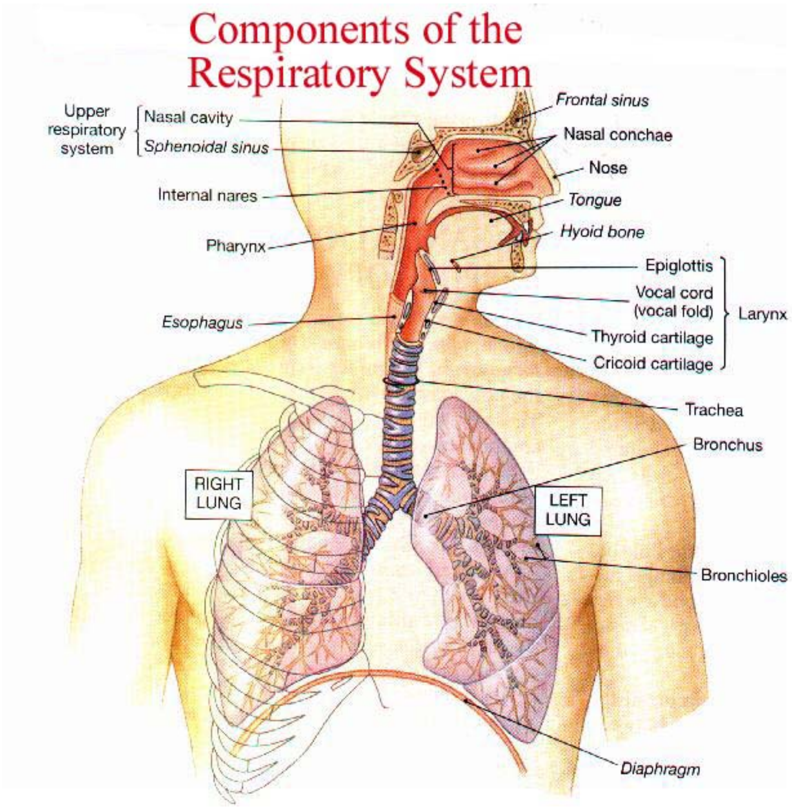
Capnography and Ventilation

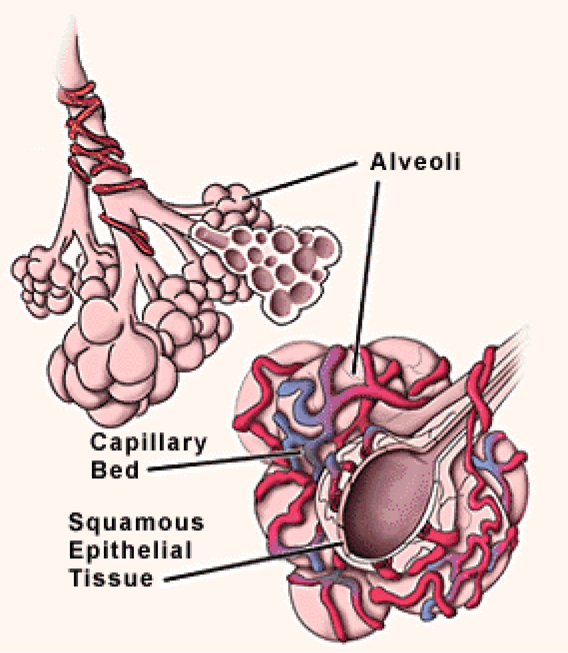
David Neubert, MD, EMT-HP

Overview

- Basics of respiratory physiology
- Basics of capnography and capnometry
- Capnometry and respiratory physiology
- Capnography: What do the waveforms mean?
- Clinical Cases
- Review

