Volumetric capnography

Dr. Vaibhav Kajaria
SR – Department of Pulmonary Medicine
PGIMER Chandigarh

- Basic Capnography
- Uses
- Waveforms
- Limitations
- Measurement of volumes
- Single breath waveform
- Uses
- Limitations
- Use in our RICU

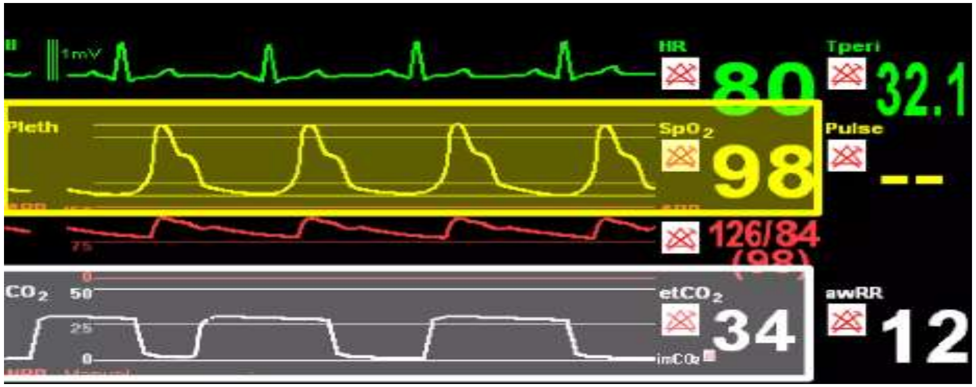
- The term Capnography refers to the non-invasive measurement of the partial pressure of carbon dioxide (CO_2) in exhaled breath ($EtCO_2$) expressed as the CO_2 concentration over time.
- Volumetric capnography is the measurement of fractional concentration or partial pressure of carbon di oxide plotted against exhaled volume.

- The relationship of CO_2 concentration to time is graphically represented by the CO_2 waveform, or capnogram.

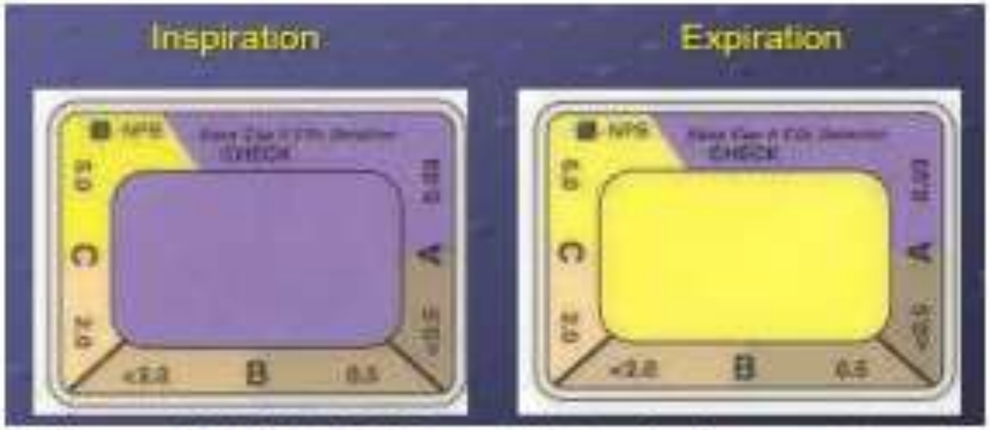
- $EtCO_2$ – Maximum Carbon dioxide level in the exhaled breath.

  Normal 35-45mmHg

- Quantitative



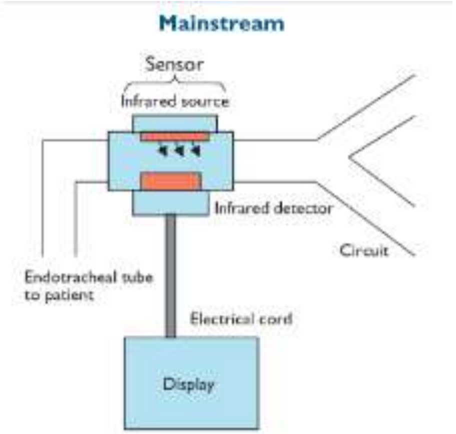
- Colorimetric – pH sensitive paper – colour change with CO2 levels- range bound



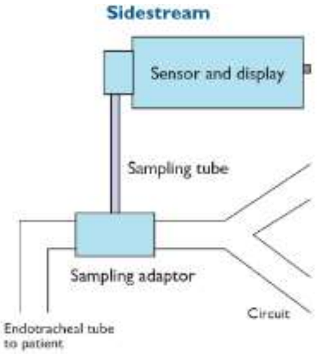
Yellow = 2%-5% (15-38 mm Hg): →tube position in trachea (interpret after 6 breaths.)

- There are 2 methods to measure CO_2 levels in exhaled air

1) Mainstream- sensor just proximal to the ET tube. Uses Infra Red device which selectively absorbs different wavelengths to measure the CO_2 levels in exhaled breath.

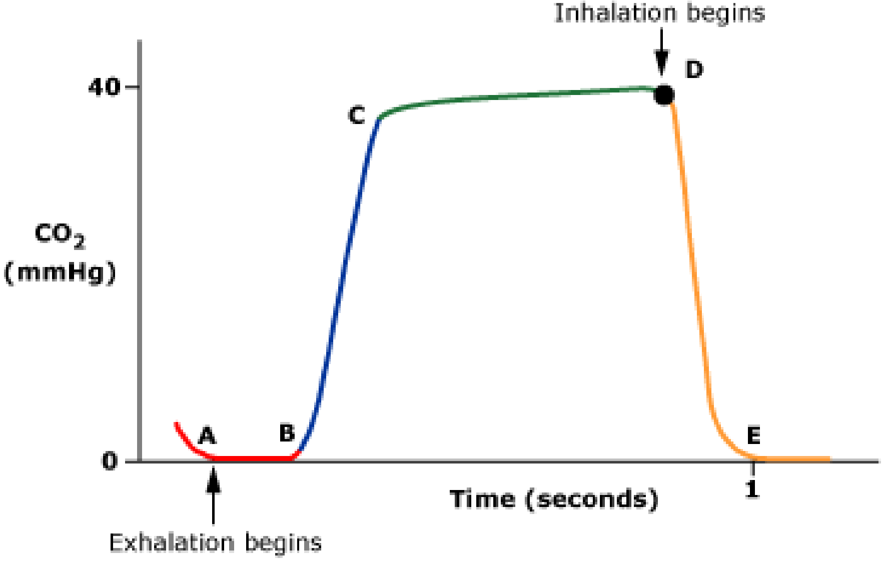


2) Side stream- small sample of exhaled air is transported to a sensor via a cannula to a sensor inside the monitor.



Normal Capnograph

- A→ B - starting of exhalation – dead space
- B →C – mix of dead space and early alveolar air
- C→D – alveolar exhaled air- highest point is EtCO2
- D→E – Inspiration



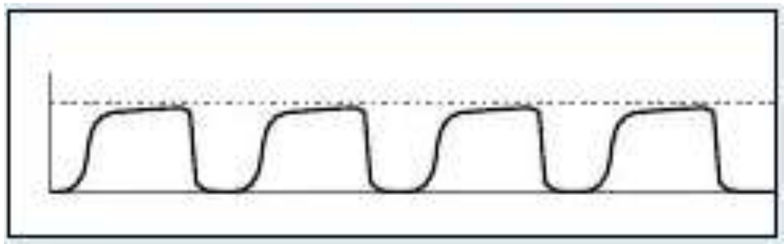
USES

- Monitoring ventilation
- Confirming Endotracheal tube position *
- Effectiveness of CPR
- Waveform specific for some disease conditions
- “Intellivent” ventilation in our ICU

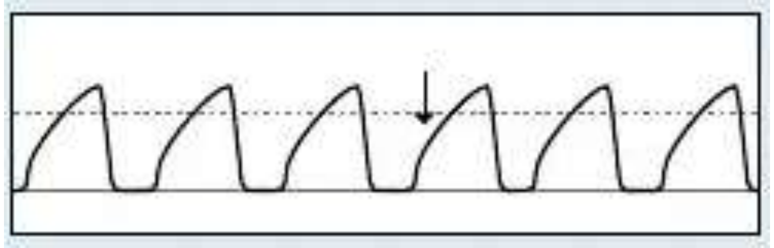
capnography is the ‘gold-standard’ method for confirmation of endotracheal tube (ETT) placement in the trachea.
Grmec S. et al., Comparison of three different methods to confirm tracheal tube placement in emergency intubation. Intensive Care Med. 2002 Jun;28(6)

