Capnometery

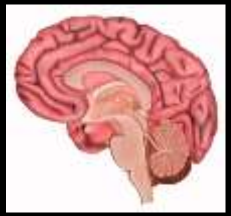
Pawan Kumar Singh

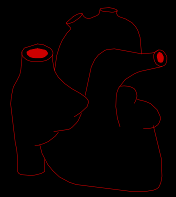
Contents

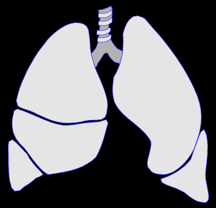
Respiratory cycle

- Breathing: Process of moving O_2 inside body and CO_2 outside
- Metabolism: Aerobic and anaerobic, producing CO_2
- Ventilation: Washing off of CO_2 from lungs

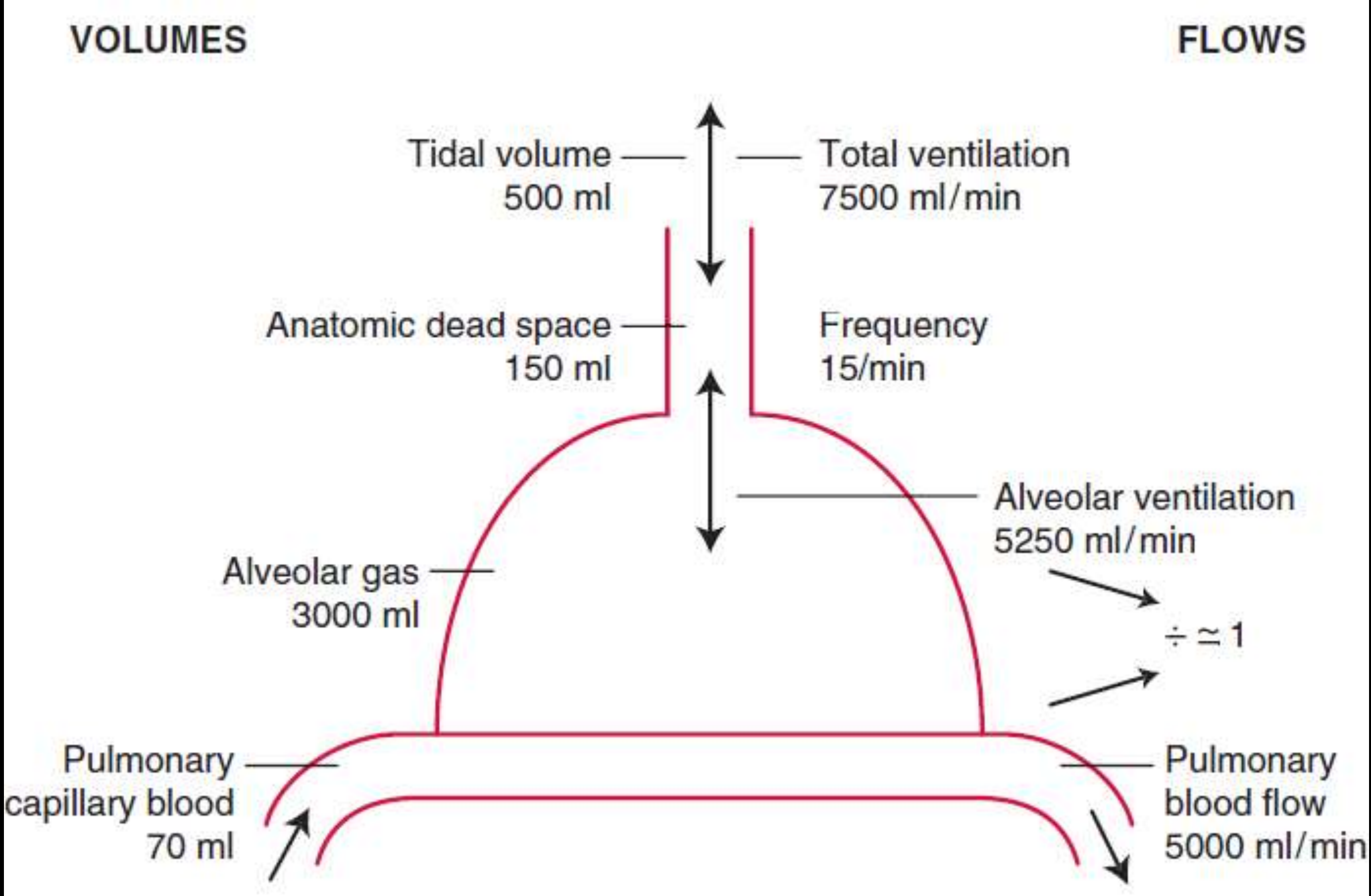
Respiration - The Big Picture

1  Cellular Metabolism of food into energy - O_2 consumption & CO_2 Production

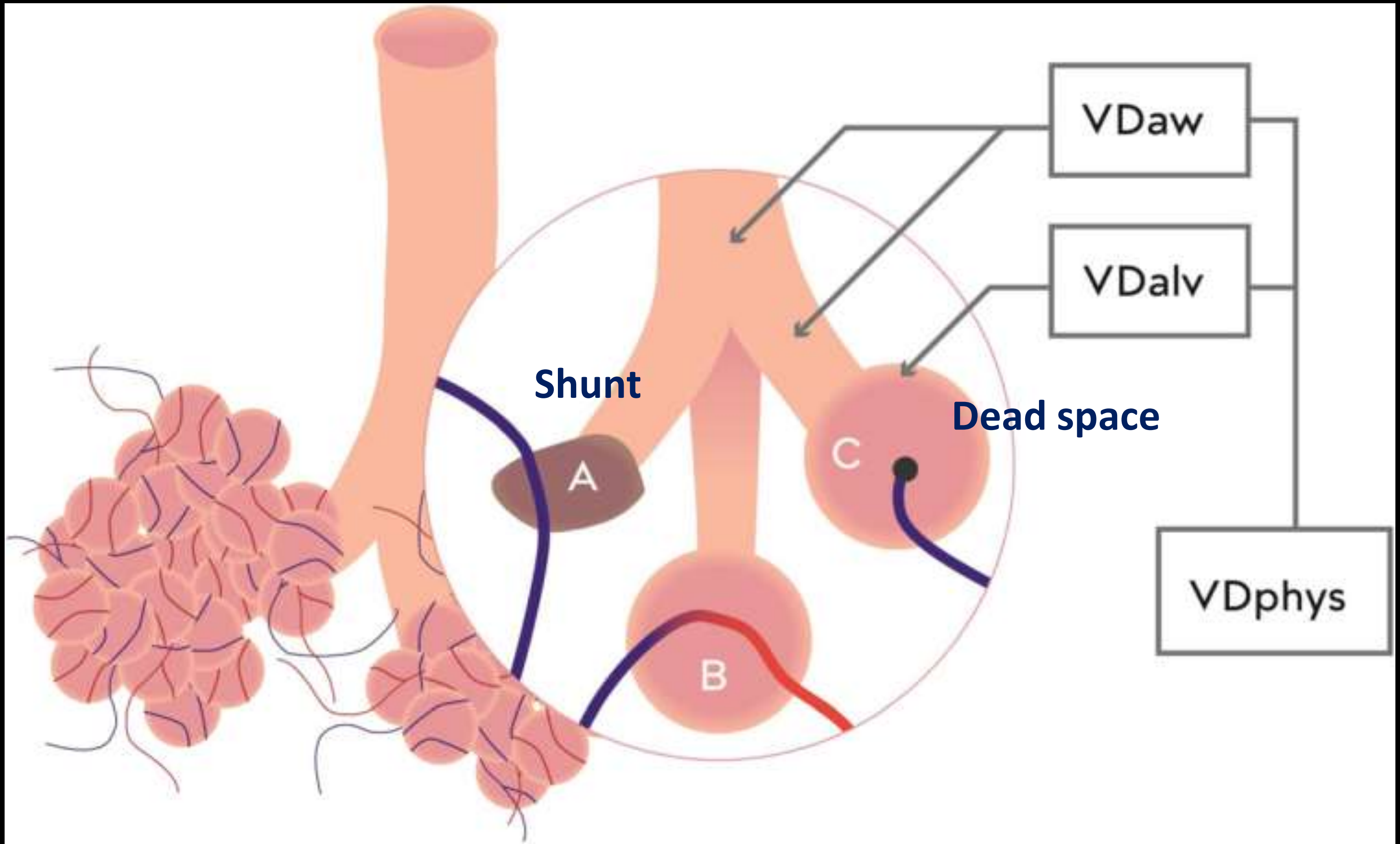
2  Transport of O_2 & CO_2 between cells and pulmonary capillaries, & diffusion.

3  Ventilation between alveoli & atmosphere

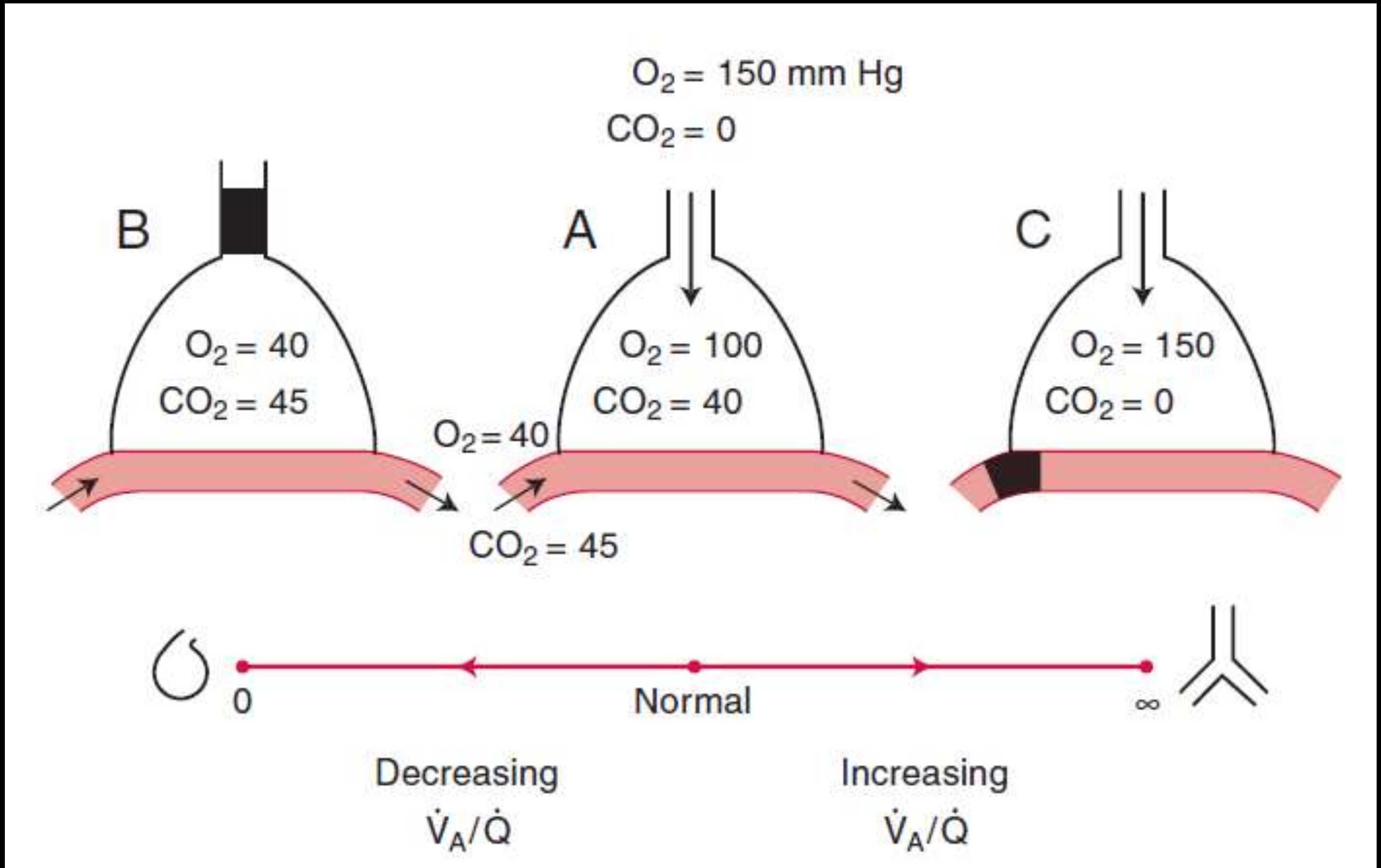
Physiology of Ventilation



Heterogeneity of Lung



Effect of shunt and dead space



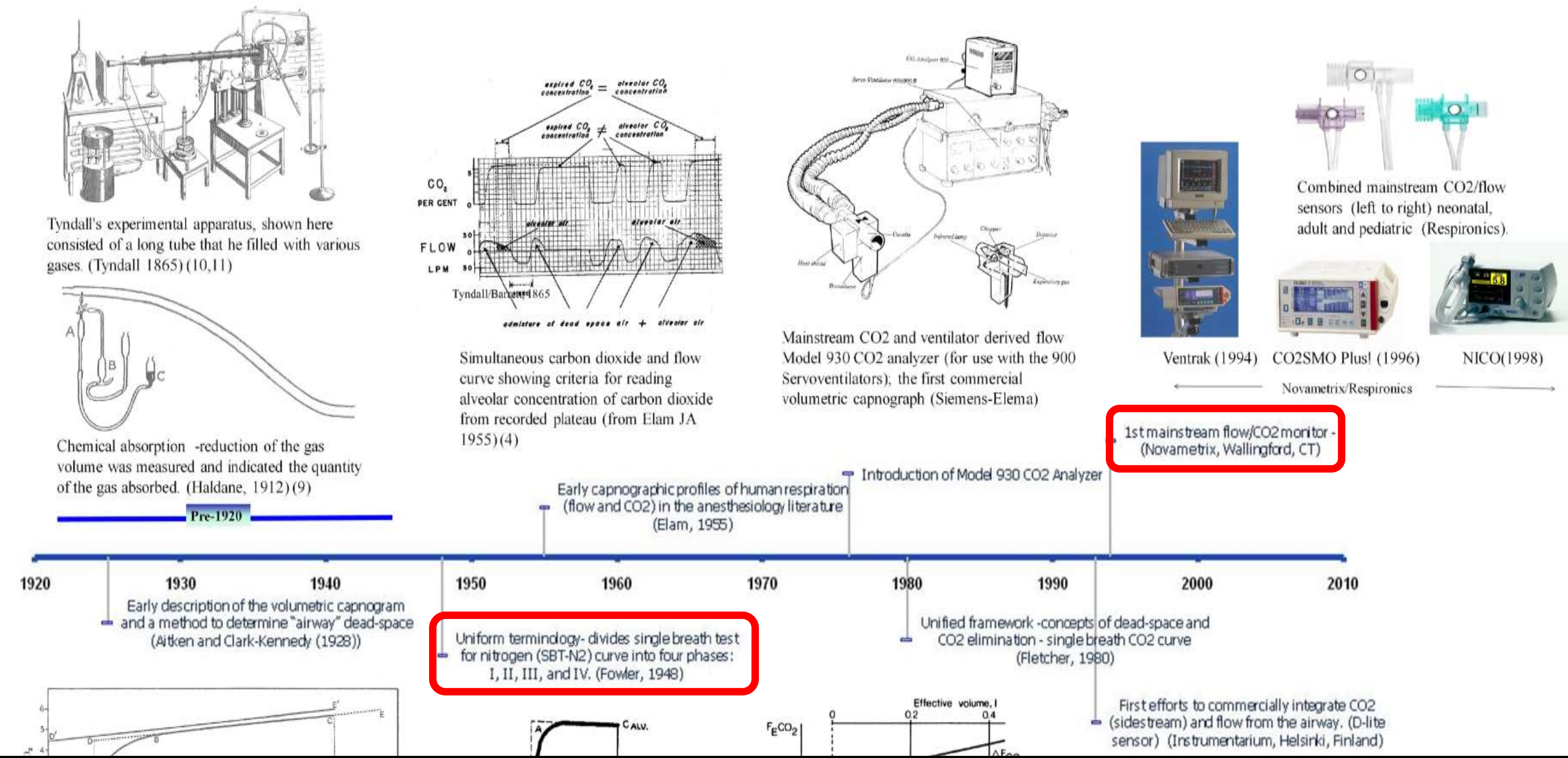
Conditions that can effect CO_2 in expired air

- Decreased production
- Decreased transport
- Decreased lung perfusion
- Decreased ventilation
- Ventilator malfunction
- Monitoring equipment malfunction

Contents

History of Capnometery

- "*Capnos*" is a Greek word meaning "Smoke"
- Measurement of CO_2 in air was first used by *Haldane* and *Tyndall* for the analysis of mine air.
- Aiken and Clark-Kennedy, in 1928, tried to analyze dead space by using expired CO_2 measurements
- ***Prof Bob Smalhout*** used the first CO_2 analyzer on a patients in Netherlands in 1962



Ref. Timeline, Hamilton Manual

Contents

Types of monitoring

- Capnometery: Provides a single time quantitative value of CO_2 fraction in one particular amount of air
- Capnography: Provides a real time graphical representation of CO_2 that can be against time or tidal volume

Types of sensors used

- Qualitative colorimetric
- Chemically absorbed from a known gas volume.
- Mass spectrometry systems
- Photoacoustic spectrography
- Infrared sensor

Colorimetric Capnometery

- Qualitative: Provides information about CO_2 by calorimetric method
- Rapid, Portable, disposable, inexpensive, single-use devices

- Limitation: false positive readings when the detectio
contaminated with gastric acid or acidic solutions ar
an endotracheal tube

Calorimeter

- Quantitative: uses infrared sensors to detect single time values

Capnography

- Capnography incorporates the additional feature of displaying the CO_2 waveform known as a *Capnograms*
- Real-time representation

Types of Capnography

Mainstream CO_2 Monitoring

- An infrared optical bench placed within the gas flow pathway at the airway.
- Real-time CO_2 values within the airway and a real-time graphical representation of the CO_2 waveform

- Limitation: Cost, potential of damage to the sensor, increases dead space, fouling with coughed up secretions and condens weight of the adapter on the circuit

Side-stream CO_2 Monitoring

- Devices aspirate a gas sample from a ventilator breathing circu
- Utilize an infrared CO_2 sensor in a monitor located away from the patient
- Can be used in non intubated patients as well
- Side-stream sample method often requires use of a water trap to prevent contamination.