Respiratory System Anatomy

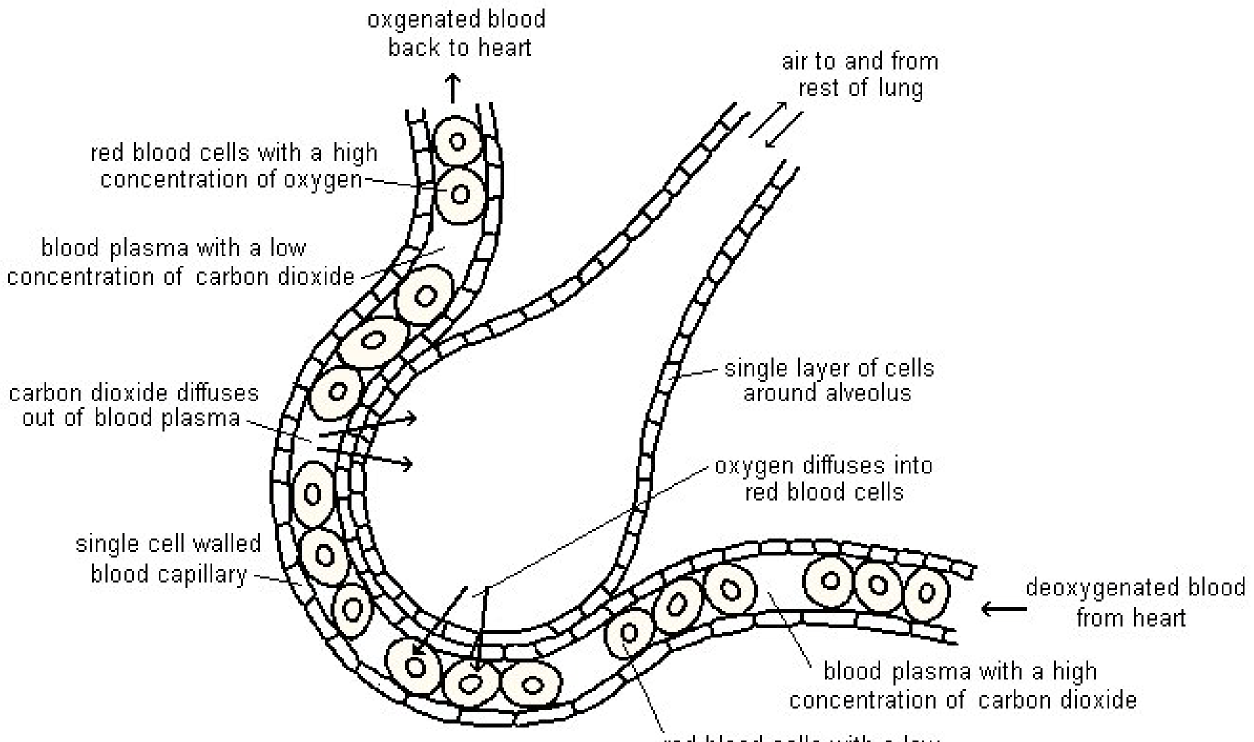




http://eng-sci.udmercy.edu/courses/bio123/Chapter43/lung%20anatomy.html

http://chickscope.beckman.uiuc.edu/explore/embryology/day15/focuson_humans.html

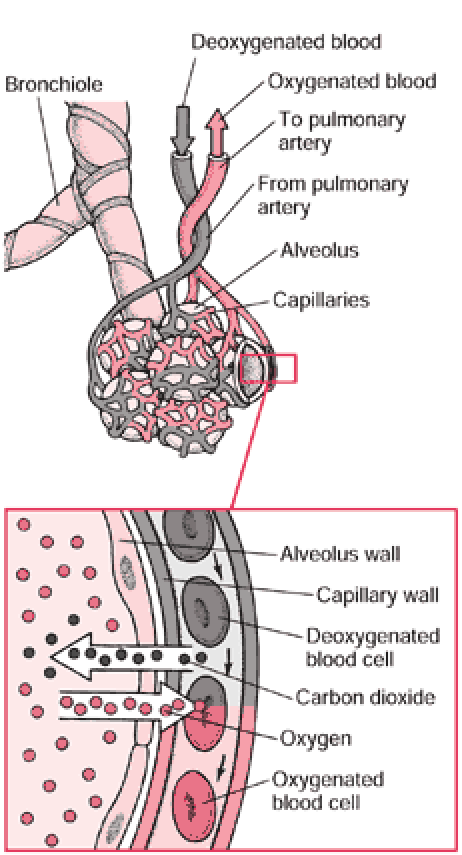
Physiology – Overview

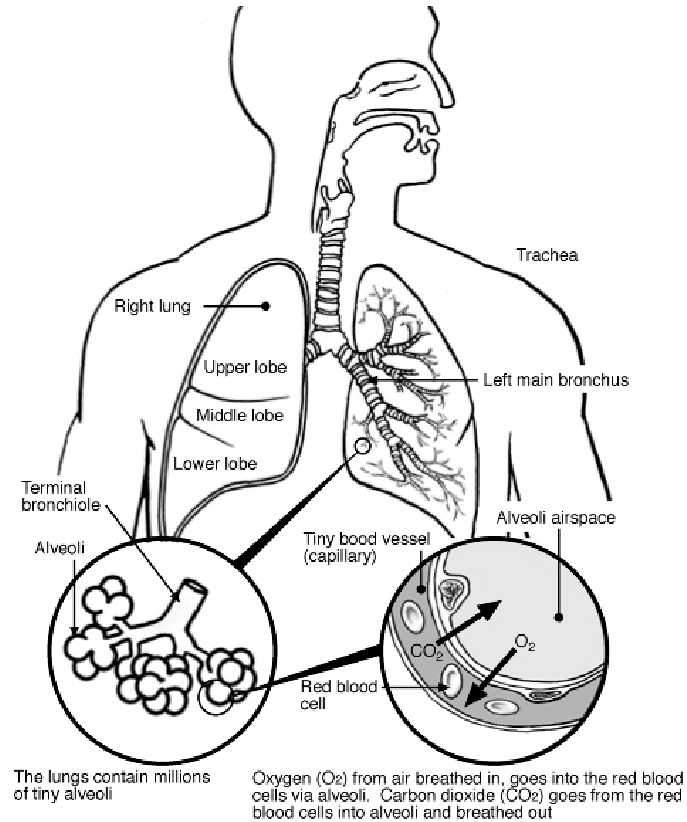


Gaseous Exchange in the Lungs

http://www.cornwallis.kent.sch.uk/intranet/elearn/science/body/organs/Alveoli.jpg

