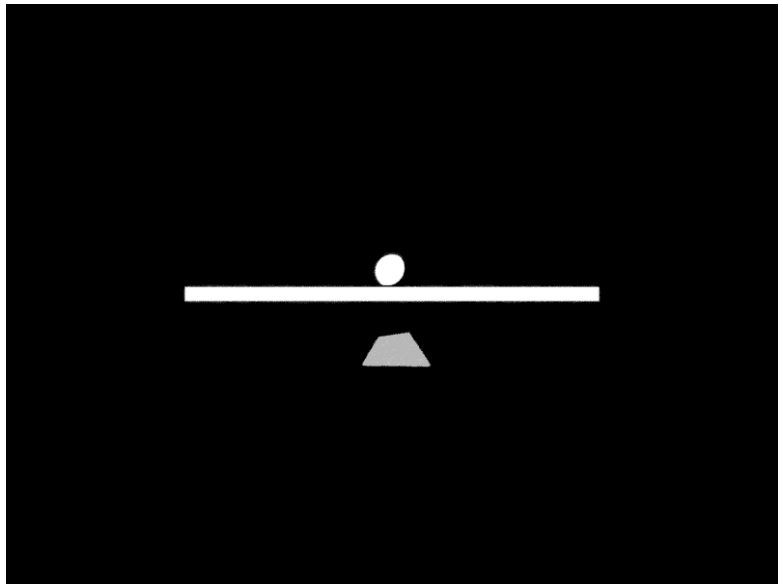
WHY IS MY PATIENT HYPERCAPNIC?

CO_2 in circulation represents a balance



CO2 production from cell metabolism

CO_2 elimination by alveolar ventilation (VA)

CO_2 in circulation represents a balance

$$V_A = \left(\frac{VCO_2}{P_ACO_2} \right) \times k$$

Alveolar Ventilation Equation

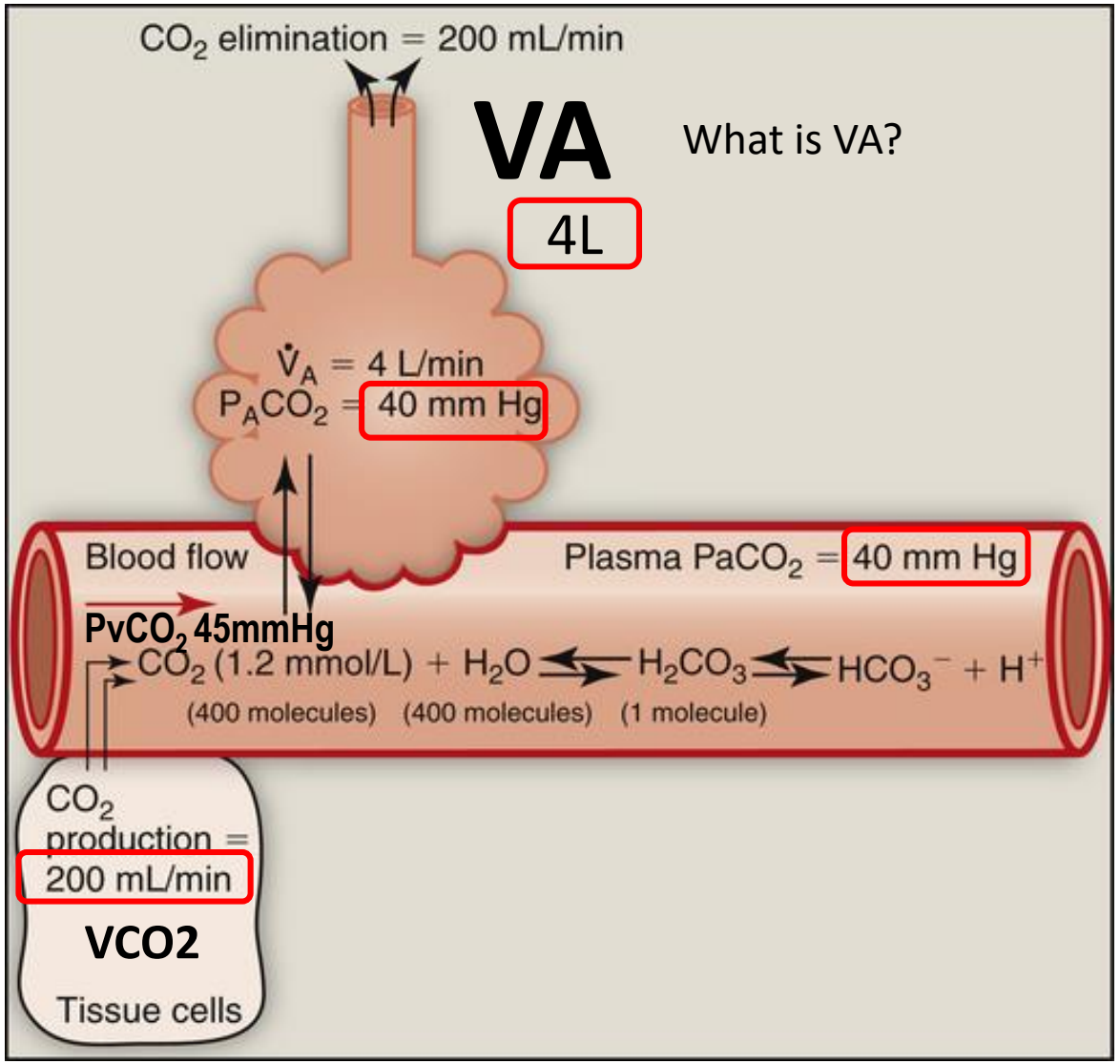
CO2 production from cell metabolism

CO_2 elimination by alveolar ventilation (VA)

$P_{Alv}CO_2$ vs. $P_{art}CO_2$

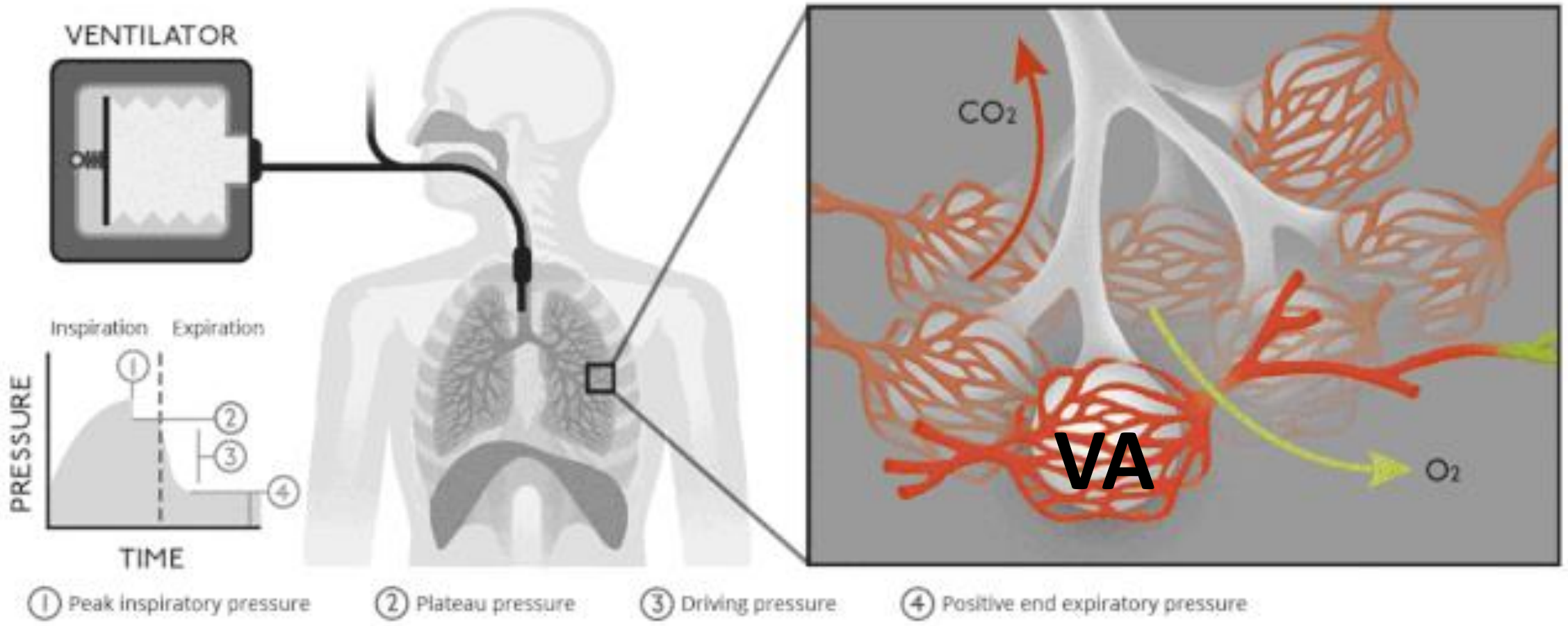
$$4L \quad V_A = \left(\frac{200 \quad VCO_2}{P_ACO_2} \right) \times k$$

40mmHg



Oxygen enters lungs and diffuses into circulation

CO_2 diffuses out of circulation and is exhaled from lungs



https://commons.wikimedia.org/wiki/File:Biology_of_ventilation.gif

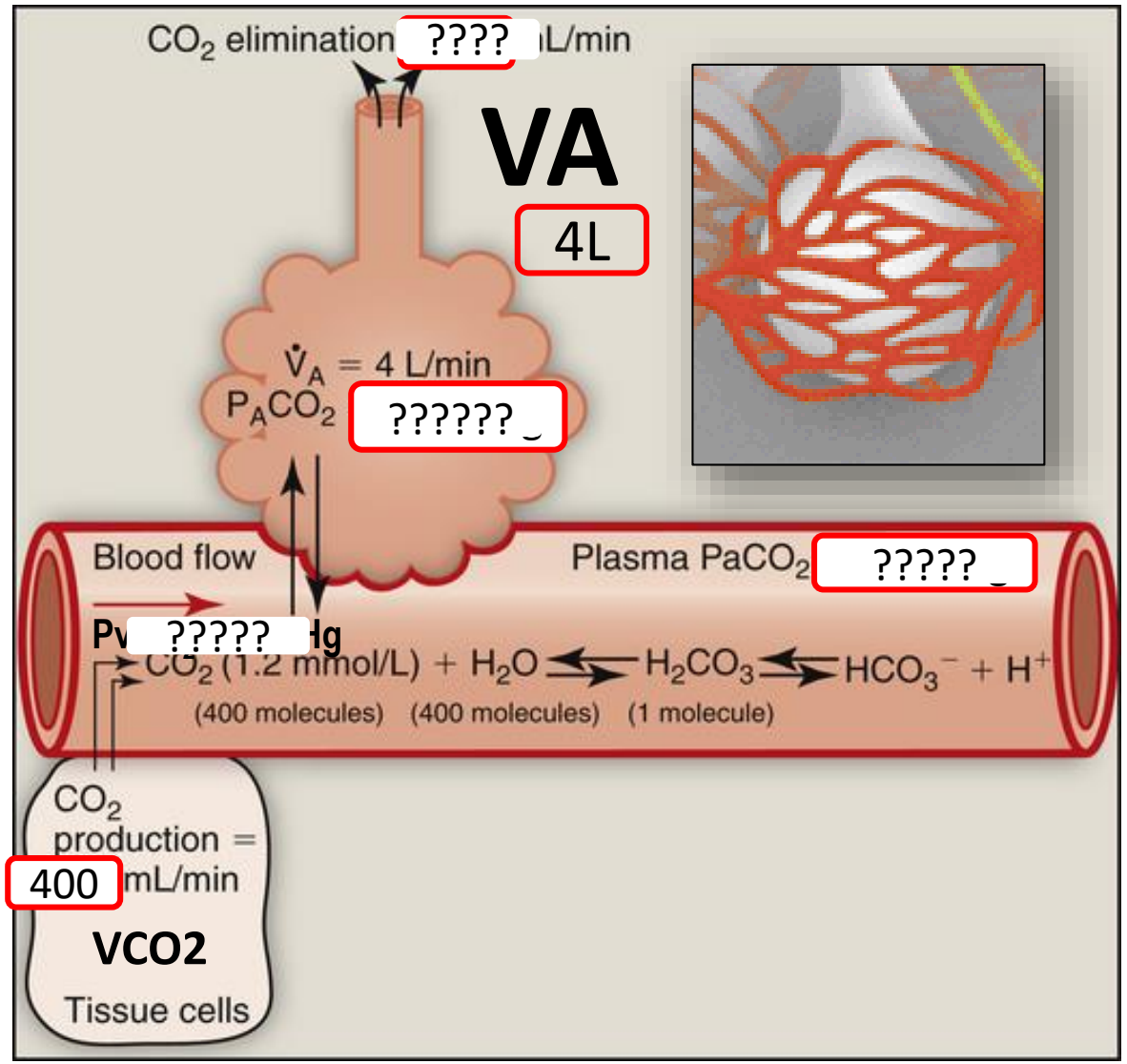
What if VCO2 (production) increases to 400ml/min? Hypercapnia? New Balance?

$$V_A = \left(\frac{VCO_2}{P_ACO_2} \right) \times k$$

4L

400

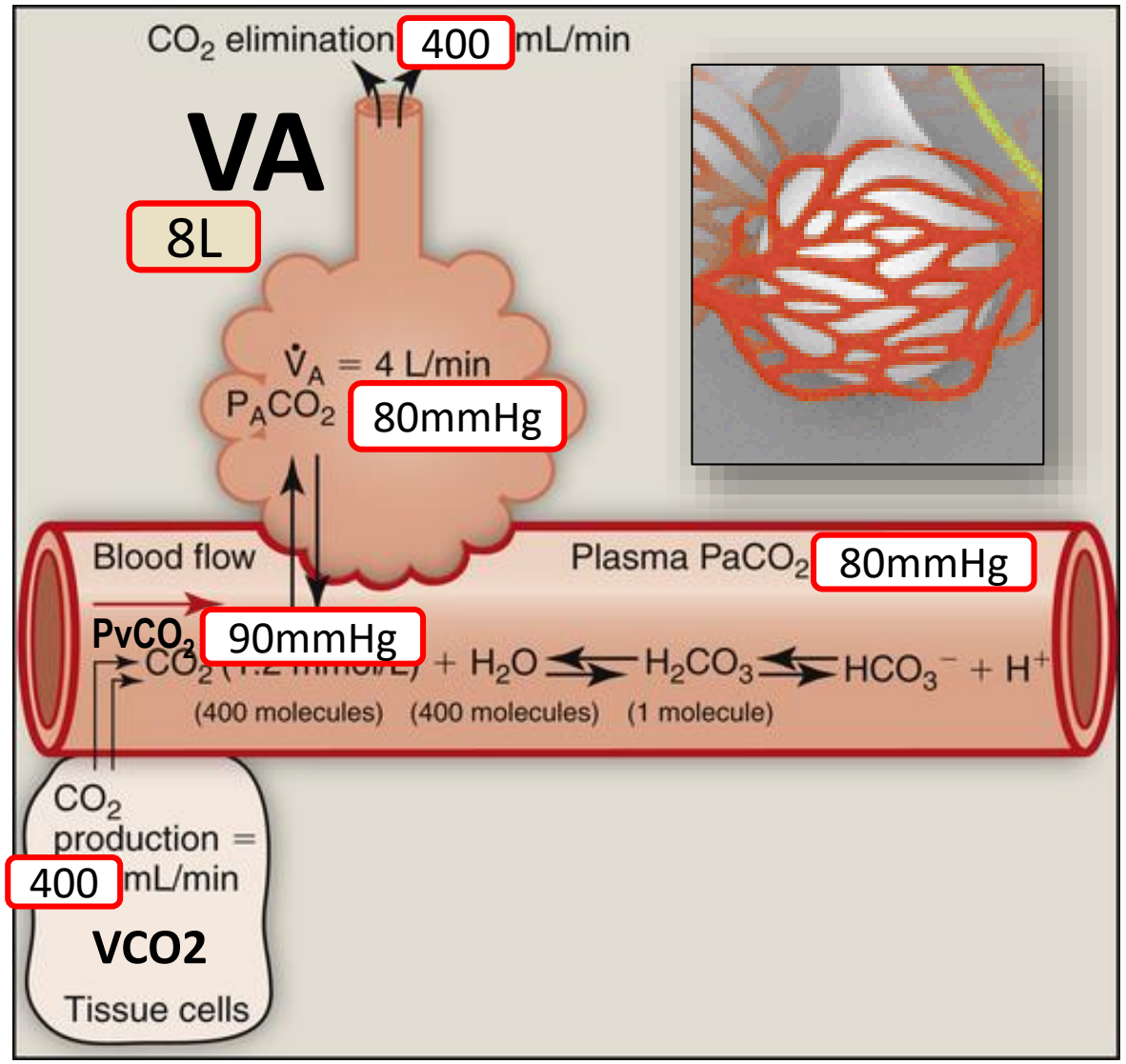
??????