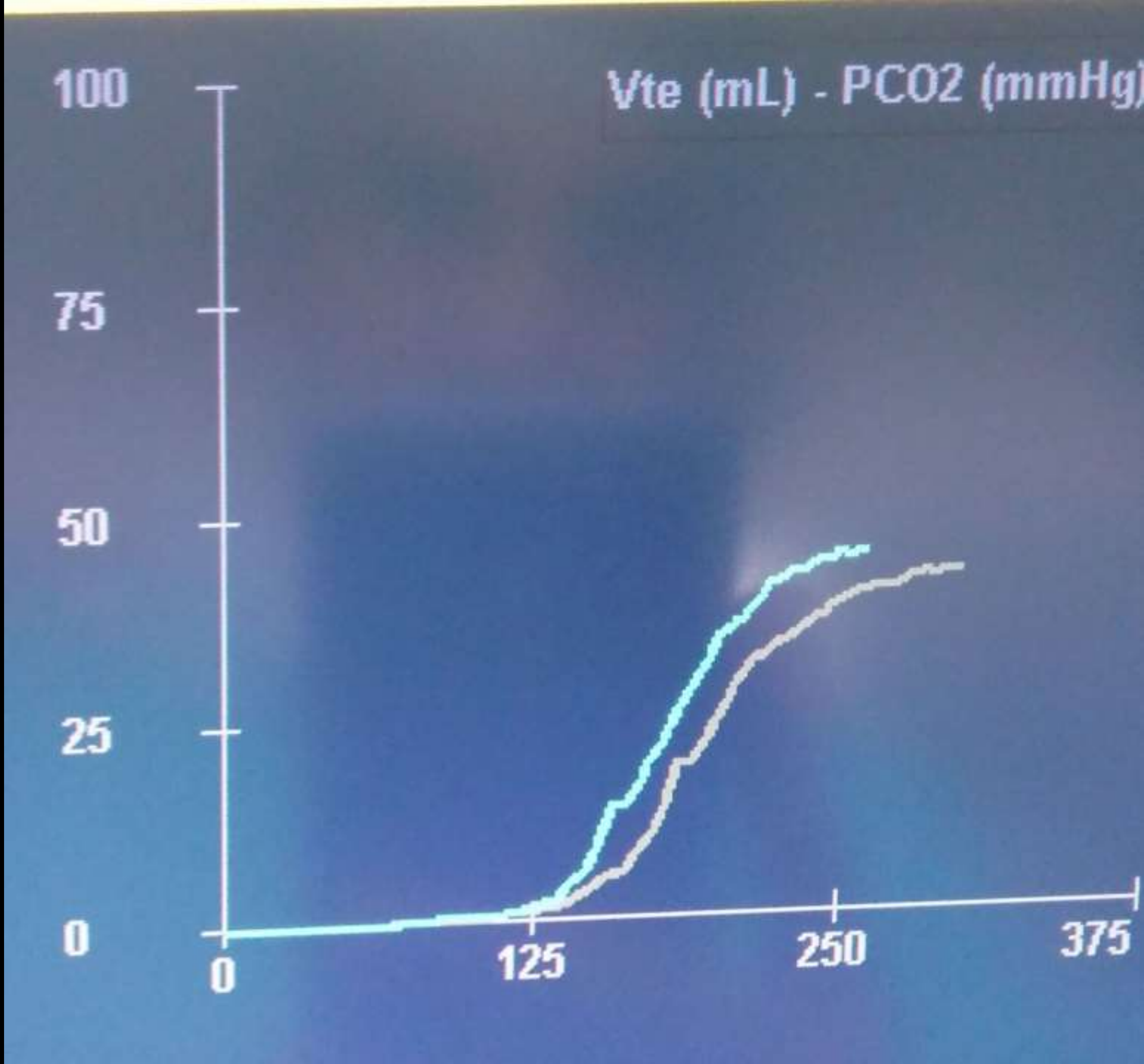
- Limitation: Cost, time delay in analysis, can interfere with the trigger system as air is actively aspirated.