Physiology – Overview



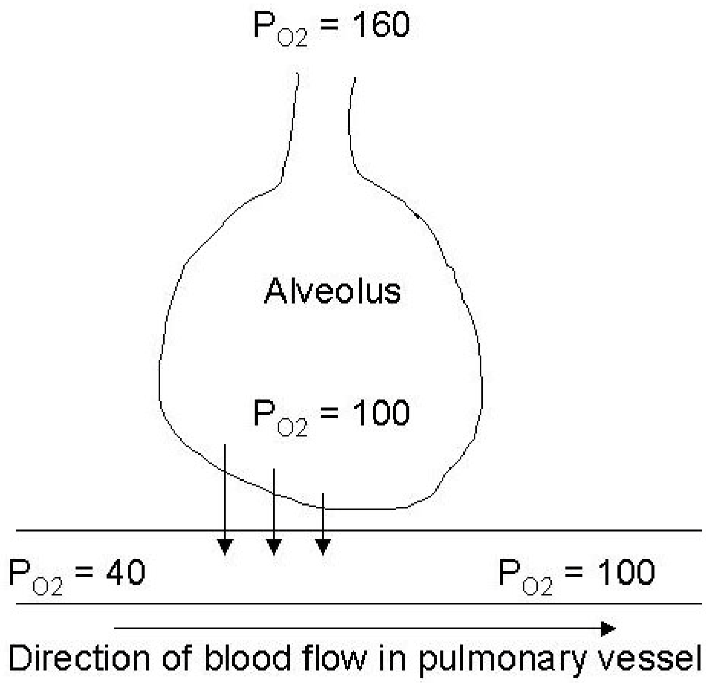


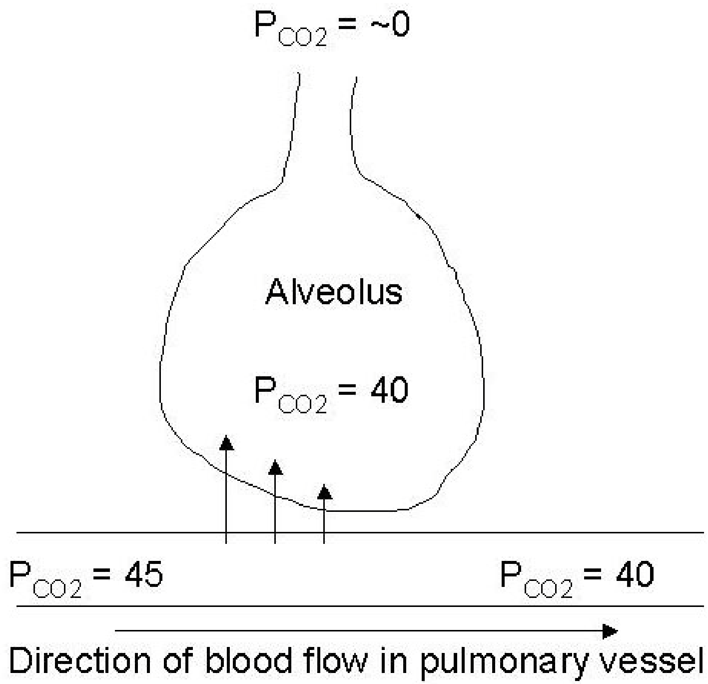
Lung showing alveoli

http://www.merck.com/mmhe/sec04/ch038/ch038d.html

http://www.patient.co.uk/showdoc/21692478/

Physiology – Gas Exchange



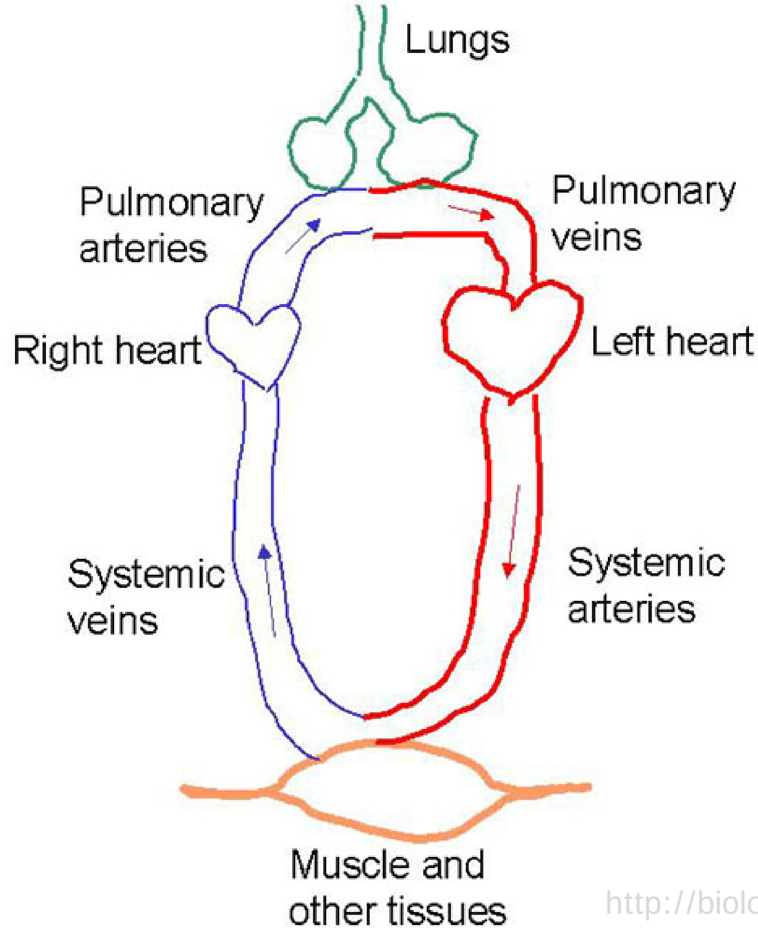


