CAPS 422
Mechanisms of Hypoxemia

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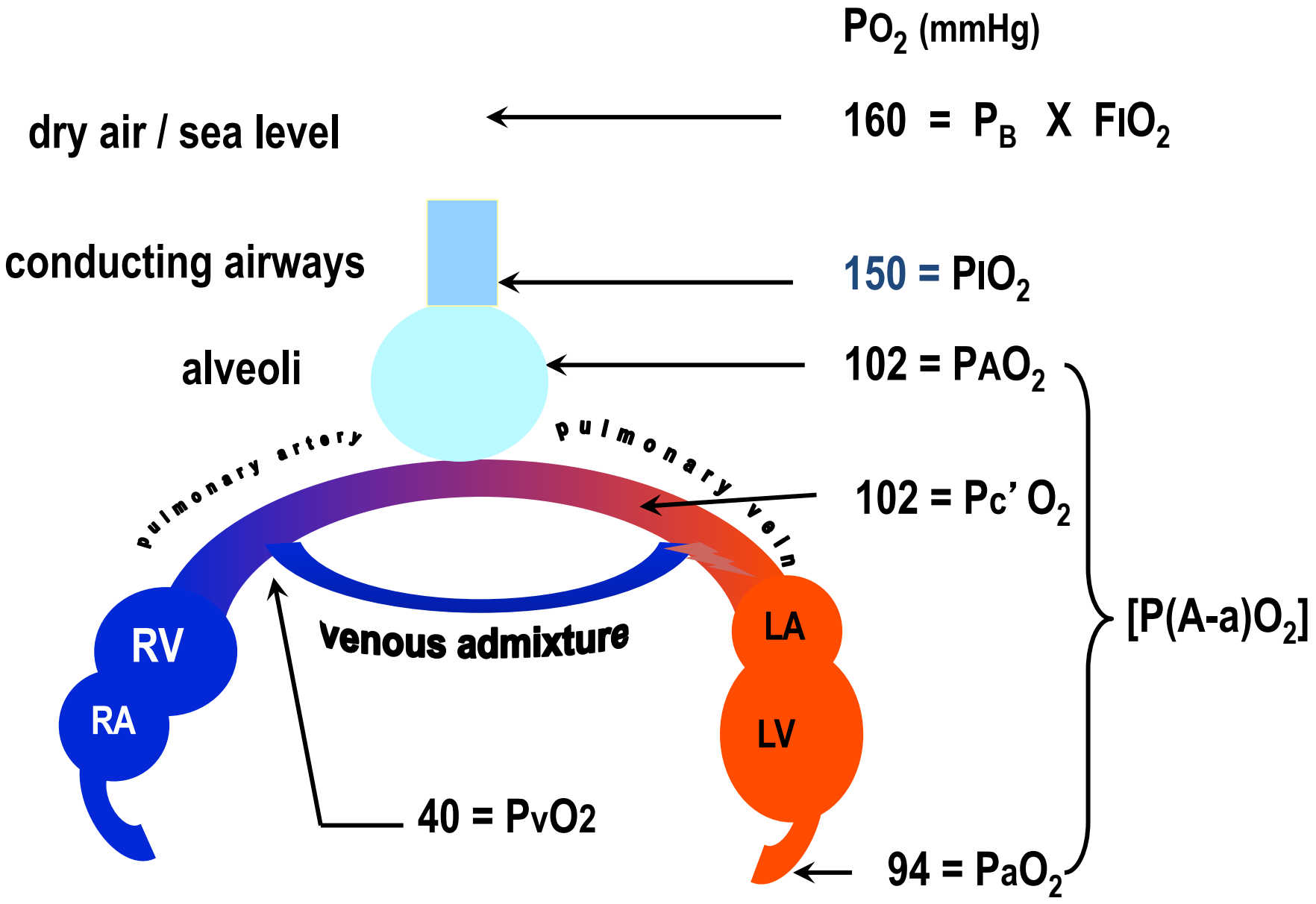
Important Terminology

Anoxia: absence of O_2 supply in the presence of perfusion- no oxygen

Asphyxia: absence of O_2 & accumulation of CO_2.

Hypoxia: ↓ O_2 in the body, often specified where in the body
e.g. tissue hypoxia, alveolar hypoxia

Hypoxemia: ↓ O_2 in the blood. Specifically, hypoxemia is determined by measuring the PO_2 of arterial blood (plasma)


P_{O_2} (mmHg)
dry air / sea level
160 = P_B X FIO_2
conducting airways
150 = PIO_2
alveoli
102 = PAO_2
pulmonary artery
pulmonary vein
102 = Pc' O_2
RV
RA
Venous admixture
LA
LV
40 = PvO_2
94 = PaO_2
[$P(A-a)O_2$]

[$P(A\text{-}a)O_2$]

Normal range=10-15 mmHg breathing room air, F_IO_2=0.21

- the normal range ↑ with age (1 mmHg per decade due to a ↓PaO_2 as a result of ↑ ventilation perfusion mismatch
- is due to venous admixture (anatomic shunt & ventilation perfusion mismatch in health)
- is due to venous admixture (anatomic shunt, ↑ventilation perfusion mismatch & physiologic shunt in disease states)