What if VCO2 (production) increases to 400ml/min? I want to keep my PaCO2 at 40

$$V_A = \left(\frac{VCO_2}{P_ACO_2} \right) \times k$$

8L = V_A ; 400 = VCO_2 ; 80mmHg = P_ACO_2



INCREASED PRODUCTION

- Fever
- Carbs
- High Metabolism
- Insulin therapy
- Seizures
- Sepsis
- Hyperthyroidism
- Increased respiratory quotient R(lipids)
- Bicarbonate infusion
- Malignant Hyperthermia

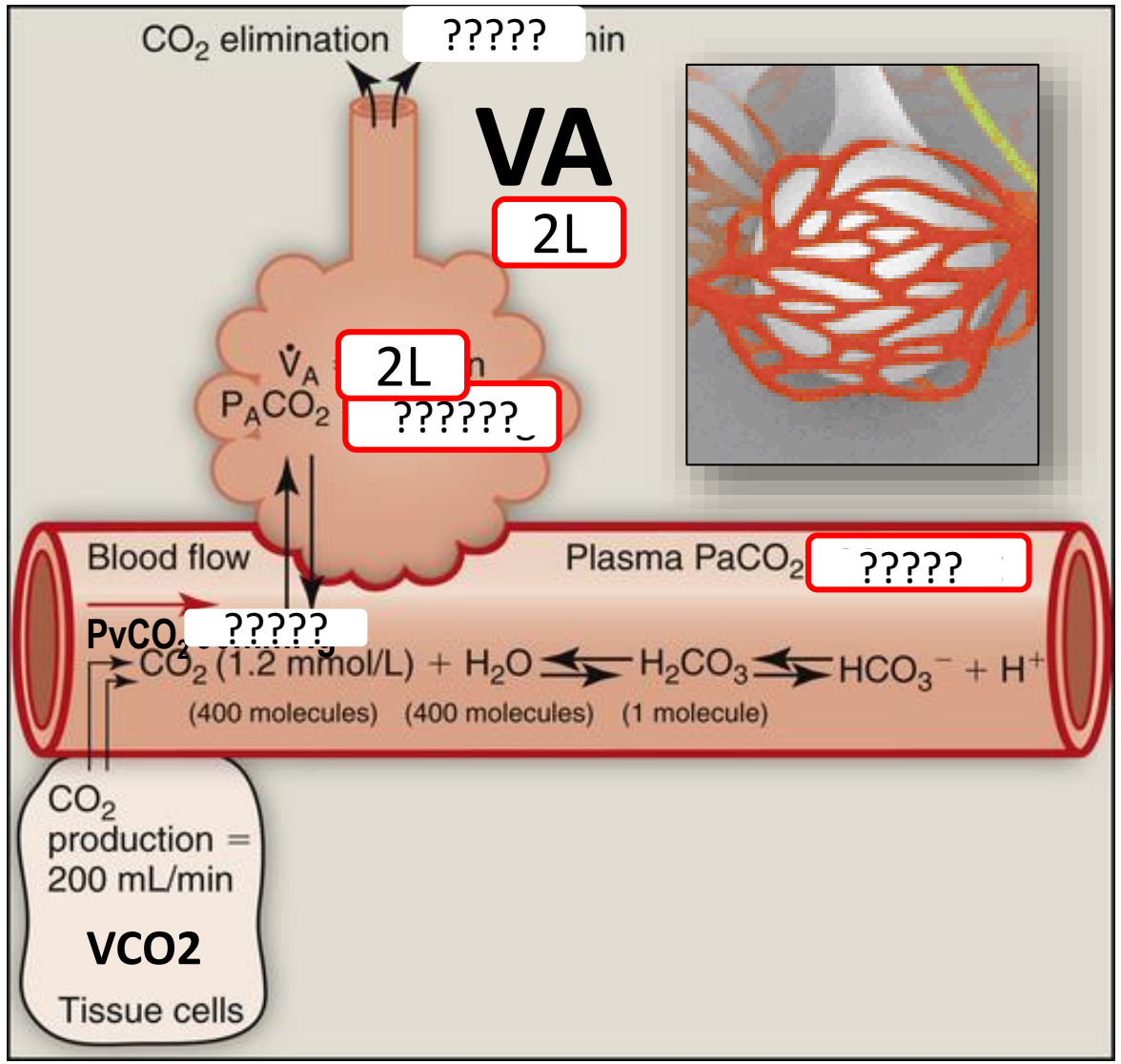
What if VCO2 (production) is constant but VA(elimination) drops in half?

2L

$$V_A = \left(\frac{VCO_2}{P_ACO_2} \right) \times k$$

200

??????

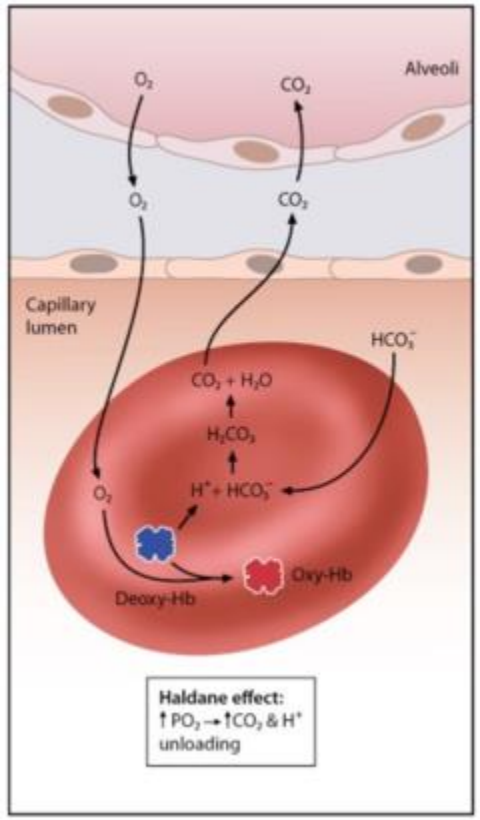


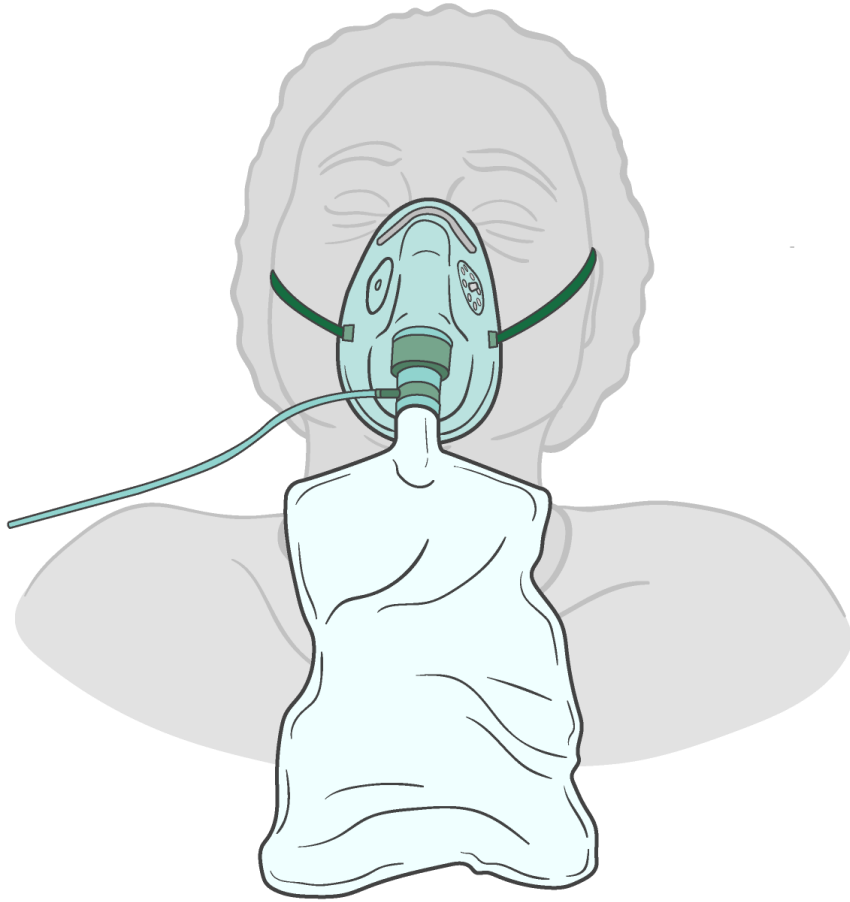
DECREASED ELIMINATION

- Low Total Ventilation and Low VA
  - Central drive
  - Neuromuscular dz
  - Low compliance
  - High resistance
  - Low vent settings

Some of the things that make a patient hypoventilate are listed here!

HALDANE EFFECT
High percent oxyhemoglobin >>
↑CO2 dissociation





DECREASED ELIMINATION

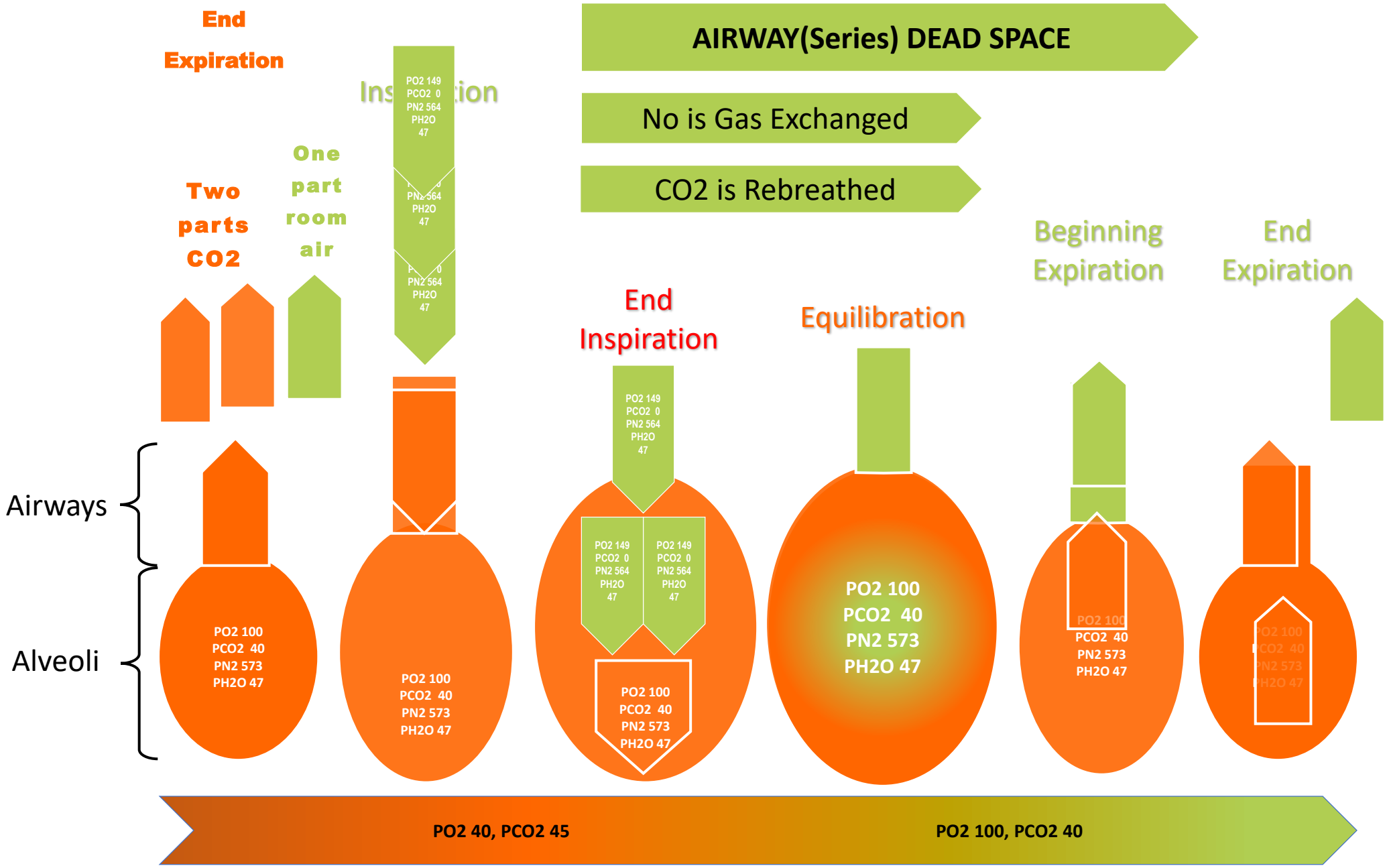
Hypoventilation with Low Effective VA

Hyperventilation with Low Effective VA

Large Dead Space Fraction

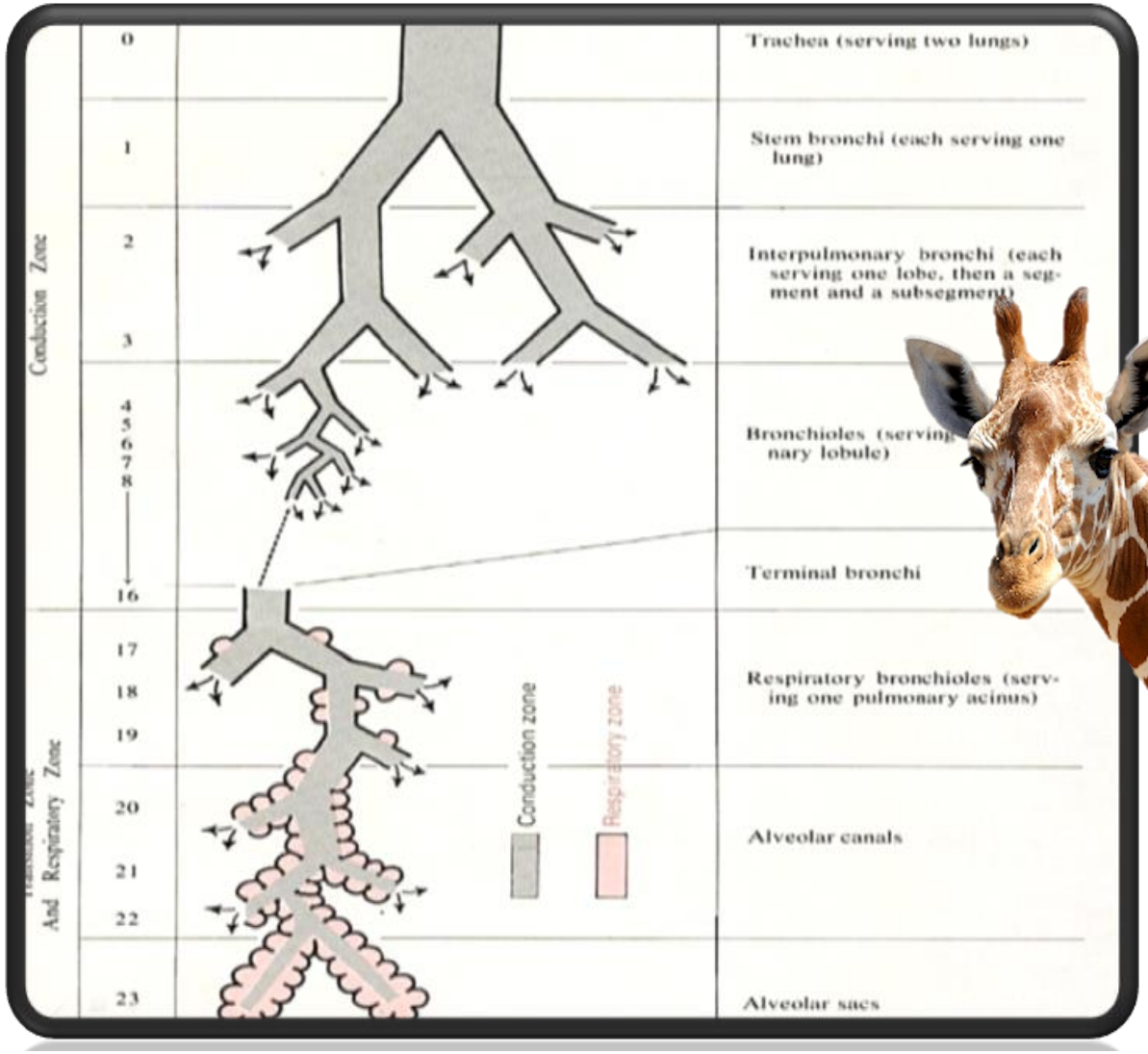
Interferes with CO_2 elimination despite vigorous respiratory efforts

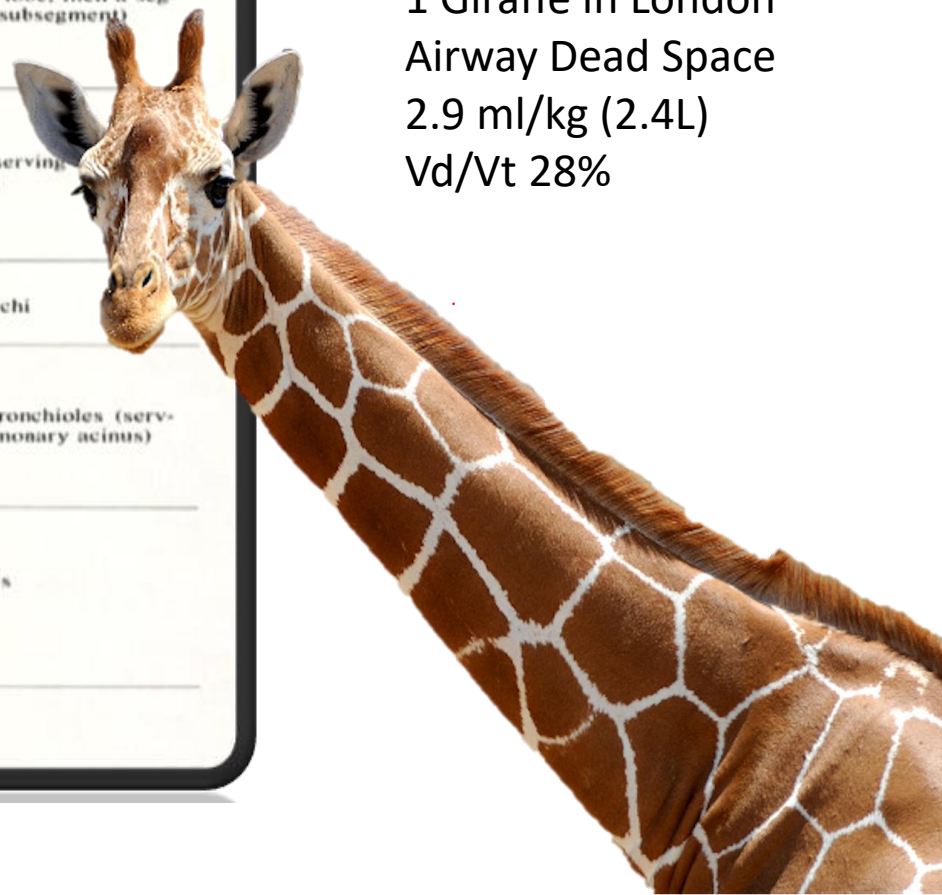
Let's look closer at the respiratory cycle!