http://biology.kenyon.edu/courses/biol105/html/lo28.htm *also modified in future slides

Physiology – Gas Exchange

High CO_2

Low O_2



High O_2

Low CO_2

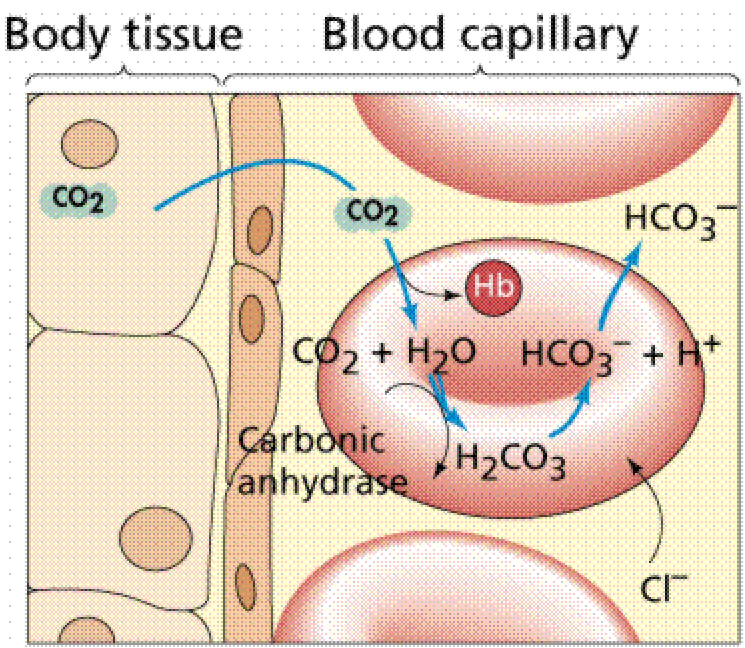
http://biology.kenyon.edu/courses/biol105/html/circulation.jpg