Specific waveforms

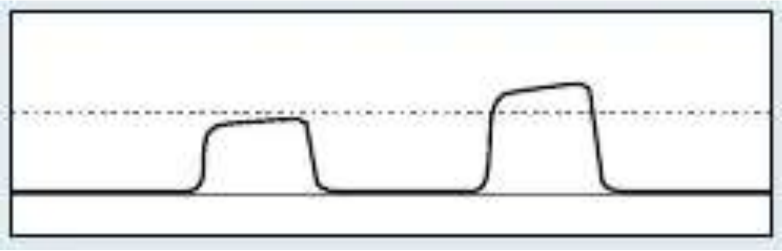
- Normal



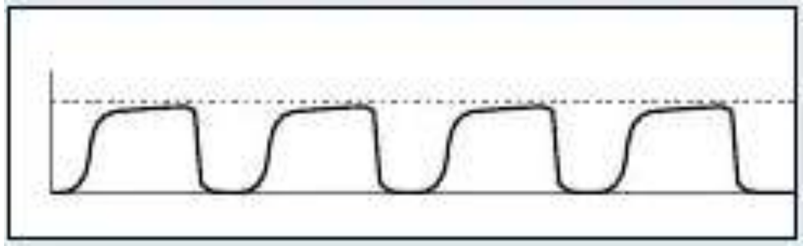
- Obstruction



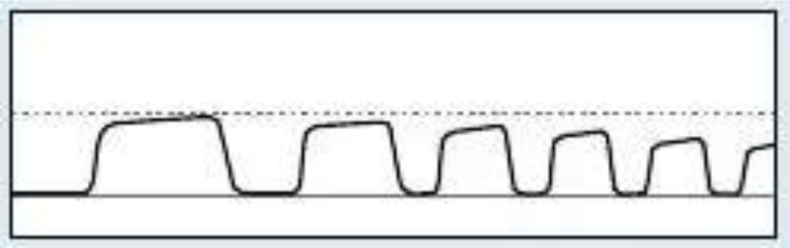
- hypoventilation



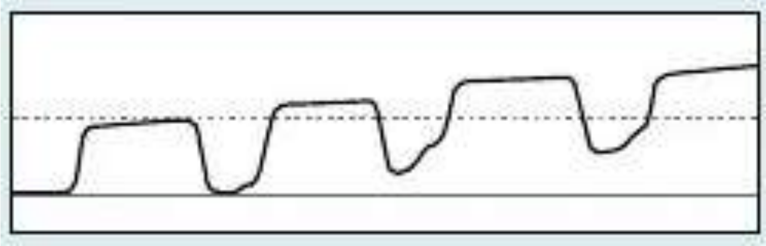
- Normal



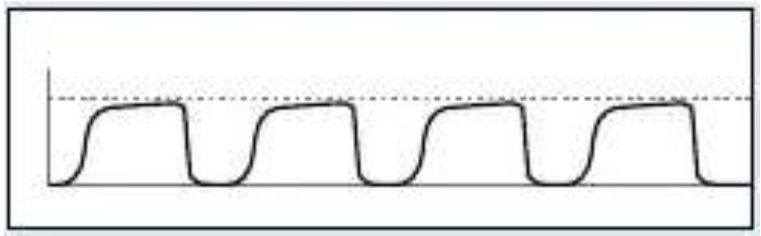
- Hyperventilation



- Rebreathing

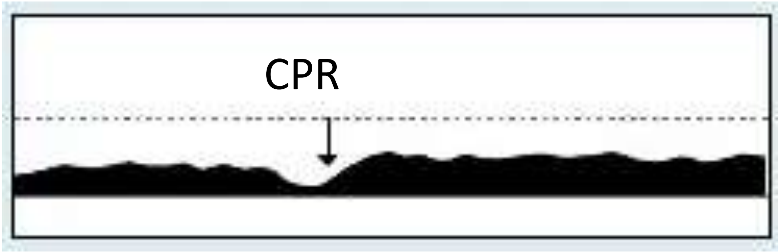


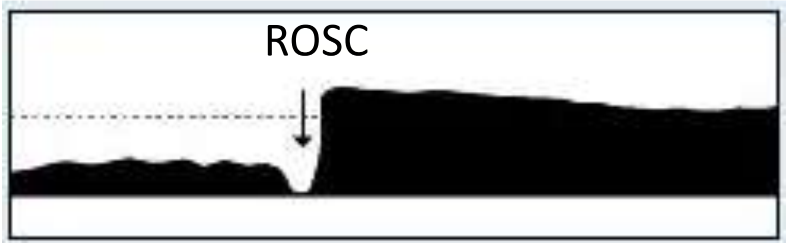
- Normal



- In prolonged out of hospital cardiac arrest, *$ETCO_2$ levels <10 mmHg are consistently associated with a poor outcome*

- CPR/ROSC





- An abrupt rise of $ETCO_2$ during CPR suggests that ROSC has occurred

Sandroni C et al., Capnography during cardiac arrest. Resuscitation. 2018 Nov;132:73-77. PMID: 30142399.

Sudden fall in CO_2 levels in a capnogram

- dislodgement of tube
- obstruction of tube
- apnea
- cardiac arrest
- massive embolism
- technical fault , instrumentation block/malfunction

Limitations

- No idea about the *quantity/volume* of CO_2 exhaled → cannot quantify effective ventilation from total ventilation
- *Dead space ventilation or alveolar ventilation or minute ventilation*
- Some difference in the fraction of CO_2 in exhaled air and in the arterial blood. (some physiological shunt is always there)

- 20 x 350ml = 7 L / min
- 35 x 200 ml = 7L / min
- Are they same?

NO

Why measure the dead space?

- RR- 20 x TV-350ml = 7 L / min

Vdaw – 150 x 20 = 3L/MIN

Valv – 4L/MIN

- RR- 35 x TV - 200 ml = 7L / min

Vdaw – 150 x 35 = 5.2L/MIN

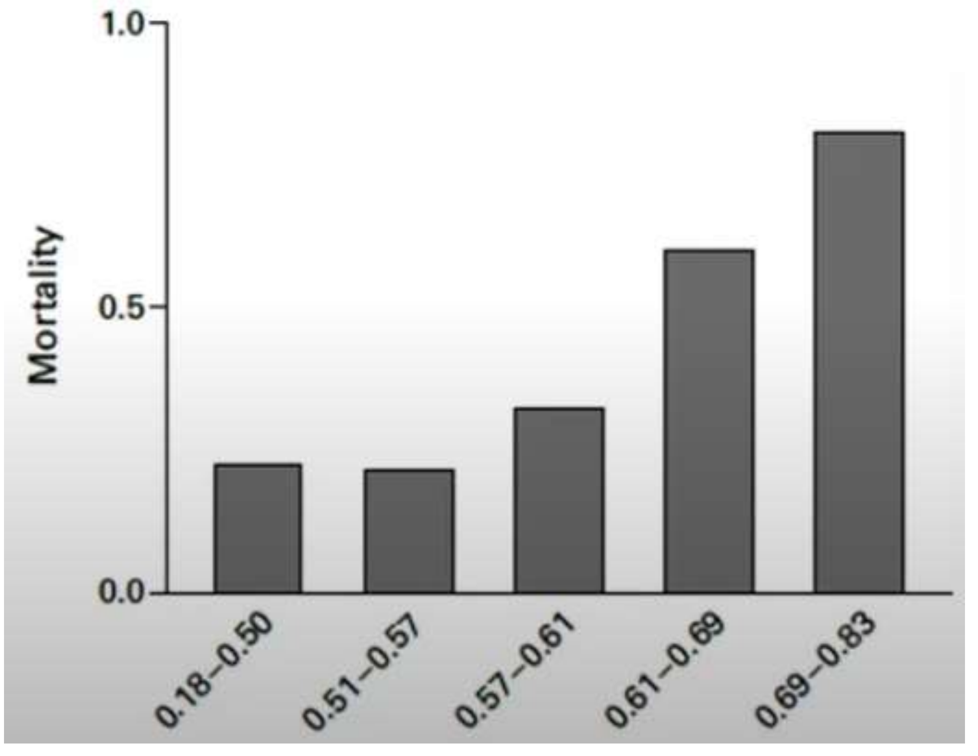
Valv – 2 L /MIN


HAMILTON-S1
SpO2: no sensor (right slot)
2023-08-25
13:44:39
INTELLiVENT
(S)CMV
Adult
Patient
Additions
Modes
18 Ppeak cmH2O
3.9 ExpMinVol l/min
299 VTE ml
14 fTotal b/min
1:2.3 I:E
90 % SpO2
70 VDaw ml
10.3 slopeCO2 %CO2/l
229 Vtalv ml
3.0 V'alv l/min
23 VDaw/VTE %
10 / 12
Paw cmH2O
Flow l/min
V ml
IntelliCuff
14 b/min Rate
300 ml Vt
5 cmH2O PEEP/CPAP
30 % Oxygen
Controls
Alarms
Monitoring
Graphics
Tools
Events
System


SpO2: no sensor (right slot)
2023-08-25
13:45:13
INTELLiVENT
(S)CMV
Adult
Patient
Additions
Modes
16 Ppeak cmH2O
4.5 ExpMinVol l/min
216 VTE ml
19 fTotal b/min
1:1.2 I:E
91 % SpO2
63 VDaw ml
12.3 slopeCO2 %CO2/l
153 Vtalv ml
3.3 V'alv l/min
29 VDaw/VTE %
10 / 12
Paw cmH2O
Flow l/min
V ml
IntelliCuff
21 b/min Rate
220 ml Vt
5 cmH2O PEEP/CPAP
30 % Oxygen
Controls
Alarms
Monitoring
Graphics
Tools
Events
System

PULMONARY DEAD-SPACE FRACTION AS A RISK FACTOR FOR DEATH IN THE ACUTE RESPIRATORY DISTRESS SYNDROME

THOMAS J. NUCKTON, M.D., JAMES A. ALONSO, R.R.T., RICHARD H. KALLET, R.R.T., M.S., BRIAN M. DANIEL, R.R.T., JEAN-FRANÇOIS PITTET, M.D., MARK D. EISNER, M.D., M.P.H., AND MICHAEL A. MATTHAY, M.D.



The dead-space fraction was an independent risk factor for death

Nuckton TJ etal Pulmonary dead-space fraction as a risk factor for death in the acute respiratory distress syndrome. N Engl J Med. 2002 Apr 25

Ventilatory failure and ARDS

Dead space ventilation in critically ill children with lung injury

Jorge A Coss-Bu [1], David L Walding, Yadin B David, Larry S Jefferson

Pulmonary dead space fraction and pulmonary artery systolic pressure as early predictors of clinical outcome in acute lung injury

Magda Cepkova [1], Vineet Kapur, Xiushui Ren, Thomas Quinn, Hanjing Zhuo, Elyse Foster, Kathleen D Liu, Michael A Matthay

Prognostic value of the pulmonary dead-space fraction during the early and intermediate phases of acute respiratory distress syndrome

Joan M Raurich [1], Margalida Vilar, Asunción Colomar, Jordi Ibáñez, Ignacio Ayestarán, Jon Pérez-Bárcena, Juan A Llompart-Pou

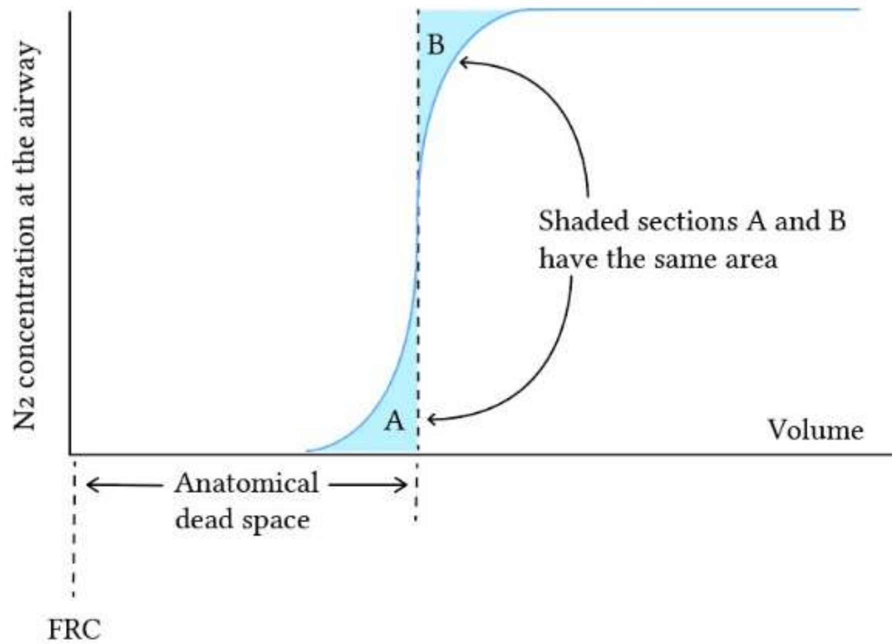
Ventilation dead space (VD) refers to the parts of the lung and airways that do not take part in gas transfer → indicates the ineffective portion of ventilation.