End
Expiration
Inspiration
AIRWAY(Series) DEAD SPACE
No is Gas Exchanged
CO2 is Rebreathed
Two parts CO2
One part room air
Beginning Expiration
End Expiration
End Inspiration
Equilibration
Airways
Alveoli
PO2 149
PCO2 0
PN2 564
PH2O 47
PO2 100
PCO2 40
PN2 573
PH2O 47
PO2 40, PCO2 45
PO2 100, PCO2 40

ANATOMICAL DEAD SPACE

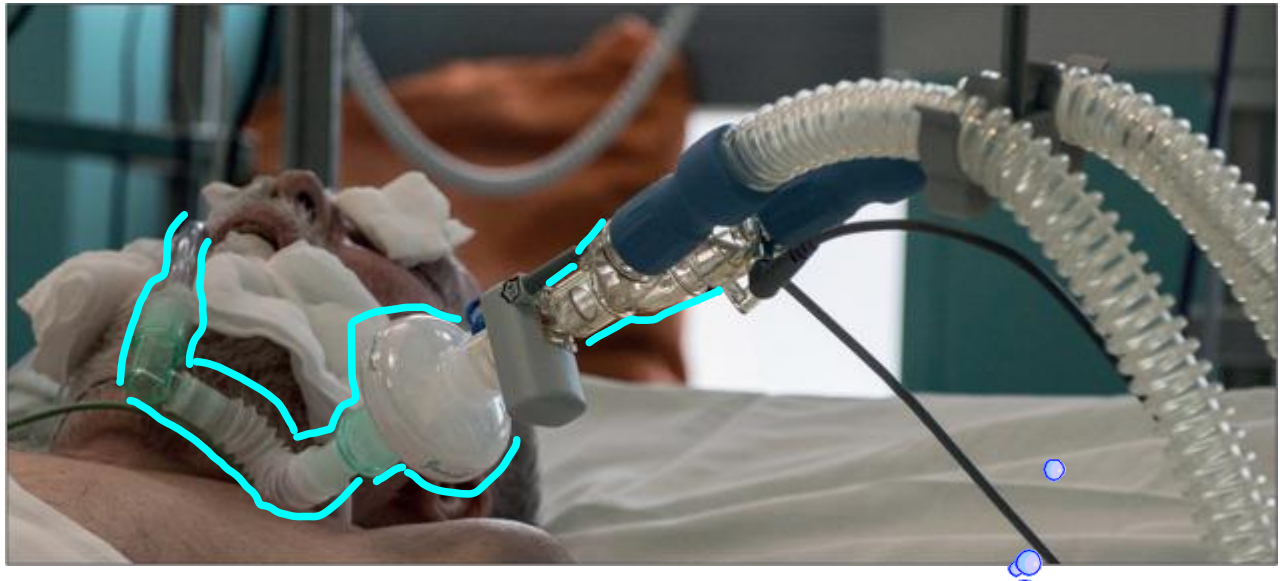
1 Human in London
Airway Dead Space
Estimate
2.2ml/kg IBW
~150ml
Vd/Vt 25-30%





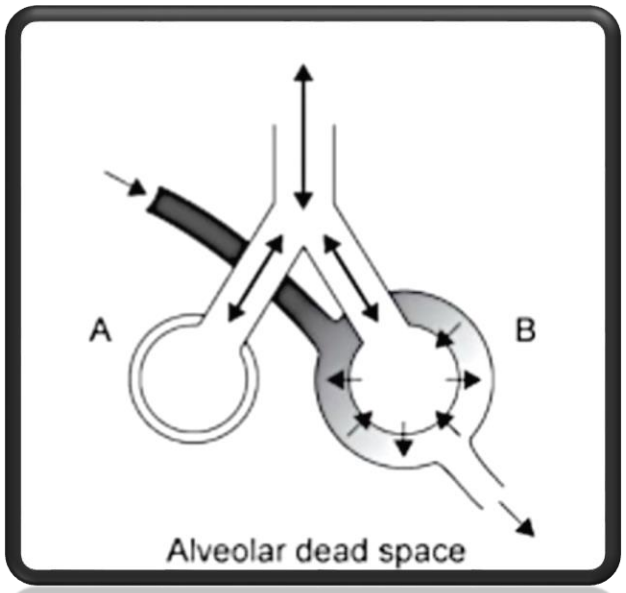
1 Giraffe in London
Airway Dead Space
2.9 ml/kg (2.4L)
Vd/Vt 28%

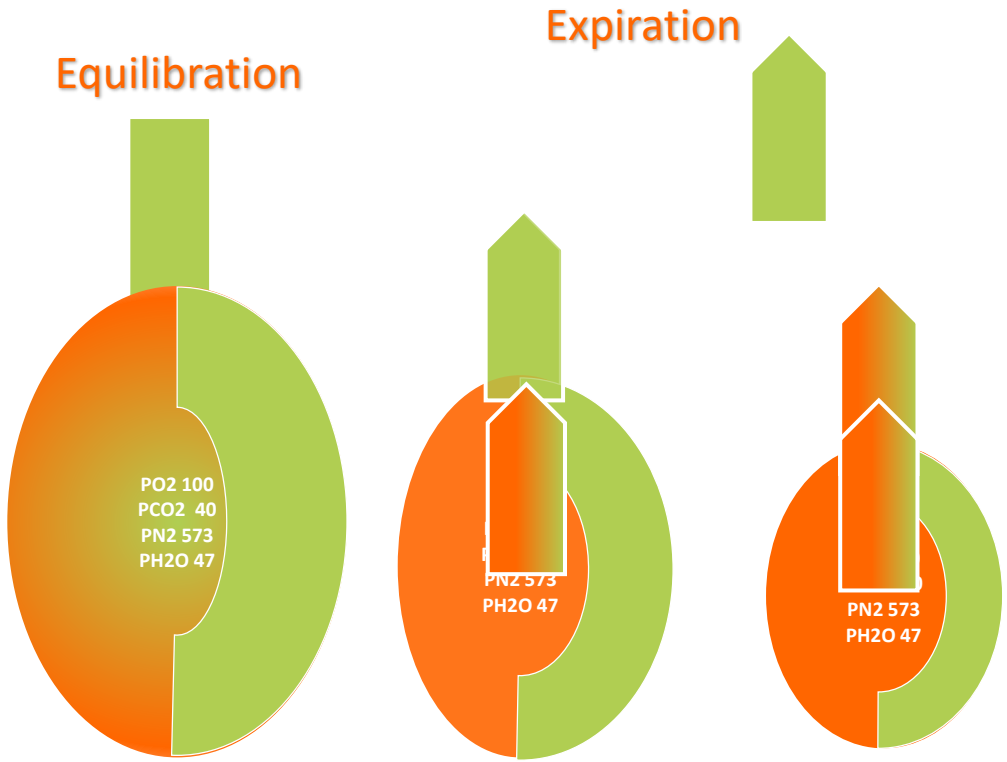
MECHANICAL DEAD SPACE



Instrumental dead space in ventilator management, François Lellouche, The Lancet: Respiratory Medicine, Vol 9 March 2021

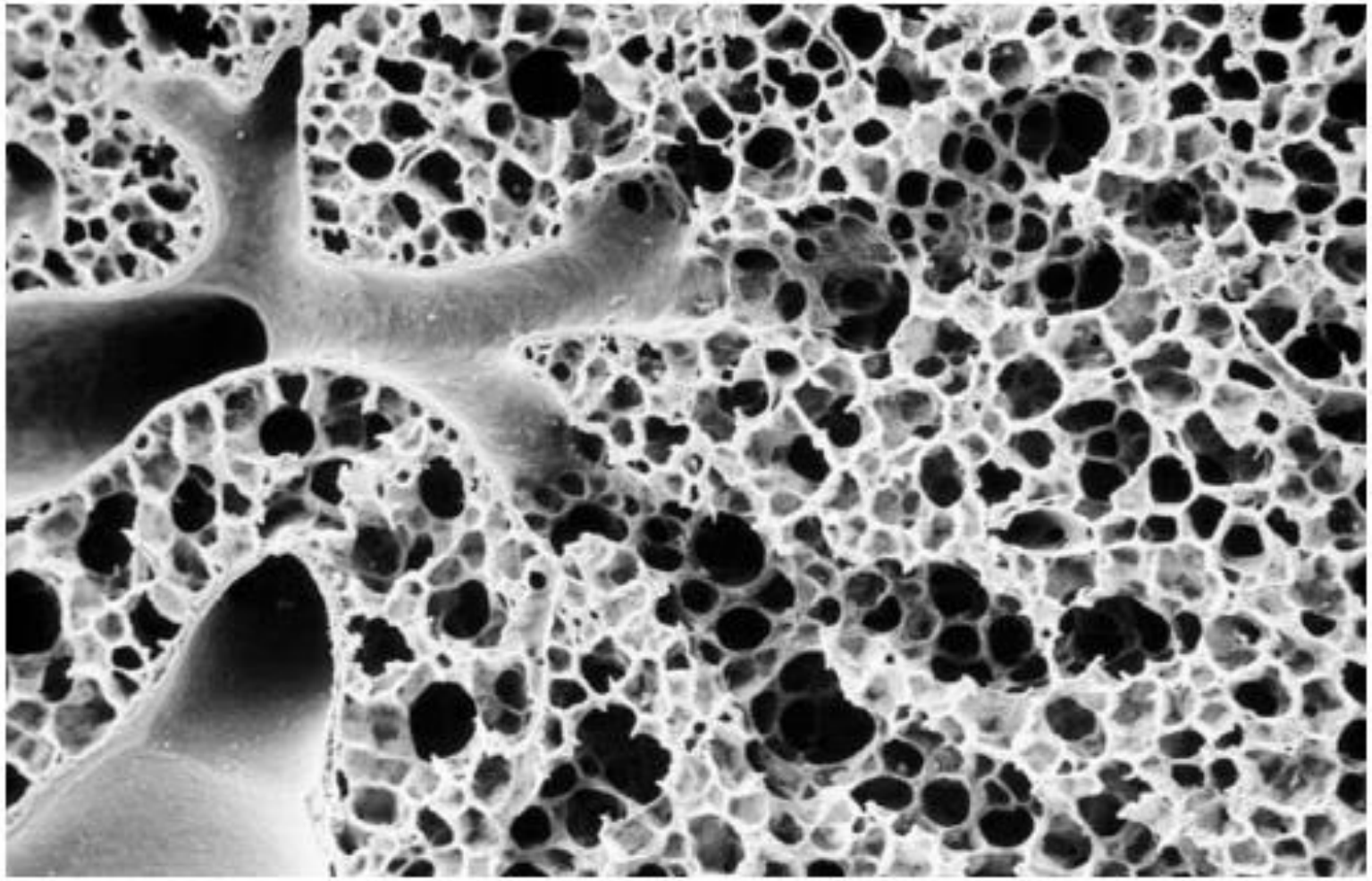
ALVEOLAR(Parallel) DEAD SPACE





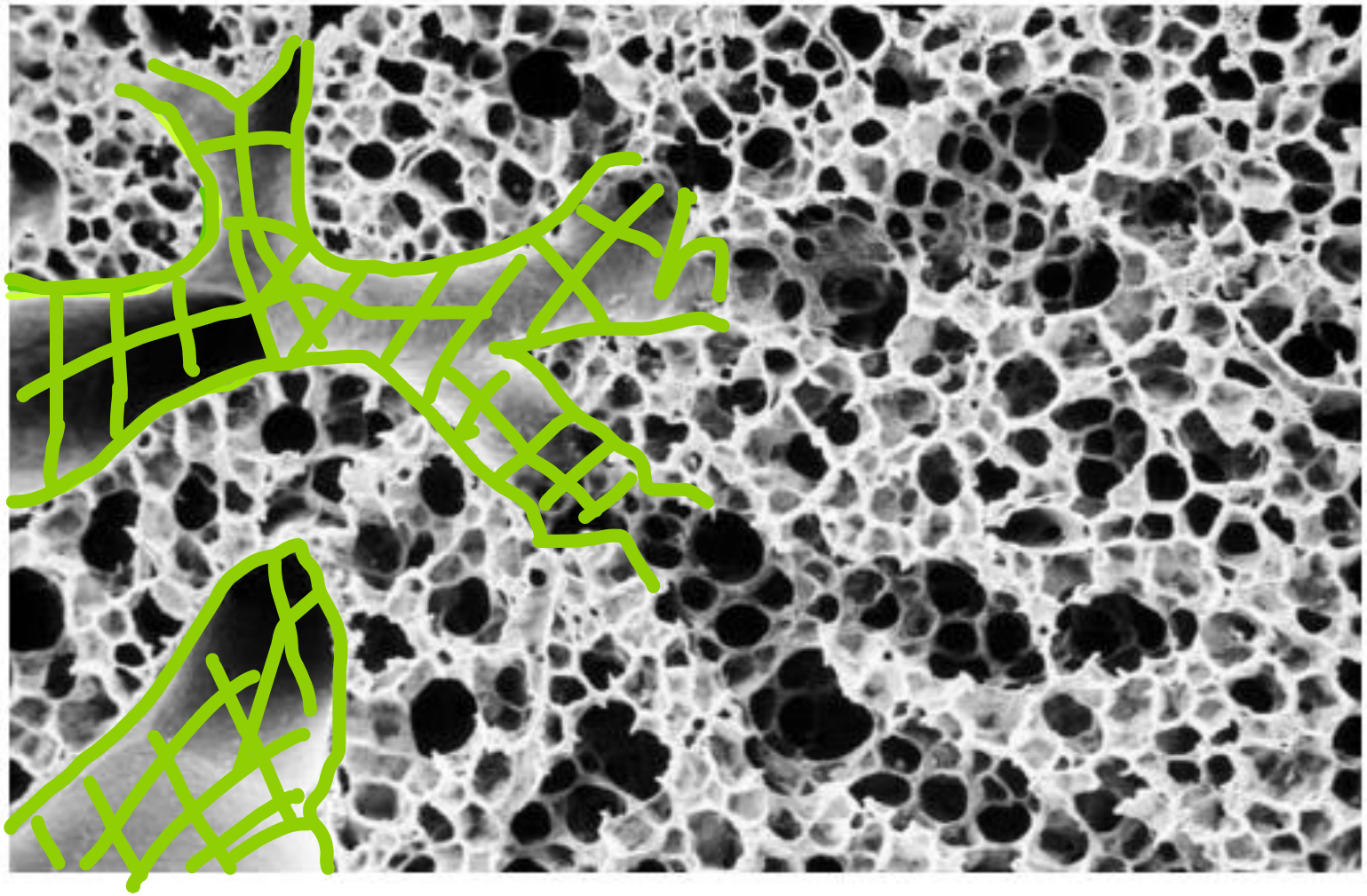
Alveoli participate in gas exchange
When they lose their blood supply, gas exchange stops

DEAD SPACE FRACTION ANATOMY



DEAD SPACE FRACTION

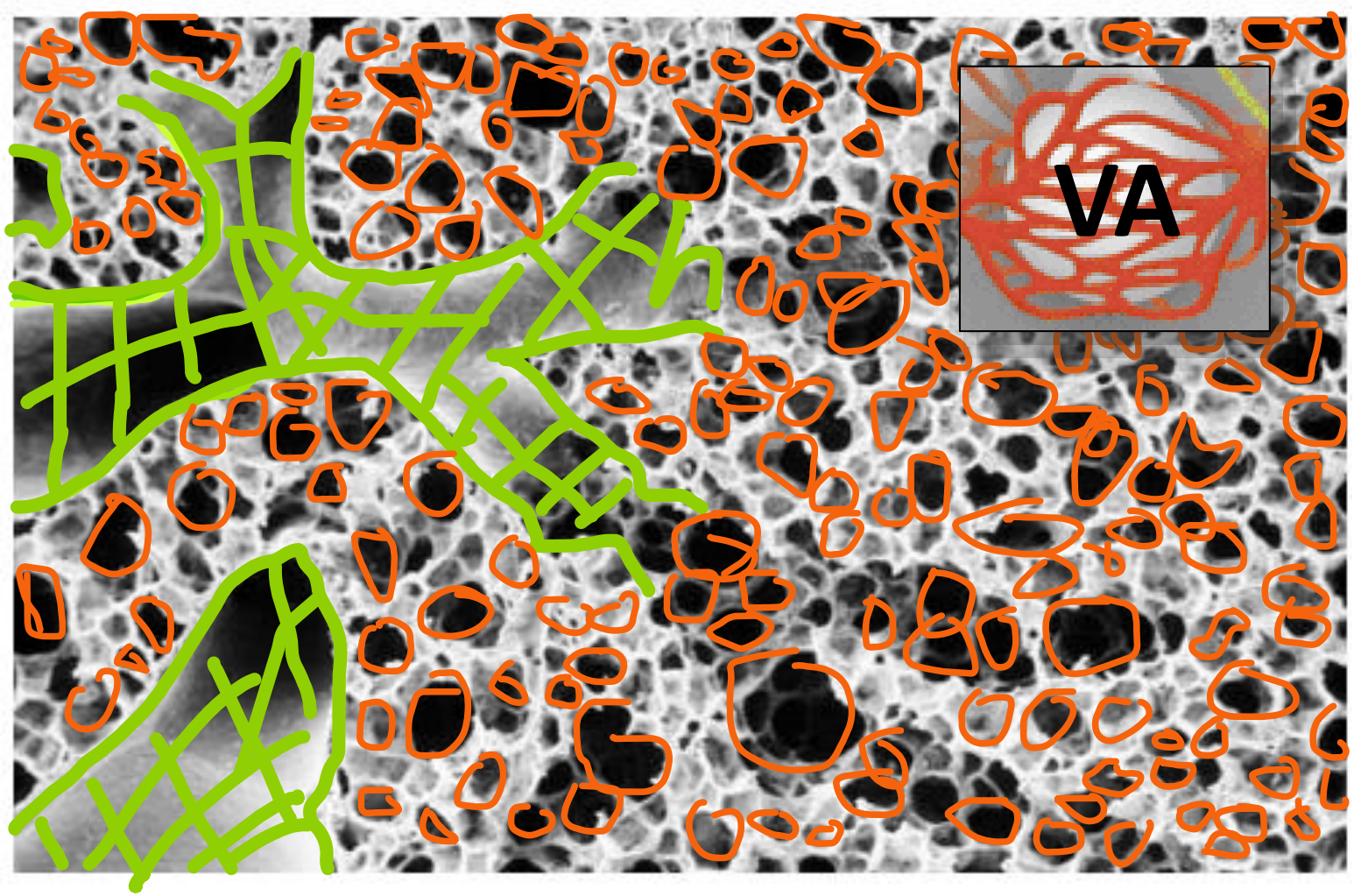
- Airway Dead Space
  - 2cc/kg IBW
  - 150cc
- VTd 25-30%