Causes of Hypoxemia

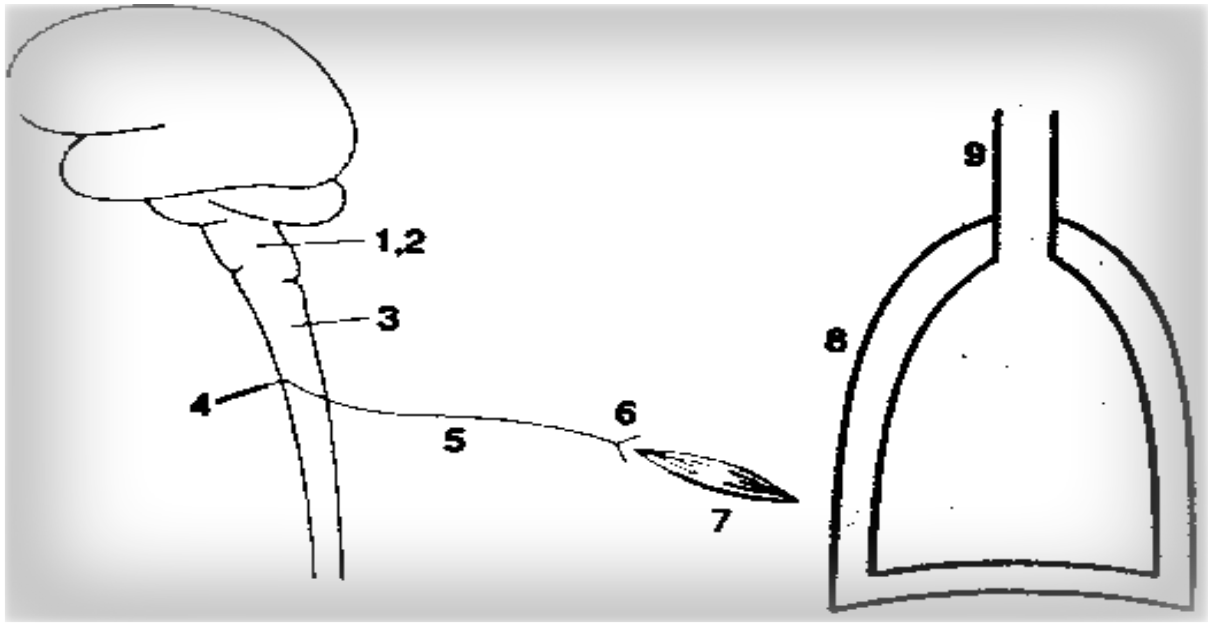
1. Hypoventilation
2. Low inspired oxygen
3. R-L shunt
4. $\dot{V}/\dot{Q}$ inequality (a.k.a. $\dot{V}/\dot{Q}$ mismatch)
5. Diffusion Impairment

Causes are subdivided into those with an increase in the $P(A\text{-}a)O_2$ and those where the A-a gradient remains within the normal range.

Hypoventilation

- ↑ $PaCO_2$ (hypercapnia)
- $P(A\text{-}a)O_2$ within normal range
- ↑ F_IO_2 alleviates the hypoxemia
- mechanical ventilation required to eliminate hypercapnia

Hypoventilation



Causes:

1. Depression of CNS by drugs
2. Inflammation, trauma or hemorrhage in the brainstem
3. Abnormal spinal cord pathway
4. Disease of the motoneurons of the brain stem/spinal cord
5. Disease of the nerves supplying the respiratory muscles.
6. Disease of the neuromuscular junction
7. Disease of the respiratory muscles
8. Abnormality of the chest wall
9. Upper airway obstruction

Low inspired oxygen (↓PIO_2)

- ↓ PIO_2 = (P_B - 47 mmHg) FIO_2
- $P(A\text{-}a)O_2$ within normal range
- ↓ $PaCO_2$ (hypocapnia due to hyperventilation in response to low arterial PO_2)