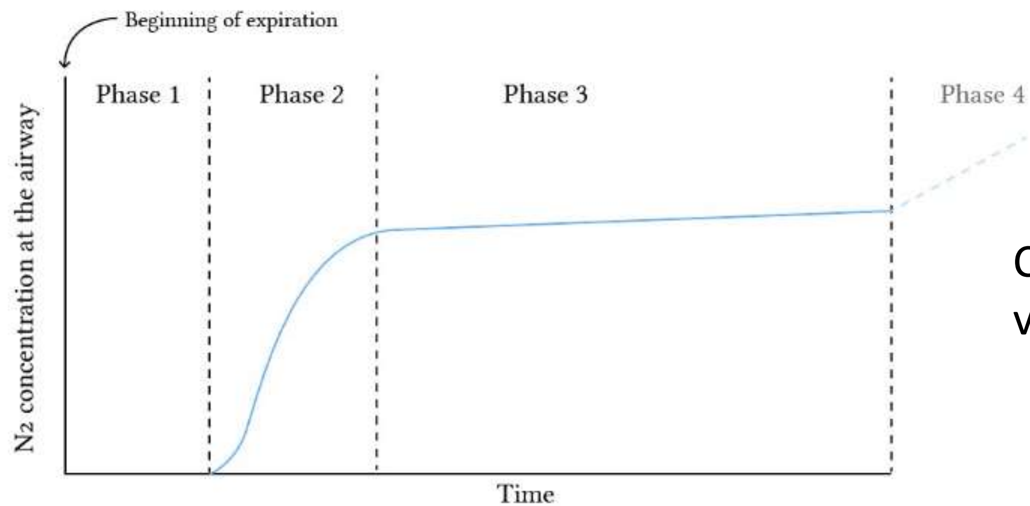
1. Anatomical - volume of conducting airways – approx 150ml.
2. Alveolar dead space – volume of air in alveoli that do not take part in gas transfer, ventilated but not perfused (West Zone 1) – V/Q→ infinite.
3. Anatomical + alveolar = physiological dead space.

Measurement

Anatomical dead space – Fowlers method

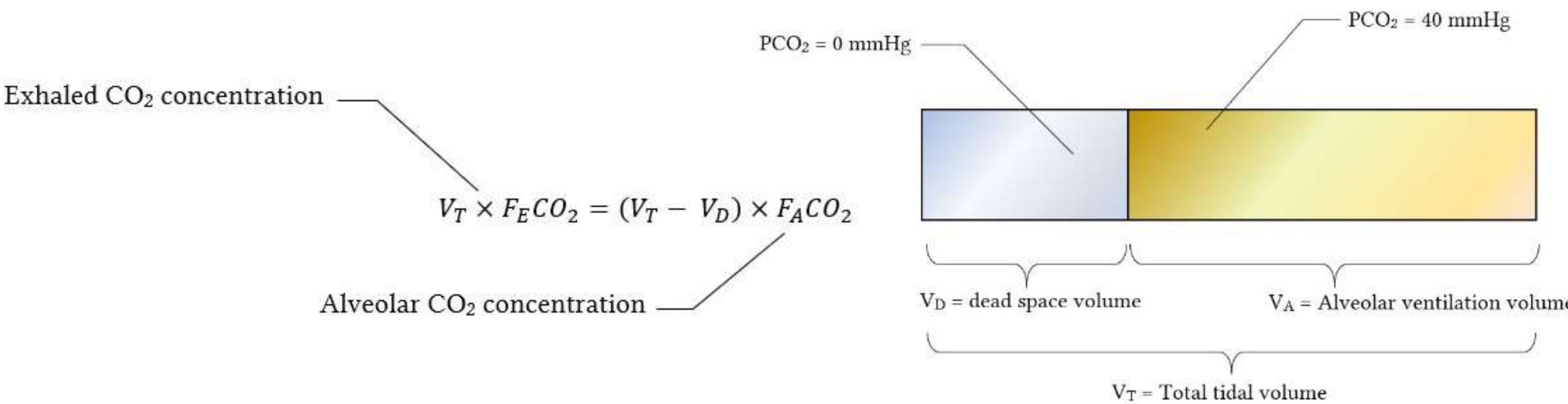
- A single breath of 100% oxygen is given to the subject
- The oxygen replaces nitrogen in the anatomical dead space
- The exhaled breath has its volume and nitrogen concentration measured
- Initial exhaled breath comprises of only dead space oxygen rich air
- Alveolar air volume calculation starts when nitrogen shows up in the exhaled air.
- The graph of nitrogen concentration over volume can be used to calculate the anatomical dead space





Closing volume

- Physiological dead space is calculated from
- **Bohr equation** –
- The Bohr equation can be used to determine physiological dead space fraction from the difference between the exhaled CO_2 and alveolar CO_2.



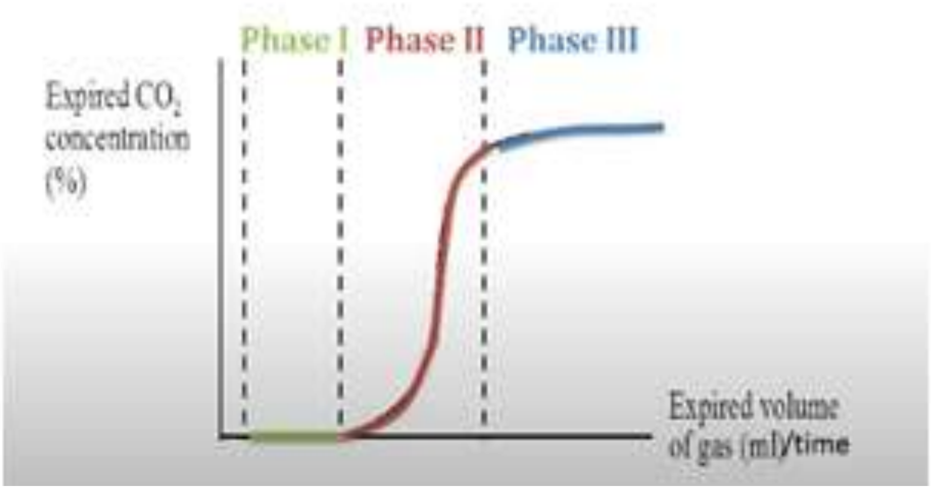
$$\frac{V_D}{V_T} = \frac{(PACO_2 - P_E CO_2)}{PACO_2}$$

$$\frac{V_D}{V_T} = \frac{(F_A CO_2 - F_E CO_2)}{F_A CO_2}$$

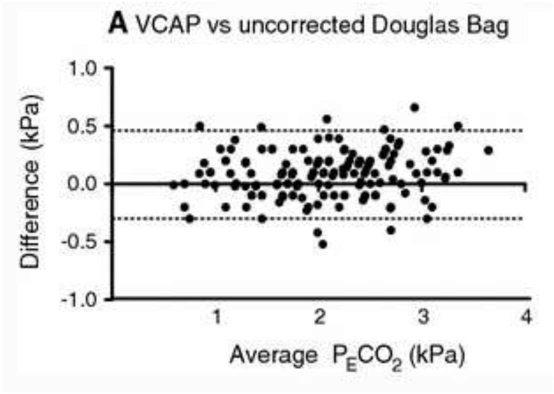
- **Enghoff modification**
- Enghoff modified the Bohr equation by using partial pressure of CO_2 in arterial blood as a surrogate for CO_2 levels in alveolar air.

Single Breath Test CO2 waveform

- Phase 1 is entirely airway gas- no CO2 – airway dead space.
- Phase 2 is mixed from distal airways and early alveolar emptying- sharp rise in CO2
- Phase 3 is plateau- alveolar air emptying in the expiratory limb



Comparison of volumetric capnography and mixed expired gas methods to calculate physiological dead space in mechanically ventilated ICU patients



- 168 paired readings taken in 48 mechanically ventilated patient
- Volumetric capnography (CO_2SMO®Novometrix Medical Systems) vs doughlas bag (bohr-enghoff method)
- There was good correlation between the two methods of measurement.

Sinha, P. etal., Comparison of volumetric capnography and mixed expired gas methods to calculate physiological dead space in mechanically ventilated ICU patients. *Intensive Care Med* **38**, 1712–1717 (2012).

Reproducibility of the respiratory dead space measurements in mechanically ventilated children using the CO2SMO monitor

- Done in 32 children who were mechanically ventilated
- SBT-CO2 was recorded using the CO(2)SMO Plus monitor and correlated with bohr enghoff
- Physiologic dead space values from the SBT-CO2 method were similar to those from Bohr-Enghoff equations.

