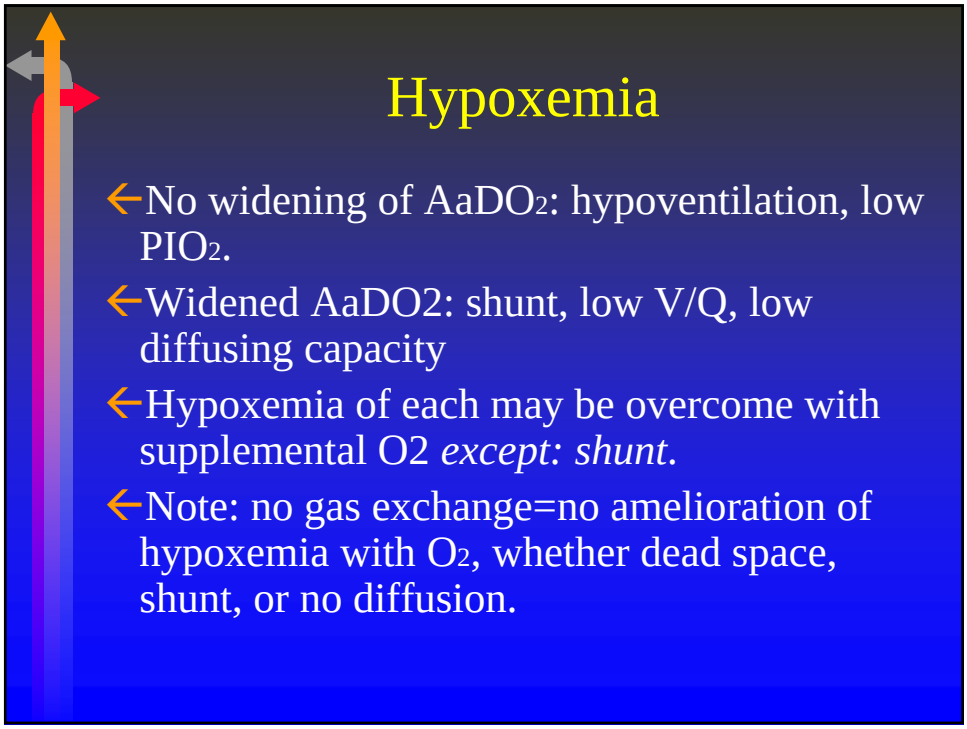

Case History
RA: PaO2=70, PaCO2=30 mmHg
No treatment: RA PaO2=50 mmHg,
PaCO2=28 mmHg

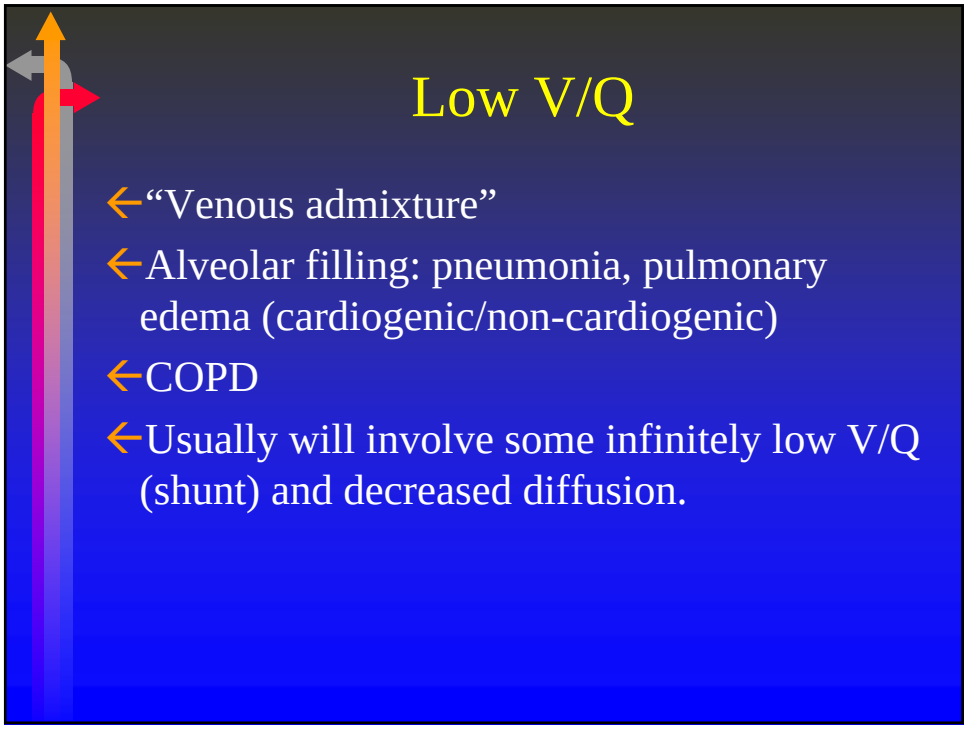
What happened?