Contents

Types of Capnograms

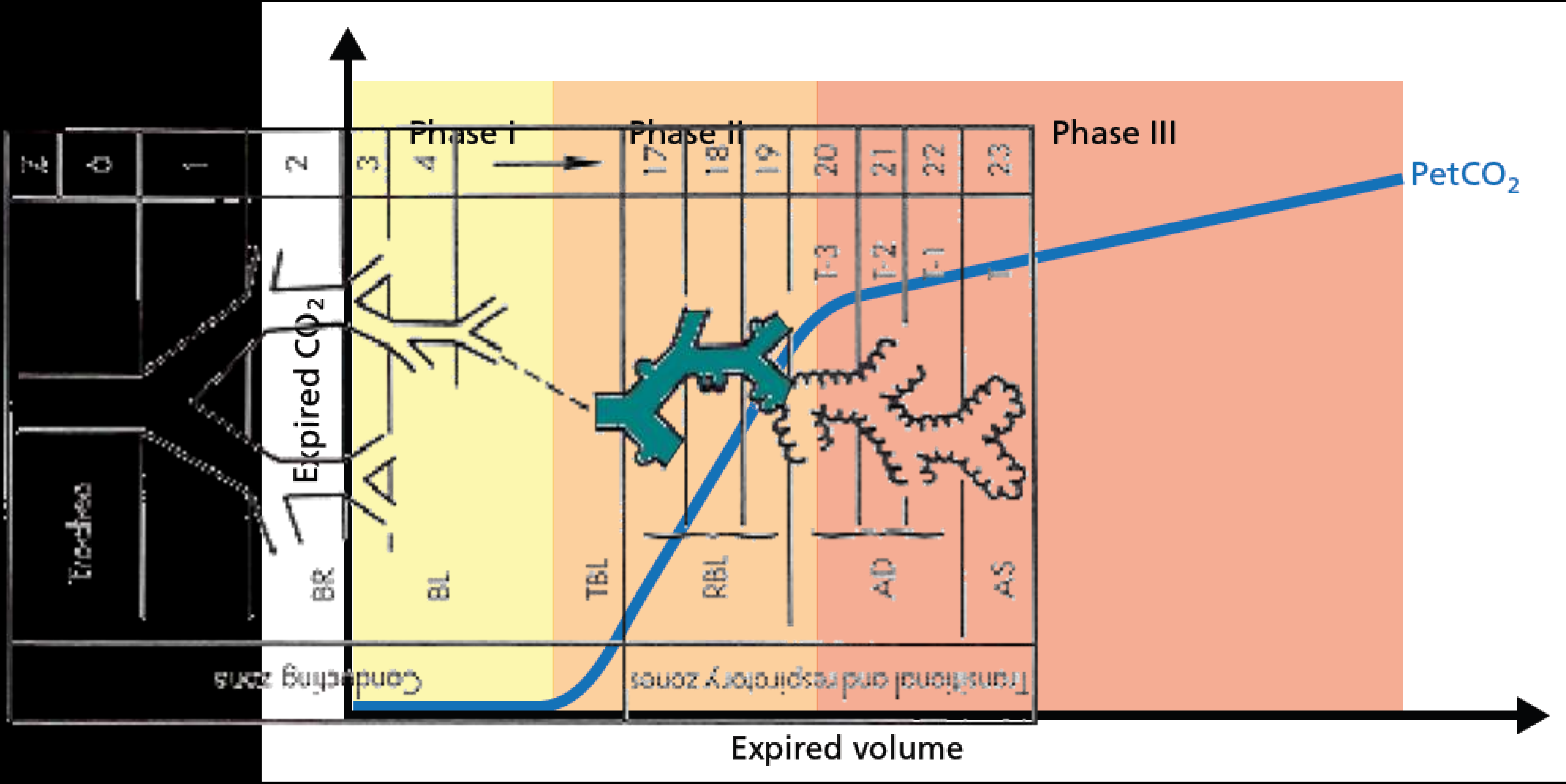
- Against time

- Against Volume

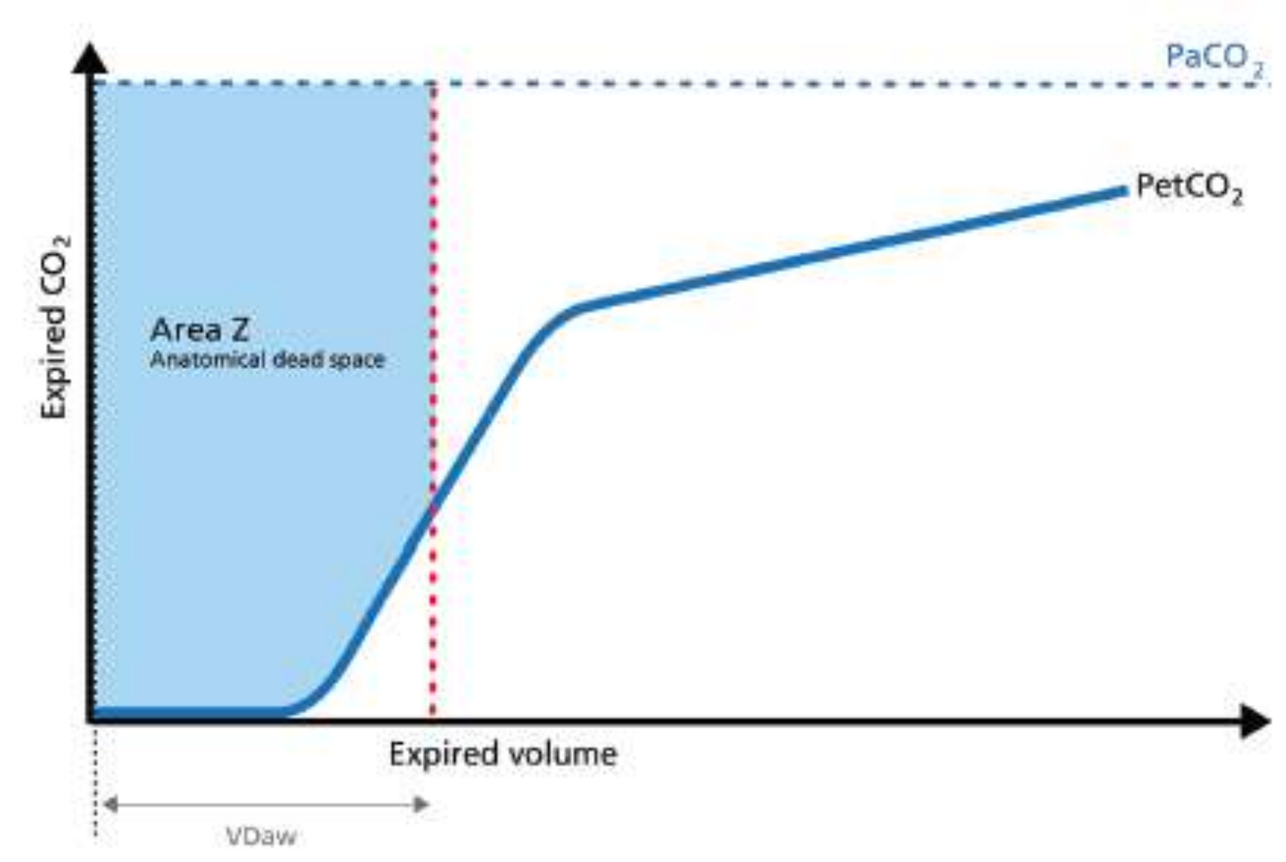


The volumetric capnogram

Description of Capnograms

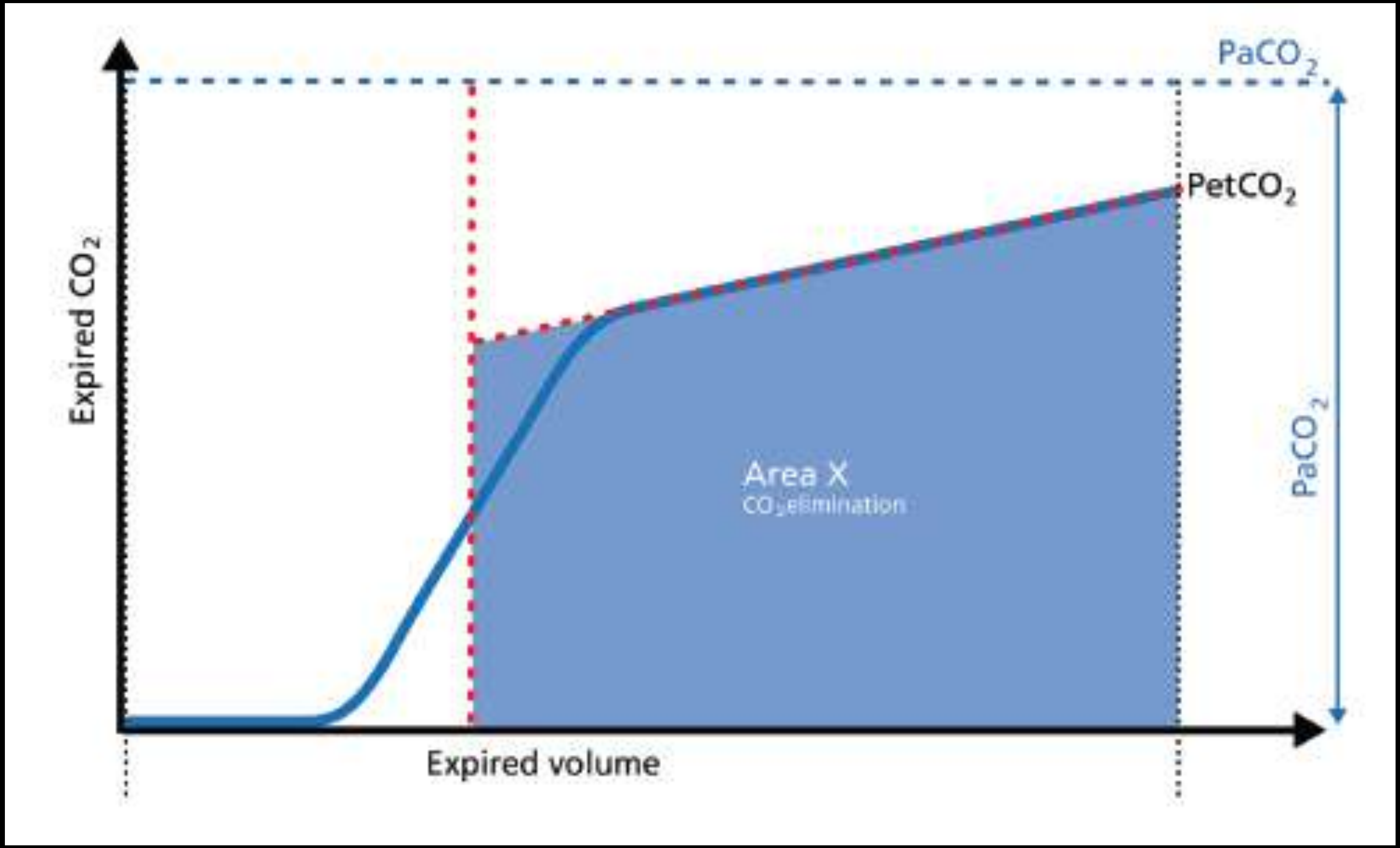


Dead space

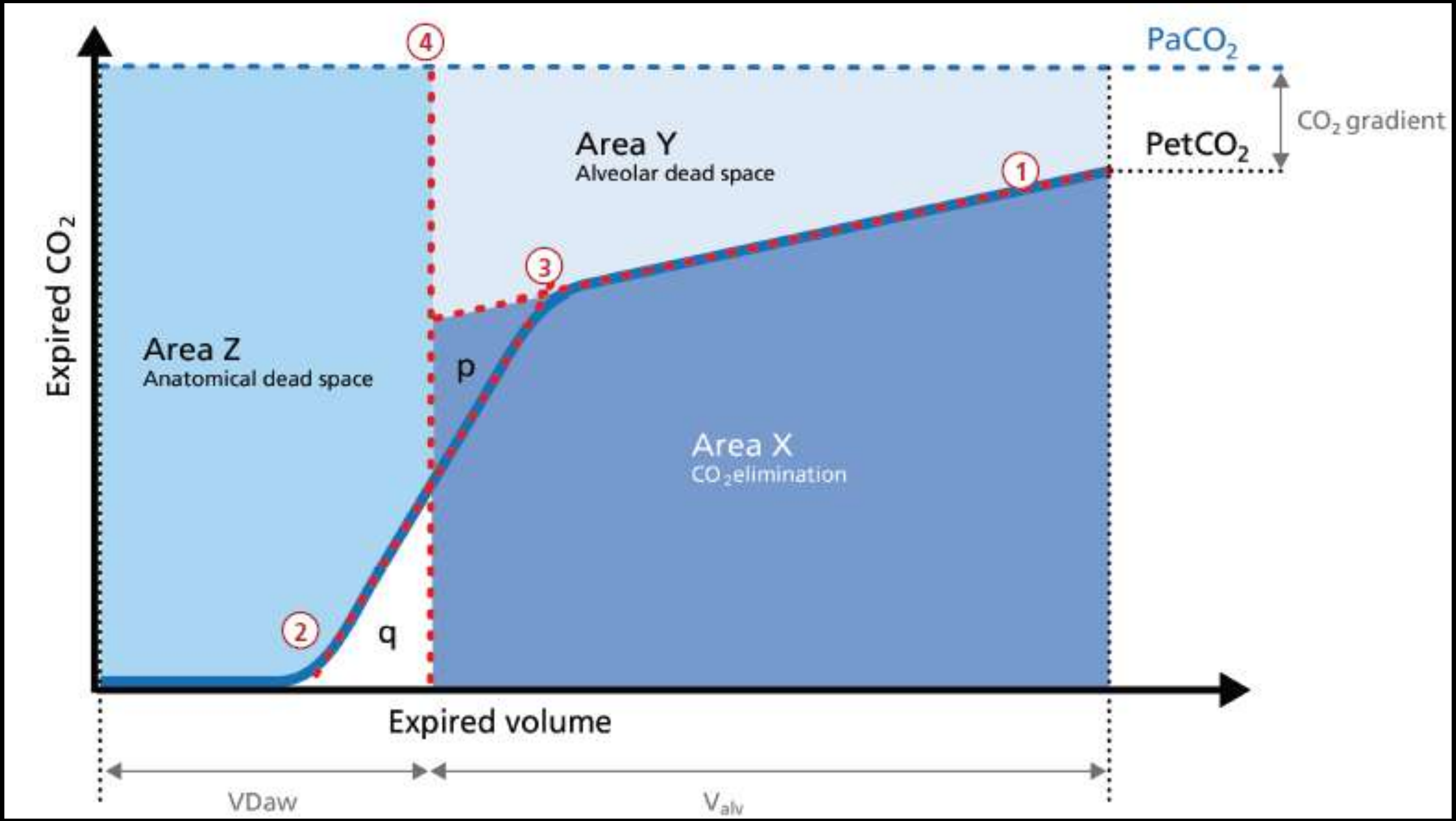


PaCO2
PetCO2
Expired CO2
Area Z
Anatomical dead space
Expired volume
VDaw

Volume of CO_2 eliminated



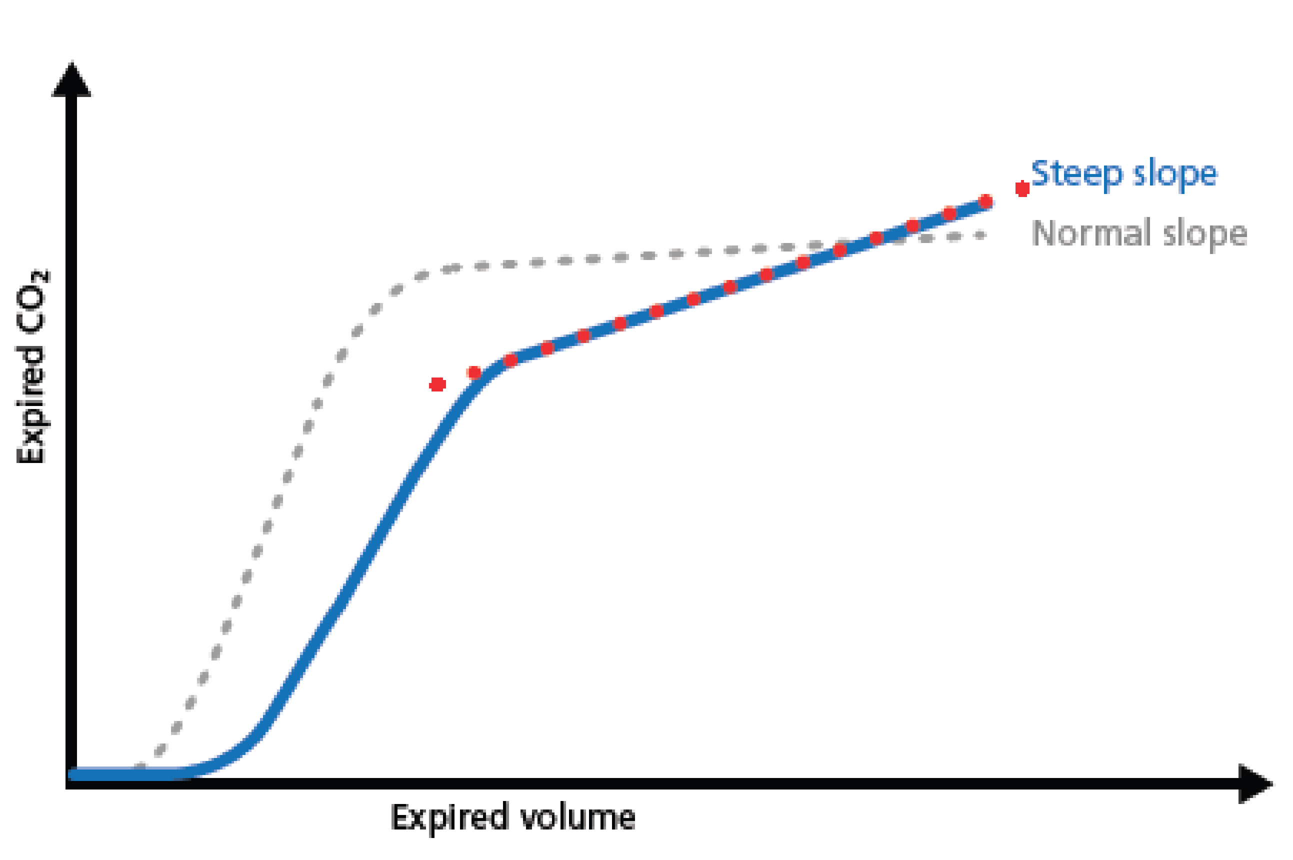
Physiological dead space



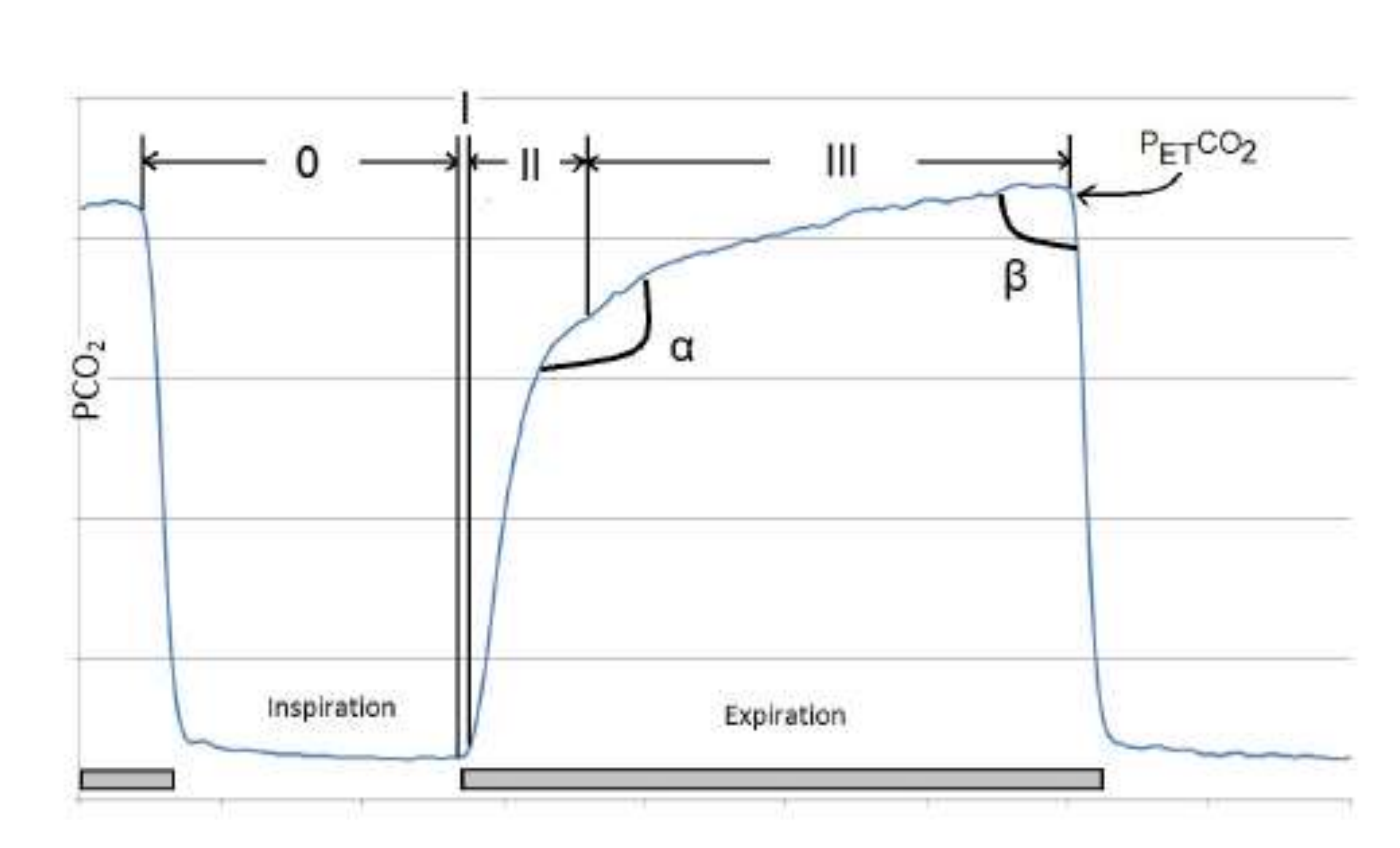
Fowler's approach

Slope of phase III

- Steeper the slope, more is the dead space
- Eg. ARDS and COPD



Time based Capnograms and its features



Kodali BS, Philips J. Anesth Analg. 2000; 91(4): 973-7

What is the difference?

Volumetric Capnography

- Phase are defined
- Dead space can be measured (by Fowler's method)
- Dead space ratio can also be measured
- *fdLate* can be measured (arterial- end tidal PCO_2 difference at 15% predicted TLC/art $pCO_{2)}$

Time-based Capnography

- Phases are not well defined
- Dead space can't be measured
- Fowler's method is not applicable
- *fdLate* cannot be measure
- Capnograms can be used to diagnose common conditions

Contents

Non Critical care applications

1. Confirmation of Endotracheal Intubation
2. Monitoring Respiratory Status
3. Monitoring During CPR

Confirmation of endotracheal intubation

- Rates of misplaced endotracheal tubes: 23%
- When continuous PETCO2 monitoring is used, the sensitivity & specificity for confirming endotracheal intubation are both 100%
- Both qualitative and quantitative calorimeters are used
- Lack of CO_2 or lack of normal Capnograms is increasingly being used to suspect no endotracheal intubation.
- Now a common practice in paramedical emergency staff

Grmec wt al Intensive Care Med 2002; 28(6):701–704

Though…

- Similarly presence of CO_2 is being recognized as non gastric placement of Ryle's tube
- Though the presence of CO_2 in the ETT increases confidence that the ETT is properly placed, it does not *assure* that it is properly placed.
- Endobronchial intubation can have a normal-appearing Capnograms

Li et al Emerg Med 2001; 20(3):223–229.

Monitoring of respiratory status

- Exhaled CO_2 offers an accurate and reliable means of measuring respiratory frequency.
- A low respiratory frequency is an indicator of respiratory depression from Sedation and can be detected early by exhaled CO_2 monitoring.
- Increased rate on the other hand can detect distress early.

J Crit Care 2014;29(6):1035-1040.

Monitoring of respiratory status…

- Because oxygenation and ventilation are separate physiologic processes, pulse oximetry monitoring of oxygenation alone should not be considered a suitable monitor of ventilatory function
- Oxygen saturation is frequently maintained, even at a low breathing frequency
- Pulse oximetry alone often fails to detect respiratory depression, hypoventilation, and apnea episodes.

Monitoring of Respiratory status…

- Measuring CO_2 at the same time helps to assess the ventilatory status
- Exhaled CO_2 monitoring in the post-anesthesia setting, during procedural sedation, and when administering opiate analgesia can provide an important early warning of ventilatory compromise

Drug-induced hypoventilation- 2 types

Type 1

- Bradypneic hypoventilation
- Characterized by a decreased respiratory frequency
- Slightly decreased tidal volume,
- And an increased PETCO2 & PaCO2

Type 2

- Hypopneic hypoventilation
- Characterized by decrease in tidal volume
- Slightly decreased respiratory frequency
- And a decreased or normal PETCO2 with elevated PaCO2

Drug-induced hypoventilation- 2 types…

Classification	Respi Rate	Tidal Vol	Anat Dead space	Vd/Vt	$P_{ET}CO_2$	$PaCO_2$
Type 1	Decreased	Static	Static	No change	Increased	Increased
Type 2	Normal	Decreased	Static	Increased	Static	Increased

Capnography for procedural sedation in the ED: a systematic review.

- **Results**: 7 studies met the eligibility criteria representing a total of 662 patients. The aggregate diagnostic accuracy for Capnography identifying an adverse event included a diagnostic OR of approximately 6 with no statistical significance.
- **Conclusion:** There is no firm evidence that capnography provides additional safety compared with standard monitoring alone during procedural sedation in adults in the ED

Dwedney et al Emerg Med J. 2016 Aug 26.
Conway et al Syst Rev. 2015 Jul 14;4:92.

Monitoring During CPR

- The correct placement of an advanced airway
- The effectiveness of cardiac compressions
- The return of spontaneous circulation
- The prediction of outcome and survival during cardiac arrest

Kalenda et al Resuscitation 1978;6(4):259–263.

Role to predict survival

- Changes in $PETCO_2$ during resuscitation attempts predicted outcomes and return of spontaneous circulation
- $PETCO_2$ less than 10 mm Hg during CPR was suggestive of poor outcome.
- This suggests that PETCO2 can be used in deciding when to terminate resuscitation efforts in adult patients.

Field et al Circulation 2010;122(18 Suppl 3): S640-S656.

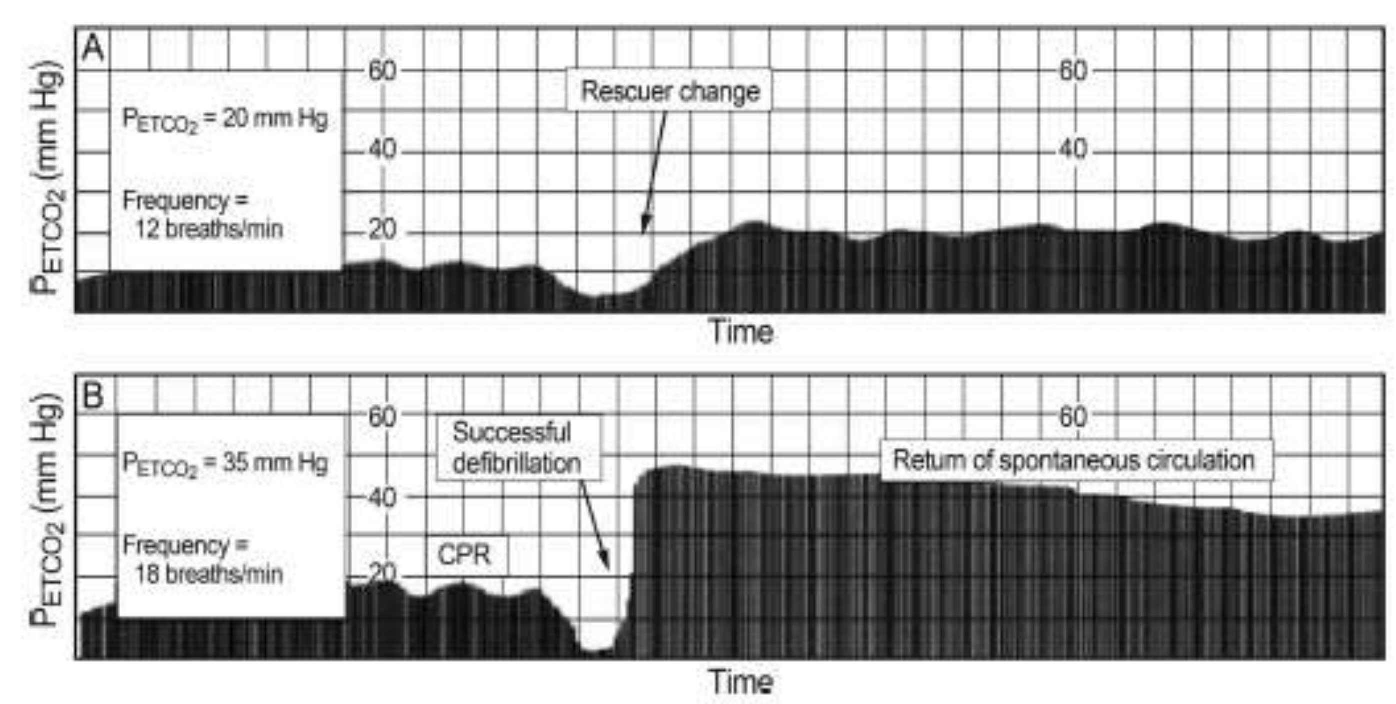
Role to predict survival…

- $P_{ET}CO_2$ at 20 min after the initiation of CPR with a threshold of 14 mmHg can be used as a screening test to predict return of spontaneous circulation
- Sensitivity, specificity, NPV, PPV of 100%.

Field et al Circulation 2010;122(18 Suppl 3): S640-S656.