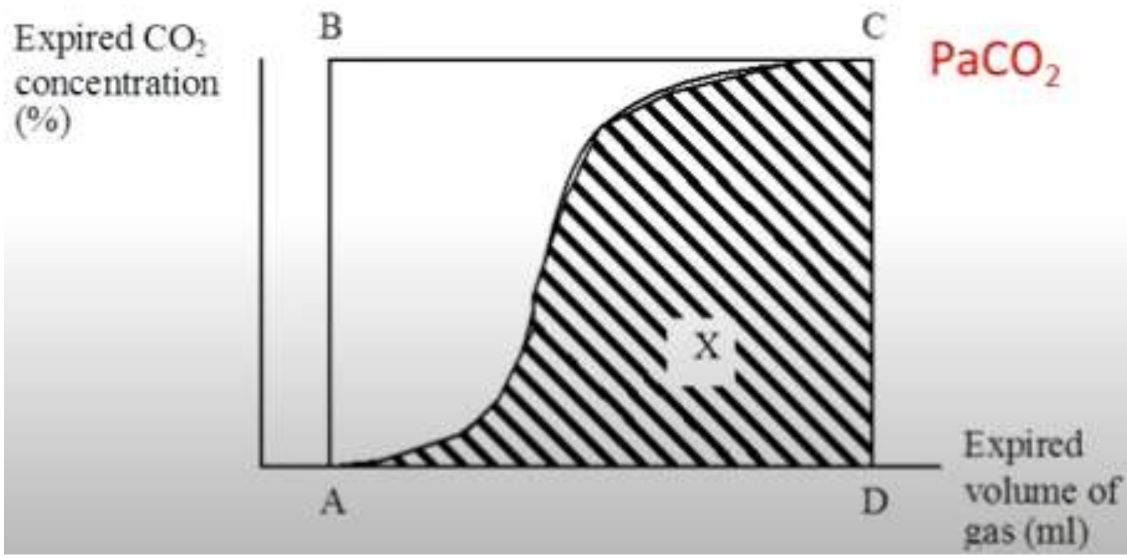
Riou Y etal.,Reproducibility of the respiratory dead space measurements in mechanically ventilated children using the CO2SMO monitor. Intensive Care Med. 2004 Jul;

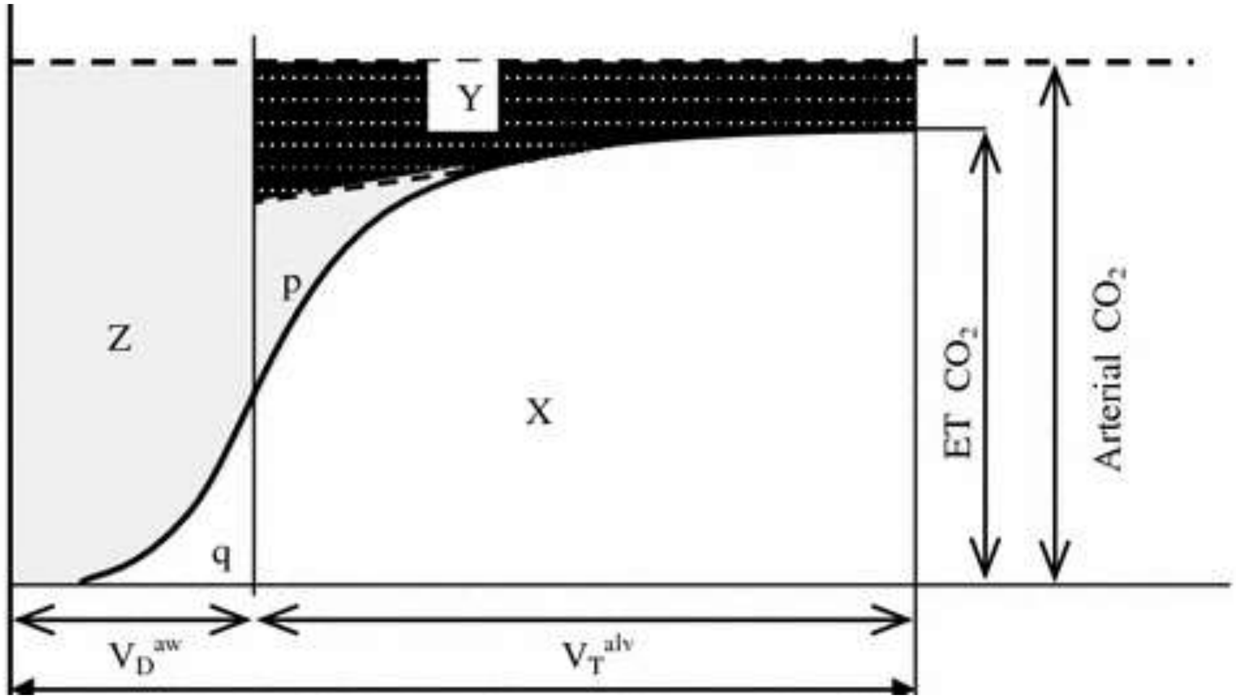
SBT – CO_2

- A- start of expiration
- D- end of expiration
- B-C – alveolar CO_2.
- Physiological Dead Space

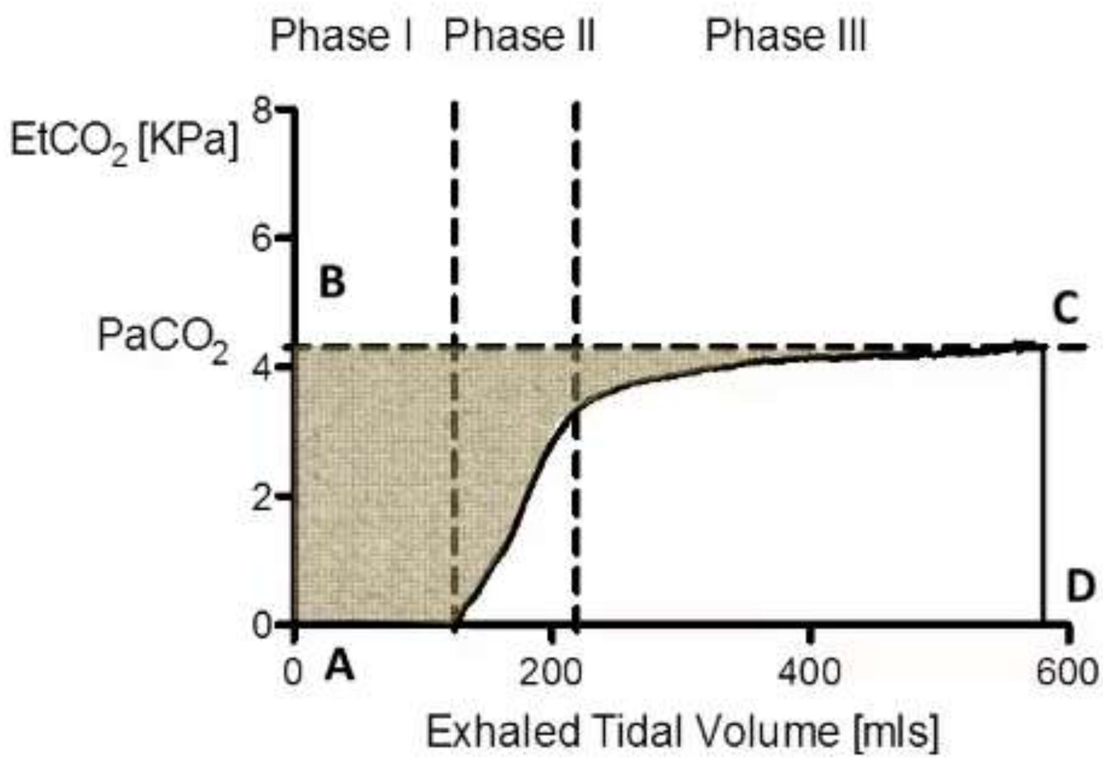
  Area ABCD – area X
- Ventilatory efficiency

  Volume X / area ABCD



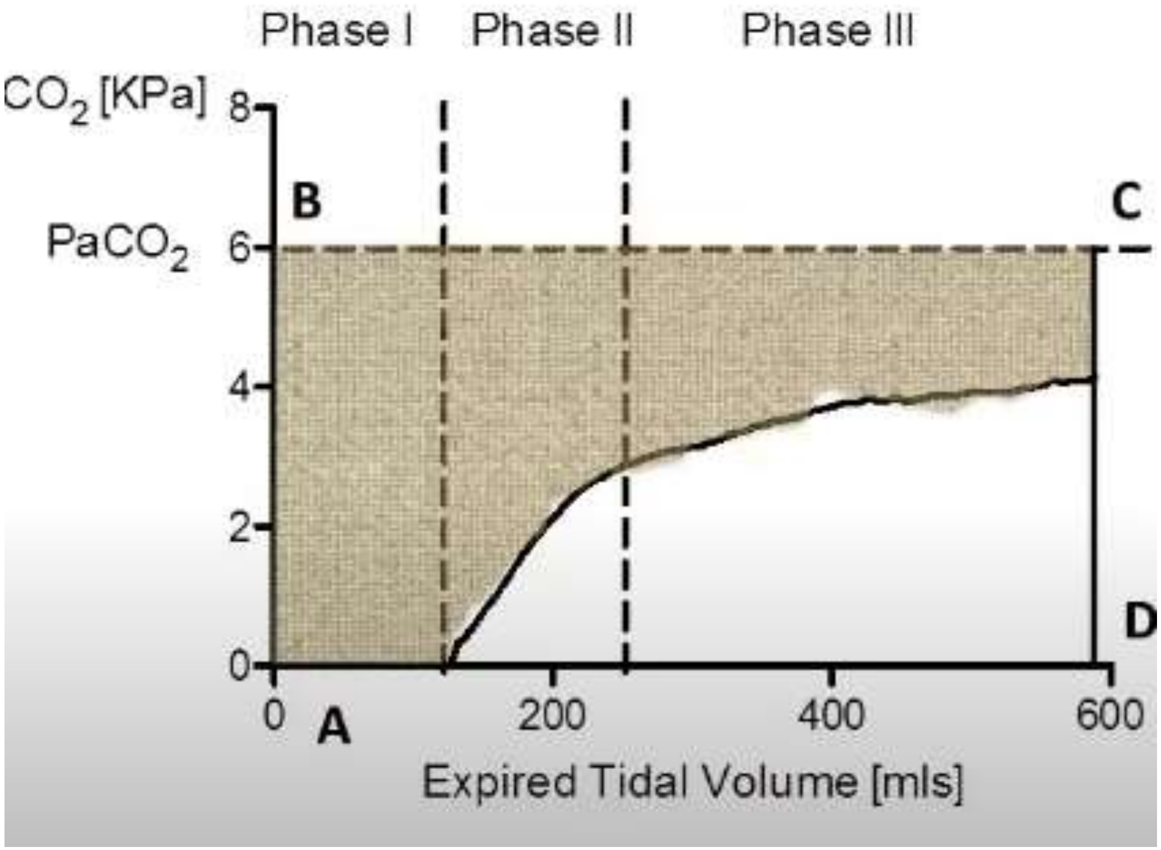


X- area of alveolar ventilation
y – alveolar dead space
z- anatomical dead space
area p= area q