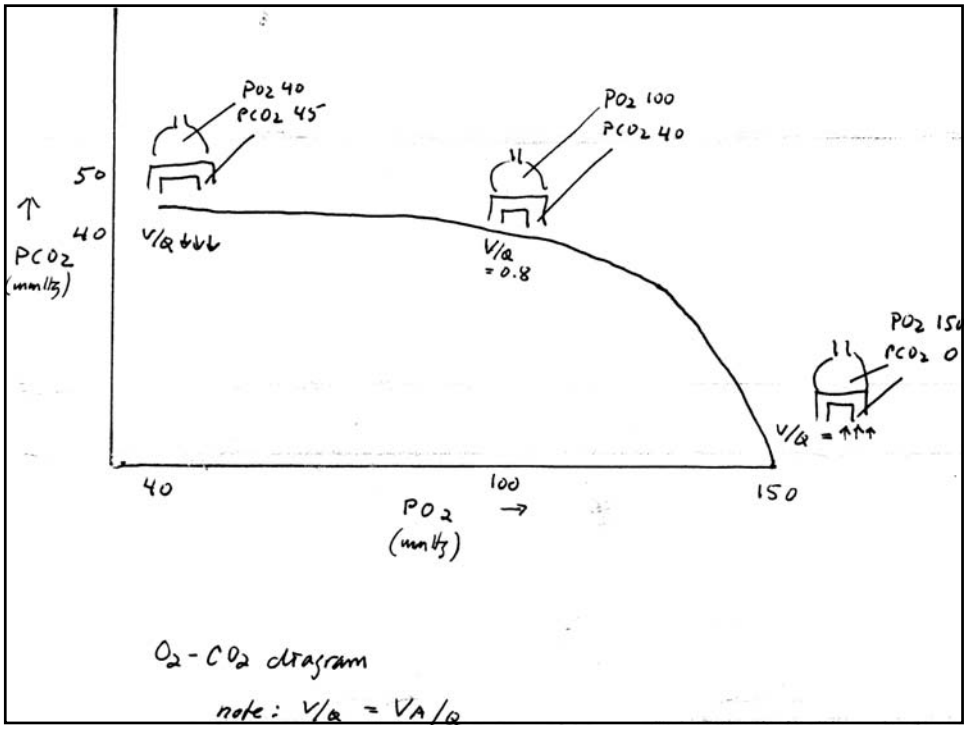
- $PAO_2 = PIO_2 - PACO_2/R$
- 0.21 FIO2, PaO2=50 mmHg, PaCO2=28 mmHg
- PAO2=0.21(713)-28/0.8=150-35= 115 mmHg
- AaDO2=115-50= 65 mmHg

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
Usually will involve some infinitely low V/Q (shunt) and decreased diffusion.