Rescuer Fatigue…

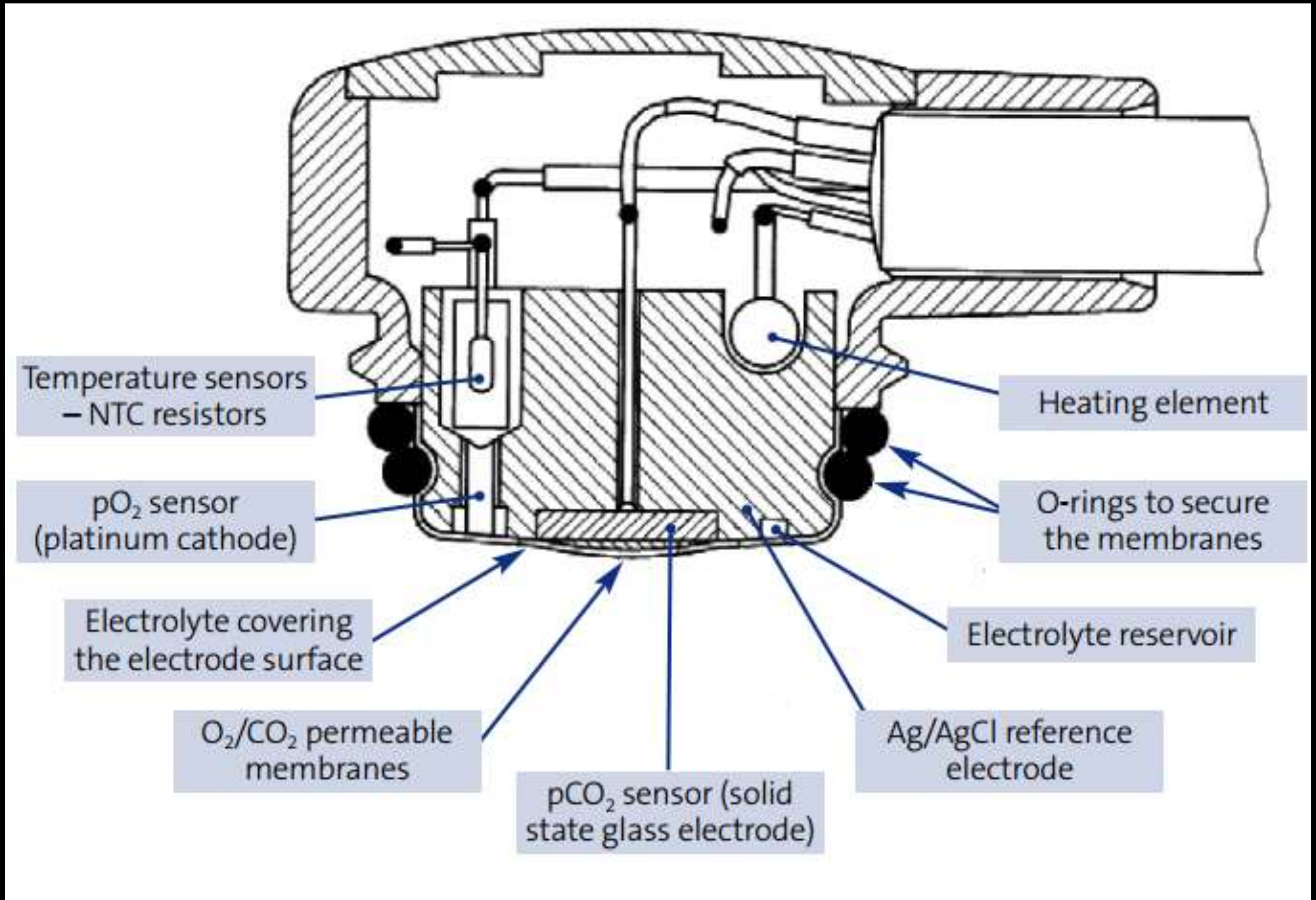
- $P_{ET}CO_2$ monitoring during CPR can be used to detect the effectiveness of external cardiac compression and the development of rescuer fatigue



Validation and evidence

Transcutaneous CO_2

Principle & functioning



Correlation of tCO_2 monitoring with $PaCO_2$

- **Methods**: 67 patients of chronic respiratory failure on NIV were included. Arterial samples and tCO_2 reading were assessed
- **Result**: 53% patients were hypercapenic and there was significant correlation between the values measure by arterial CO_2 and tCO_2
- **Conclusion**: With the device tested, in stable patients under NIV treatment for CRF, tCO_2 accurately reflects PaCO2.

Transcutaneous CO_2 monitoring

- **Methods**: Data from 136 procedure of endoscopy with sedation with Ramifentanil and Propofol was reviewed for correlation of $ETCO_2$ and incidence of respiratory depression
- **Results**: Respiratory depression was significantly associated with rise in Transcutaneously measured pCO_2
- **Conclusions**: Transcutaneous CO_2 can be used to detect respiratory depression in conscious sedation procedures.

Hannam et al J Pharmacol Exp Ther 356:563–573, March 2016

Use of tCO_2 in Chronic Hypercapenic respiratory failures requiring NIV

- **Methods**: Titration polysomnography studies were done on 12 patients with transcutaneous CO_2 measurements in awake and asleep state
- **Results**: Patients were followed up with Epworth sleepiness score before and after transcutaneous CO_2 guided titration. 6 patients improved, 5 detiorated and one worsened
- **Conclusion**: Cutaneous capnography is feasible and permits the optimization of non-invasive ventilation pressure settings in patients with chronic hypercapenic respiratory failure

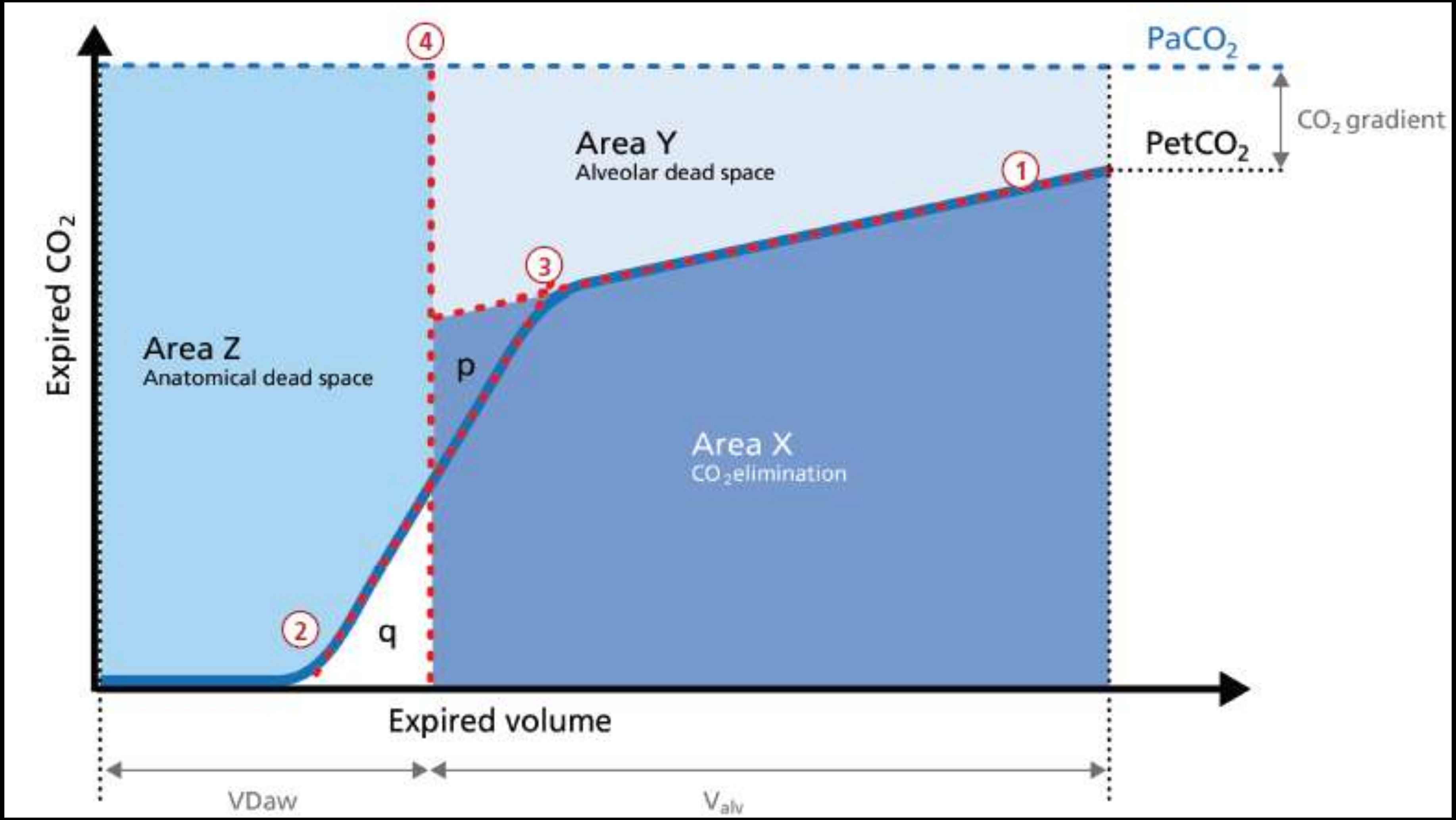
Hajed et al Journal of Clinical and Diagnostic Research. 2016 Sep, 10(9)

Contents

Volumetric Capnography (against volume)

- Volumetric capnography differs from standard capnography in that exhaled CO_2 is plotted against the exhaled tidal volume.
- Can reveal important information in regarding efficiency of ventilation and perfusion, the physiological dead space fraction, and the metabolic rate of the patient
- These features are indications of use of Volumetric capnography in ICU

Physiological dead space



Fowler's approach

Monitoring Adequacy of Ventilation

- $P_{ET}CO_2$ closely approximates $PaCO_2$ and is usually 2–5 mm Hg lower, therefore can be an effective index of the adequacy of ventilation
- *Catch*: Diseased states, such as ARDS, COPD and asthma, ventilation/perfusion ($\dot{V}/\dot{Q}$) mismatch in the lungs can cause the $PaCO_2$-$P_{ET}CO_2$ difference to increase.
- $PaCO_2$-$P_{ET}CO_2$ difference can be an indication of the degree of lung injury and correlates with increased V_D/V_T
- $PaCO_2$-$P_{ET}CO_2$ difference has been shown to predict mortality in trauma patients.
- $P_{ET}CO_2$ can be measured non invasively hence decreases frequency of arterial sampling

Why bother if we have pulse ox?

- Reflects oxygenation not ventilation
- SpO2 changes lag behind the detection of hypoventilation
- Procedures are usually done with supplemental oxygen there by decreasing sensitivity of picking up over-sedation

Few uses in critical care

- Measuring dead space and hence adequacy of ventilation
- Recruitment monitoring in ARDS
- Monitoring ventilation, tube positions, tube block, system leaks
- *Diagnosing PTE*

Contents

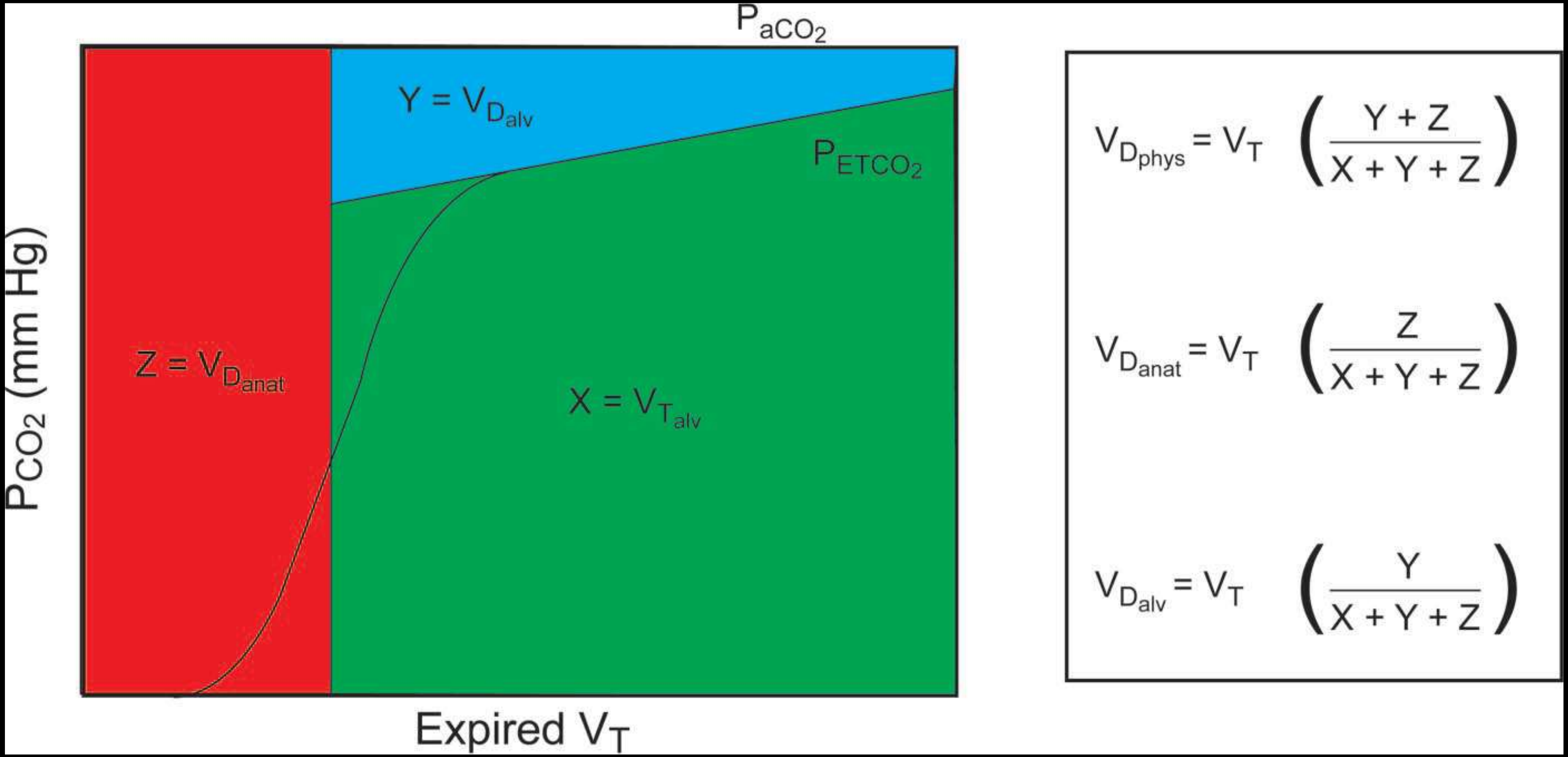
Capnometery and ARDS

- Dead space measurement
- Prognosis by volume Capnometery
- Recruitment
- Ventilation

Dead space measurement

- Four most common methods

Fowler’s method



Bohr’ equations

- $Vt = Va + Vd$
- $Va = Vt – Vd$
- *$Vt \times Feco2 = Va \times Faco2$*
- *$Vt \times Feco2 = (Vt – Vd) \times Faco2$*
- *$Vd/Vt = Faco2 - Feco2/Faco2$*
- $Fco2 = K \times Pco2$
- $Vd/Vt = PACo2 – Peco2/ PAco2$………………… (Bohr’s Equation)

Enghoff modification of Bohr equation

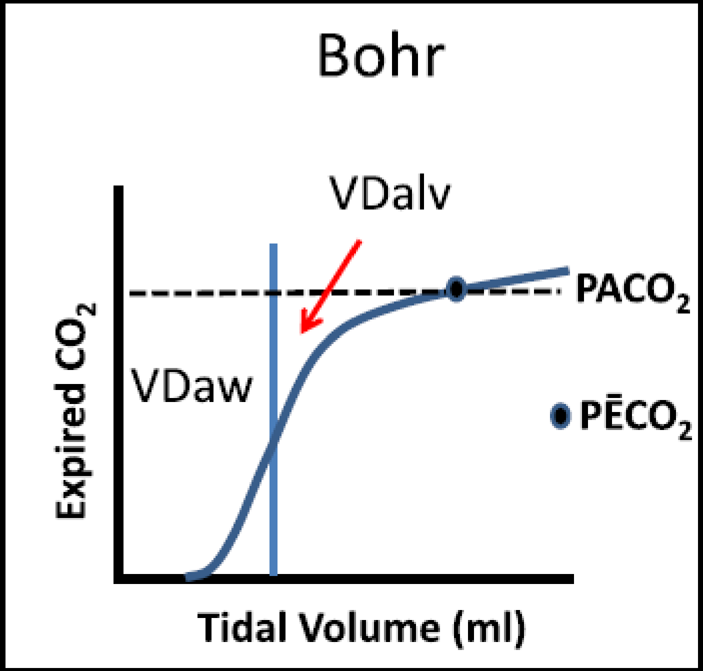
- CO_2 is easily diffusible gas
- So partial pressure of CO2 in alveoli and arterial blood should be same
- $PACO_2 = PaCO_2$
- *Vd/Vt(enghoff) = Paco2 – Peco2/Paco2*

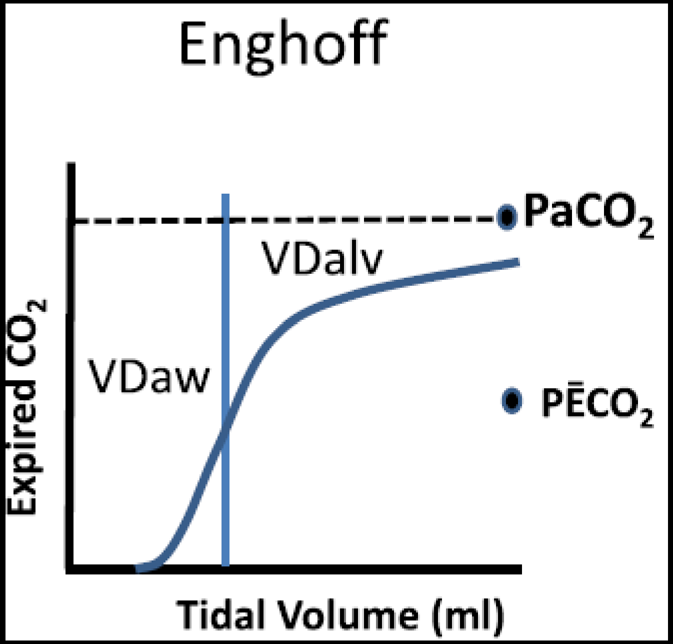
What is the difference than?