Right to Left Shunt

- ↑ $P(A\text{-}a)O_2$
- $PaCO_2$ within the normal range

Anatomic Shunt

A portion of Blood bypasses the Lungs through an Anatomic Channel

In all Healthy Individuals

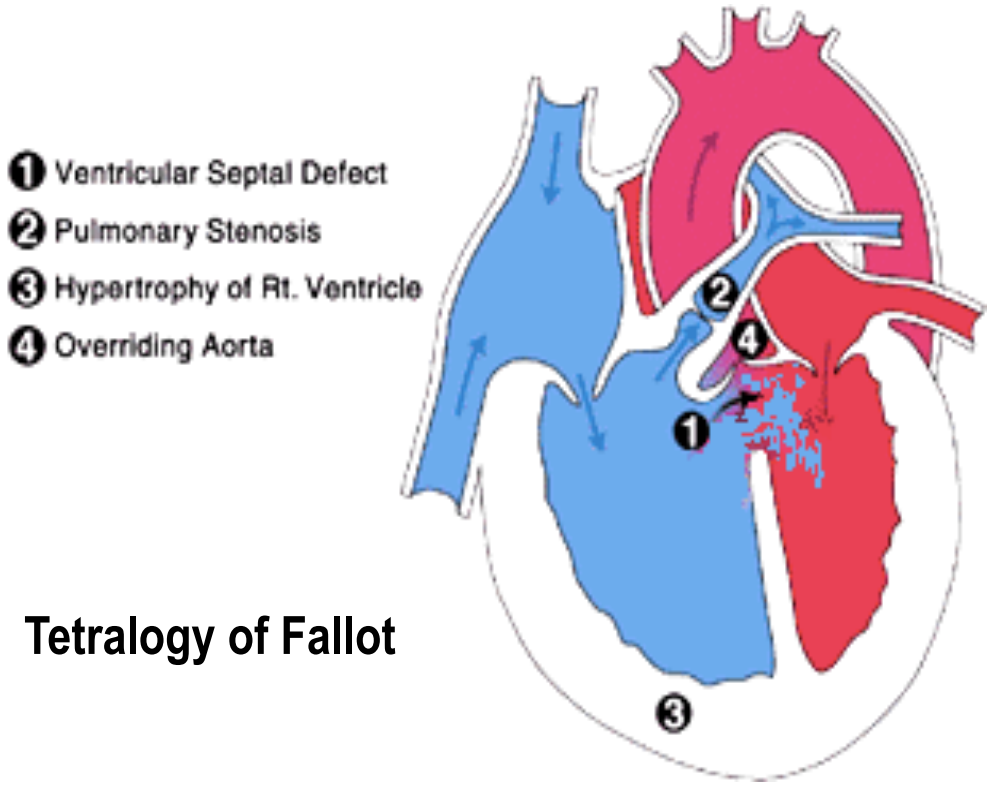
- a portion of the bronchial circulation's venous blood drains into the pulmonary vein.
- a portion of the coronary circulation's venous blood drains through the thebesian veins into the left ventricle.

Anatomic Shunt

A portion of Blood bypasses the Lungs through an Anatomic Channel

Disease States
(Congenital abnormalities)