Low V/Q

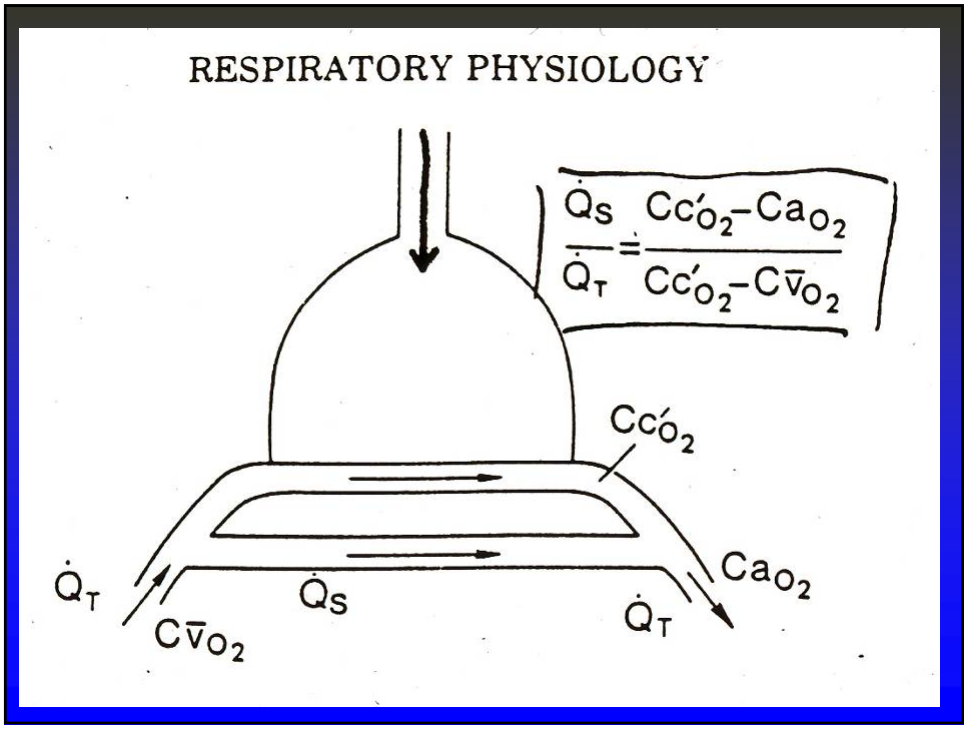
- Low relationship of V to Q; NOT low ventilation
- That is, hypoventilation NOT low V/Q
- Low V/Q NOT hypoventilation

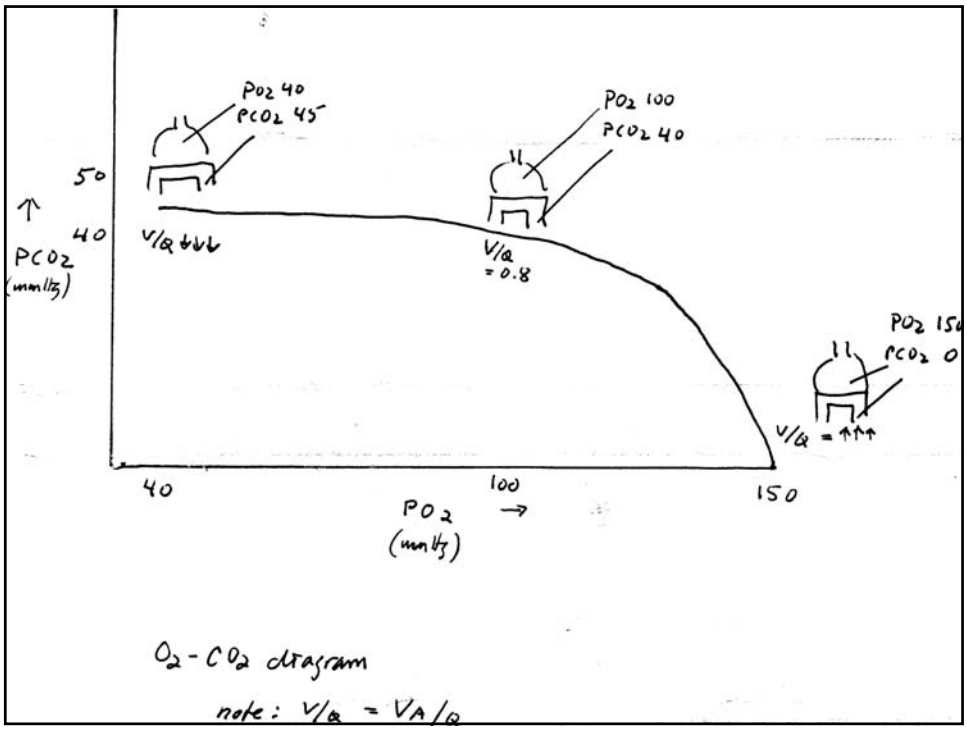
Diffusing Abnormality

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


PO2 40
PCO2 45
PO2 100
PCO2 40
PO2 150
PCO2 0
50
40
PCO2 (mmHg)
V/Q ↓↓↓
V/Q = 0.8
V/Q = ↑↑↑
40
100
150
PO2 (mmHg)
O2 - CO2 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 or hypoventilation is *absolute (eg shunt or dead space)*