Table 2. Differences Between the Approaches of Bohr and Enghoff

	Bohr's approach	Enghoff's approach
Formula	$V_{D_{Bohr}} = (P_{ACO_2} - P_{ECO_2})/P_{ACO_2}$	$V_{D_{B\text{-}E}} = (P_{aCO_2} - P_{ECO_2})/P_{aCO_2}$
Origin of P_{ACO_2}	Mean P_{ACO_2} as the average PCO_2 coming from all lung units	P_{aCO_2} replaces P_{ACO_2} following Riley's concept of an ideal lung
Type of $\dot{V}/\dot{Q}$ analyzed	$\dot{V}/\dot{Q}$ of ∞ (units C) High $\dot{V}/\dot{Q}$ >1 but <∞	$\dot{V}/\dot{Q}$ of ∞ (units C) High $\dot{V}/\dot{Q}$ >1 but <∞ $\dot{V}/\dot{Q}$ of 0 (unit A) Low $\dot{V}/\dot{Q}$ <1 but >0
Type of measurement	Noninvasive, continuous, breath by breath	Invasive, discontinuous provides information only when arterial blood samples are obtained
Physiological factors having an influence on parameter	Alveolar overdistension by excessive PEEP and/or V_T, pulmonary embolism, hypovolemia, pulmonary hypotension	Idem Bohr's approach plus all causes of shunt and low $\dot{V}/\dot{Q}$: atelectasis, pneumonia, COPD, asthma, etc.

On the Graph


Bohr
VDalv
PACO2
VDaw
PĒCO2
Expired CO2
Tidal Volume (ml)


Enghoff
PaCO2
VDalv
VDaw
PĒCO2
Expired CO2
Tidal Volume (ml)

Basically

- Enghoff’s modification measure the end result of overall ventilator-perfusion status.
- Thereby measuring the extra-pulmonary shunts as well
- Two corrections for the shunt fraction were proposed *Kuwabara* and *Niklason’s* modifications
- But even after correction for the shunt fraction Enghoff still over estimates true dead space

Sipmann et al Respiratory Physiology & Neurobiology 189 (2013) 99– 105

Kuwabara's Correction of Enghoff equation

$$V_D/V_T = \frac{\left(PvCO_2 - \dfrac{PvCO_2 - PaCO_2}{1 - Qs/Qt}\right) - PECO_2}{\left(PvCO_2 - \dfrac{PvCO_2 - PaCO_2}{1 - Qs/Qt}\right)}$$

Frankenfield equation

- $Vd/Vt = 0.32 + 0.0106\,(PaCO_2 - ETCO_2) + 0.003\,(RR) + 0.0015\,(age)$

Frankenfield et al Crit Care Med. 2010 Jan;38(1):288-91

Different methods of dead space measurement

Methods	Physiological dead space	Anatomical dead space	Shunt	Severity of V/Q mismatch
Bohr	+	-	-	+
Engohoff	+	-	+	+
Fowler	+	+	-	-

Tang et al Br J Anaesth 2005; 95: 538–48

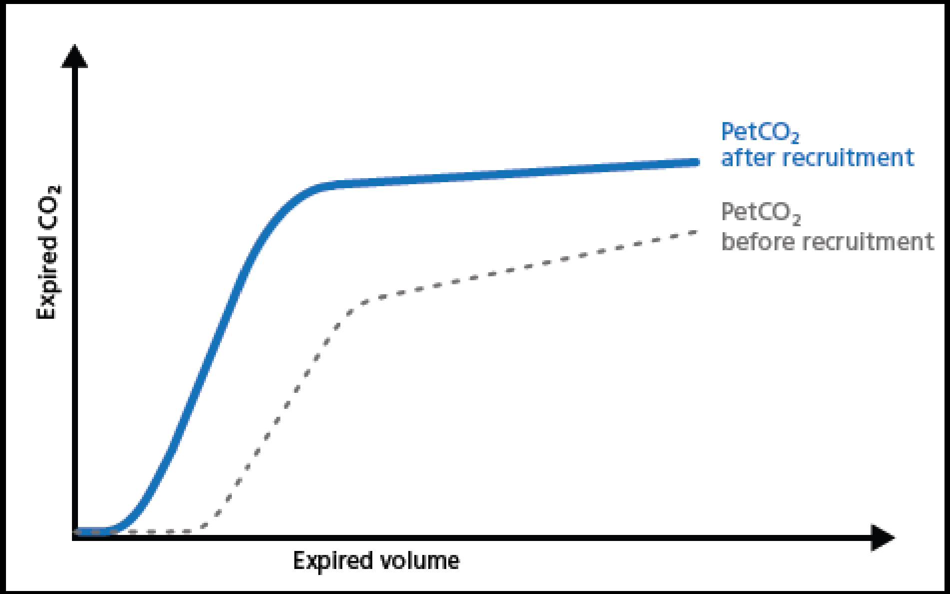
Can transcutaneous CO_2 be used for measuring dead space?

- **Methods**: 30 consecutive post-cardiac surgery mechanically ventilated patients had Vd/Vt calculated separately using volumetric capnography & substituting $PtcCO_2$ for $PaCO_2$
- **Results**: The mean Vd/Vt calculated using PaCO2 and PtcCO2 was 0.48 ± 0.09 and 0.53 ± 0.08, respectively, with a strong positive correlation between the two methods of calculation.
- **Conclusion**: $PtcCO_2$ measurements can provide a noninvasive means to measure Vd/Vt in normal lung patients.

Lakshminarayana et alCrit Care Res Pract. 2016;2016

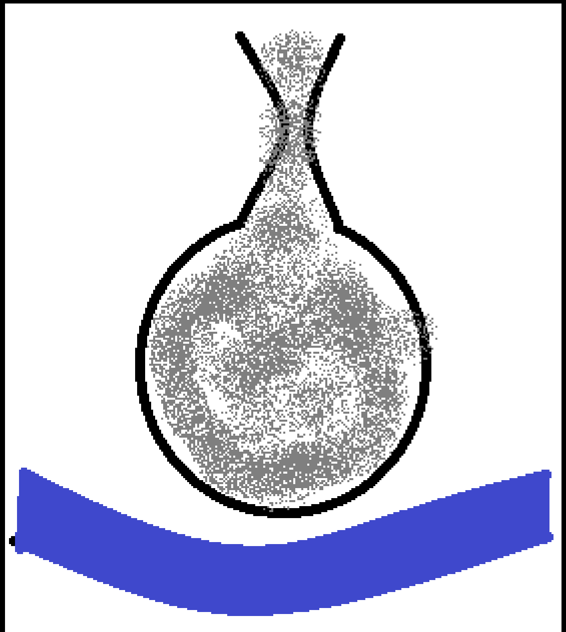
Recruitment

- VCO_2 increase with dead space
- Ratio V_d/V_t improves and dead space decreases
- Slope of phase III decreases

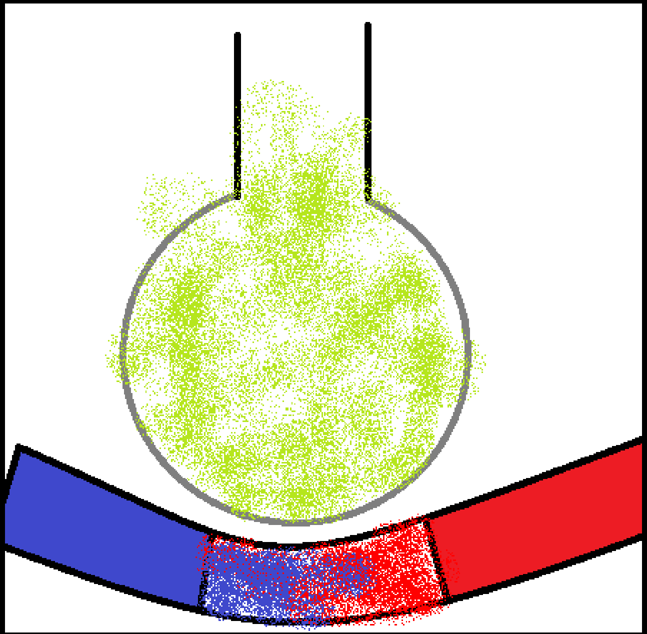


PEEP and its affect on Dead space

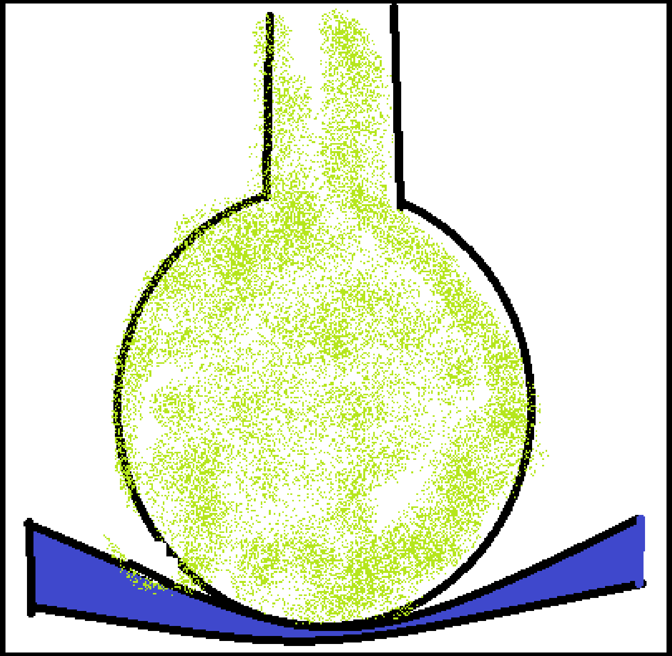
With less PEEP: Collapse aka SHUNT



With optimum PEEP

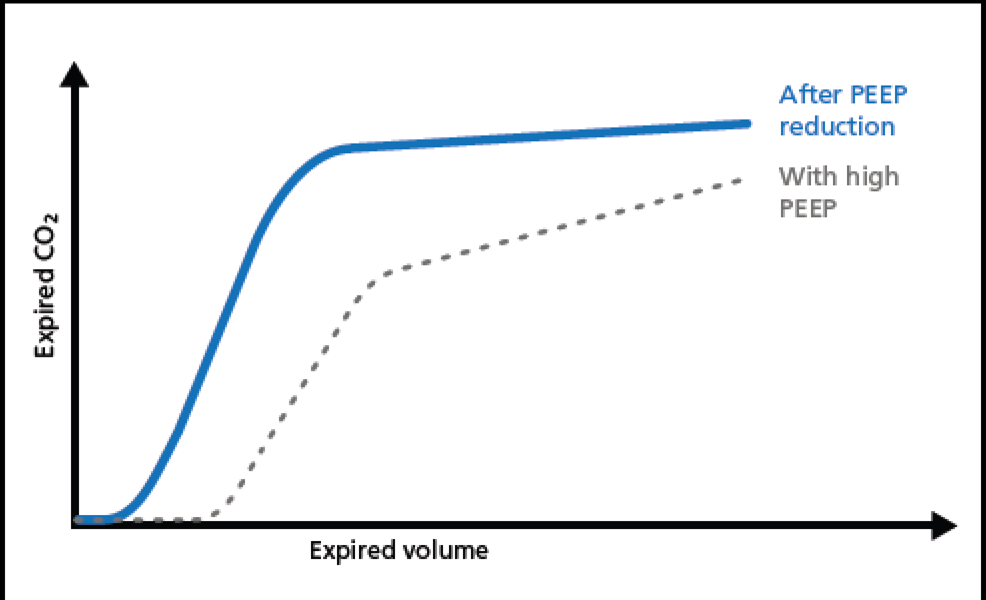


With high PEEP: over distention aka DEAD SPACE



PEEP its affect on volumetric capnography

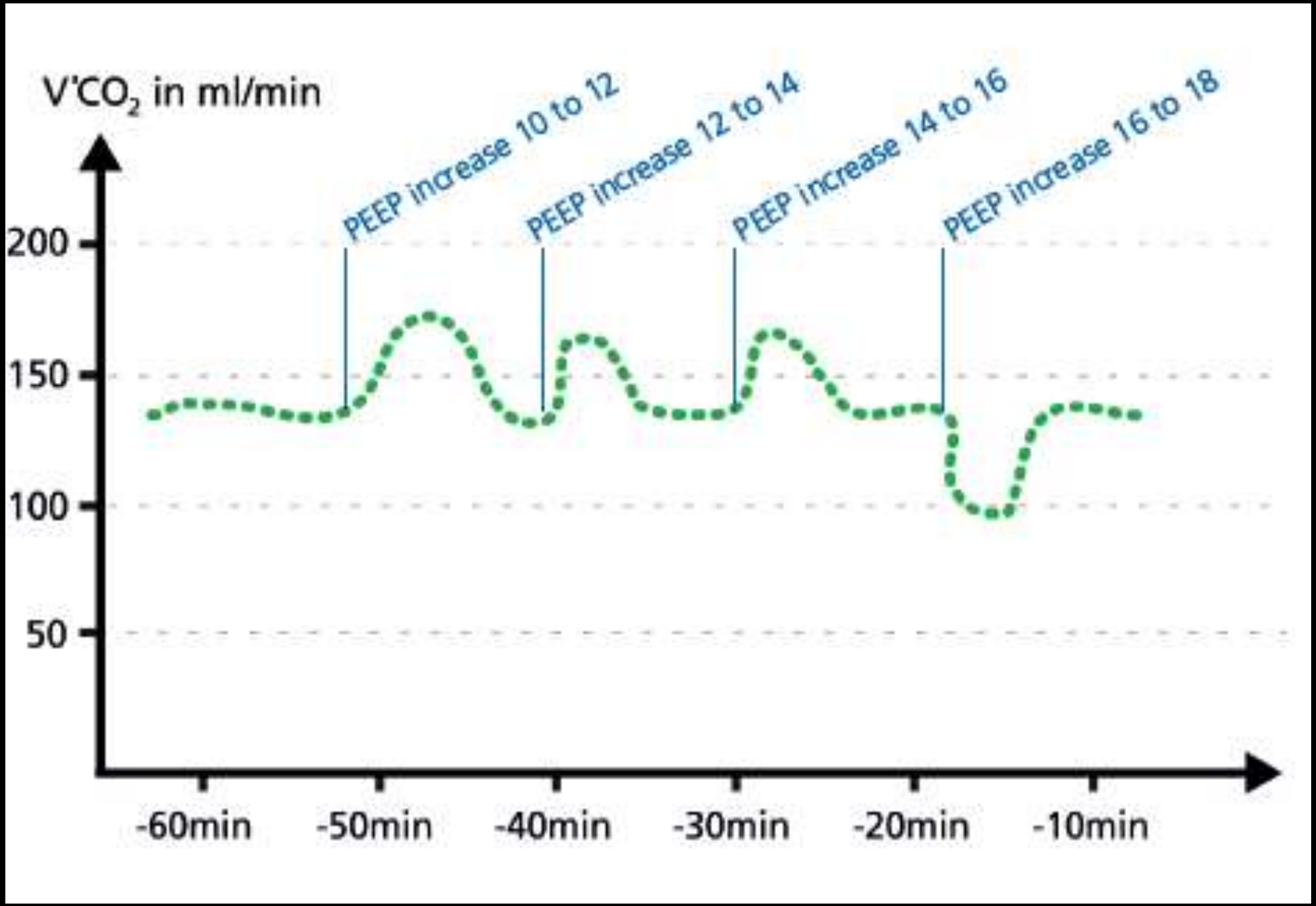
- Low peep increases shunt by causing collapse
- High peep increases dead space by decreasing perfusion



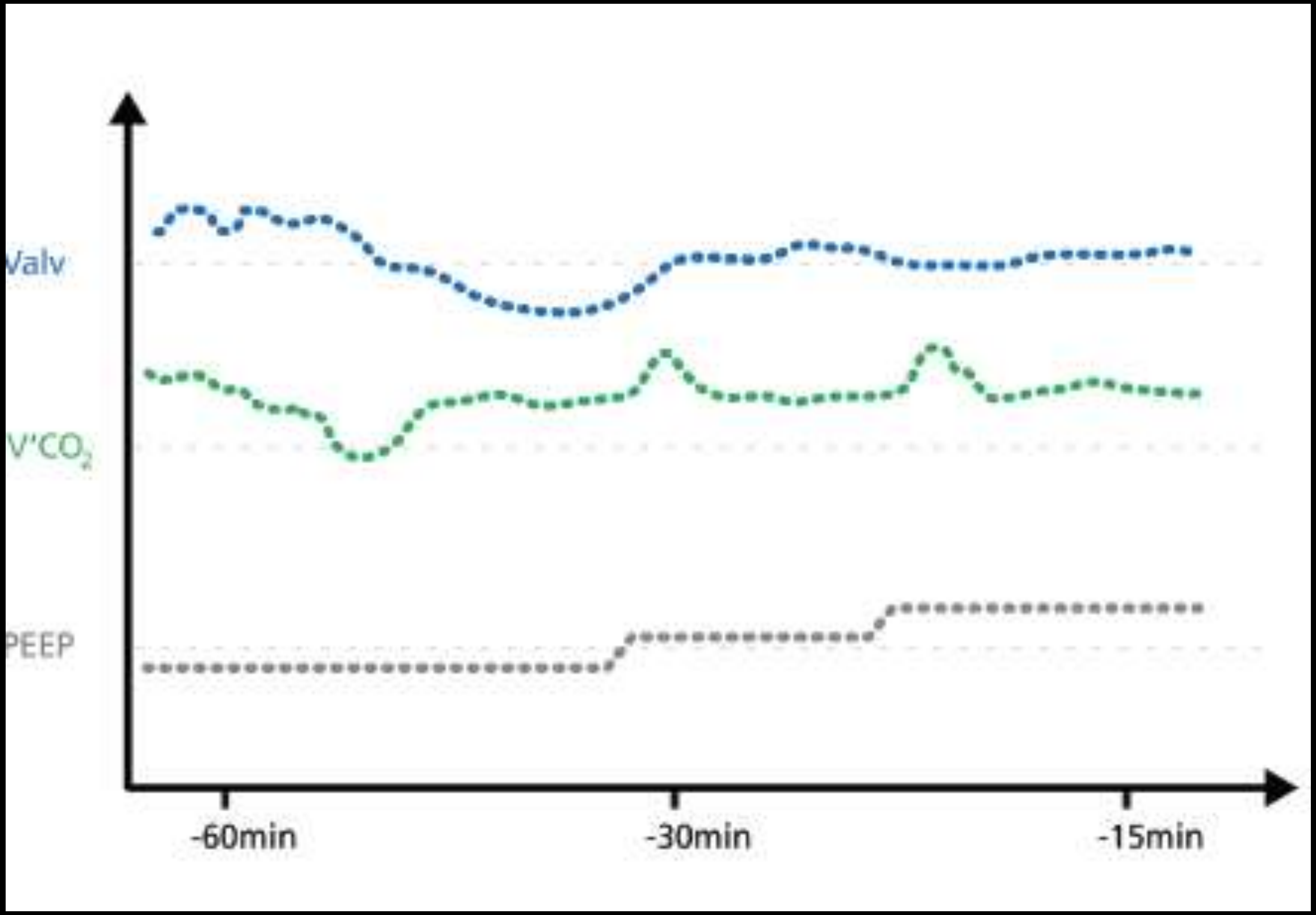
So how can you detect the difference between the two sides of PEEP?