- intra-cardiac shunts
- intrapulmonary fistulas

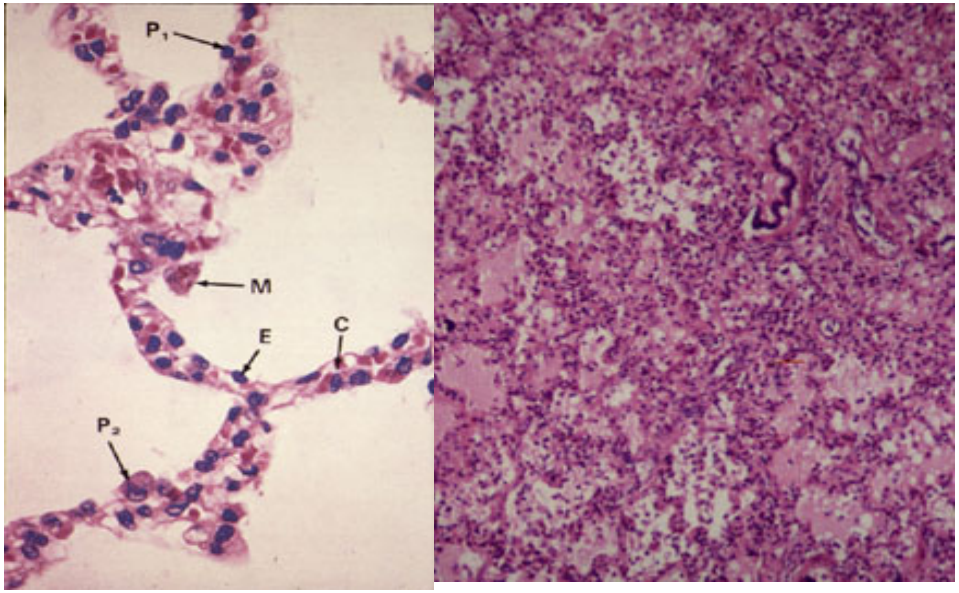


Tetralogy of Fallot

Physiologic Shunt

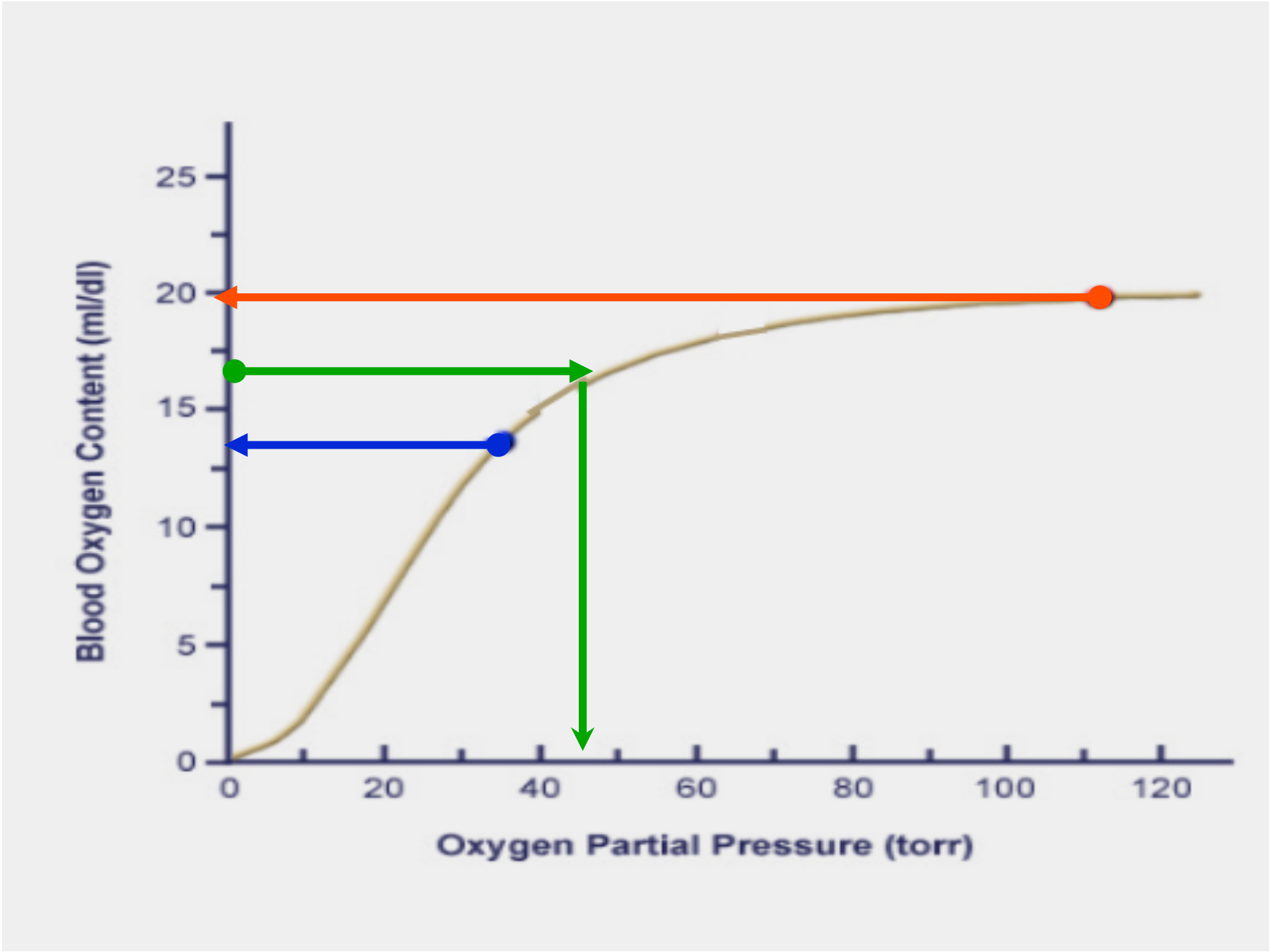
A portion of cardiac output that goes through the normal pulmonary vasculature does not come into contact with alveolar air due to filling of the alveolar spaces with fluid