Normal lungs - ventilation

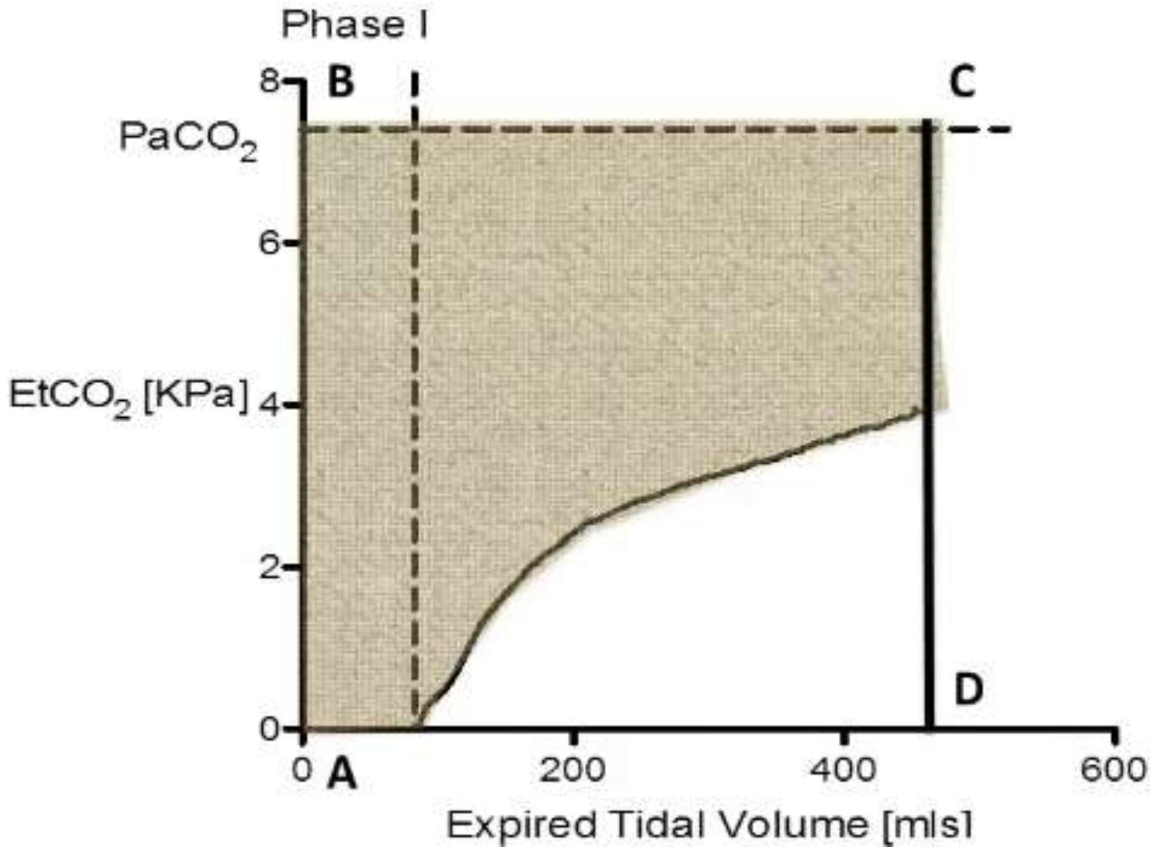
Vd/Vt- 0.35



Phase I
Phase II
Phase III
CO_2 [KPa]
$PaCO_2$
8
6
4
2
0
B
C
D
A
0
200
400
600
Expired Tidal Volume [mls]

COPD

Vd/Vt – 0.6



ARDS

Vd/Vt – 0.75

- If minute ventilation and total CO_2 production remain constant, *arterial CO_2 rises proportional to the ventilation dead space.*

- Conventional CO_2-time capnography gives us no idea about the ***volumes.***

- Ventilator settings alter the dead space volume and volumetric capnography helps estimating the dead space volume.

USES

- Assessing the adequacy of ventilation
- Assessing volume responsiveness
- Alveolar recruitment in patients with ARDS
- Alveolar recruitment in obese patients
- Excluding pulmonary embolism
- Measuring cardiac output

Kreit JW. Volume Capnography in the Intensive Care Unit: Potential Clinical Applications. Ann Am Thorac Soc. 2019 Apr;16(4)

Assessing the adequacy of ventilation

- $PetCO_2$ is used as a surrogate for $PaCO_2$ and thus we can adjust ventilation parameters, quickly diagnose tube dislodgement, bronchospasm, pulmonary oedema or dip in cardiac output. Decrease in frequency of blood gas measurements.
- $PetCO_2$ is the highest level of slope 3 and may be higher then the mean alveolar PCO_2.
- Limitation is the wide differences between arterial and ET CO_2 measurements.

Reference	Year	No. of Patients	Patient Characteristics	Samples	r^2 Value	Range of $Pa_{CO_2} - P_{ET_{CO_2}}$ (*mm Hg*)	
6	1987	17	Medical ICU	17	NP	0 to 39.0	
7	1989	20	Medical-surgical ICU	116	0.61	−9.5 to 19.0	
8	1990	59	Post-cardiac surgery	382	0.41	−8.0 to 21.9	
9	1991	24	Post-cardiac surgery	113	0.67	−5.0 to 16.0	
10	1994	9	Multiple trauma	171	0.41	−2.0 to 36.0	
11	2009	72	Multiple trauma	144	0.28	−8.0 to 25.0	
						Bias* (*mm Hg*)	**Limits of Agreement**† (*mm Hg*)
12	2008	34	General ICU	170	0.53	+5.3	+17.5 to −6.9
13	2011	20	Post-cardiac surgery	165	0.47	−5.3	+10.9 to −21.5
14	2014	25	Brain injury	85	0.34	+0.68	+12.1 to −10.7
15	2017	32	General ICU	160	0.41	+5.5	+16.7 to −5.7

Studies comparing arterial CO2 partial pressure and end-tidal CO2 partial pressure in mechanically ventilated intensive care unit patients

Comparison of arterial-end-tidal PCO2 difference and dead space/tidal volume ratio in respiratory failure

M K Yamanaka [1], D Y Sue

- compared the difference between PETCO2 and PaCO2 in 17 patients undergoing mechanical ventilation in a medical ICU.
- Large differences were found between PaCO2 and PETCO2 in individual patients; P(a-et)CO2 correlated closely with VD/VT.
- PetCO2 is a poor estimate of PaCO2 in patients with respiratory failure.

Yamanaka MK etal., Comparison of arterial-end-tidal PCO2 difference and dead space/tidal volume ratio in respiratory failure. Chest. 1987

Transcutaneous PTCCO$_2$ measurement in combination with arterial blood gas analysis provides superior accuracy and reliability in ICU patients

Oliver Spelten [1], Fritz Fiedler [2], Robert Schier [3], Wolfgang A Wetsch [3], Jochen Hinkelbein [3]

- Correlation between CO2 measurements by different techniques

1. Arterial PaCO2 blood gas analysis with Radiometer ABL
2. Arterial PaCO2 analysis with IRMA
3. End-tidal PETCO2
4. Transcutaneous PTCCO2

- *Arterial CO2 partial pressure by IRMA (PaCO2) and PTCCO2 provided greater accuracy compared to the reference measurement (ABL) than the end-tidal CO2 measurements in critically ill in mechanically ventilated patients patients.*

Spelten O etal., Transcutaneous PTCCO$_2$ measurement in combination with arterial blood gas analysis provides superior accuracy and reliability in ICU patients. J Clin Monit Comput. 2017 Feb;

Assessing volume responsiveness

- In a *steady state* the rate of CO_2 production and elimination are constant
- If Cardiac output is increased , there is increased perfusion to lungs → increased CO_2 delivery and consequently elimination
- Both PLR and fluid challenge transiently increases CO_2 elimination
- Increase in $PetCO_2$ by 5% has been used in many studies to classify fluid responders and non responders in hypotensive patients

End-tidal carbon dioxide is better than arterial pressure for predicting volume responsiveness by the passive leg raising test

Xavier Monnet [1], Aurélien Bataille, Eric Magalhaes, Jérôme Barrois, Marine Le Corre, Clément Gosset, Laurent Guerin, Christian Richard, Jean-Louis Teboul

PLR was performed in 40 patients

Volume expansion increased CI > 15% in 21 – *volume responders*

In these 21 patients EtCO2 increased > 5% (sensitivity 71%, specificity 100%)

Monnet X, etal., End-tidal carbon dioxide is better than arterial pressure for predicting volume responsiveness by the passive leg raising test. Intensive Care Med. 2013 Jan;

Non-invasive assessment of fluid responsiveness by changes in partial end-tidal CO2 pressure during a passive leg-raising maneuver

Manuel Ignacio Monge García [1], Anselmo Gil Cano, Manuel Gracia Romero,

- Under steady state and fixed MV
- Increase in $PEtCO_2$ >5% or >12% in CO predicted fluid responsiveness (sensitivity 90.5% and specificity 93.7%)

Monge García MI, etal., Non-invasive assessment of fluid responsiveness by changes in partial end-tidal CO2 pressure during a passive leg-raising maneuver. Ann Intensive Care. 2012 Mar 26

The Sensitivity and Specificity of Pulmonary Carbon Dioxide Elimination for Noninvasive Assessment of Fluid Responsiveness

Gerardo Tusman [1], Iván Groisman, Gustavo A Maidana, Adriana Scandurra, Jorge Martinez Arca,

- PEEP challenge of 1-minute increase in PEEP from 5 to 10 cm H_2O
- At PEEP of 5 cm H_2O, patients were preloaded with 500 mL IV saline solution after which a second PEEP challenge was performed
- Twenty-one of 52 patients were identified as fluid responders (40%)
- PEEP maneuver before fluid administration decreased CI from 2.65 ± 0.34 to 2.21 ± 0.32 L/min/m ($P = 0.0011$) VCO_2 from 150 ± 23 to 123 ± 23 mL/min ($P = 0.0036$) in responders
- The PEEP challenge after fluid administration induced no significant changes in CI and VCO_2, in neither responders nor nonresponders.
- During the PEEP challenge, a decrease in VCO_2 by 11% predicted fluid responsiveness with a sensitivity of 0.90 and a specificity of 0.95.