- High PEEP: More Dead Space: : Higher Bohr’s Vd
- Low PEEP: More Shunt: : Higher Enghoff Vd

Optimizing PEEP by trends



Detecting decruitment



Evidence

Calculation of Physiologic Dead Space: Comparison of Ventilator Volumetric Capnography to Measurements by Metabolic Analyzer and Volumetric CO2 Monitor

- **Methods**: A total of 67 measurements in 36 subjects of ALI were compared. Thirty-one ventilator derived measurements were compared to measurements using 3 different metabolic analyzers. Ventilator used was Dragger XL ventilator
- **Results**: There was a strong agreement between ventilator derived measurements and metabolic analyzer or volumetric CO2 monitor measurements of PECO2 and VD/VT.
- **Conclusion:** Volumetric capnography as measured by Ventilator in study had good correlation with MIGET

Siobal et al Respir Care 2013;58(7):1143–1151

Assessment of Vd by Volumetric capnography in Patients with ARDS

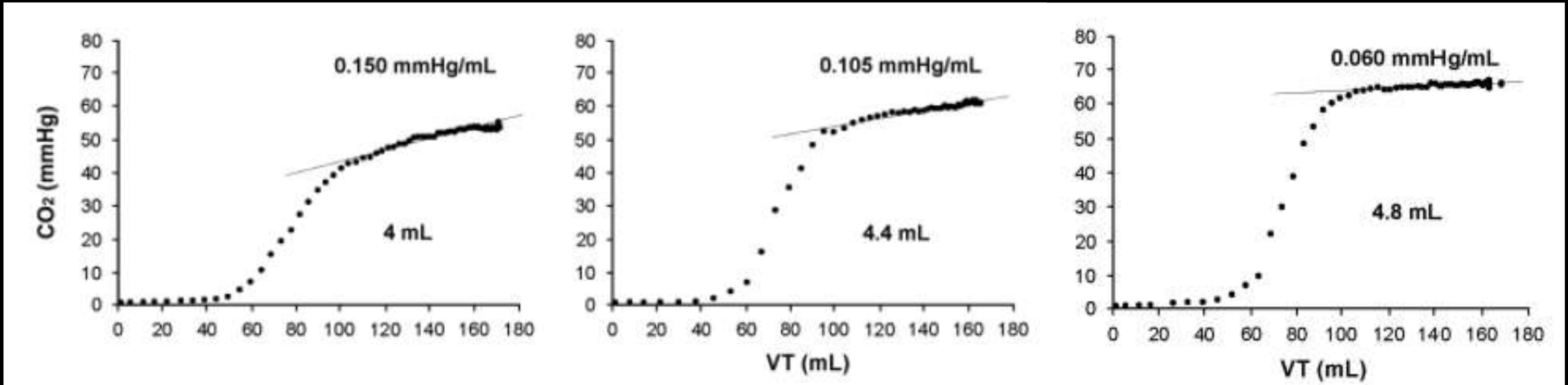
- **Methods**: In 15 post-cardiac surgery patients and 15 patients with ARDS, $PACO_2$ was measured using VCap to calculate Bohr dead space. PeCO2 was measured in expired air using three techniques: Douglas bag, indirect calorimetry and VCap.
- **Results**: There was good agreement in PeCO2 calculated with DBag vs. VCap and relatively low agreement with DBag vs. InCal.
- **Conclusion**: Volumetric capnography is a promising technique to calculate true Bohr dead space.

Capnography reflects ventilation/perfusion distribution in a model of acute lung injury

- **Methods**: Seven lung-lavaged pigs received VCV at tidal volumes of 6ml/kg. PEEP was given starting at 4 and increased by 2 cm of water.
- Ventilation-perfusion distribution (using multiple inert gas elimination technique), hemodynamics, blood gases and volumetric capnography data were recorded.
- **Results**: *SIII* showed the lowest value with PEEP and was associated with the lowest dispersion of ventilation-perfusion, the lowest ratio of alveolar dead space fraction and the lowest difference between arterial and end-tidal pCO_2.

Tusman at al Acta Anaesthesiol Scand 2011; 55: 597–606

Slope of Phase III

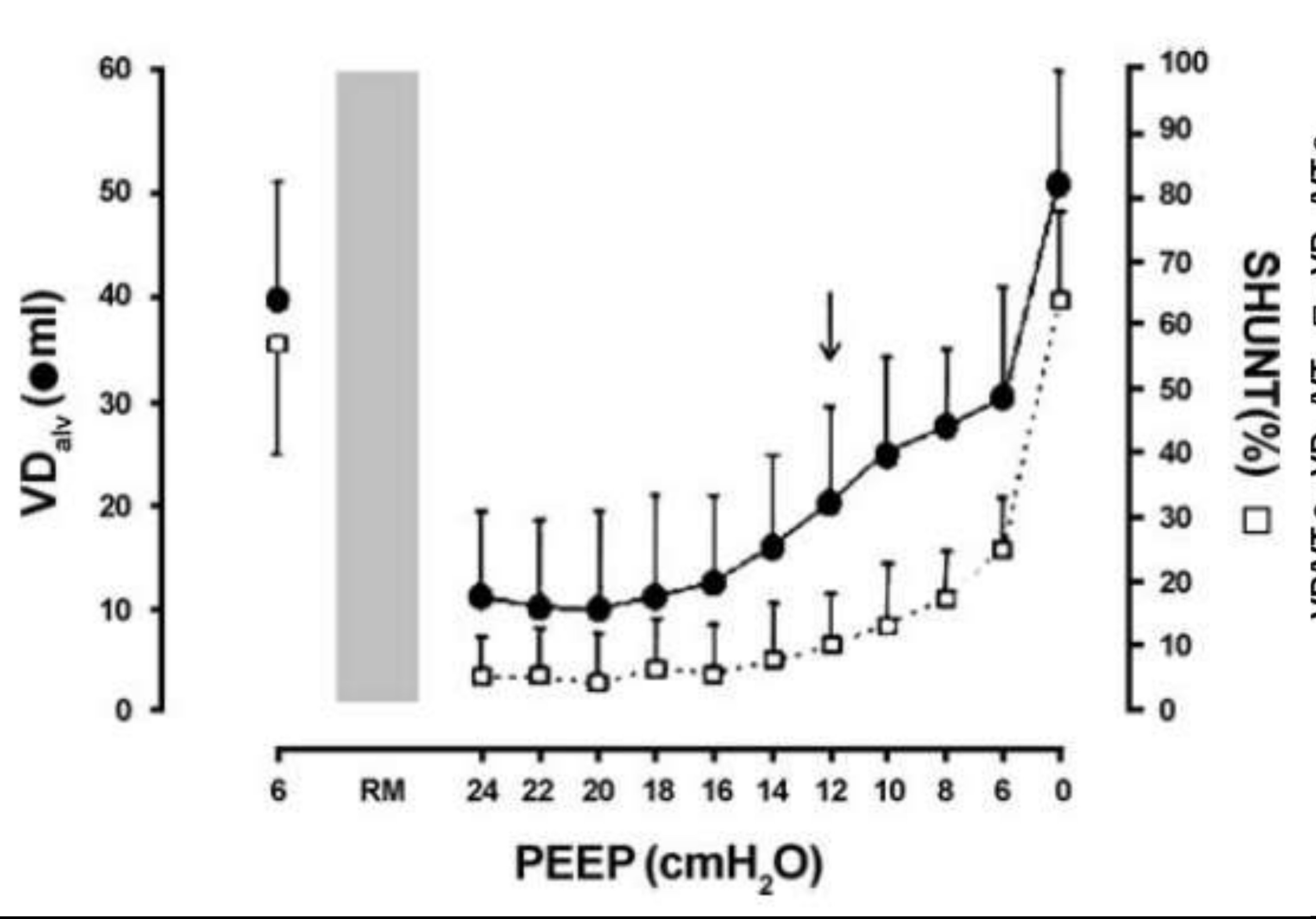


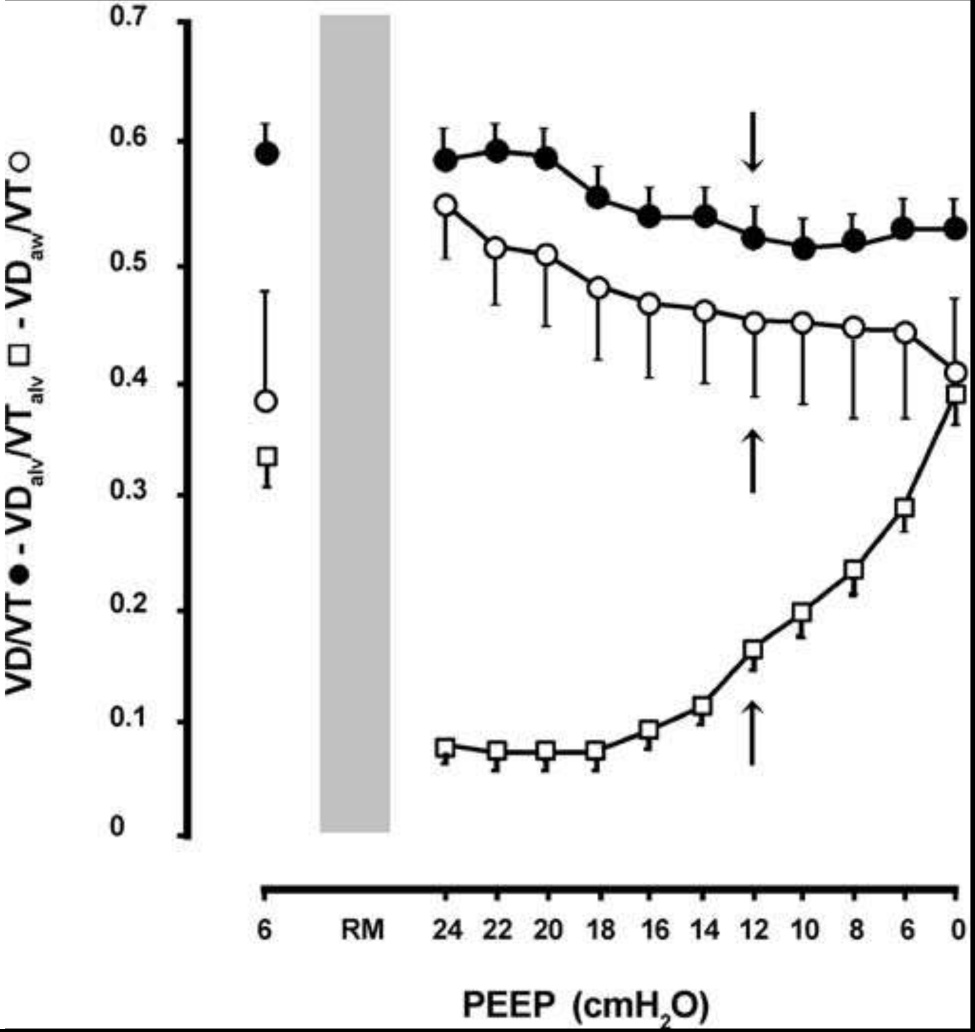
Tusman at al Acta Anaesthesiol Scand 2011; 55: 597–606

Monitoring dead space during recruitment and PEEP titration in an experimental model

- **Methods**: 8 lung lavaged pigs were ventilated at 6ml/kg and after recruitment maneuver PEEP was decreased from 24cm of water at an interval on 2 cm.
- VDalv, VDalv/VTalv, and Pa-etCO_2 were monitored.
- **Results**: PEEP titration was achieved with compliance and Sat O_2 monitoring. VDalv/VTalv and Pa-etCO2 showed good co-relation.
- **Conclusion**: Monitoring of dead space was useful for detecting lung collapse and for establishing open-lung PEEP after a recruitment maneuver.

Tusman et al Intensive Care Med (2006) 32:1863–1871

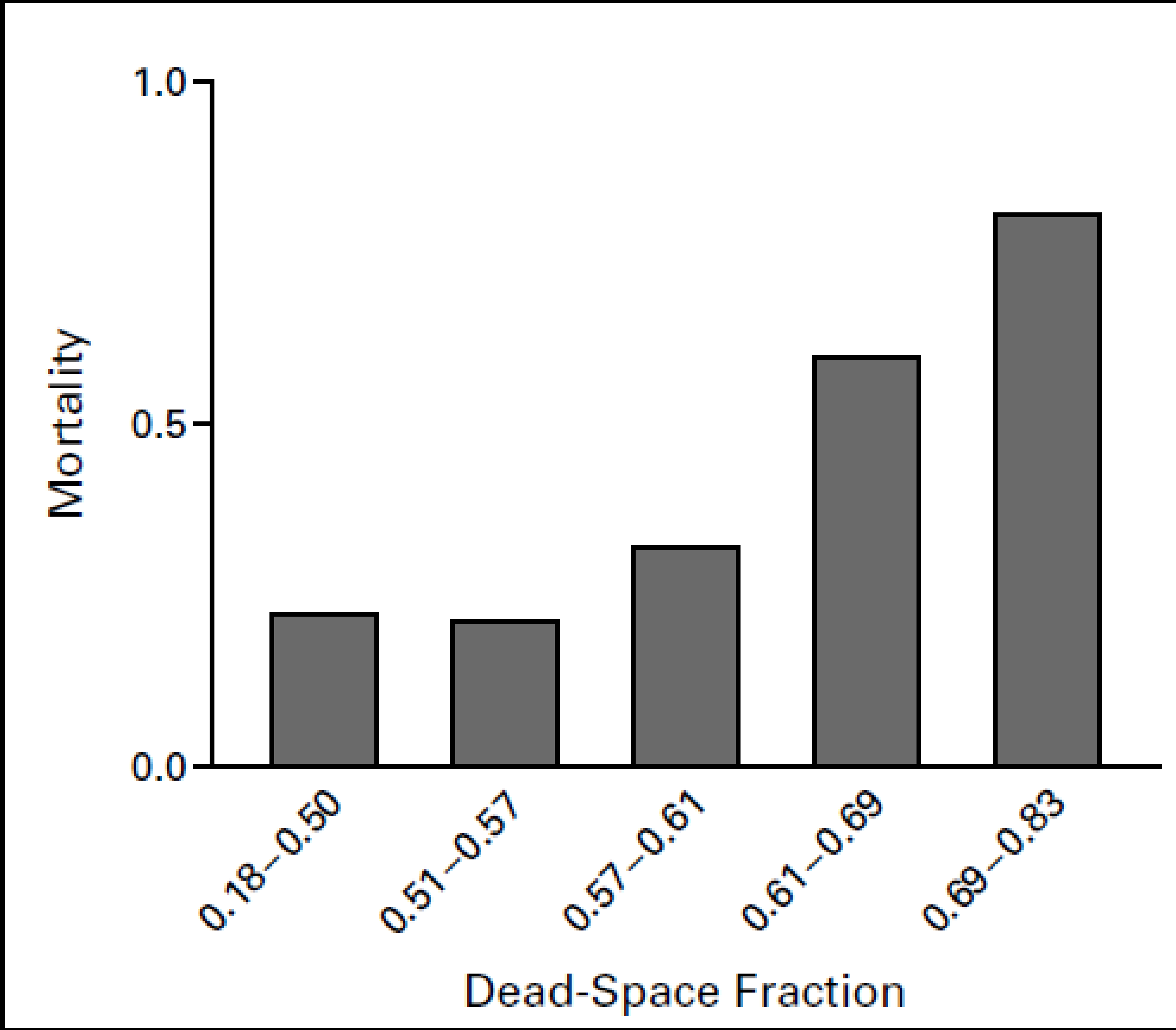

VD alv (●ml)
SHUNT(%) □
PEEP (cmH2O)
RM


VD/VT ● - VDalv/VTalv □ - VDaw/VT ○
PEEP (cmH2O)
RM

Pulmonary dead-space fraction as a risk factor for death in the acute respiratory distress syndrome

- **Methods**: Dead-space fraction was prospectively measured in 179 intubated patients after the acute respiratory distress syndrome had developed
- **Results**: Mean dead space was significantly increased in patients who died as compared to the patients who survived.
- ***Conclusions:*** Increased dead-space fraction is a feature of the early phase of the acute respiratory distress syndrome. Elevated values are associated with an increased risk of death.