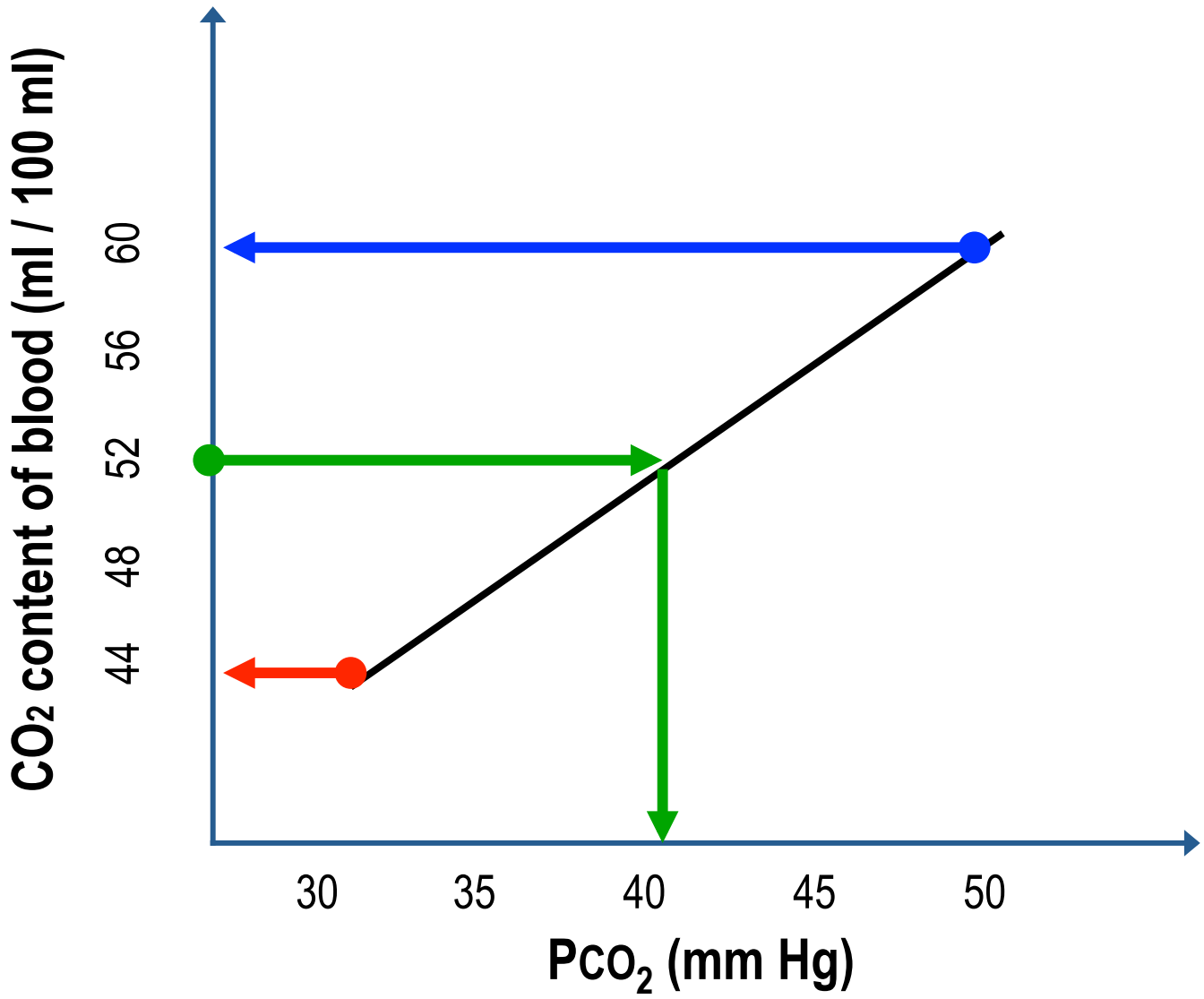
e.g.
- drowning
- pulmonary edema



Key Clinical Feature of R-L Shunts

"the accompanying hypoxemia can not be corrected with supplemental oxygen"