Tusman G etal., The Sensitivity and Specificity of Pulmonary Carbon Dioxide Elimination for Noninvasive Assessment of Fluid Responsiveness. Anesth Analg. 2016 May;

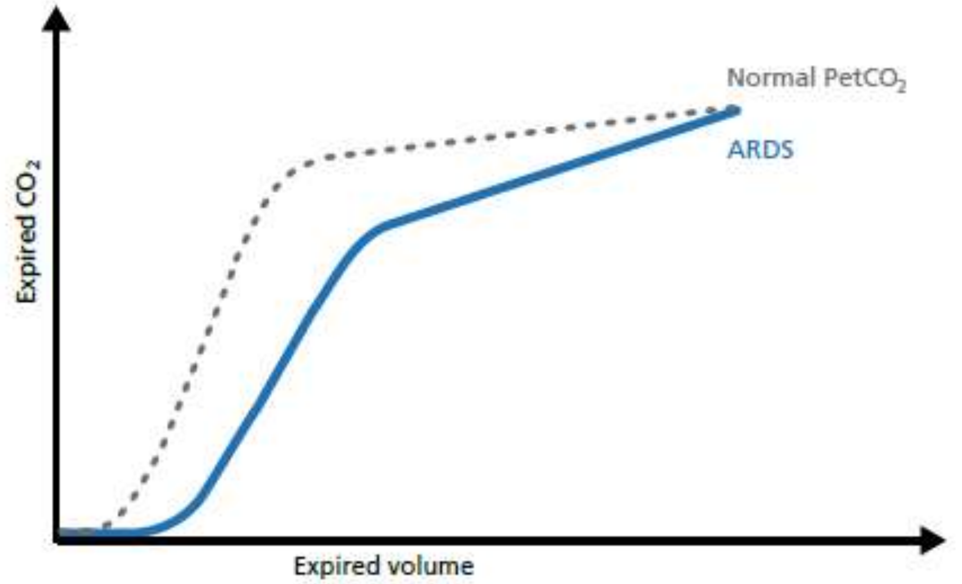
Alveolar recruitment in ARDS

- PEEP allows recruitment of alveoli throught the respiratory cycle.
- Opens alveoli to reroute the TV from over distended alveoli to non ventilated ones → homogeneity
- Transient increase in CO_2 elimination followed by reaching the baseline.
- Too much PEEP will cause over distension of alveoli and increase the V/Q, decrease the venous return → decreasing CO_2 elimination

ARDS

- Phase 1 – increased anatomical dead space
- Phase 2 & 3 – slope altered due to ventilation and perfusion heterogeneity
- Vdaw/VT – increased to 50-80%

  normal 25-30%



Dead space fraction changes during PEEP titration following lung recruitment in patients with ARDS

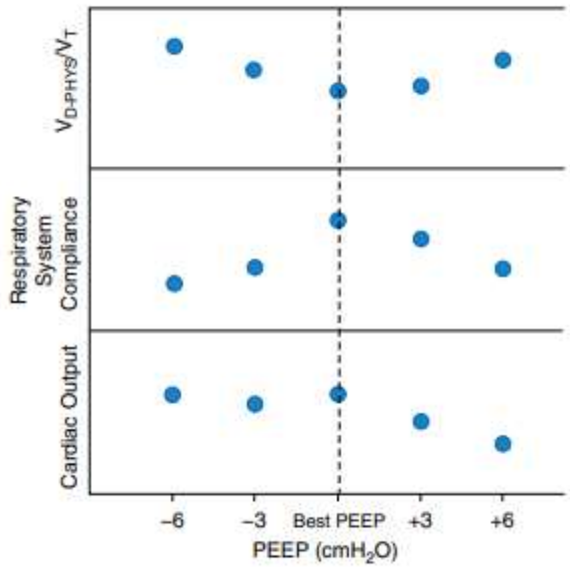
Guo Fengmei [1], Chen Jin, Liu Songqiao, Yang Congshan, Yang Yi

- Recruitment manuever in 23 patients with ARDS→ stepwise PEEP reduction from 20cm to 0 cm → Vphy/Vt initially reduced and then increased →lowest value recorded and coincided with highest compliance.
- Monitoring of V(D)/V(T) was useful for detecting collapse of alveoli and for establishing open-lung PEEP after a recruitment maneuver.
- Similar to PEEP titration in ARDS.

Fengmei G etal., Dead space fraction changes during PEEP titration following lung recruitment in patients with ARDS. Respir Care. 2012 Oct

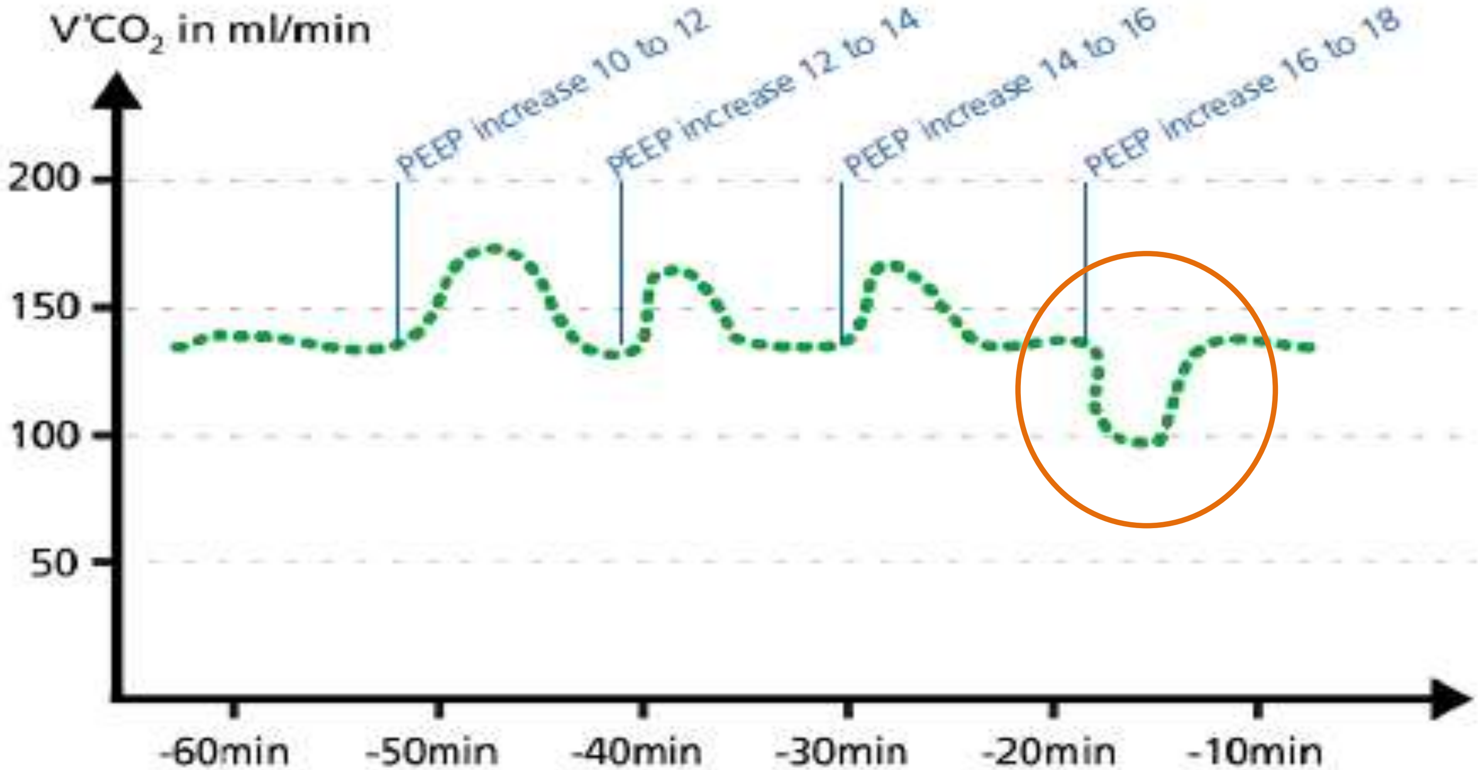
Optimum end-expiratory airway pressure in patients with acute pulmonary failure

P M Suter, B Fairley, M D Isenberg



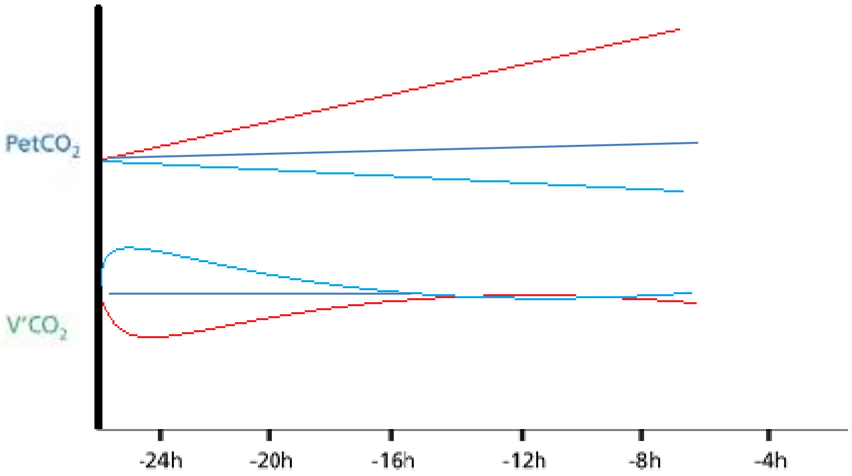
Stepwise increase in PEEP → noted that Vphys/Vt and Valv/Vt reached the lowest value at a PEEP at which the cardiac output and compliance were highest.