Nuckton et al N Engl J Med 2002; 346:1281-128


1.0
0.5
0.0
Mortality
0.18–0.50
0.51–0.57
0.57–0.61
0.61–0.69
0.69–0.83
Dead-Space Fraction

Prognostic Value of Different Dead Space Indices in Mechanically Ventilated Patients With Acute Lung Injury

- **Methods**: In 36 patients with ALI, at ICU admission, 24 h, and 48 h SAPS II; PaO2/FIO2 ratio; Compliance; and capnographic indexes (Bohr dead space) and physiologic dead space (Enghoff dead space [VDphys/VT]), expired normalized CO2 slope, carbon dioxide output, and the alveolar ejection volume (VAE)/tidal volume fraction (VT) ratio were measured.
- **Results:** PaO2/Fio2, Vae/Vt, dead space measurements predicted outcome significantly among non-surviors
- **Conclusions***:* VAE/VT at ICU admission and 48 hr provided useful information on outcome in critically ill patients with ALI

Lucangelo et al Chest 2008; 133:62–71

Comparison of the pulmonary dead-space fraction derived from ventilator volumetric capnography and a validated equation in the survival prediction of patients with acute respiratory distress syndrome

- **Methods**: Vd/Vt was determined in 46 ARDS patients, before intubation and at 2, 3, 4, 5 and 6 days after intubation by Frankenfield method and volume Capnometery.
- **Results**: Vd/Vt was significantly higher in non survivors, Vd/Vt_{Fr} on the fourth day was more accurate to predict survival than Vd/Vt.
- **Conclusion**: Compared with Vd/Vt derived from ventilator volumetric CO2, VD/VT on day 4 calculated by Frankenfield et al's equation can more accurately predict the survival of ARDS patients

Y.-J. Zhang et al Chinese Journal of Traumatology 19 (2016) 141e145

PaCO2 and alveolar dead space are more relevant than PaO2/FiO2 ratio in monitoring the respiratory response to prone position in ARDS patients: a physiological study

- **Methods**: In 13 patients with a ARDS, Pplat, PEEP, ABG and expiratory CO_2 were recorded in supine position and after 3, 6, 9, 12 and 15 hours in the PP. Responders to PP were defined after 15 hours of PP as either an increase in P/F ratio > 20mmHg or by a decrease in $PaCO_2$ > 2mmHg.
- **Results**: VDalv/VT correlated with changes in Crs, but not with changes in P/F ratios, similarly responders as defined by pCO_2 criteria did well on ventilatory parameters as compared to those defined by P/F method
- **Conclusion**: PP induced a decrease in VDalv/VT ratio and an improvement in respiratory mechanics. The respiratory response to PP appeared more relevant when $PaCO_2$ rather than the PaO_2/FiO_2 ratio was used.

Charron et al. Critical Care 2011, 15:R175

Recruitment in non ARDS morbidly obese patients

The Effects of Lung Recruitment on the Phase III Slope of Volumetric Capnography in Morbidly Obese Patients

- **Methods**: Eleven morbidly obese patients, ventilated. ARS was performed by increasing PEEP in steps of five. TV, arterial blood gases, and lung mechanics data were determined for each PEEP step.
- **Results**: *S*III decreased and PaO_2 and compliance increased with fall in pCO_2 when 0 end-expiratory pressure was compared against 15 cm H2O of PEEP after ARS
- **Conclusion:** The *S*III in VC was useful to detect the optimal level of PEEP after lung recruitment in anesthetized morbidly obese patients

Bohm et al Anesth Analg. 2009 Jul;109(1):151

Capnography and PTE

End Tidal Carbon Dioxide as a Screening Tool for Computed Tomography Angiogram

- **Method**: All patients admitted for orthopedic surgery and who had a CTA performed for PE were eligible
- **Results:** 121 patients enrolled, 84 had a negative CTA examination, 25 had a positive examination, and 12 had a non diagnostic examination. An $ETCO_2$ cutoff value of 43 mm Hg was 100% sensitive with a negative predictive value of 100% for absence of PE on CTA
- **Conclusion:** ETCO2 value >43 mm Hg is 100% sensitive for the absence of PE.

Ramne et al J Arthroplasty. 2016 Oct;31(10):2348-52

Role of end-tidal CO2 as a screening tool Pulmonary embolism

- **Methods:** 100 patients with suspected pulmonary embolisms were enrolled. $ETCO_2$ was measured within 24 hours.
- **Results:** PE was diagnosed in 38% of cases. The average ETCO2 in patients with a positive CTPA was 3.35 kPa. The average ETCO2 in patients without PE was 4.41 kPa. All patients positive for a PE obtained an ETCO2 <4.3 kPa (32.3 mmHg). This value had a sensitivity and specificity (100% and 68% respectively), NPV of 100% and PPV of 66%.
- **Conclusion:** ETCO2 may reliably be used to screen and exclude patients with suspected PEs.

Clinical Medicine 2014 Vol 14, No 2: 128–33

D-Dimer and Exhaled CO_2/O_2 to Detect Segmental Pulmonary Embolism in Moderate-Risk Patients

- **Methods**: Patients with one sign, one symptom and CTPA done were enrolled. Two groups on the basis of D Dimer cut off. The median $etCO_2/O_2$ less than 0.28 from seven or more breaths was group1 and $etCO_2/O_2$ greater than 0.45 was group 2.
- **Results**: 495 patients, including 60 (12%) with segmental or larger, and 29 (6%) with subsegmental. Positive D-dimer and $etCO_2/O_2$ less than 0.28 significantly increases the probability of PE and $etCO_2/O_2$ greater than 0.45 predicts the absence of PE.
- **Conclusions:** $etCO_2/O_2$ add to the specificity of D dimer in PPV for PTE

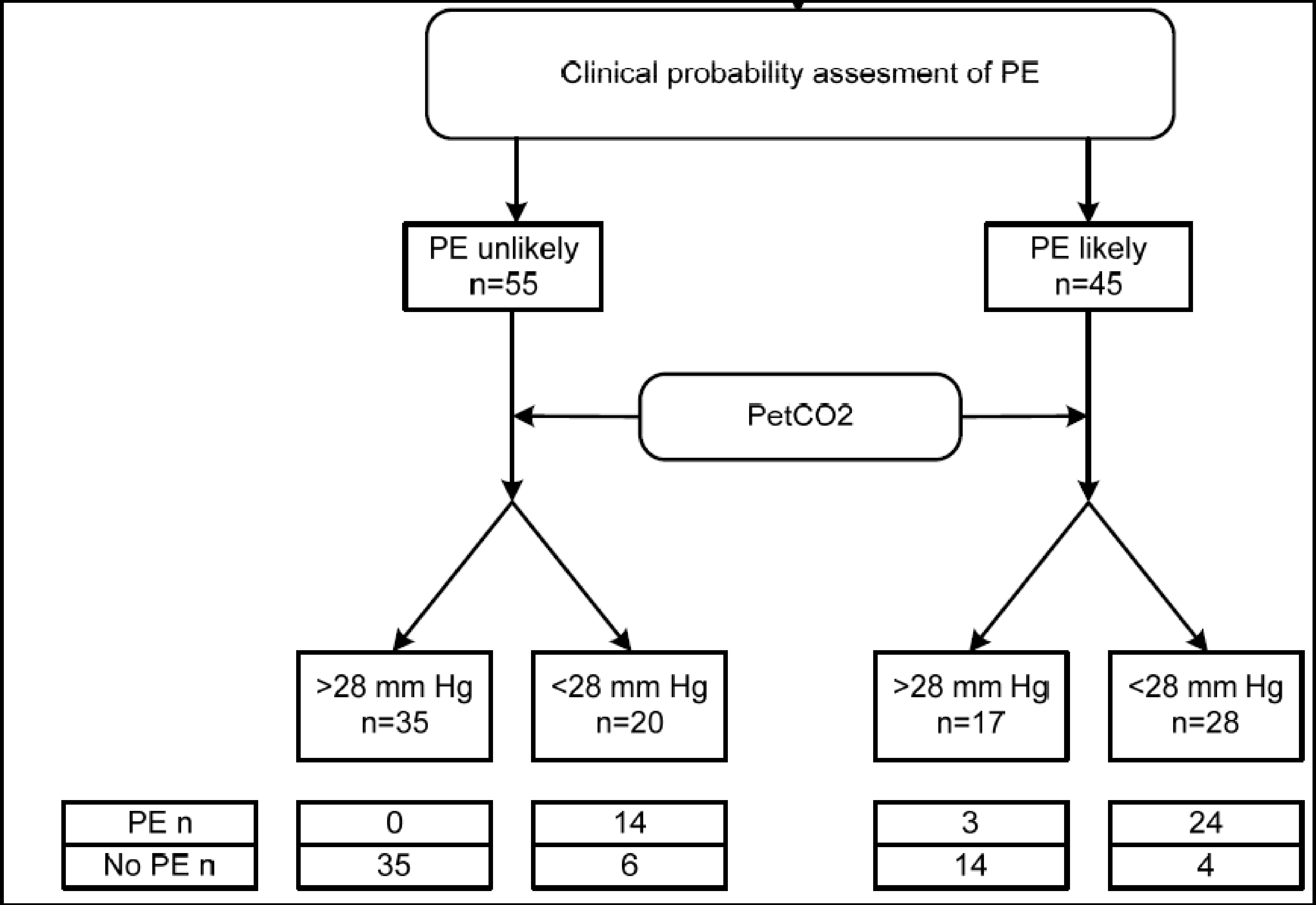
Kline et al Am J Respir Crit Care Med Vol 182. pp 669–675, 2010

Test Result	Test Interpretation	Number with Result PE(+)	PE(−)	Sensitivity	Specificity
D-dimer > 499 ng/ml	(+)	60	307	100	29.4
D-dimer < 500 ng/ml	(−)	0	128		
95% CI				94.0–100	25.2–34.0
$etCO_2/O_2 < 0.28$*	(+)	27	99	100	34.9
$etCO_2/O_2 > 0.45$*	(−)	0	53		
95% CI				87.2–100	27.3–43.0
D-dimer > 499 and $etCO_2/O_2 < 0.28$	(+)	27	68	100	71.2
D-dimer < 500 or $etCO_2/O_2 > 0.45$	(−)	0	168		

Capnometery in suspected pulmonary embolism with positive D-dimer in the field

- **Methods:** 100 patients with suspected PE and positive D-dimer recruited. $PetCO_2 > 28$ mmHg was considered as the best cut-off point.
- **Results:** PE was confirmed in 41 patients. $PetCO_2$ had a sensitivity of 92.6% NPV of 94.2%, a specificity of 83% & PPV of 79.2%
- Low clinical probability with $PetCO_2$ less than 28 excluded PE with a sensitivity of 100% & a negative predictive value of 100%
- **Conclusions:** The combination of clinical probability and $PetCO_2$ may safely rule out PE in patients with suspected PE and positive D-dimer in the prehospital setting.

Rumpf et al Crit Care. 2009;13(6):R196


Clinical probability assesment of PE
PE unlikely
n=55
PE likely
n=45
PetCO2
>28 mm Hg
n=35
<28 mm Hg
n=20
>28 mm Hg
n=17
<28 mm Hg
n=28
PE n
No PE n
0
35
14
6
3
14
24
4

Clinical probability and Vd measurement for suspected PE in patients with an abnormal D-dimer test result

- **Methods**: 270 consecutive in- and outpatients with suspected PE and positive D-dimer. An alveolar dead space fraction< 0.15 was considered normal.
- **Results:** PE was confirmed in 108 patients (40%). Capnography had a sensitivity of 68.5% and a specificity of 81.5% for PE.
- **Conclusion**: Capnography alone does not exclude PE accurately. The combination of clinical probability and capnography accurately excludes or confirms PE and avoids further testing in up to 30% of patients.

Sanchez et al Journal of Thrombosis and Haemostasis, 4: 1517–1522

Volumetric Capnography as a Screening Test for Pulmonary Embolism in the Emergency Department

- **Methods:** 45 patients with D-dimer levels of > 500 ng/mL enrolled. Several variables were calculated: Vd/Vt, Vdalv, Vdaw,, the slope of phase 3; and the late dead space fraction (Fdlate)
- **Results***:* Four variables of the VCap exhibited a statistical difference between both groups, as follows: the VDalv/Vdaw, the slope of phase 3; the VDalv/VDphys; and Fdlate. PaCO2-EtCO2 gradient was also significantly different in two groups
- **Conclusion***:* Fdlate had a statistically better diagnostic performance in suspected PE than the PaCO2-EtCO2 gradient. VCap is a promising application of pulmonary pathophysiology.

Verschuren et al CHEST 2004; 125:841–850

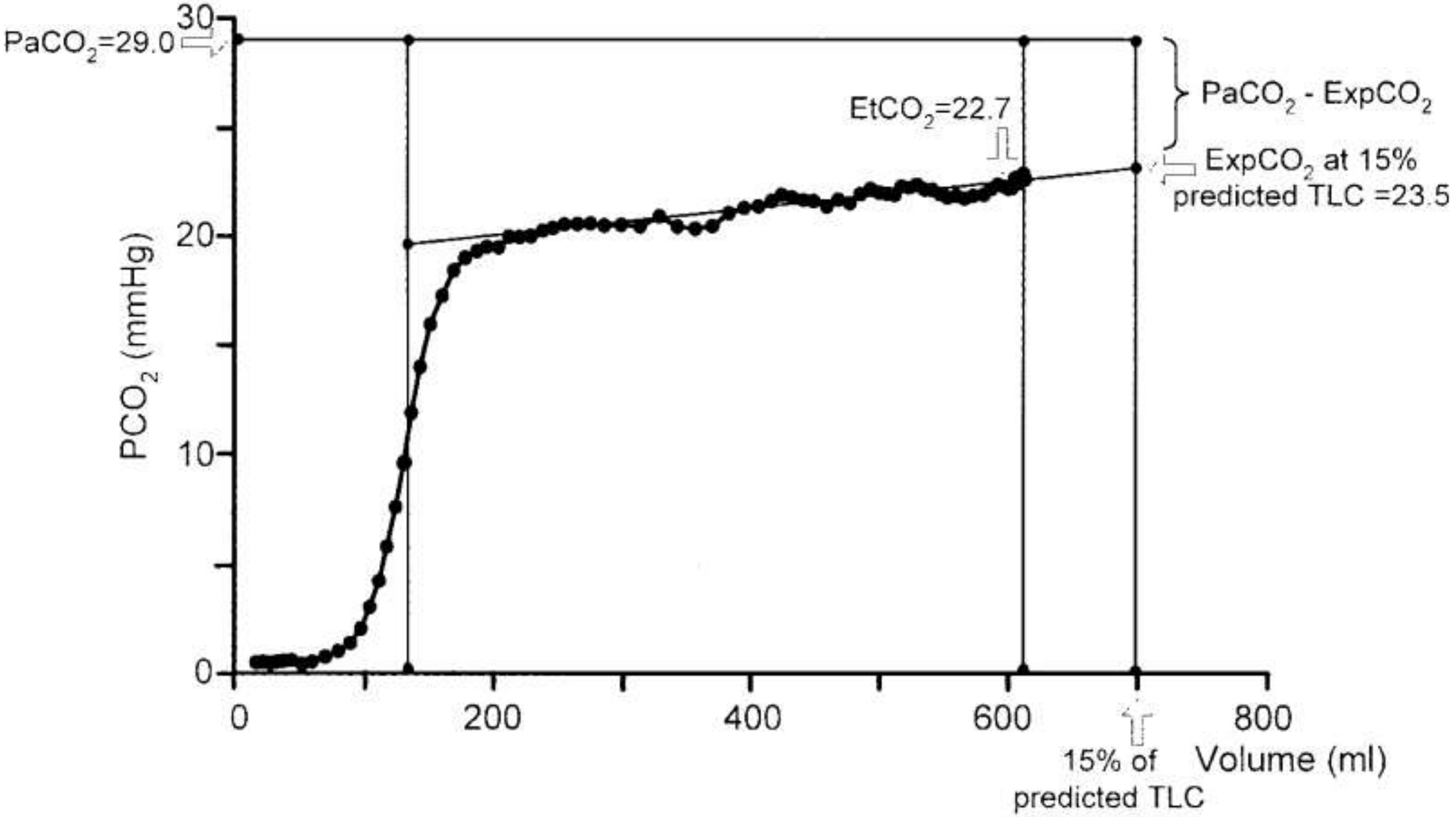


FIGURE 2. An example of a VCap curve registered during one expiration in a spontaneously breathing patient with a proven PE diagnosis. This patient had a VT of 612 mL. The Pa_{CO_2} was 29 mm Hg, the $EtCO_2$ was 22.7 mm Hg, and 15% of her predicted TLC was calculated to be 699 mL. The fractional CO_2 value at this volume of 699 mL was 23.5 mm Hg, after extrapolation of phase 3 of the curve. The Fdlate then was calculated as follows: Fdlate = 1 − ($ExpCO_2$ 15% TLC/Pa_{CO_2}) = 19%. This relatively high percentage theoretically separates a patient with a PE from a healthy patient or a COPD patient.