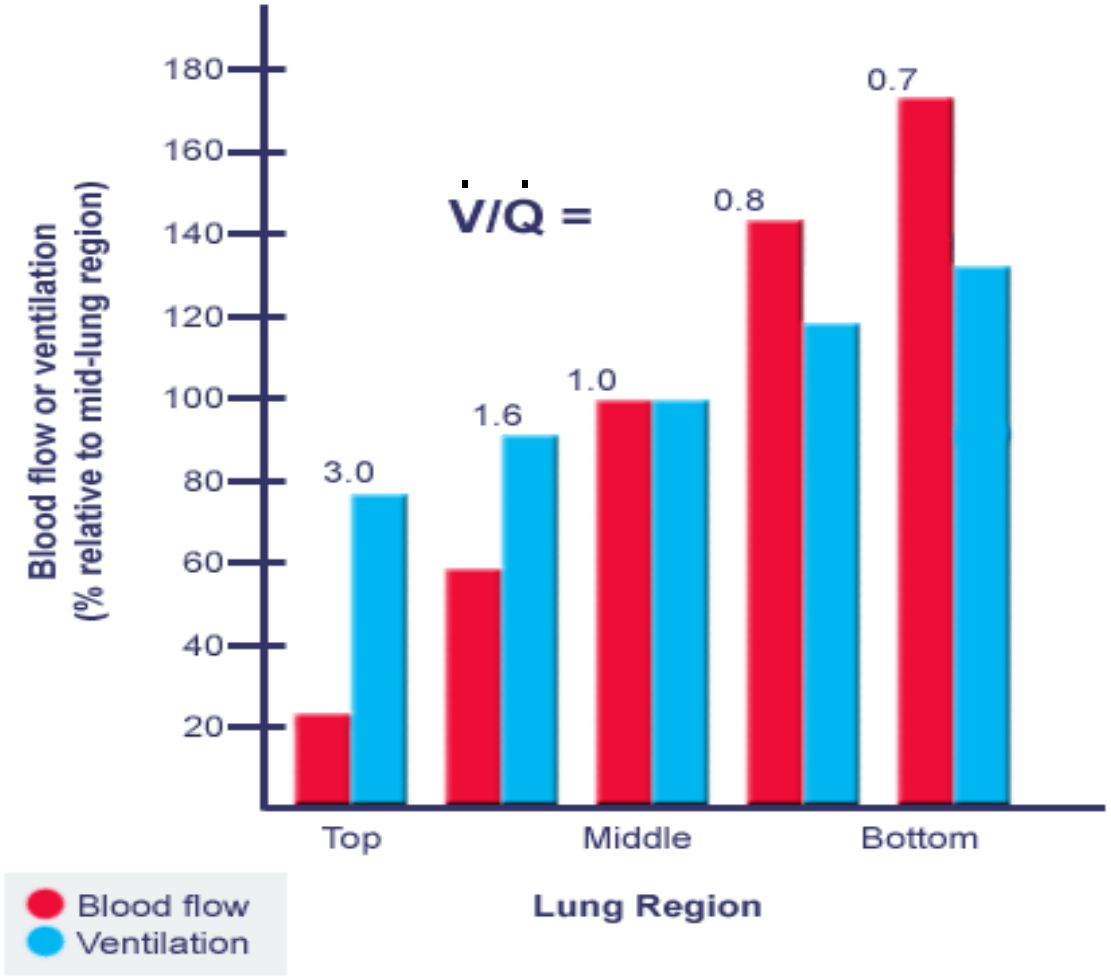

Blood Oxygen Content (ml/dl)
25
20
15
10
5
0
0
20
40
60
80
100
120
Oxygen Partial Pressure (torr)

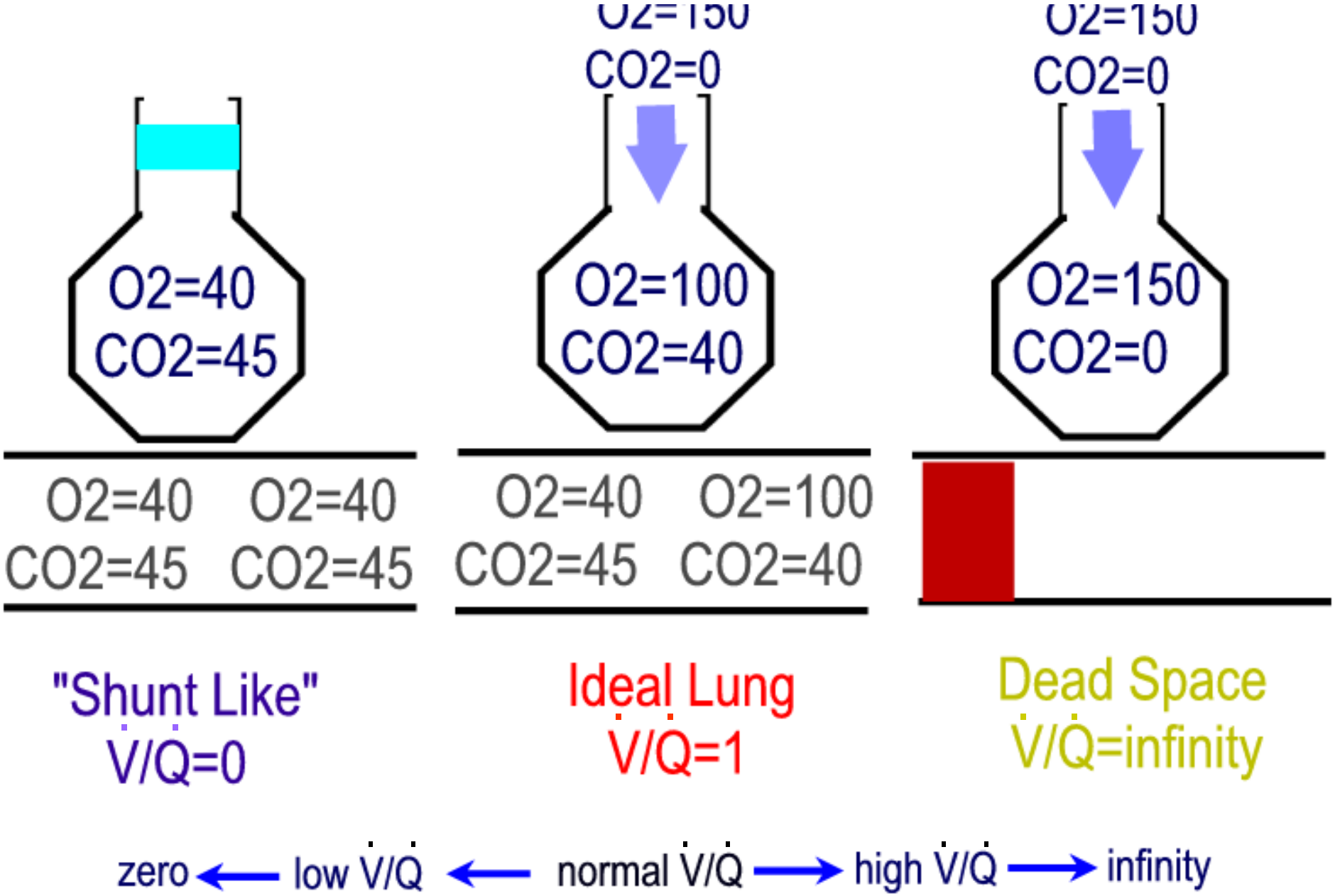

CO_2 content of blood (ml / 100 ml)
60
56
52
48
44
30
35
40
45
50
Pco_2 (mm Hg)