Suter PM etal., Optimum end-expiratory airway pressure in patients with acute pulmonary failure. N Engl J Med. 1975 Feb 6;292(6):284-9. doi: 10.1056/NEJM1975



V'CO2 in ml/min
200
150
100
50
PEEP increase 10 to 12
PEEP increase 12 to 14
PEEP increase 14 to 16
PEEP increase 16 to 18
-60min
-50min
-40min
-30min
-20min
-10min

- RED – derecruitment, worsening ventilation
- Blue – recruitment , improved ventilation



Noninvasive monitoring of lung recruitment maneuvers in morbidly obese patients: the role of pulse oximetry and volumetric capnography

Gerardo Tusman [1], Iván Groisman, Felipe E Fiolo, Adriana Scandurra, Jorge Martinez Arca, Gustavo Krumrick, Stephan H Bohm, Fernando Suarez Sipmann

- lung recruitment maneuver was performed in pressure control ventilation → during an ascending limb, the lungs opening pressure was detected. The opening pressure was attained when SpO_2 exceeded 97% → During a subsequent decreasing limb, the lungs closing pressure was identified. PEEP was decreased in steps of 2 cm H_2O. The closing pressure was determined as the PEEP value at which respiratory compliance decreased from its maximum value
- Observation at the end of the study → Cdyn reached its highest value at a PEEP level at which CO_2 elimination was highest and minimum Vphys/Vt.

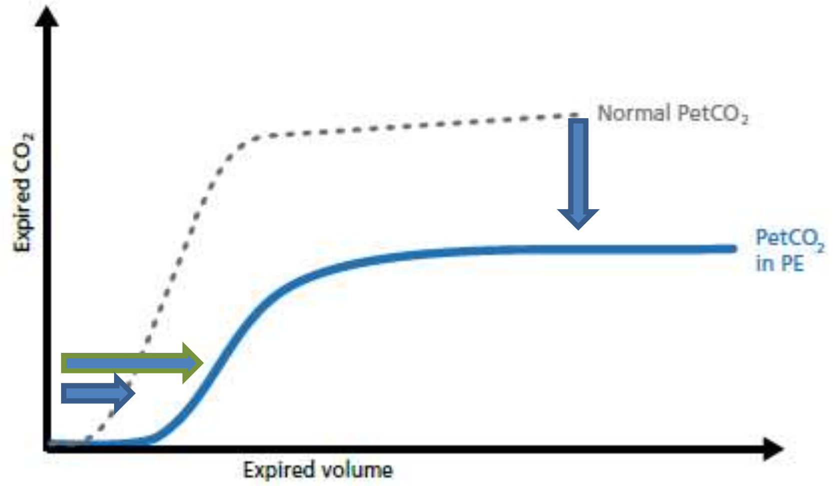
Tusman G etal., Noninvasive monitoring of lung recruitment maneuvers in morbidly obese patients: the role of pulse oximetry and volumetric capnography. Anesth Analg. 2014 Jan;

Rule out pulmonary embolism

- Alveolar dead space fraction (ADSF) can be calculated by (artCO2-EtCO2/arterialCO2) → Normal ADSF – 0.15
- Regardless of clinical probability if ADSF is normal + normal D-dimer levels – pulmonary embolism is ruled out
- If the clinical probability is low and ADSF is normal + elevated D-dimer levels – pulmonary embolism cannot be ruled out
- Dead space fraction measurement did not help in a study done in out patient department in 400 patients with suspected pulmonary embolism and presenting with chest pain*
- No common consensus to rule out embolism by using volumetric capnography – needs more investigation

*Hogg K etal., Respiratory dead space measurement in the investigation of pulmonary embolism in outpatients with pleuritic chest pain. Chest. 2005

- Increased anatomical dead space
- Phase 2 slope is decreased due to poor perfusion
- Normal plateau with low ETCO2
- Sudden drop in V'CO2

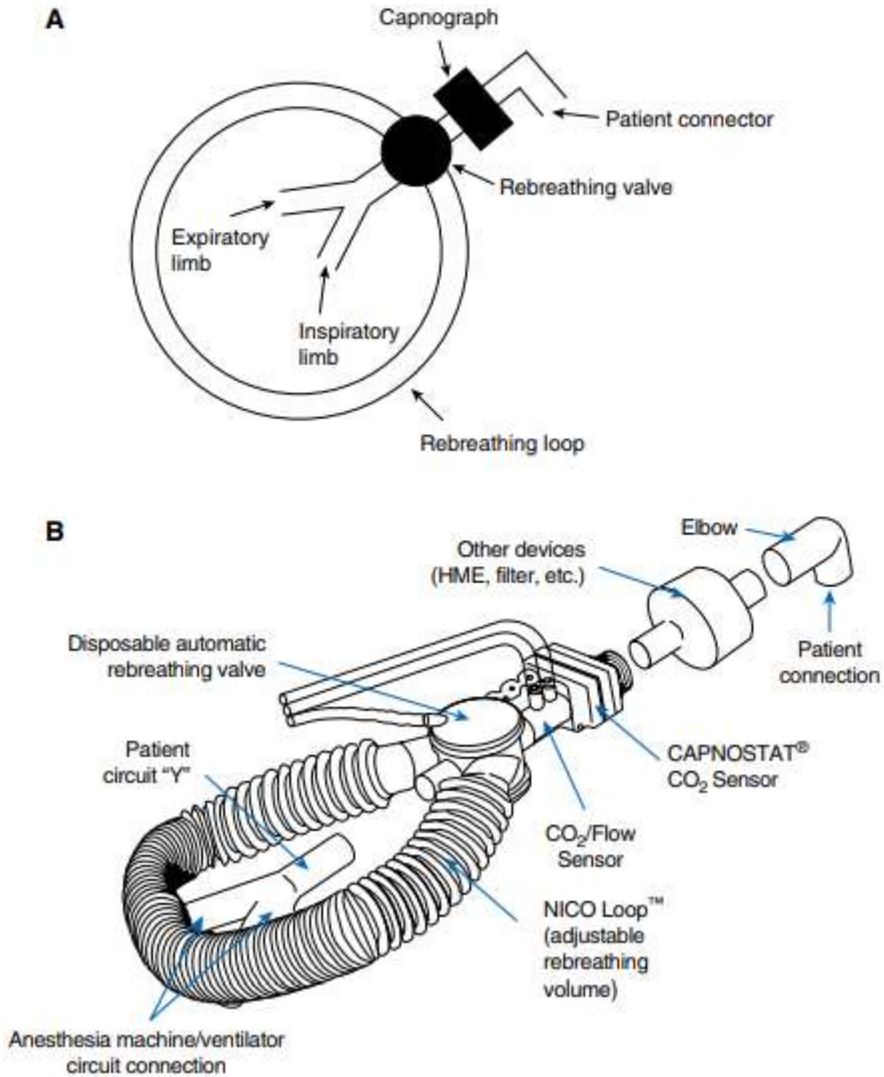


Measuring cardiac output

- Based on Ficks principle that rate of CO_2 elimination should equal the difference in mixed venous and arterial CO_2
- Blood flow = CO_2 elimination / (CO_2 venous – CO_2 arterial)
- Bias is present because of intrapulmonary shunts and right to left cardiac shunts.
- Difference between CO global = CO epbf + CO shunt
- Small volume of expired air containing CO_2 of phase 3 is rebreathed during inspiration which also creates a bias
- Rebreathing technique used to overcome this bias using a rebreathing loop.
- Sudden increase in $ETCO_2$ level is indicative of ROSC during CPR.

Re breathing technique

- Done to account for the small fraction of CO_2 in the ventilator tubes that is inspired.
- A specially designed rebreathing tube is used (NICO philips respironics)
- Tube has a inbuilt valve that is initially open to allow patient to rebreathe (45secs) his exhaled air and towards the later part of the study the valve are closed and patient resumes respiration normally without the additional dead space (2 mins)
- CO_2 fraction before rebreathing is measured as the baseline and CO_2 after rebreathing is calculated
- **CO epbf = $\Delta VCO_2 / \Delta CaCO_2$**


A
Capnograph
Patient connector
Rebreathing valve
Expiratory limb
Inspiratory limb
Rebreathing loop
B
Elbow
Other devices (HME, filter, etc.)
Patient connection
Disposable automatic rebreathing valve
Patient circuit "Y"
CAPNOSTAT® CO_2 Sensor
CO_2/Flow Sensor
NICO Loop™ (adjustable rebreathing volume)
Anesthesia machine/ventilator circuit connection

Reference	Year	No. of Patients	Patient Characteristics	Samples	r^2 Value	Bias* (*L/min*)	Limits of Agreement† (*L/min*)
34	2001	30	Post–cardiac surgery	30	NP	+0.16	+1.96; −1.64
35	2002	22	Acute lung injury	79	0.71	+0.18	+2.95; −2.59
36	2002	15	During major surgery	125	0.92	−0.04	+1.68; −1.76
37	2003	28	During AAA repair	112	0.64	−0.58	NP
38	2003	25	Post–cardiac surgery	25	0.62	−0.67	+0.79; −2.13
39	2003	22	Post–cardiac surgery	33	NP	+0.17	+3.07; −2.73
40	2004	12	General ICU	36	0.62	−1.20	+1.80; −4.10
41	2006	22	During and after cardiac surgery	4,372	0.48	+0.10	+3.30; −2.80
42	2007	12	During thoracotomy	76	NP	−0.29	+1.43; −1.69
43	2007	10	During total hip arthroplasty	2,455	0.43	−0.30	+1.90; −2.50
44	2009	42	During AAA repair	194	0.65	+0.18	+1.84; −1.48
45	2009	20	ARDS	140	0.42	−0.80	+3.70; −2.10

Studies comparing thermo dilution and partial CO2 rebreathing cardiac output measurements

Pulmonary capillary blood flow and cardiac output measurement by partial carbon dioxide rebreathing in patients with acute respiratory distress syndrome receiving lung protective ventilation

- Agreement between partial rebreathing and thermodilution for the determination of pulmonary capillary blood flow and cardiac output in the setting of ARDS
- Lung protective ventilation strategy
- Over 2 hrs 7 values were recorded
- Thermodilution was more accurate
- Values obtained by CO2 re breathing were in agreement with values obtained by thermodilution.