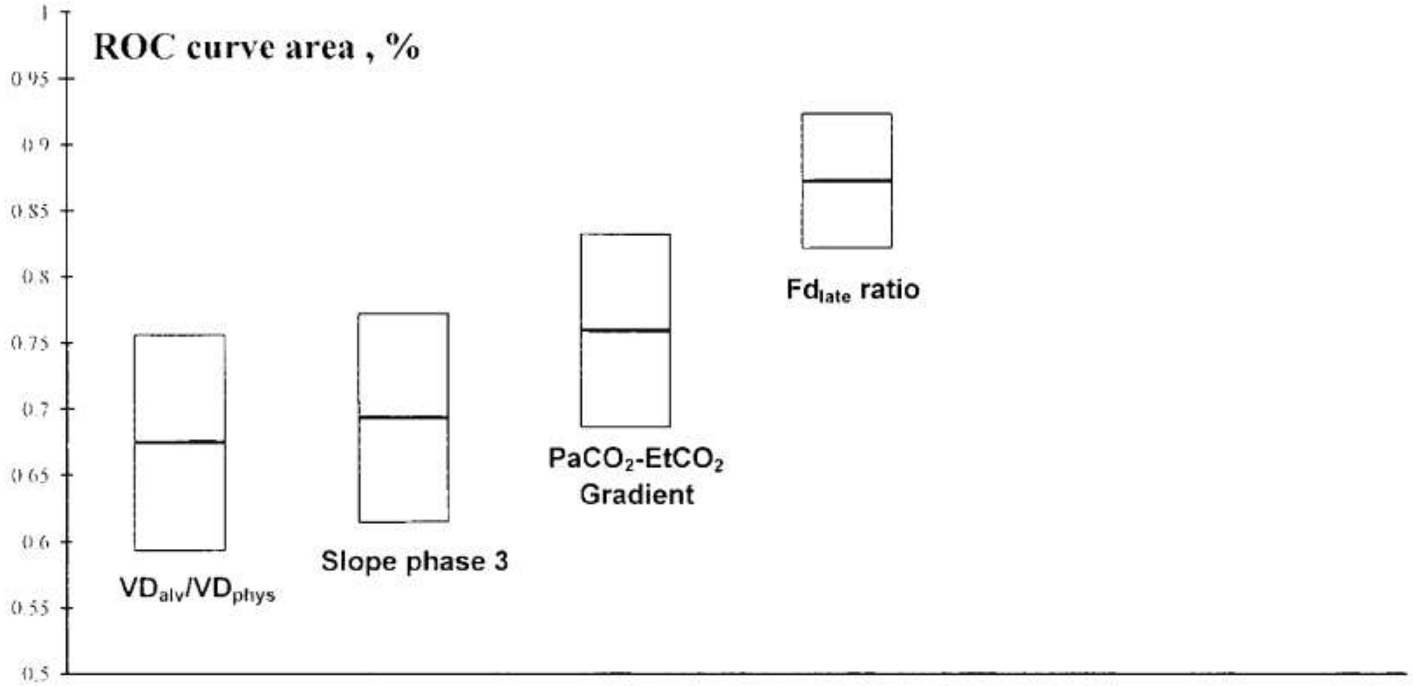


FIGURE 3. ROC curve comparison of single parameters from VCap: VDalv/VDphys; slope of phase 3; $Pa\text{CO}_2$-$EtCO_2$ gradient; and Fdlate ratio. The bold horizontal lines are the ROC curve mean values, which are surrounded by two thin horizontal lines representing the 95% CI for the difference in means.

The diagnostic role of capnography in pulmonary embolism

- **Methods: 58** patients were assessed using the Wells score, capnography, CTPA, D-dimer, lower-extremity venous Doppler ultrasonography, and V/Q scintigraphy
- **Results:** Forty patients (69%) had PE. The AVDSf value with the highest sensitivity and specificity, was 0.09. Sensitivity of capnography was 70%, with a specificity of 61.1%, PPVof 80%, and NPV of 47.8%.

Kurt et al American Journal of Emergency Medicine (2010) 28, 460–465

The diagnostic role of capnography in pulmonary embolism

Table 4 Comparison of our study results on capnography for PE with other reports from the literature

	Test	Sn (%)	Sp (%)	PPV (%)	NPV (%)
Kar Kurt et al	AVDSf (0.09)	70	61.1	80	47.8
	AVDSf + Wells scores	80	61.1	82.1	57.9
	AVDSf + D-dimer	89.7	27.8	72.9	55.6
	AVDSf + VDUSG	82.5	55.6	80.5	58.8
	V/Q + AVDSf	82.5	52.9	80.5	56.2
Kline et al [8]	AVDSf (0.20)	67.2	76.3		
	D-dimer	93.8	67.1		
	D-dimer + AVDSf	98.4	51.6		
Rodger et al [9]	AVDSf (0.15)	79.5	70.3		
	D-dimer	83	57.6		
Hogg et al [10]	AVDSf (0.32)	95.3	20	6.2	98.7
Sanchez et al [11]	AVDSf (0.15)	68.5	81.5	71.1	79.5
	AVDSf + Wicki scores	70	61.1	80	47.8

Kurt et al American Journal of Emergency Medicine (2010) 28, 460–465

Volumetric capnography in the exclusion of pulmonary embolism at the emergency dept

- **Methods:** New parameters (V_{CO2} X *Slope III* /RR). 30 subjects were included, of which in 13 had PE on CTPA.
- **Results: Median** of the novel parameter V_{CO2} slopeIII RR × / was 1.85 min.kPa dl_{-1} in the no PE group versus 1.18 min.kPa dl_{-1} in the PE group ($p = 0.006$).
- **Conclusion:** Using a threshold for the new parameter of 1.90 min.kPa dl_{-1} to exclude PE results in NPV of 100%

Timon et al J Breath Res. 2016 Dec 17;10(4):046016.

In nut shell.

- Various Capnographic parameters have been evaluated and co-related
- Have higher negative predictive value but not PPV
- Does not work alone, have to be used in combination with clinical probability and D dimer
- $etCO_2$, VCO_2, Vd/Vt, are the most commonly used parameters.

Weaning and capnography

- During SBT successful weaning is represented by VCO_2 staying stable followed by slight increase suggestive of increasing work of breathing
- Unsuccessful weaning is represented with *dramatic/ chaotic/ decrease* in VCO2 or increase in dead space fraction
- Among several parameters $ETCO_2$, Slope III, Expiratory time, VCO_2 were significantly found to be different in two groups.

Rasera et al Physiol Meas. 2015 Feb;36(2):231-42.

$EtCO_2$concentration can estimate the appropriate timing for weaning off from ECMO

- **Methods:** 25 patients on ECMO were studied with two groups, one with successful weaning and without. Parameters were assessed on ECMO introduction and at 40 % decrease in flow. BP, Lactate, CRP, $ETCO_2$ were measure
- **Results:** on examining the individual parameters against time only $ETCO_2$ had changed steeply in all patients successfully weaned off. Change was defined as more than 5 mmHg
- **Conclusion:** ETCO2 being a ventilatory parameter can successfully predict the improvement in respiratory failure and hence weaning from ECMO

Naruke et al Int Heart J. 2010 Mar;51(2):116-20.

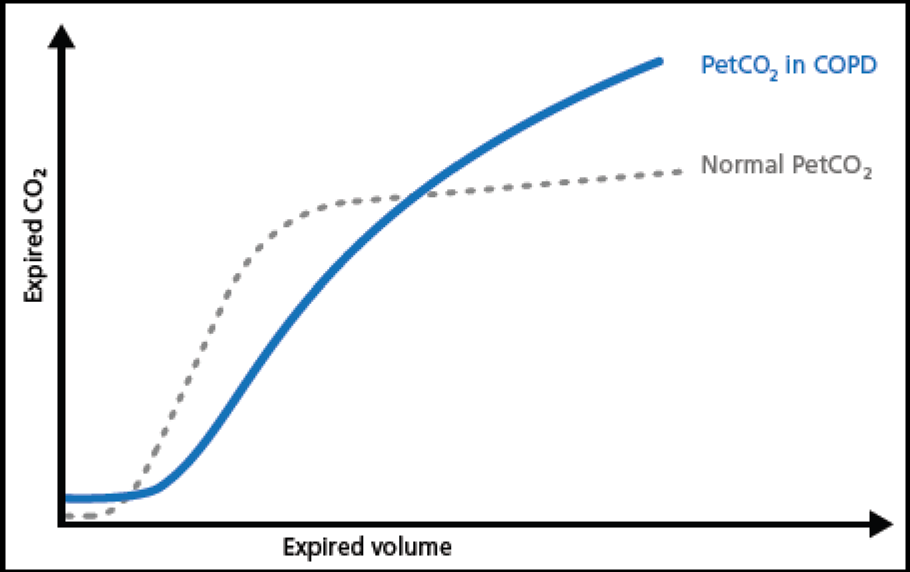
Resting energy expenditure

- Weir equation
- REE = $(3.9 \text{ X } VO_2) + (1.1 \text{ X } VCO_2) \text{ X } 1.44$
- $VO_2 = VCO_2/0.85$
- So, REE $(CO_2) = 8.19 \text{ X } VCO_2 = 1.44 \text{ X } CO_2 \text{ eq X V } CO_2$

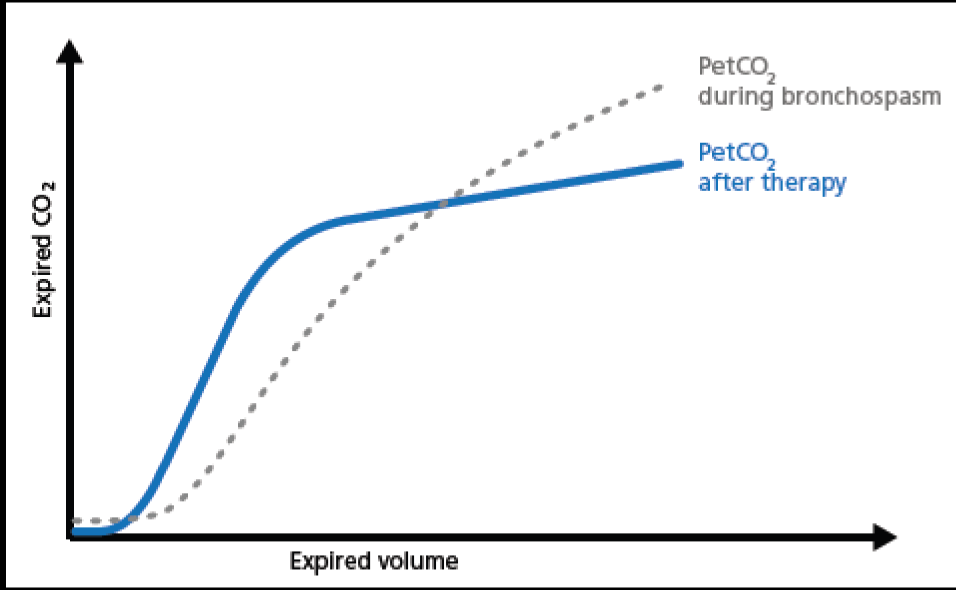
Substrate	Respiratory Quotient	Oxygen Caloric Equivalent (kcal/L)	Carbon Dioxide Caloric Equivalent (kcal/L)
Carbohydrate	1.0	5.05	5.05
Mixed	0.90	4.83	5.52
Protein	0.80	4.46	5.57
Fat	0.71	4.74	6.67

Hess et al Respir Care 1986;31(12):1197-1203

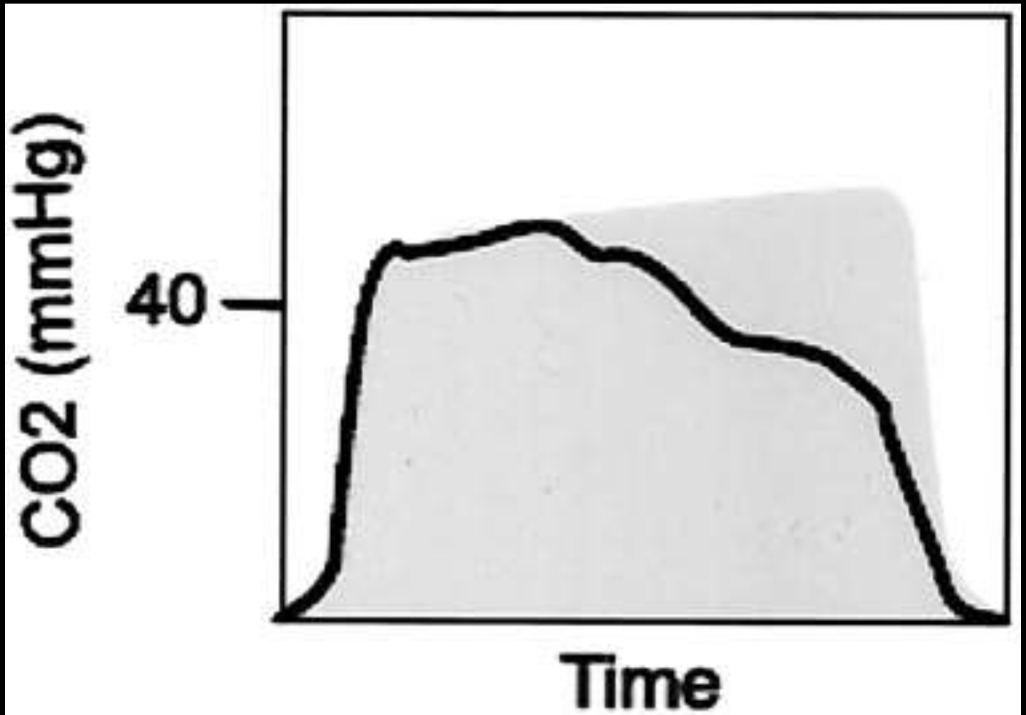
Role of capnography in bronchospasm



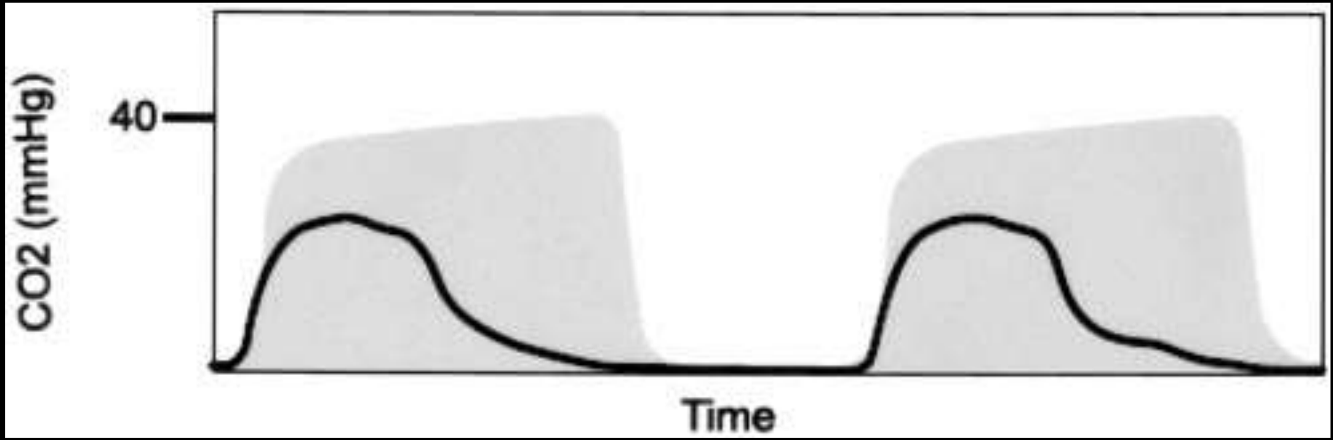
Bronchodilator therapy



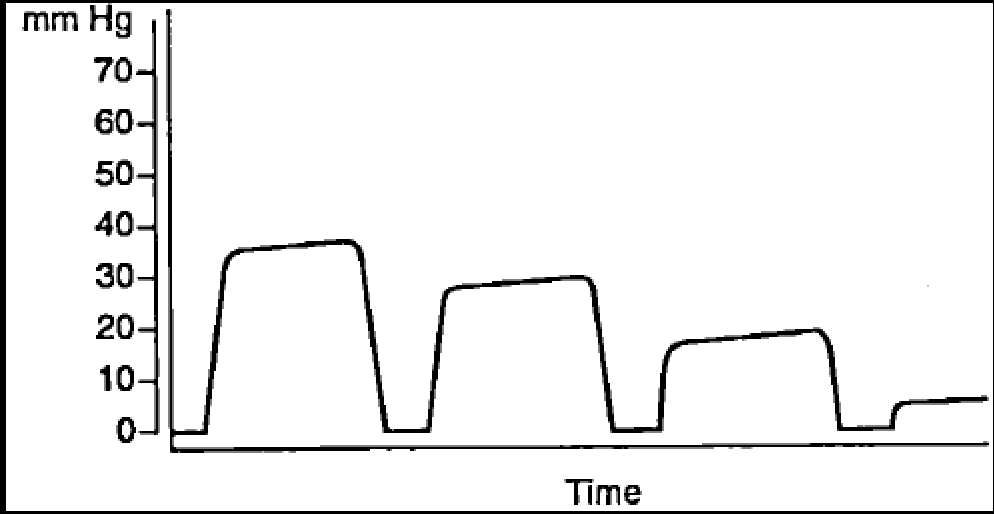
Pneumothorax : loss of alveolar phase



Migration of ET into right main bronchus



Pulmonary thromboembolism



Summarizing

- Capnometery and capnography are evolving tools of monitoring
- Capnometery is a portable tool helping measure the sixth vital sign
- Capnography is used in confirming ET tube placement, Ryle's tube placement, monitoring sedation and revival chances in CPR
- Volumetric capnography in ICU will be an new addition in monitoring the ventilation strategy in various disease
- Dead space calculation is just one aspect of the spectrum of uses of Volumetric Capnography

Summarizing…

- While using dead space calculations, it is important to realize what Bohr and Enghoff measures exactly
- Neither of them is better than others and it all depends on what your possibilities are
- Volumetric capnography is not here to replace other established investigations but act as an adjunct to increase the predictable values of other tests
- Caloric requirement calculation by VC determines the incidence of under nutrition in ICUs

Summarizing…

- Higher $ETCO_2$ rules out PTE n can help in decreasing over use of CTPA
- Vd/Vt can help in prognosis, PEEP titration and detecting decruitment in ARDS
- Capnography is like ECG, once you know the pattern it is easy to make the diagnosis
- It is not longer a data without any use