DEAD SPACE FRACTION

- Airway Dead Space
  - 2cc/kg IBW
  - 150cc
- VTd 25-30%
- VTalv 70-75%

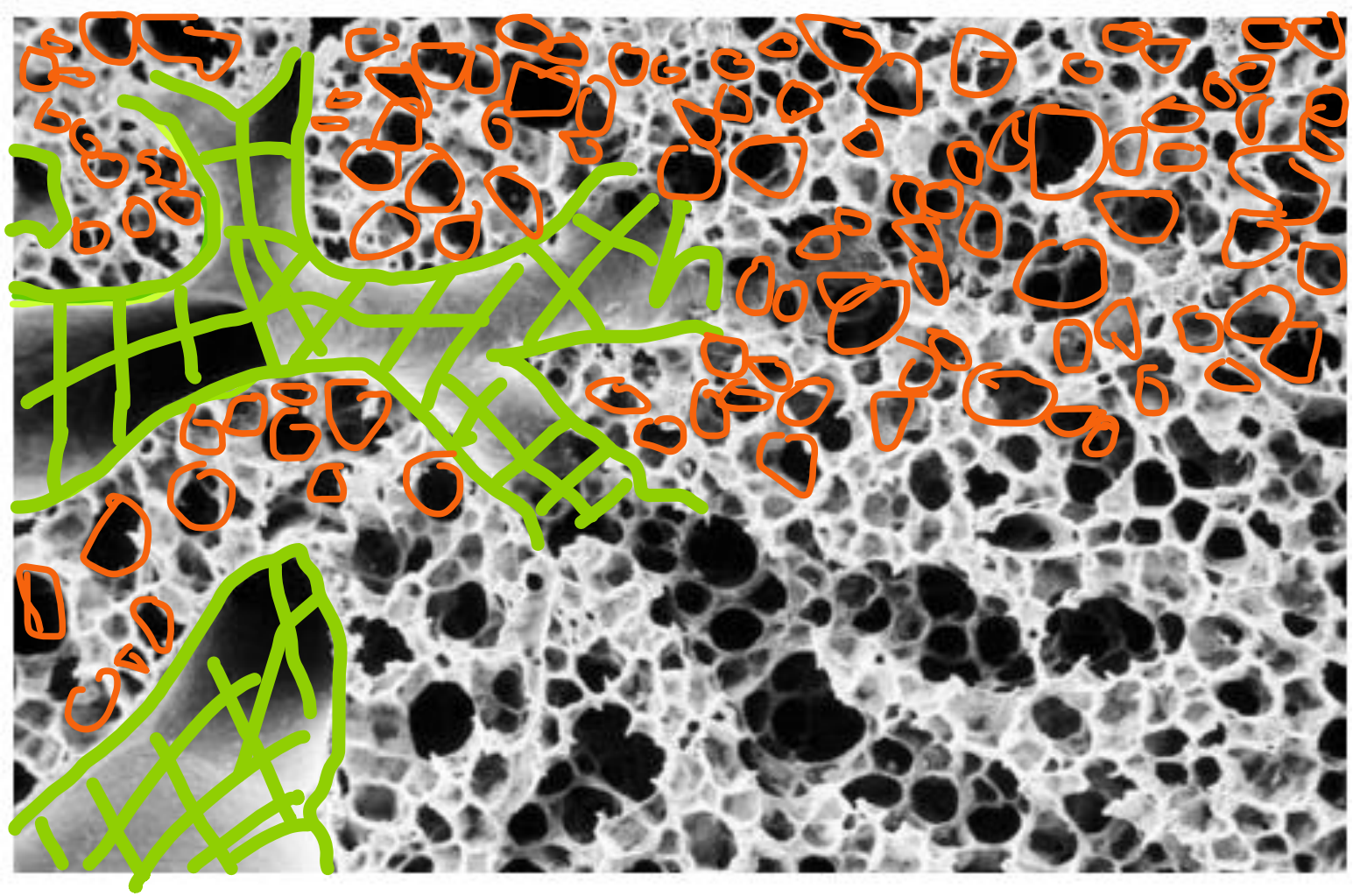
- VA= VTalv x RR
  - Total MVe -(VTd x RR)
- 70-75%



DEAD SPACE FRACTION

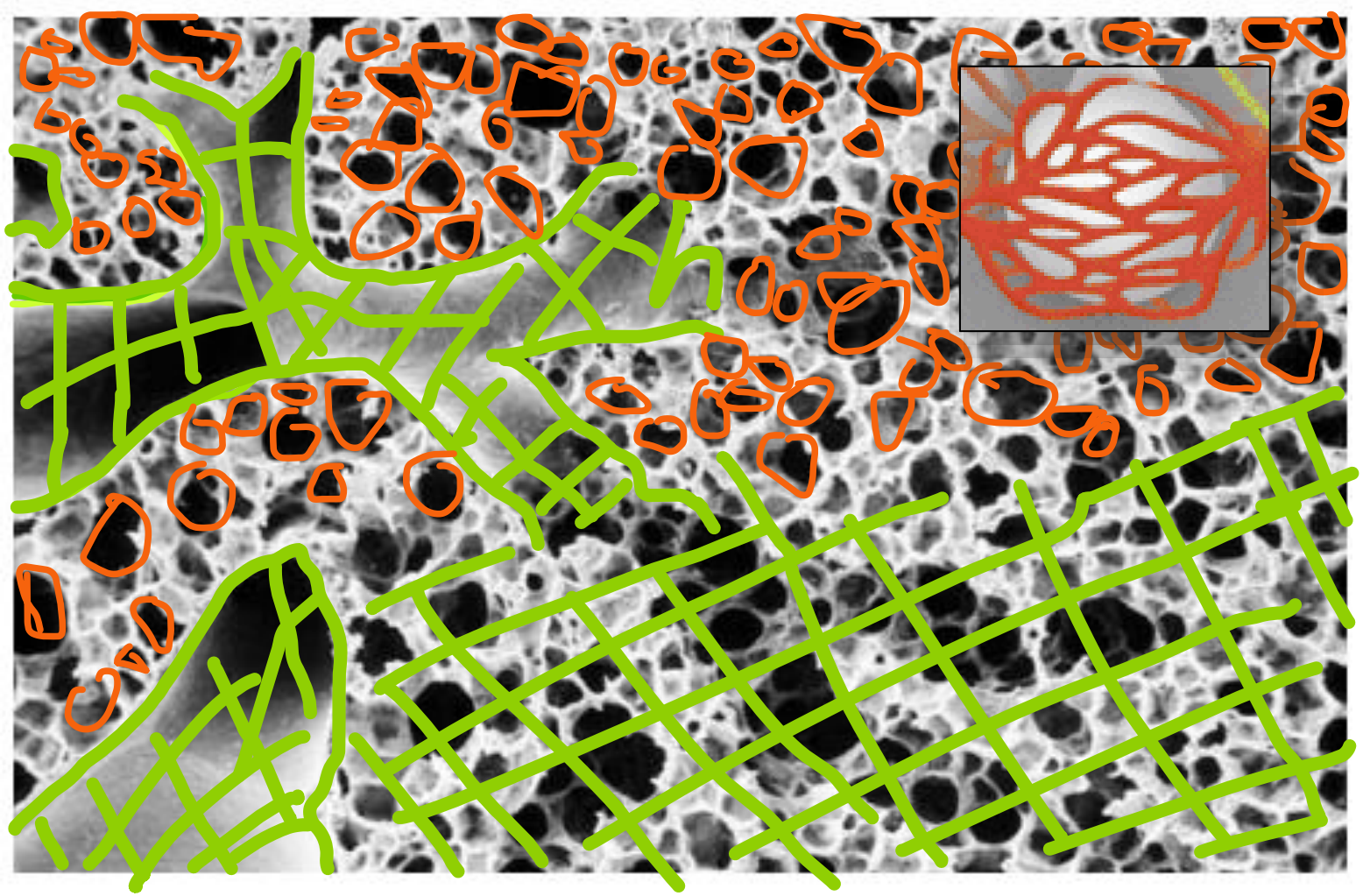
- Airway Dead Space
  - 2cc/kg IBW
  - 150cc
  - VTd 25-30%

- Perfusion disappears from half of the alveoli
  - Alveolar Dead space appears in addition to airway dead space



DEAD SPACE FRACTION

- Airway Dead Space
  - 2cc/kg IBW
  - 150cc
  - VTd 25-30%
- Perfusion disappears from half of the alveoli
  - Alveolar Dead Space
  - VTdalv 35%
- Total Dead Space 65%
- Effective VA 35%



DEAD SPACE FRACTION

- VA 35% of MVe
- We need VA 4.2L/min
  - To keep PaCO2 40

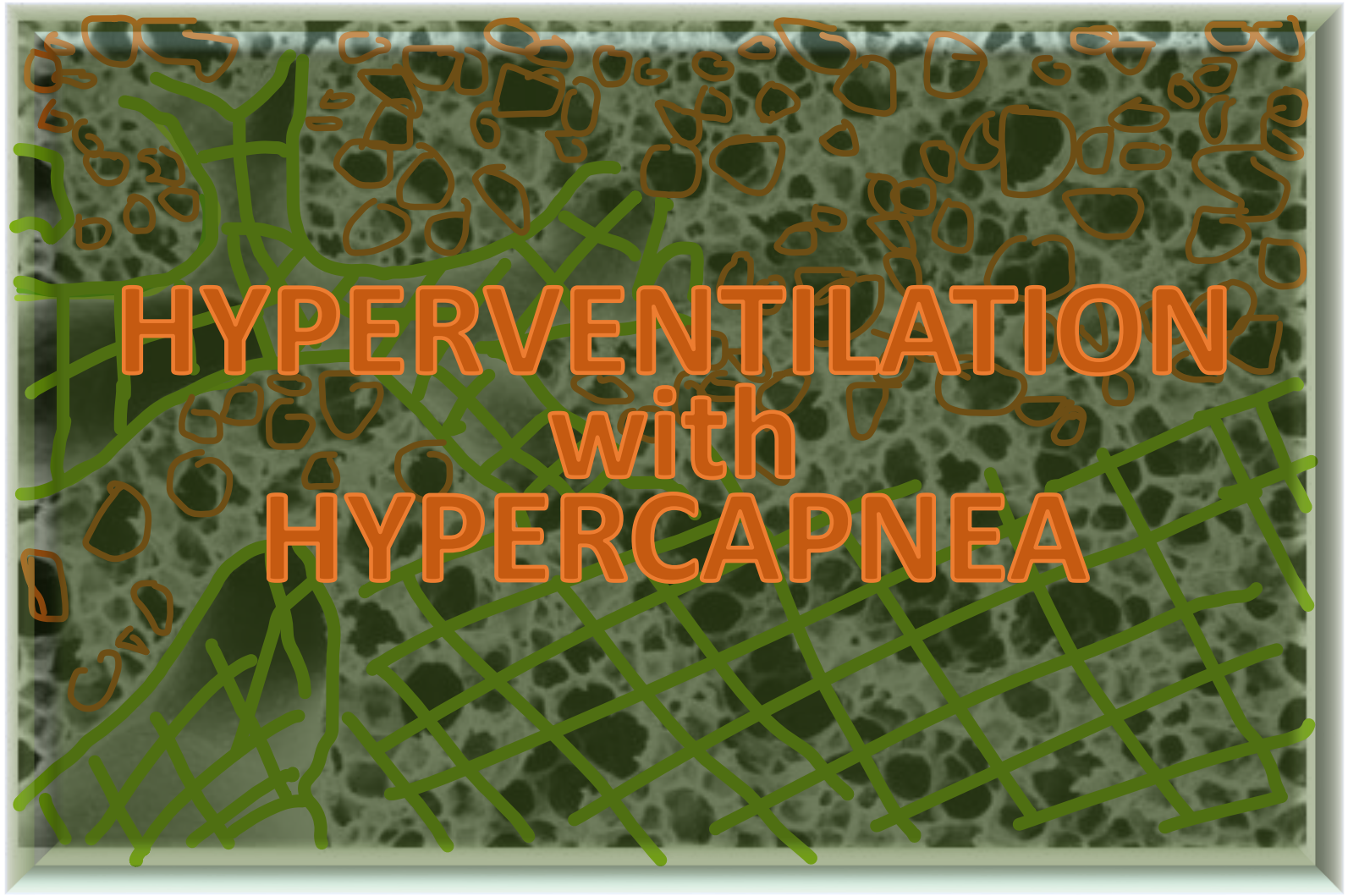
- Total Minute Vent=

  (effVTalvxRR)+(VTdsxRR)

  35% + 65%

  4.2L/min + 7.8L/min

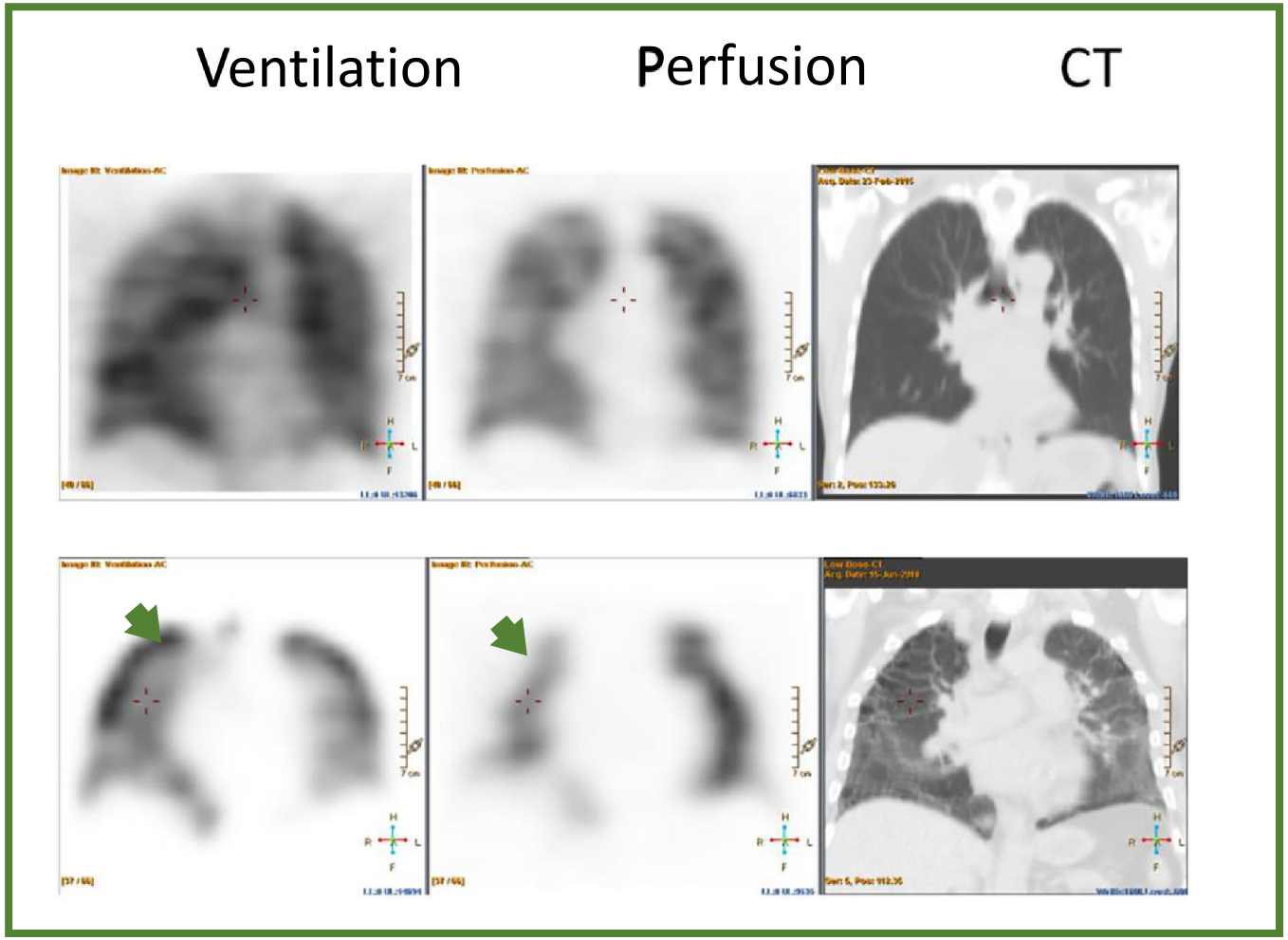
  = 12L/min



High DEAD SPACE FRACTION

HYPERVENTILATION WITH HYPERCAPNEA

- Hyperventilation
- Low effective VA
  - VQ mismatch
  - COPD
  - High Vent pressures
  - PEEP
  - PE
  - Covid Microthrombi

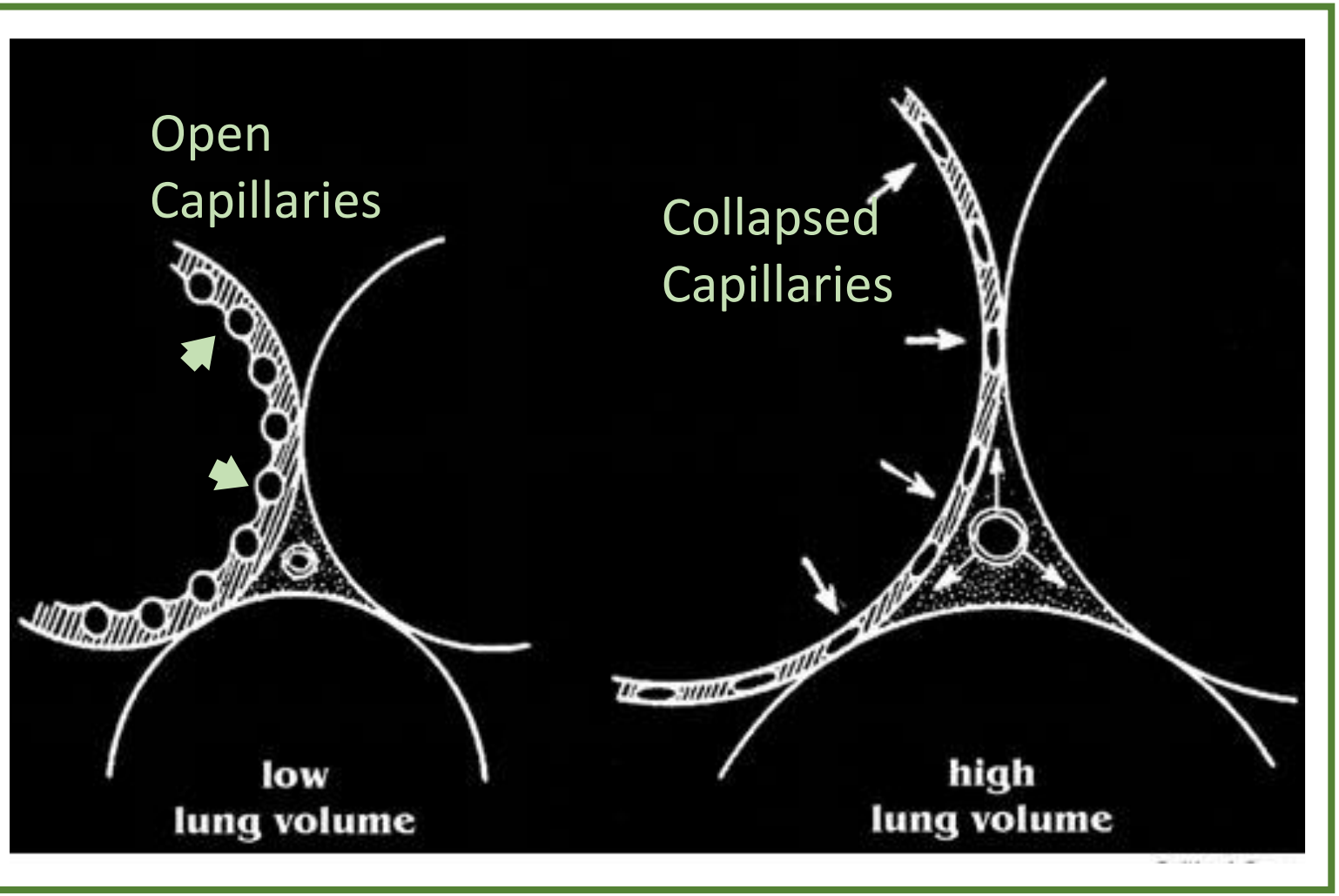


Lung Scintigraphy in COPD; Mortensen, Seminars in Nuclear Medicine 2019

High DEAD SPACE FRACTION

HYPERVENTILATION WITH HYPERCAPNEA

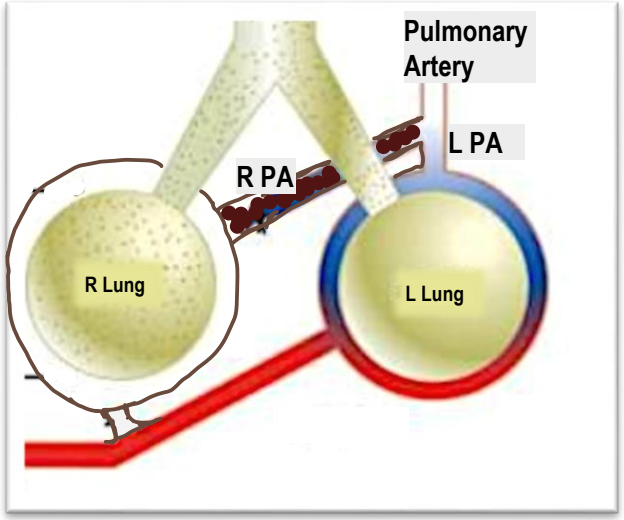
- Hyperventilation
- Low effective VA
  - VQ mismatch
  - COPD
  - High Vent pressures
  - PEEP
  - PE
  - Covid Microthrombi