Allardet-Servent Jetal., Pulmonary capillary blood flow and cardiac output measurement by partial carbon dioxide rebreathing in patients with acute respiratory distress syndrome receiving lung protective ventilation. Anesthesiology. 2009

- Modification of this complicated technique were made by adding a inspiratory pause to let patient build up the CO_2 and then let the CO_2 elimination happen with normal ventilation (1)
- Another method was developed using the ELV (effective lung volume) (2)

1) Peyton PJ etal.,. Noninvasive, automated and continuous cardiac output monitoring by pulmonary capnodynamics: breath-by-breath comparison with ultrasonic flow probe. Anesthesiology. 2006
2) Albu G etal.,Comparison of static end-expiratory and effective lung volumes for gas exchange in healthy and surfactant-depleted lungs. Anesthesiology. 2013

[Utility of the dead space fraction (Vd/Vt) as a predictor of extubation success]

[Article in Spanish]

A González-Castro [1], V Suárez-Lopez, V Gómez-Marcos, C González-Fernandez, D Iglesias-Posadilla, J Burón-Mediavilla, J C Rodríguez-Borregan, E Miñambres, J Llorca

-The study included 76 patients on mechanical ventilation (MV)

- Vd/Vt was calculated as the ratio (PaCO(2)-Pє CO(2))/PaCO(2), (alveolar dead space fraction)

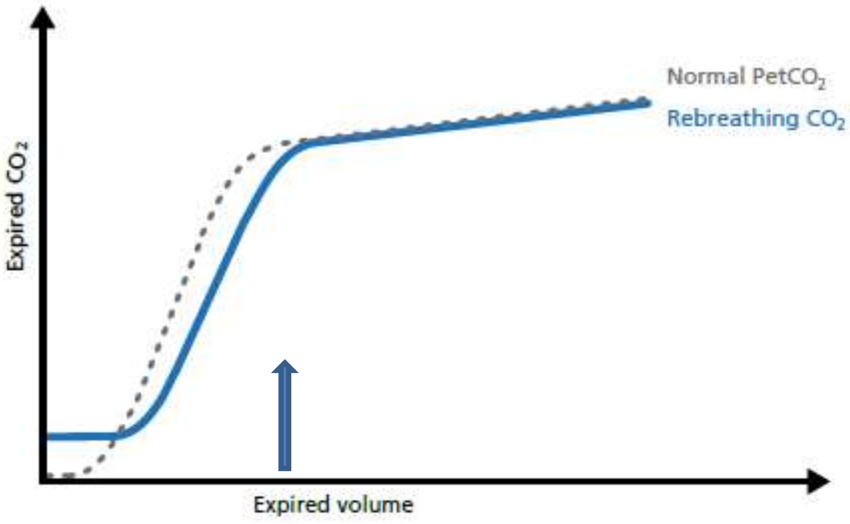
-significant association between the Vd/Vt and extubation failure,

- Vd/Vt is a powerful predictor of extubation failure in patients on MV.

González-Castro A etal., Valor de la fracción de espacio muerto (Vd/Vt) como predictor de éxito en la extubación [Utility of the dead space fraction (Vd/Vt) as a predictor of extubation success]. Med Intensiva. 2011 Dec;35(9):529-38. Spanish.

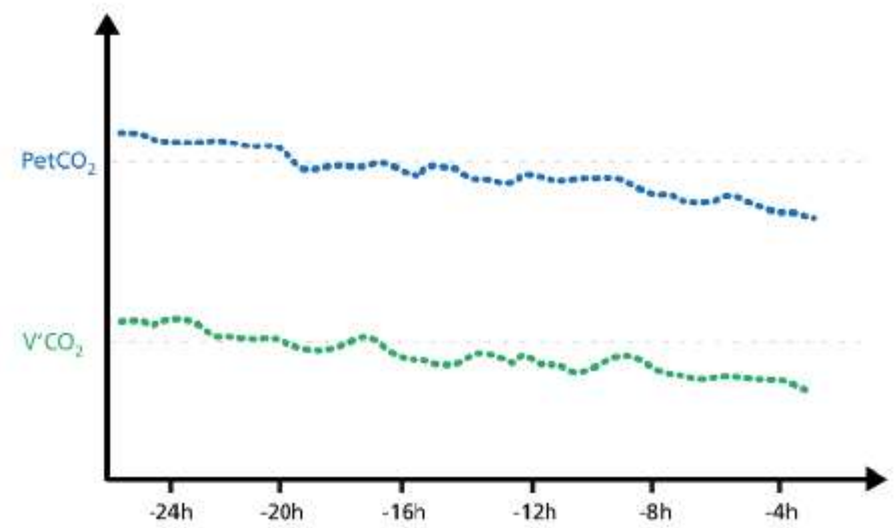
Rebreathing

- Presence of CO2 in the Phase 1



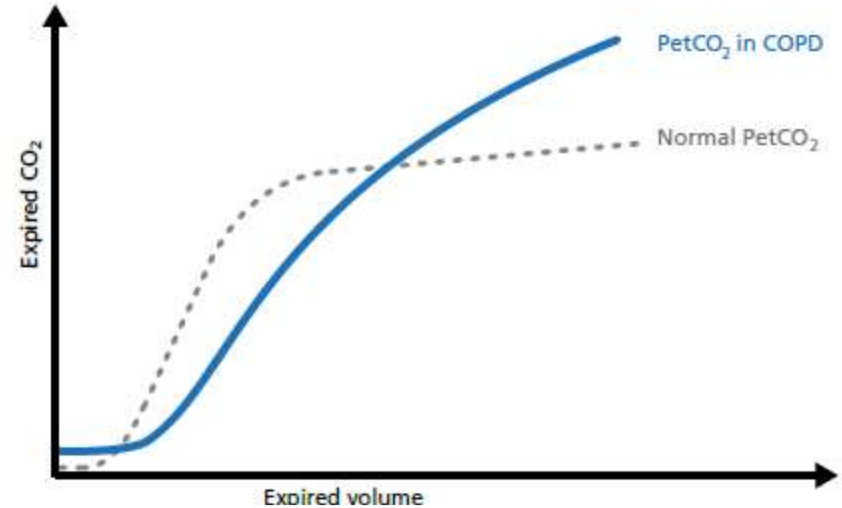
Increasing / decreasing V'CO2

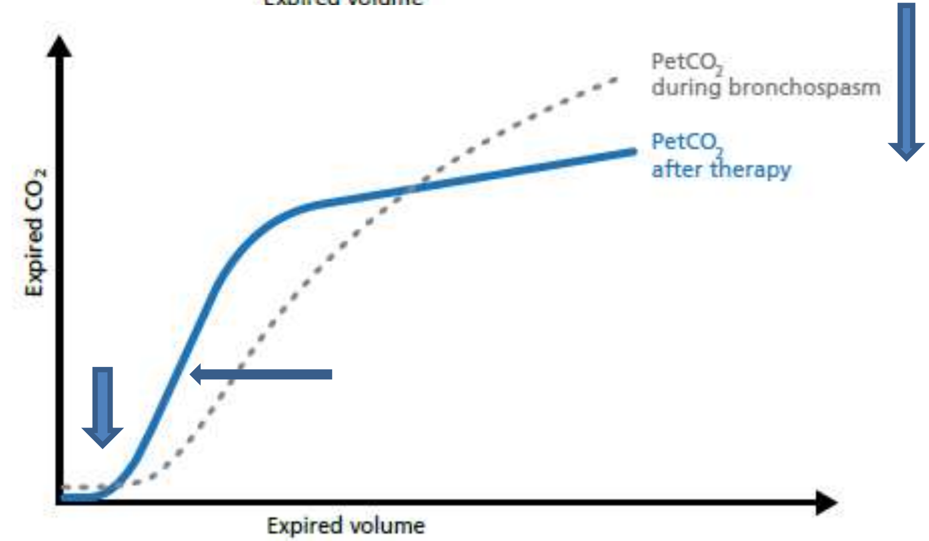
- If PetCO2 and V'CO2 – decreasing on same ventilation strategy --> decreasing CO2 production
- If PetCO2 and V'CO2 – increasing on same ventilation strategy --> increasing CO2 production
- Increasing CO2 – fever, stress, pain, sepsis , nutritional carbohydrate



COPD

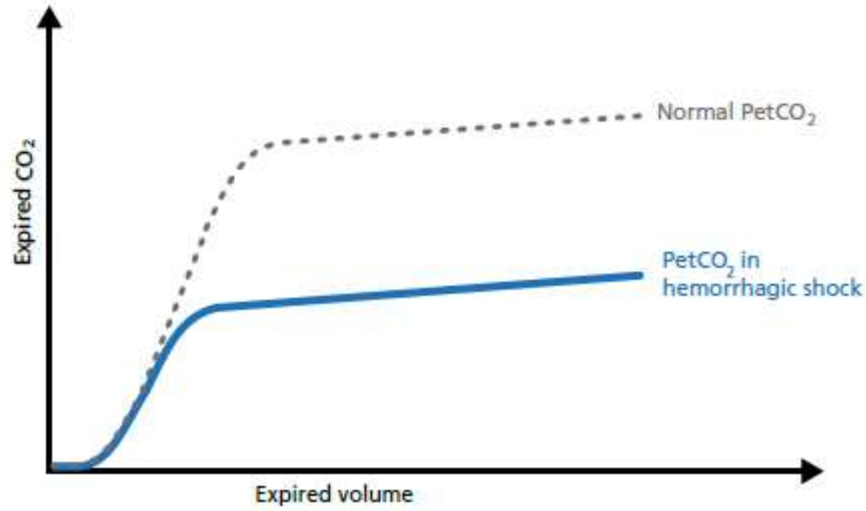
- asynchronous emptying of compartments with different ventilation/perfusion ratios.
- Increase in ETCO2 during the end as the last emptying alveoli have highest CO2 due to longer gas exchange time.
- Curve looks continuously ascending with no plateau
- Distinct improvement seen after relief from exacerbation





Sudden Hypovolemia

- No change in dead space, slope of phase 2 or 3 but the ETCO2 drops.



Limitations

- Most of the studies have a small sample size
- Well designed trials required
- Needs more evidence
- Expensive equipment and well trained personnel required

How to use it in our RICU

- Monitoring of patients of ARDS by using the Vd/Vt
- Optimizing the PEEP in ARDS patients
- Alveolar recruitment in patients where we cannot use recruitment maneuver
- Graph can give us idea about the response to treatment in cases of COPD
- We can suspect Pulmonary embolism if we look for it??