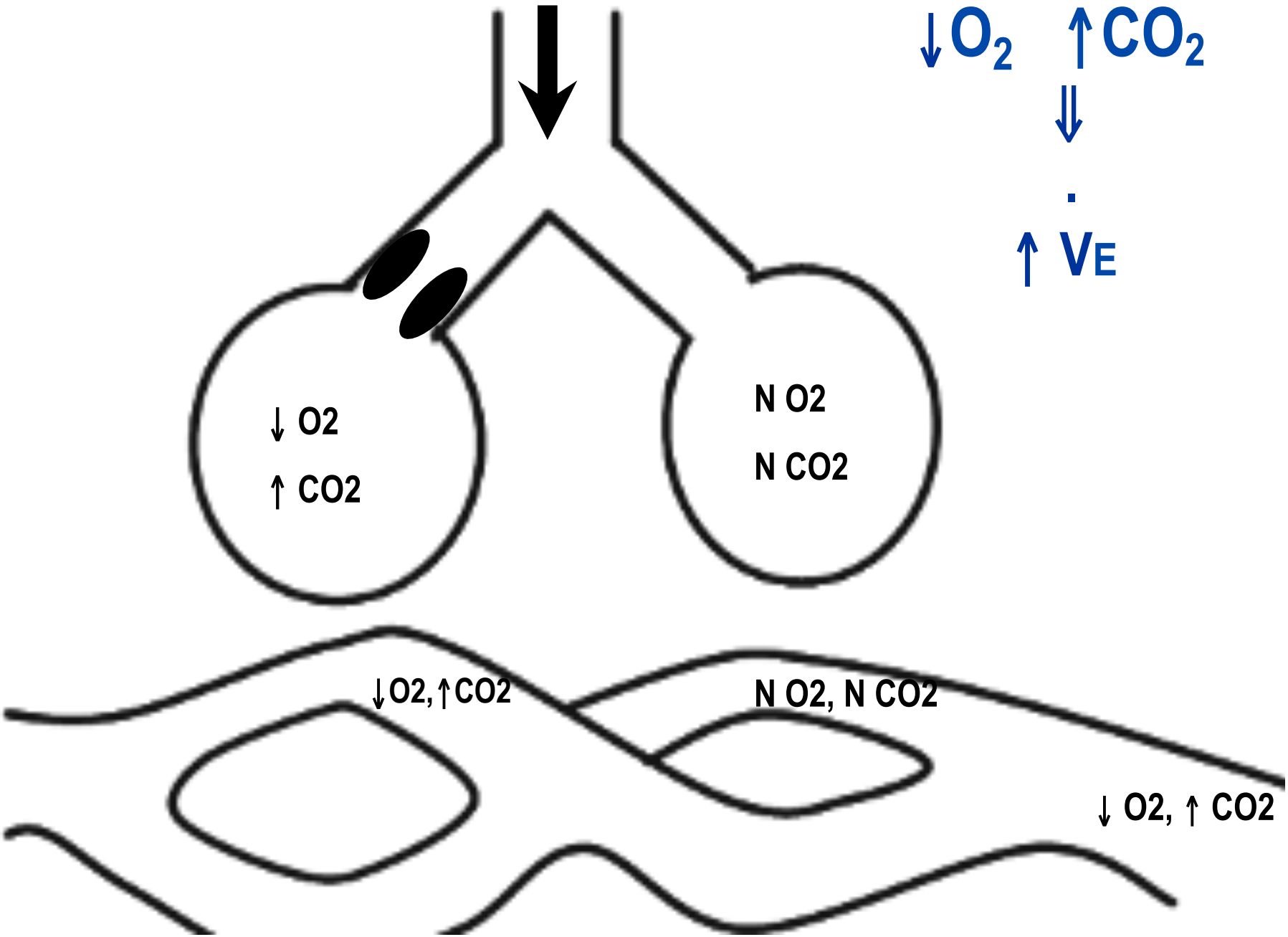
Ventilation Perfusion Inequality

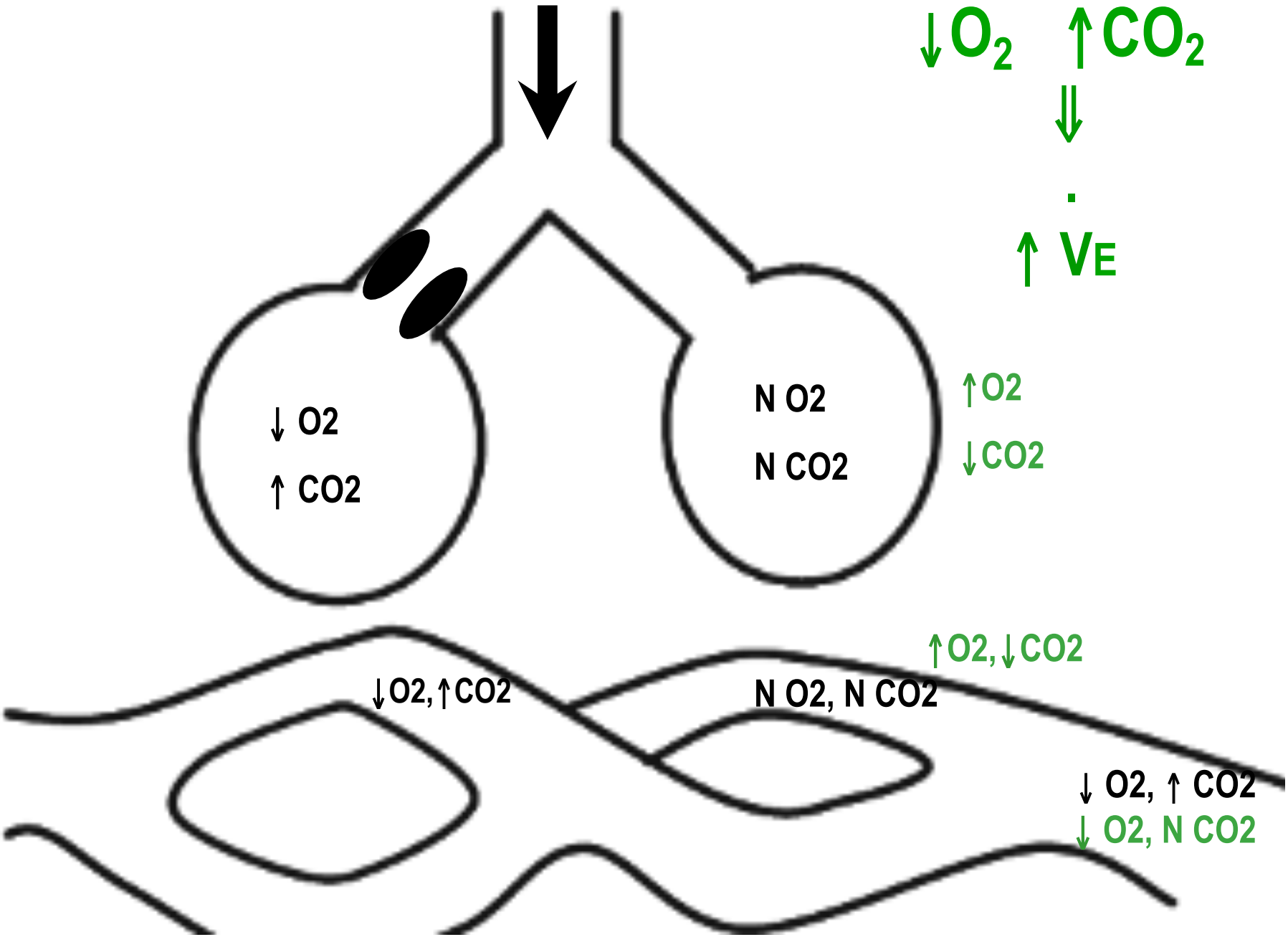
- ↑ $P(A\text{-}a)O_2$
- PaCO2 within the normal range
- most common cause of hypoxemia in disease states

Normal V/Q Inequality from the Apex to Base of the Lungs




O2=40
CO2=45
O2=40 O2=40
CO2=45 CO2=45
"Shunt Like"
V/Q=0
O2=150
CO2=0
O2=100
CO2=40
O2=40 O2=100
CO2=45 CO2=40
Ideal Lung
V/Q=1
O2=150
CO2=0
O2=150
CO2=0
Dead Space
V/Q=infinity
zero ← low V/Q ← normal V/Q → high V/Q → infinity


↓O2 ↑CO2
↑ VE
↓ O2
↑ CO2
N O2
N CO2
↓O2,↑CO2
N O2, N CO2
↓ O2, ↑ CO2


↓O2 ↑CO2
↑ VE
↓ O2
↑ CO2
N O2
N CO2
↑O2
↓CO2
↑O2,↓CO2
↓O2,↑CO2
N O2, N CO2
↓ O2, ↑ CO2
↓ O2, N CO2

Diffusion Impairment

- $P(A\text{-}a)O_2$ normal at rest, ↑s with exercise
- $PaCO_2$ within the normal range
- a rare observation in clinical setting

Summary	arterial blood		venous blood			Does supplemental oxygen (↑F_IO_2) increase PaO2 substantially?
	PO_2	PCO_2	PO_2	PCO_2	$P(A\text{-}a)O_2$	
Hypoxemia						
Hypoventilation	↓	↑	↓	↑	normal	yes
↓ P_IO_2	↓	↓	↓	↓	normal	yes
R-L Shunt	↓	normal	↓	normal	↑	no (depends on magnitude of tl shunt)
Diffusion defect	↓	normal	↓	normal	↑ during exercise	yes
VA/Q inequality	↓	normal	↓	normal	↑	yes
Tissue hypoxia						
Anemic hypoxia	normal	normal	↓	normal	normal	no
CO poisoning	normal	normal	↓	normal	normal	possibly
Stagnant hypoxia	normal	normal	↓	normal	normal	no
Histotoxic hypoxia	normal	normal	↑	normal	normal	no

Important note that mixed causes of hypoxemia occur frequently. It is often impossible to define the extent of the contribution of each mechanism in the acutely ill patient.