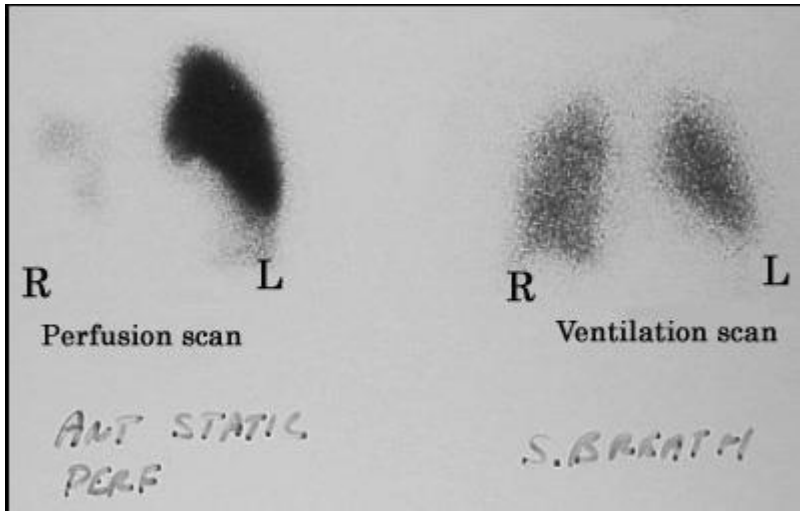


High DEAD SPACE FRACTION

- Hyperventilation
- Low effective VA
  - VQ mismatch
  - COPD
  - High Vent pressures
  - PEEP
  - PE
  - Covid Microthrombi

HYPERVENTILATION WITH HYPERCAPNEA



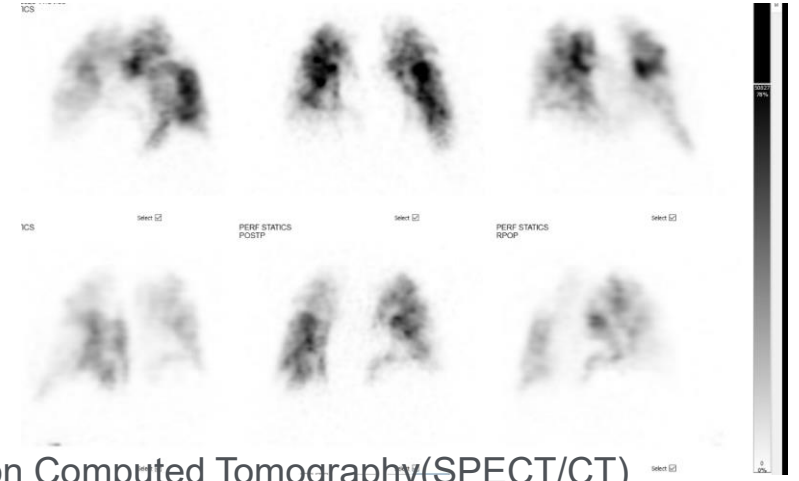


High DEAD SPACE FRACTION

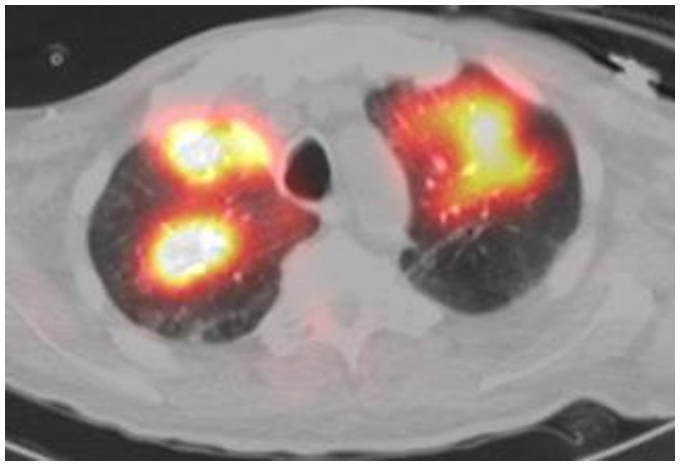
HYPERVENTILATION WITH HYPERCAPNEA

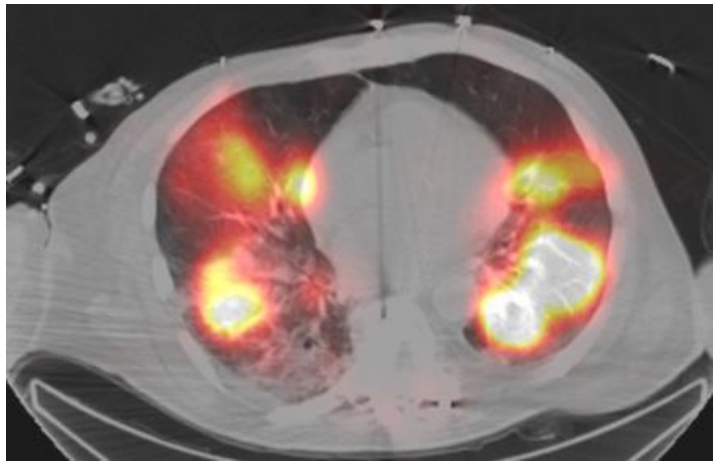
- Hyperventilation
- Low effective VA
  - VQ mismatch
  - COPD
  - High Vent pressures
  - PEEP
  - PE
  - Covid Microthrombi

Moth Eaten Appearance Perfusion Images

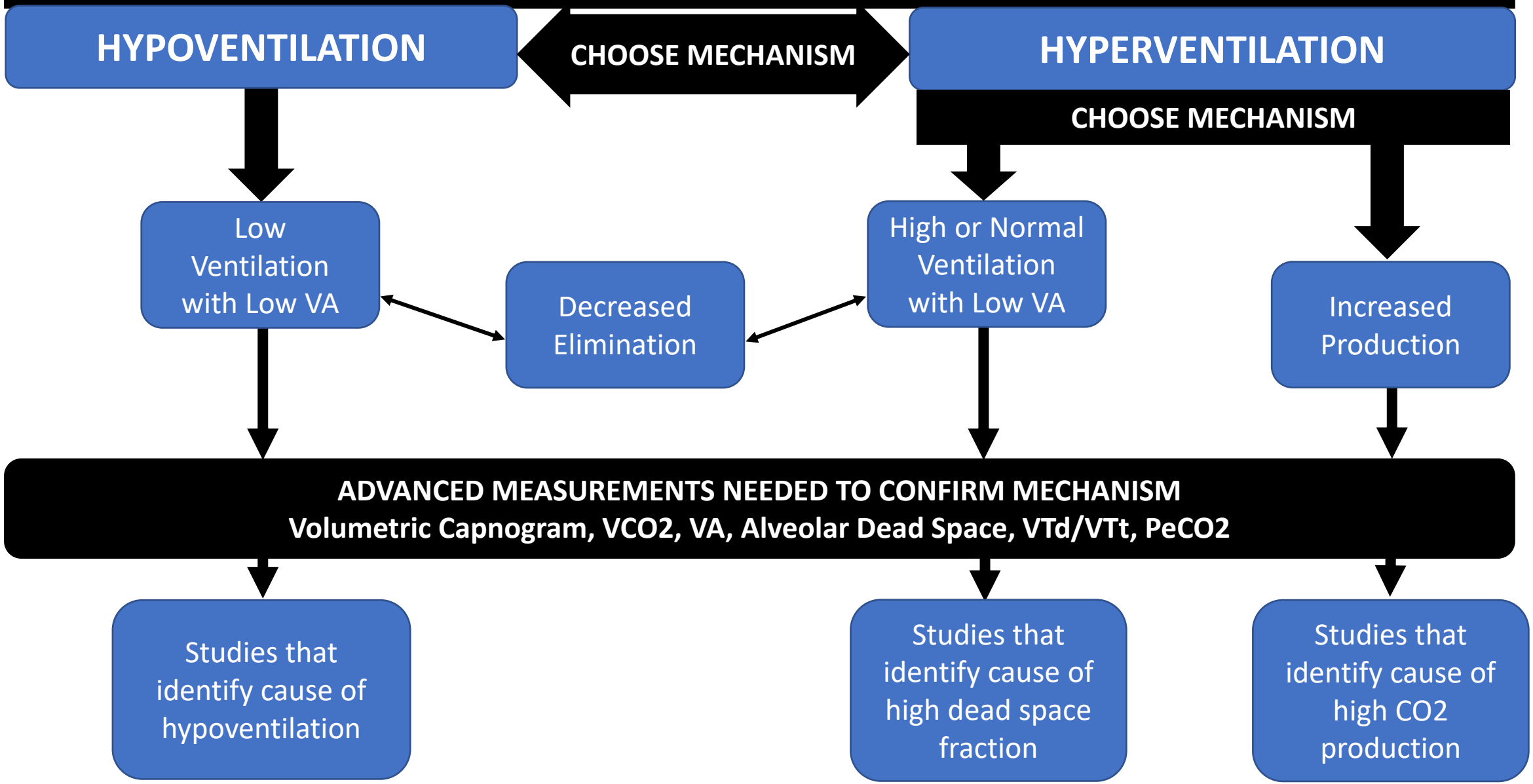


Fused Perfusion Single Photon Emission Computed Tomography (SPECT/CT)





HYPERCAPNIA ROADMAP/DECONSTRUCTOR



HYPOVENTILATION

Low Ventilation with Low VA

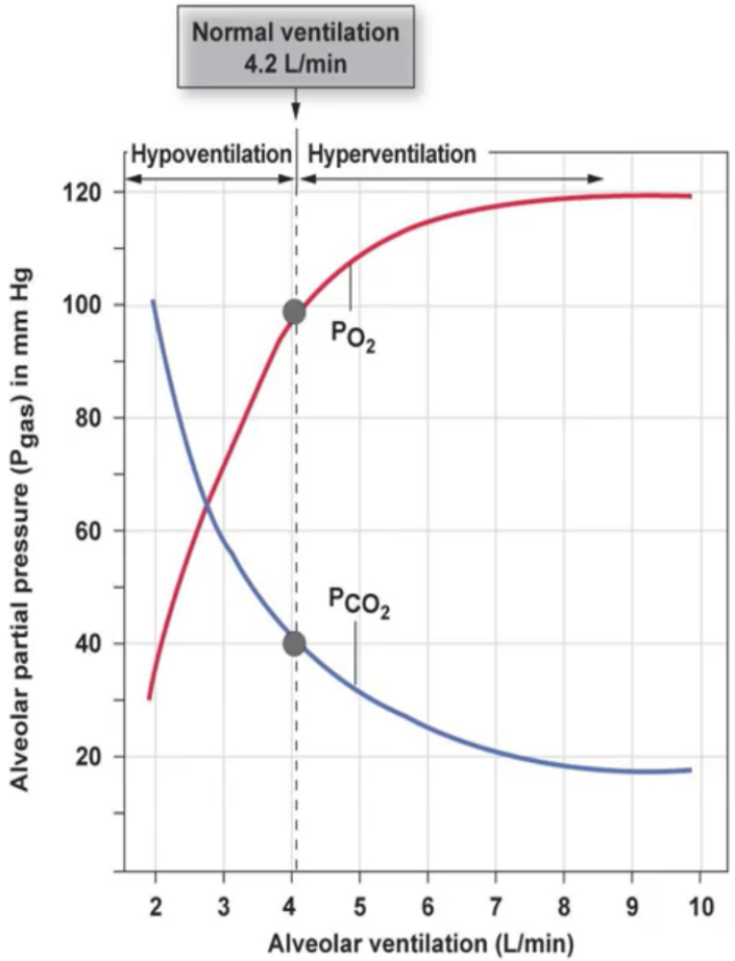
- What do you mean by that?
  - Clinical diagnosis:
  - daytime PaCO2 > 45

- Total MVe < 70-110ml/kg/min
  - MVe < 5-8L/min

    MVe = Tidal Volume x RR

  - VA < 4.2L/min

    VA = (Tidal Volume – Dead Space) x RR



Case 1

- Is this hypoventilation?
  - Is PaCO2 > 45?
  - Is total MVe < 5-8L/min?
  - Is VA < 4.2L

PaCO2 is 55
MVe is 4.28

VA = (Tidal Volume – Dead Space) x RR
368ml - 150ml x 12 = 2.6L/min

VA is likely much less than 4.2L/min

ABG 7.31/55/114

HYPERCAPNIA ROADMAP

HYPOVENTILATION

CHOOSE MECHANISM

HYPERVENTILATION

Ventilated patient:
Low MVe
And therefore by definition low VA
Advanced measurements not necessary but could rule in additional causes!

Low Ventilation with Low VA

Decreased Elimination

High or Normal Ventilation with Low VA

CHOOSE MECHANISM

Increased Production

ADVANCED MEASUREMENTS NEEDED TO CONFIRM MECHANISM
Volumetric Capnogram, VCO2, VA, Alveolar Dead Space, VTd/VTt, PeCO2

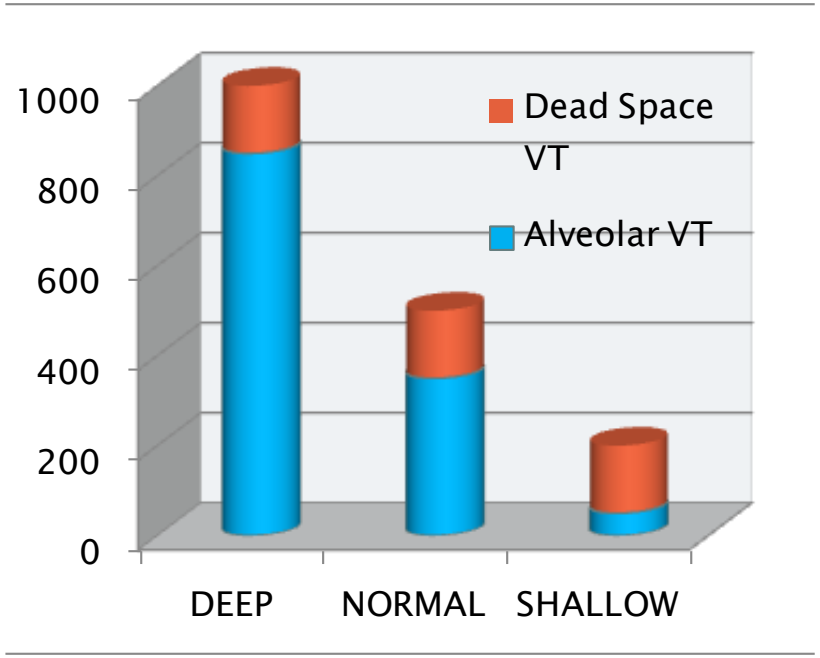
Studies that identify cause of hypoventilation
Central drive, Neuromuscular dz
Low compliance, High resistance
Low vent settings
Measure Resistance, Autopeep and Compliance on the vent, NIF
PSV to assess central drive

Studies that identify cause of high dead space fraction

Studies that identify cause of high CO2 production

Case 2 Breathing Patterns Can Vary

- High dose Opiates for cancer pain
  - 7.44/61/63
  - RR 8
  - sometimes RR 4 after opiate bolus
  - sometimes RR 20 between boluses



- Is this hypoventilation?
- Is $PaCO_2 > 45$? Yes
- Is total MVe < 5-8L/min???????
- Is VA < 4.2L/min?
- If the patient is not intubated, not possible to judge hypo vs hyperventilation

Case 2 Breathing Patterns Can Vary

- Is this hypoventilation?
  - 7.44/61/63
  - RR 8
  - sometimes RR 4 after opiate bolus
  - sometimes RR 20 between boluses
- Is PaCO2 > 45? yes
- Is total MVe < 5-8L/min?
- Is VA < 4.2L/min?

MVe is Low!
< 5-8L/min

VA is Low!
< 4.2L/min

MVe is VT x 4

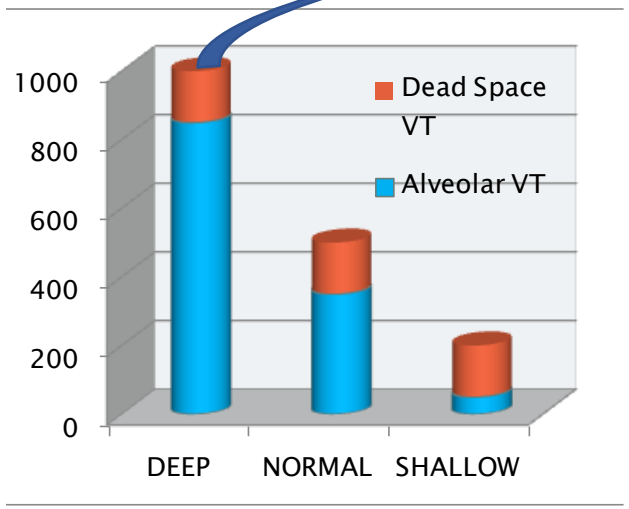
Hypothetically: Vt 1000ml RR 4

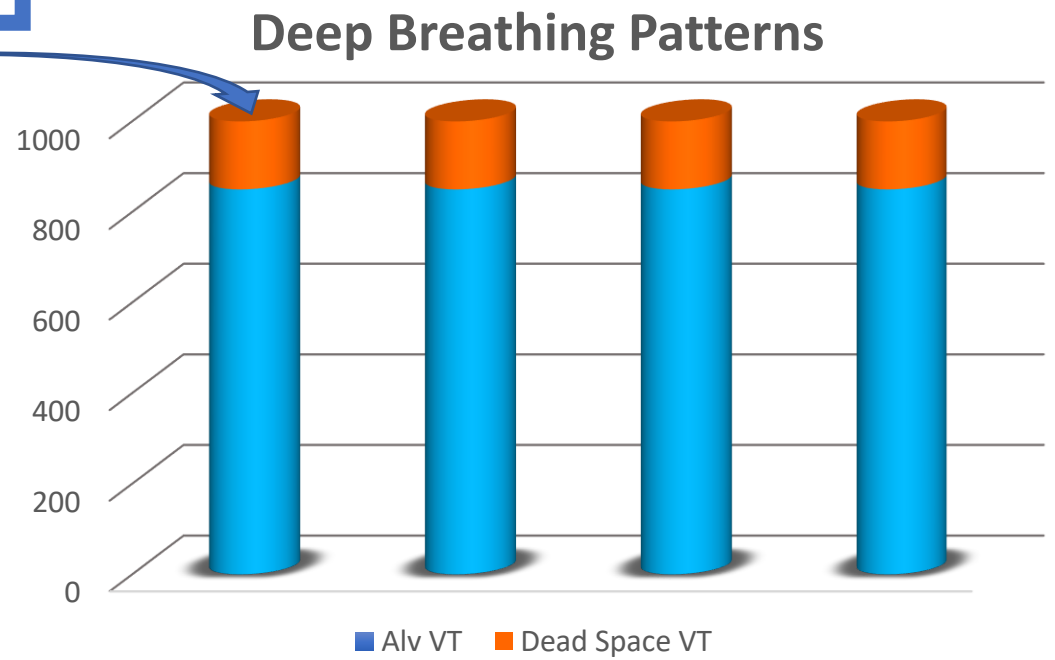
1000 ml x 4 = 4L/min

VA = (Tidal Volume – Dead Space) x RR

1000ml - 150ml x 4 = 3.4L/min

RR 4





Case 2 Breathing Patterns Can Vary

- Is this hypoventilation?
  - 7.44/61/63
  - RR 8
  - sometimes RR 4 after opiate bolus
  - sometimes RR 20 between boluses
- Is PaCO2 > 45? yes
- Is total MVe < 5-8L/min?
- Is VA < 4.2L/min?

MVe is NL!
5-8L/min

VA is NL!
> 4.2L/min

MVe is VT x 6

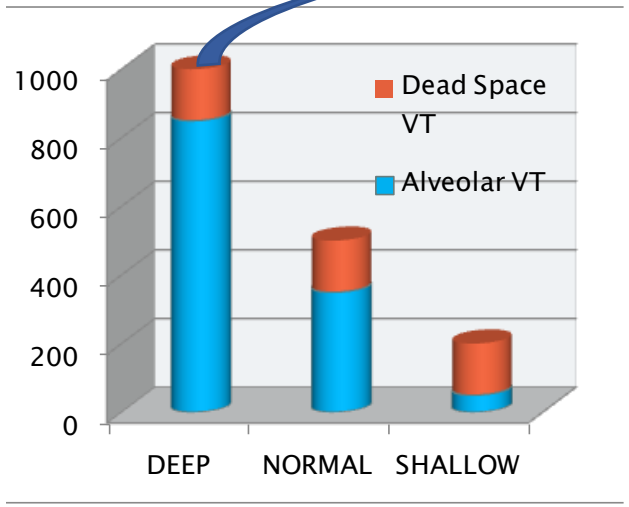
Hypothetically: Vt 1000ml RR 6

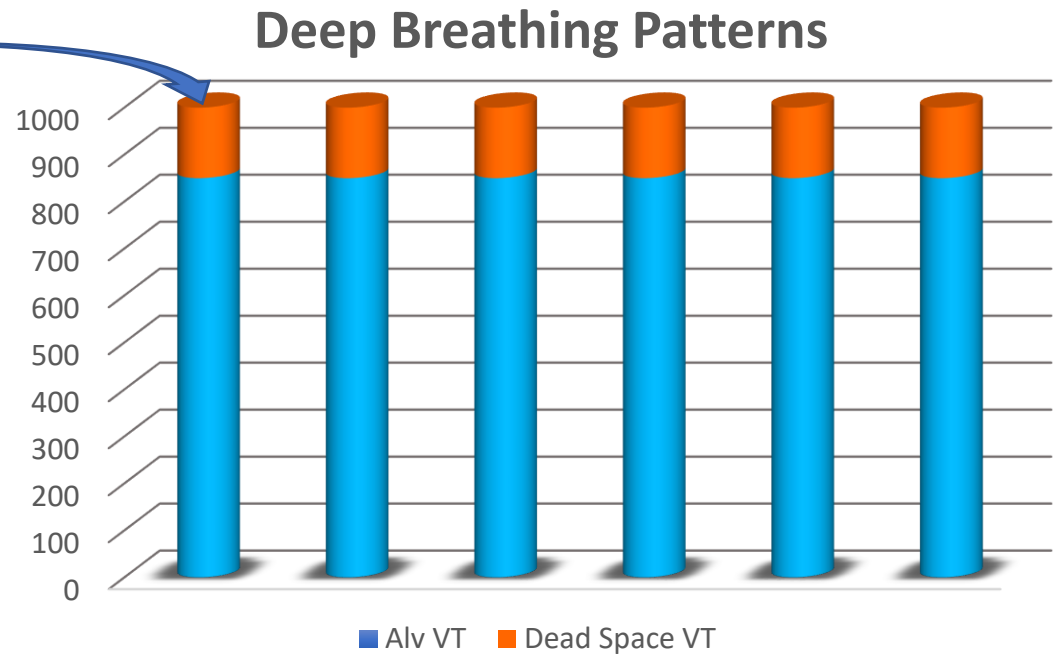
1000 ml x 6 = **6L/min**

VA = (Tidal Volume – Dead Space) x RR

1000ml - 150ml x 6 = **5.1L/min**

RR 6





HYPERCAPNIA ROADMAP

HYPOVENTILATION

CHOOSE MECHANISM

HYPERVENTILATION

CHOOSE MECHANISM

Low Ventilation with Low VA

Decre
Elimin

Normal MVe
and Normal VA
tracting
ad
sts
ar
or
02

Increased Production

ADVANCED MEASUREM
Volumetric Capnogram, VC

STUDIES THAT IDENTIFY CAUSE OF HIGH DEAD SPACE FRACTION:

==========

VQ mismatch, COPD,
High Vent pressures, PEEP,
PE, Covid Microthrombi

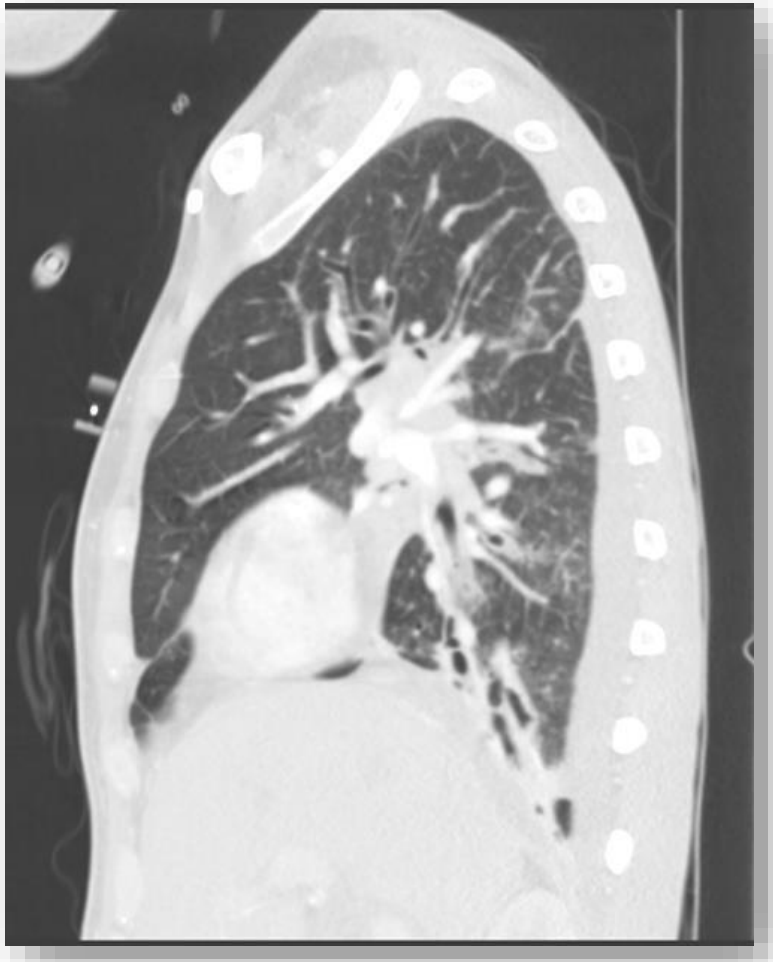
****

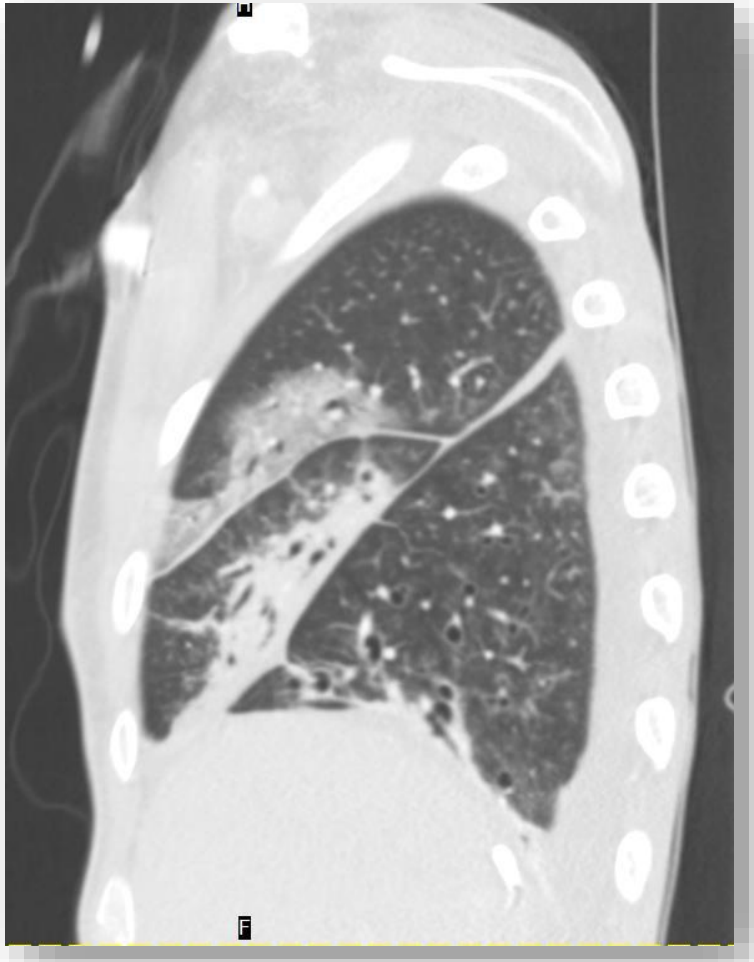
CT PE protocol
VQ scan
Assess Vent pressures/PV loops

Studies that identify cause of hypoventilation

Studies that identify cause of high CO2 production

Case 2 Breathing Patterns Can Vary





Case 2 Breathing Patterns Can Vary

- Is this hypoventilation?
  - 7.44/61/63
  - RR 8
  - sometimes RR 4 after opiate bolus
  - sometimes RR 20 between boluses
- Is PaCO2 > 45?
- Is total MVe < 5-8L/min?
- Is VA < 4.2L/min?

MVe is NL!
5-8L/min

VA is Low!
<4.2L/min

RR 20

MVe is VT x 20

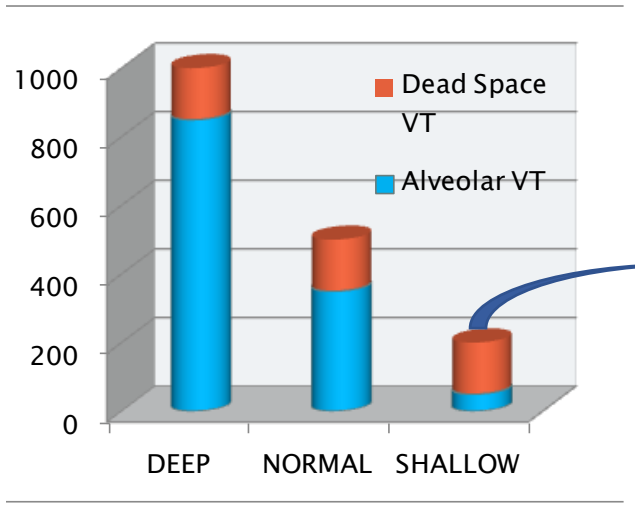
Hypothetically: Vt 300ml RR 20

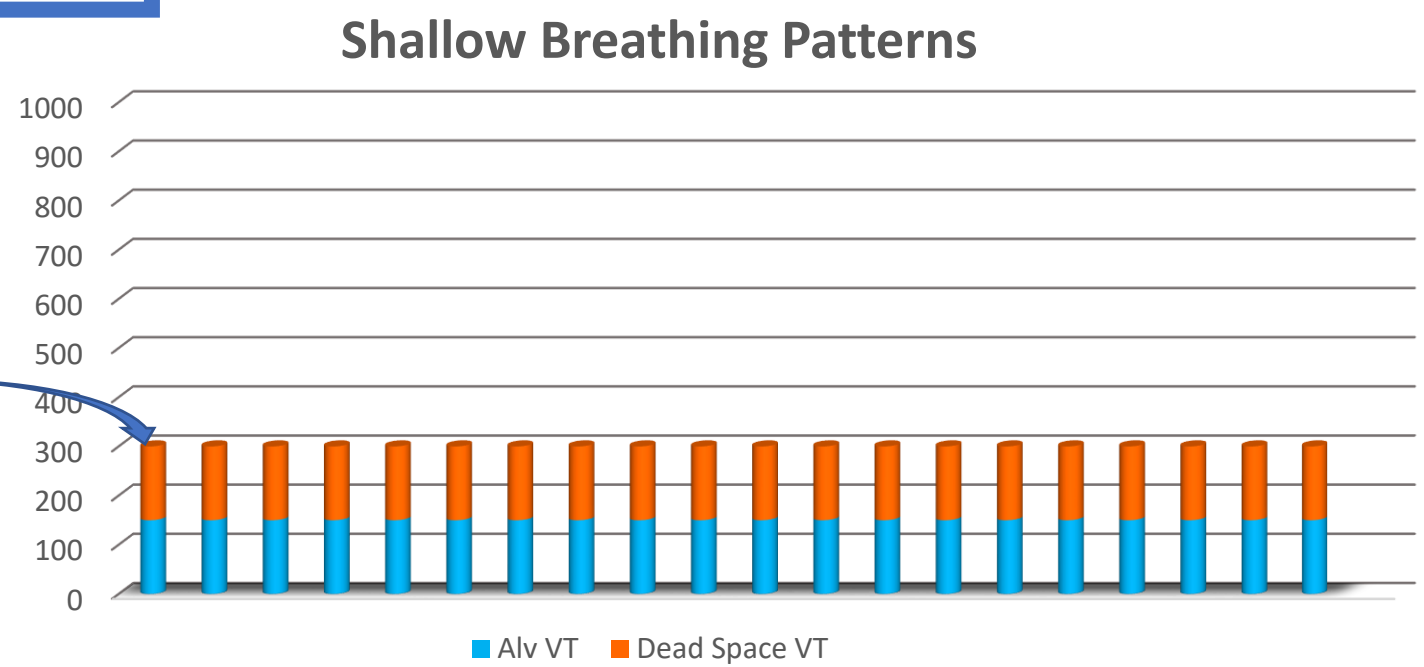
300 ml x 20 = **6L/min**

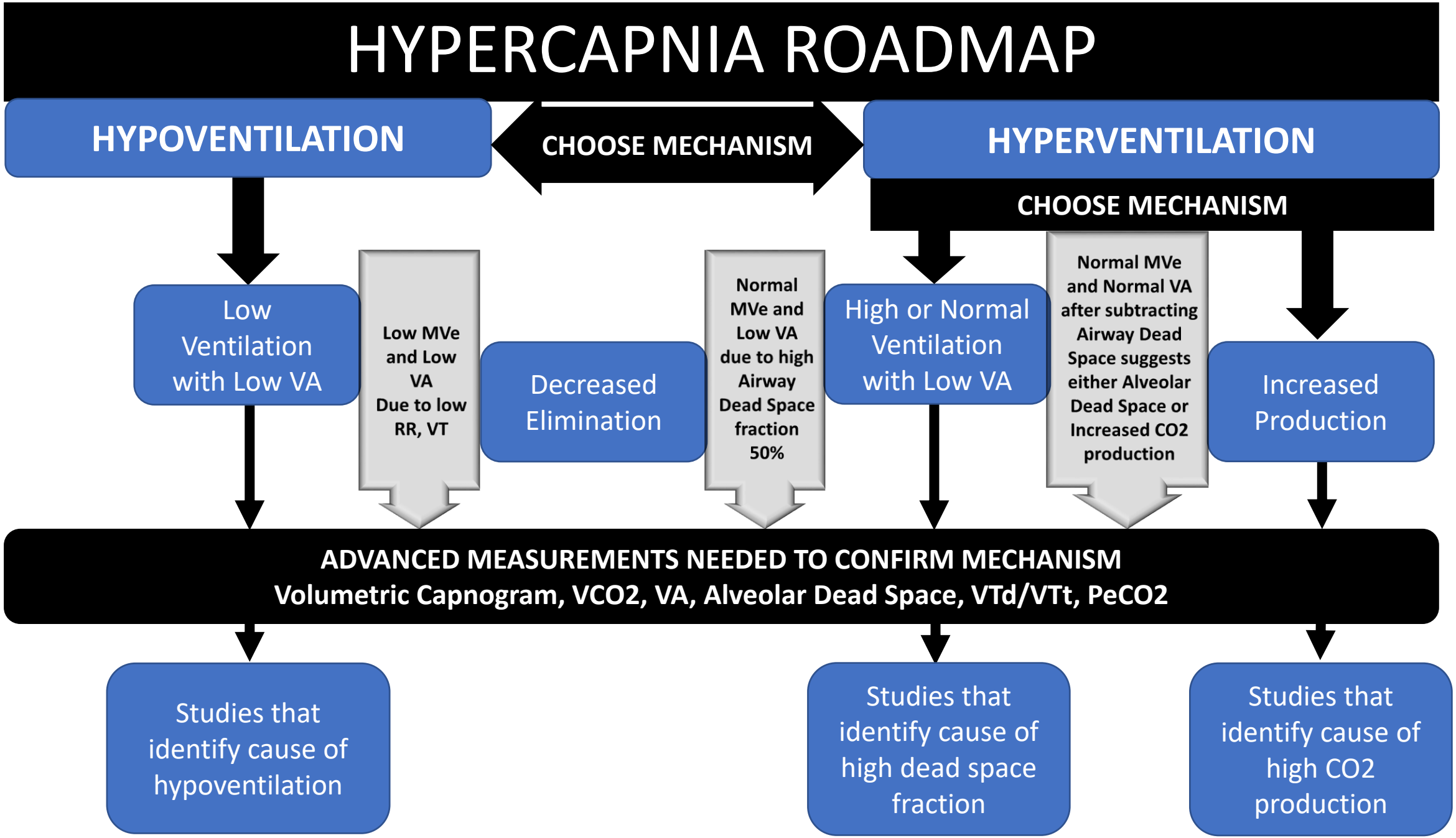
VA = (Tidal Volume – Dead Space) x RR

300ml - 150ml x 20 = **3L/min**

VTd/VTt=50%






HYPERCAPNIA ROADMAP
HYPOVENTILATION
CHOOSE MECHANISM
HYPERVENTILATION
CHOOSE MECHANISM
Low Ventilation with Low VA
Low MVe and Low VA Due to low RR, VT
Decreased Elimination
Normal MVe and Low VA due to high Airway Dead Space fraction 50%
High or Normal Ventilation with Low VA
Normal MVe and Normal VA after subtracting Airway Dead Space suggests either Alveolar Dead Space or Increased CO2 production
Increased Production
ADVANCED MEASUREMENTS NEEDED TO CONFIRM MECHANISM
Volumetric Capnogram, VCO2, VA, Alveolar Dead Space, VTd/VTt, PeCO2
Studies that identify cause of hypoventilation
Studies that identify cause of high dead space fraction
Studies that identify cause of high CO2 production

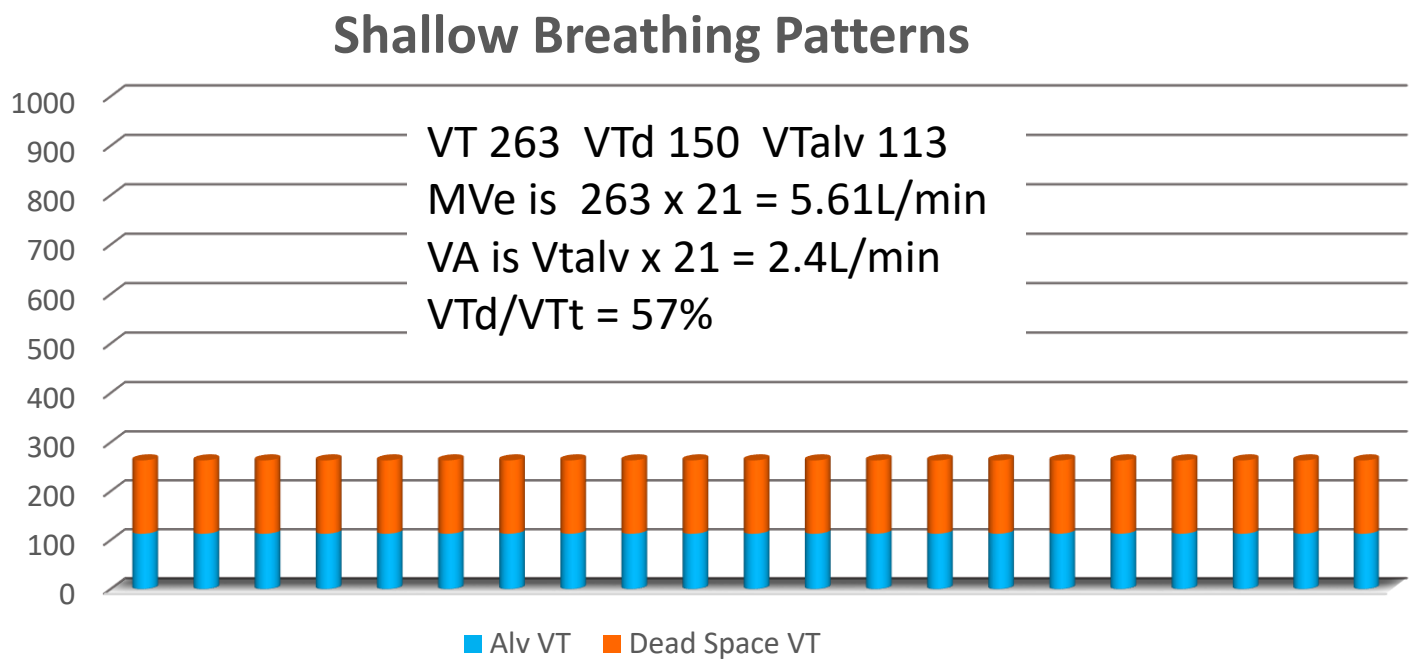
Case 3 Same Breathing Patterns But on Vent

7.34/54/317

- Is PaCO2 > 45?
- Is total MVe < 5-8L/min?
- Is VA >4.2L/min

MVe is NL!
5-8L/min

VA is Low!
<4.2L/min



HYPERCAPNIA ROADMAP

HYPOVENTILATION

CHOOSE MECHANISM

HYPERVENTILATION

Low Ventilation with Low VA

Decreased Elimination

Normal MVe and Low VA due to hi
Airw
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57

High or Normal

sed
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CHOOSE MECHANISM

ADVANCED MEASUREMENTS NEEDE
Volumetric Capnogram, VCO2, VA, Alvec

Studies that identify cause of hypoventilation

Central drive, Neuromuscular dz
Low compliance, High resistance
Low vent settings
Measure Resistance, Autopeep and Compliance on the vent, NIF
PSV to assess central drive

STUDIES THAT IDENTIFY CAUSE OF HIGH DEAD SPACE FRACTION:

==========

VQ mismatch, COPD,
High Vent pressures, PEEP,
PE, Covid Microthrombi

****

CT PE protocol
VQ scan
Assess Vent pressures/PV loops

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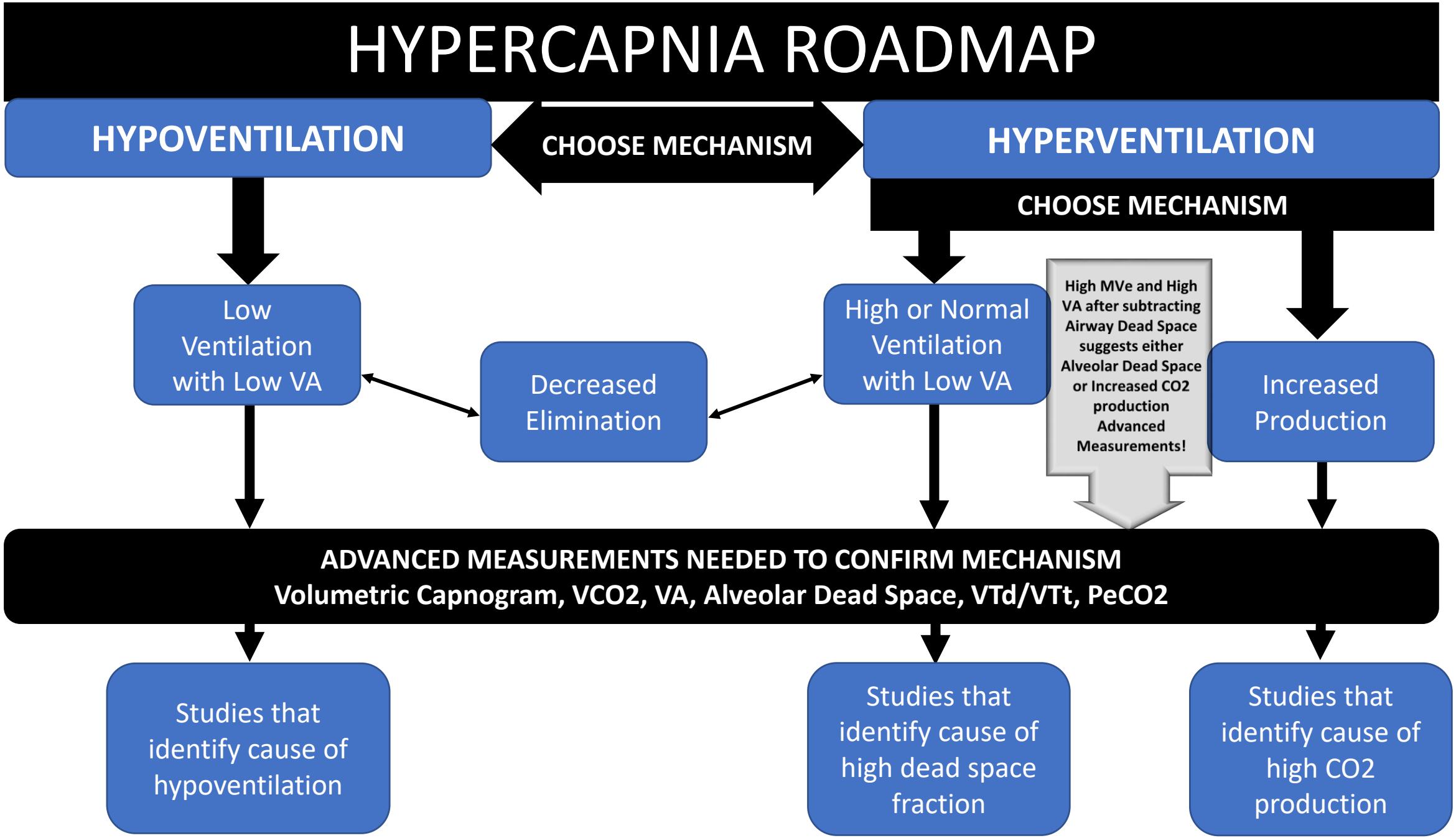
Case 4

- 55-year-old female former Smk, type 2 DM, HLD, HTN who was diagnosed with squamous cell carcinoma of the right lung metastatic to mediastinal lymph nodes and underwent VATS RLL resection and MLND
- The postoperative course complicated by PNA/resp failure requiring intubation
- Extubated and d/c home
- 4 days later re-admitted for acute hypoxic and hypercarbic respiratory failure attributed to bacterial PNA vs. ARDS and required intubation
- Initially on Pressure Support ventilation with PS 15 PEEP 12 FIO2 80%
  - VT rising 700>900>1000ml RR 20's Minute Ventilation 14-18L/min
  - ABG: 7.43/48/52
- Patient paralyzed for hypoxemia and high VT
  - ACPC ΔP 25 RR 25 VT 300ml, Minute Ventilation 7.4 L/min
  - ABG: 7.13/>90/79

Case 4 Vent adjustments were made: 7.39/51.5/127

- Is this patient Hypoventilating or Hyperventilating?
- Tidal Volume is 373ml
  - Alveolar VT **261ml**
  - Dead Space **112ml(51kg x 2.2ml/kg)**
- RR 40
- Minute Ventilation is **373 x 40 = 15L/min**
  - Alveolar Minute Ventilation VA

    261ml x 40 = 10.4L/min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Low Ventilation with Low VA
Decreased Elimination
High or Normal Ventilation with Low VA
High MVe and High VA after subtracting Airway Dead Space suggests either Alveolar Dead Space or Increased CO2 production Advanced Measurements!
Increased Production
ADVANCED MEASUREMENTS NEEDED TO CONFIRM MECHANISM
Volumetric Capnogram, VCO2, VA, Alveolar Dead Space, VTd/VTt, PeCO2
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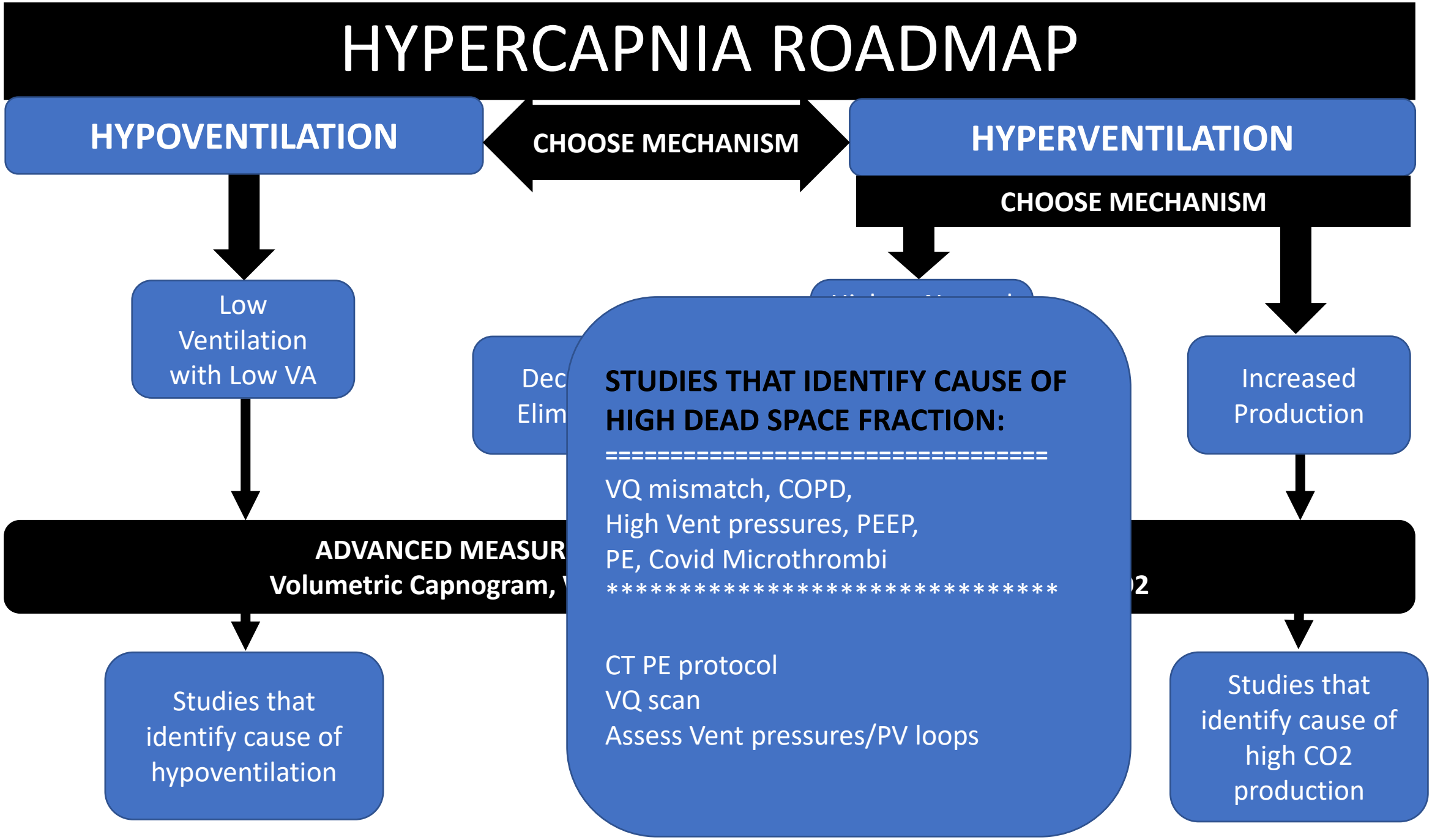
Studies that identify cause of high dead space fraction
Studies that identify cause of high CO2 production

7.427/51.2/59.5 >>> 7.31/77/61

hyperventilation with low VA vs. increased production

?

- VCO2 138
- Vd/Vt 80%
- MVe on Vent Screen
  - 15L hyperventilation
- VA is 20% of MVe
  - 3L(low and will give hypercapnia)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Volumetric Capnogram,
2
STUDIES THAT IDENTIFY CAUSE OF HIGH DEAD SPACE FRACTION:
==========
VQ mismatch, COPD,
High Vent pressures, PEEP,
PE, Covid Microthrombi
****
CT PE protocol
VQ scan
Assess Vent pressures/PV loops
Studies that identify cause of hypoventilation
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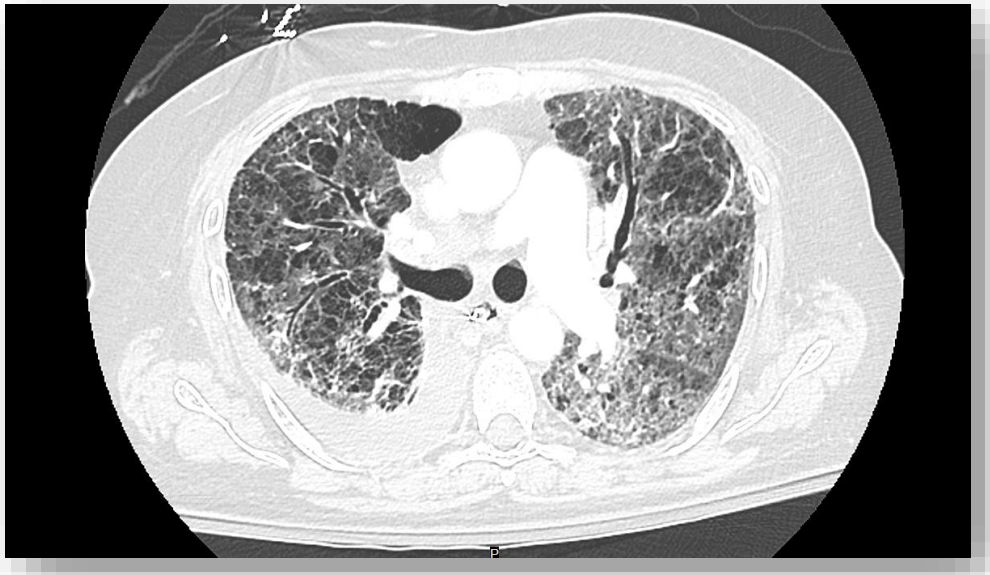
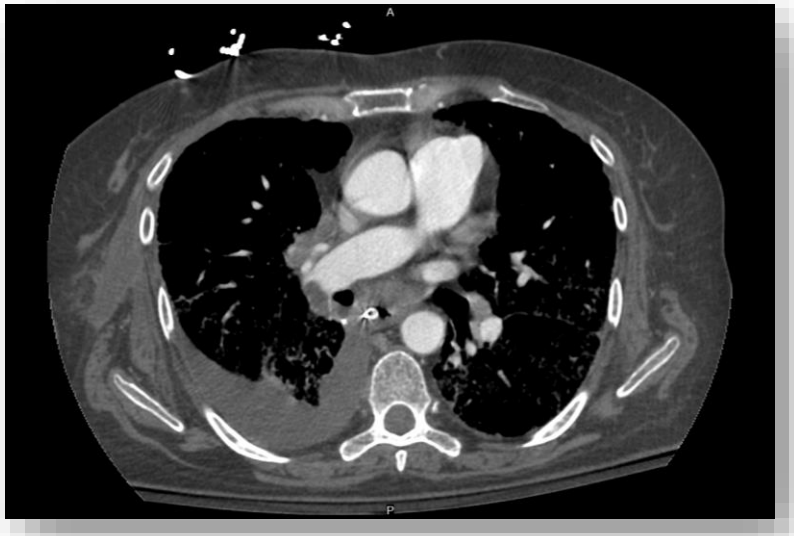
Case 4

- Investigation of underlying causes of:
  - Shark-finn capnogram
  - 80% dead space

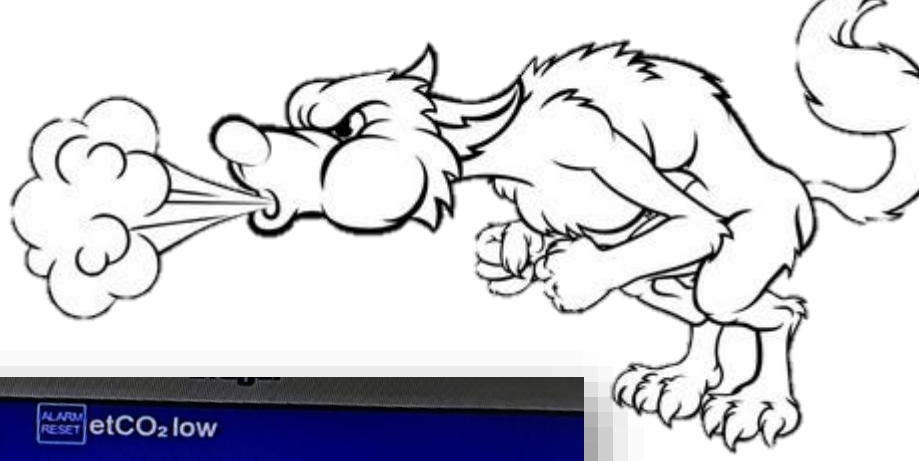




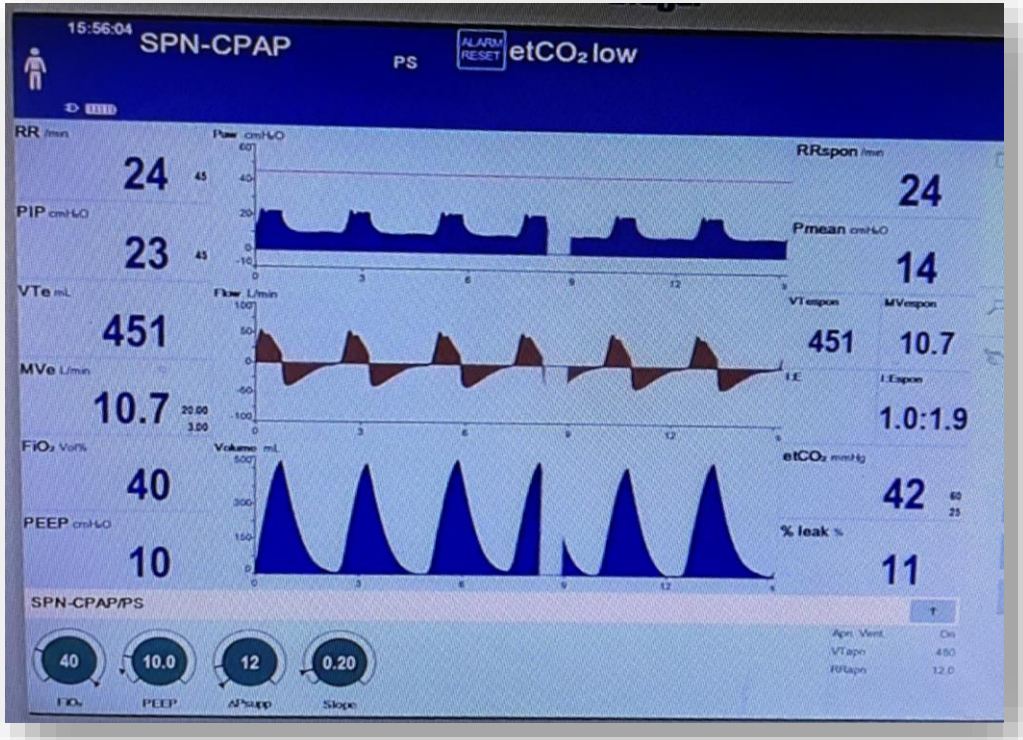
Case 5

- 56-year-old male smoker with PMH significant for Asthma, diagnosed with a biliary tumor and underwent an open laparotomy, cholecystectomy, partial left hepatectomy, and portal lymphadenectomy for a malignant intraductal mass.
- The intraoperative and postoperative courses were uneventful.
- He was discharged home.
- 6 days later readmitted with a perihepatic fluid collection, underwent percutaneous placement of a 10-Fr drainage catheter and evacuation of 20 mL of purulent fluid.
- His course was complicated by
  - Afib with RVR
  - Acute hypoxic respiratory failure due to pulmonary edema and ARDS initially on BIPAP but eventually required intubation.
  - Blood cultures grew various gut species Streptococcus anginosus and Granulicatella adiacens..

Should we extubate this guy?

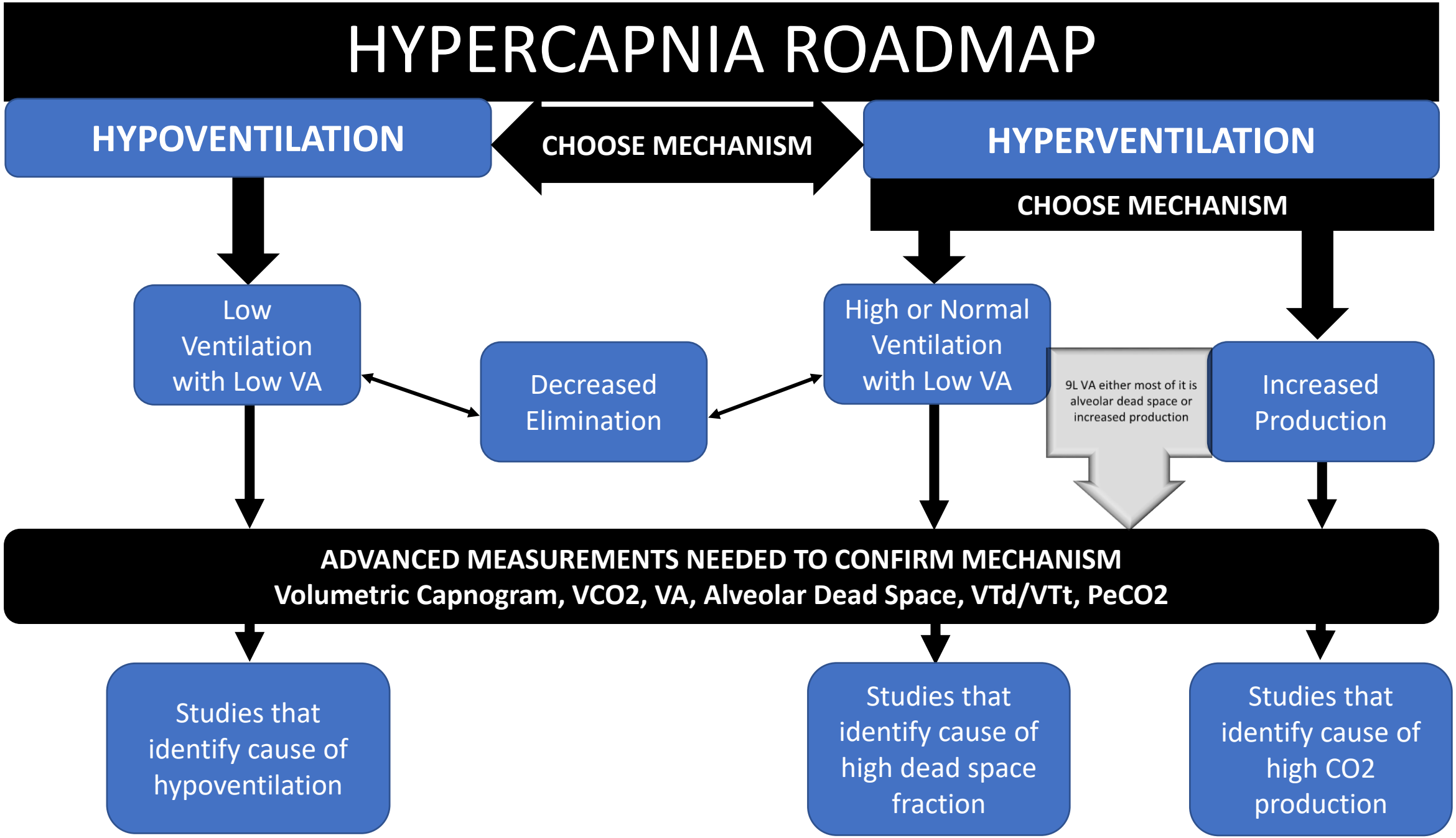


What is this huffing and puffing all about?



- Tidal Volume is 526ml, RR24
  - Alveolar VT 376
  - Dead Space VT 150

- Minute Ventilation is 12L/min
- Alveolar Minute Ventilation VA 9L/m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9L VA either most of it is alveolar dead space or increased production
Increased Production
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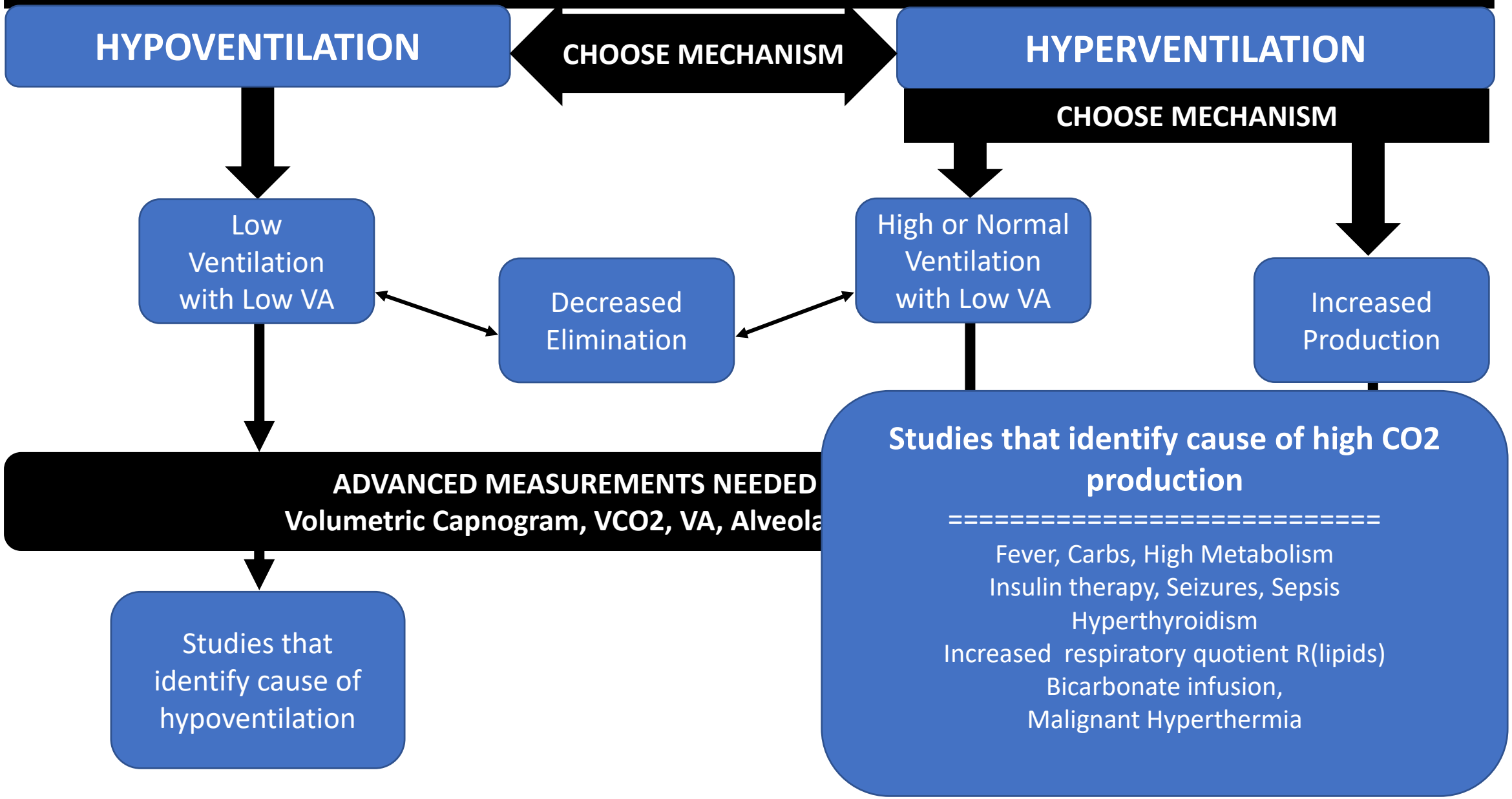
Studies that identify cause of high CO2 production

So what could be the explanation for all the huffing and the puffing?

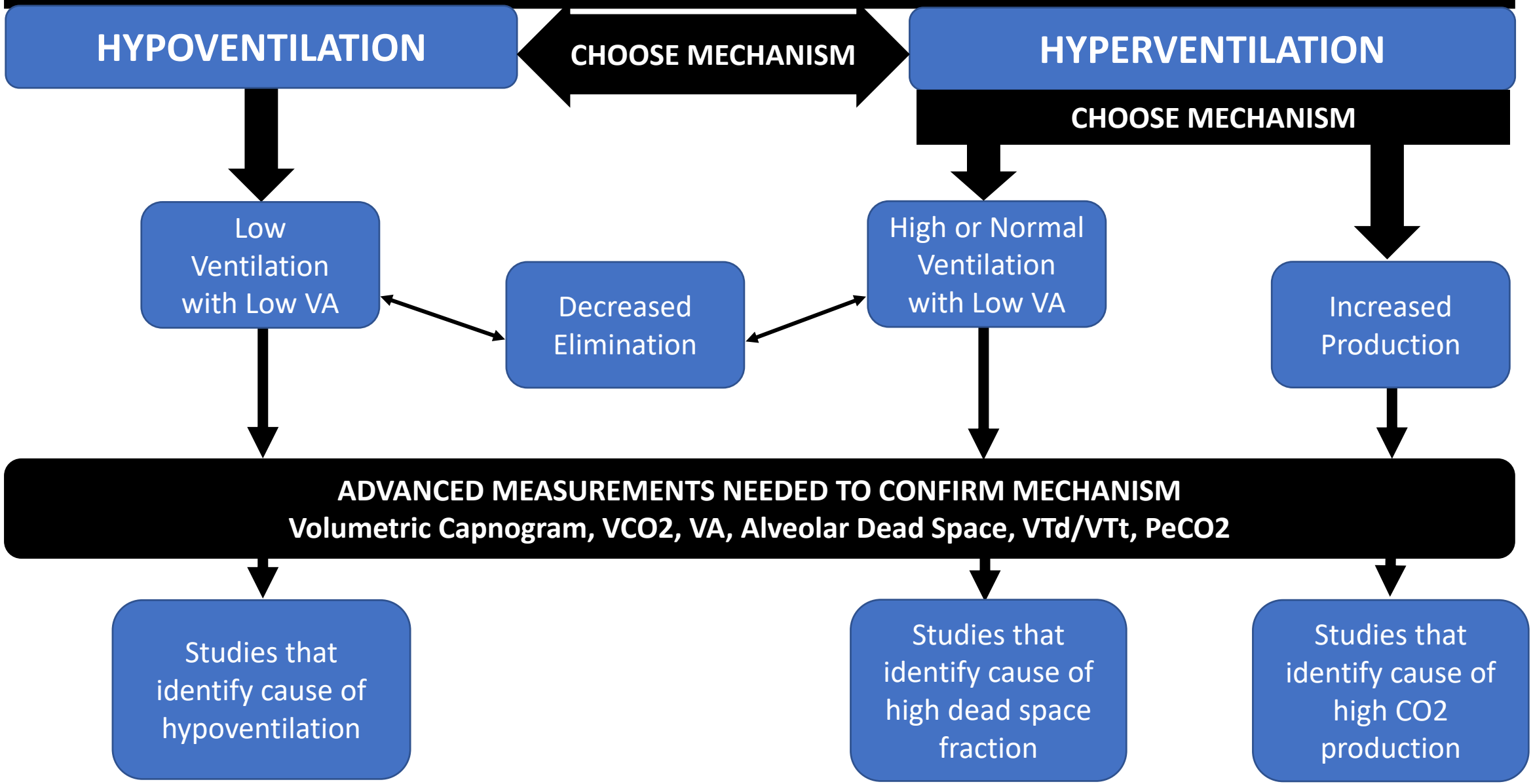
- Volumetric capnography showed
  - VCO2/min = 316-360ml/min
  - Likely cause of hyperventilation.
  - Vd/Vt = 20%.
  - mild shark fin morphology(Asthma)
  - Abdomen distended on exam
  - Tube feeds were stopped.

HYPERCAPNIA ROADMAP



The next day the huffing and the puffing went away?

HYPERCAPNIA DECONSTRUCTOR



HYPERCAPNEA DECONSTRUCTOR

It's not a device, it's a thought process