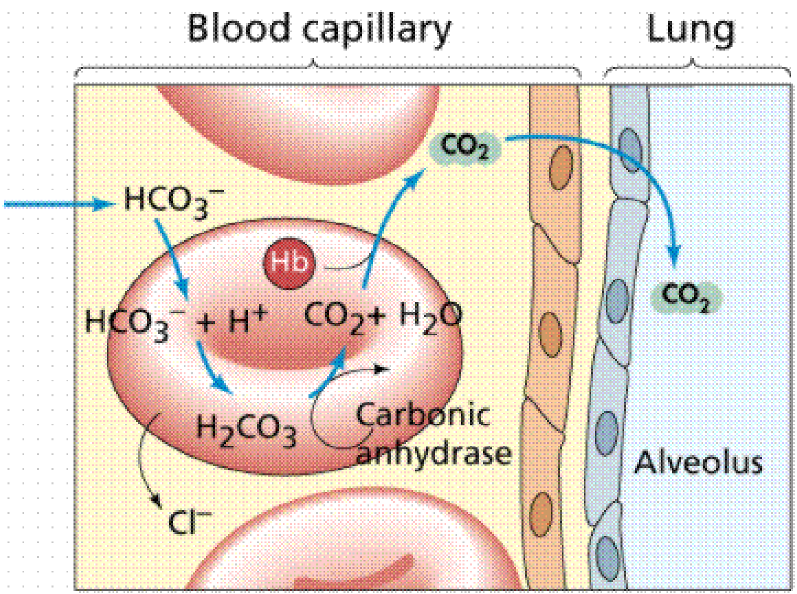
Physiology – CO_2 Exchange

$$H_2O + CO_2 \leftrightarrow H_2CO_3 \leftrightarrow H^+ + HCO_3^-$$

Water + Carbon Dioxide ←→ Carbonic Acid ←→ Hydrogen + Bicarb

Physiology – CO_2 Exchange



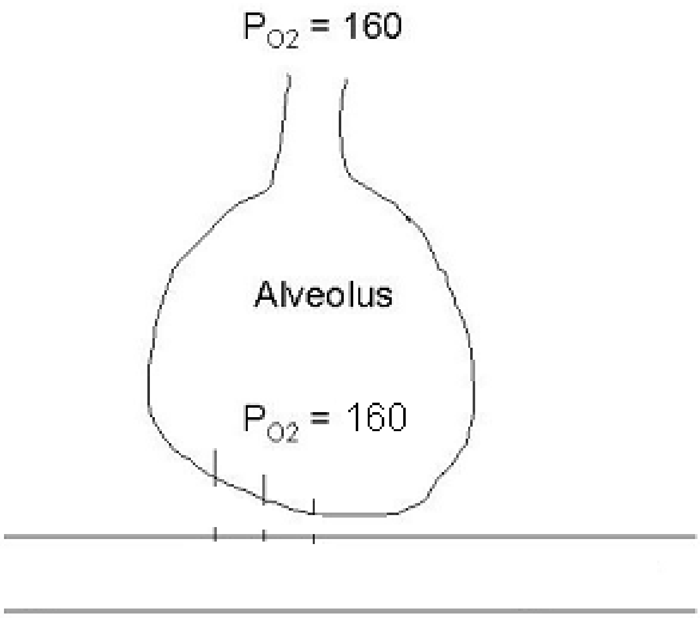


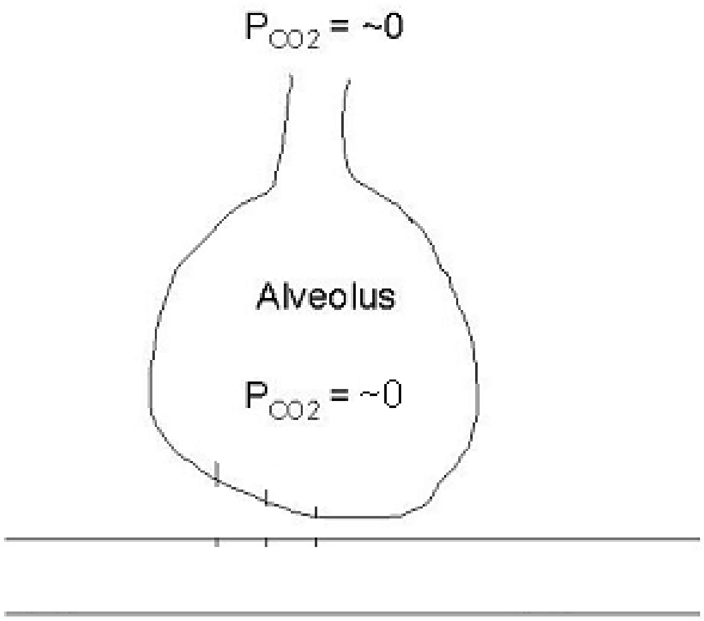
http://www.emc.maricopa.edu/faculty/farabee/BIOBK/BioBookRESPSYS.html

Dead Space and Shunt

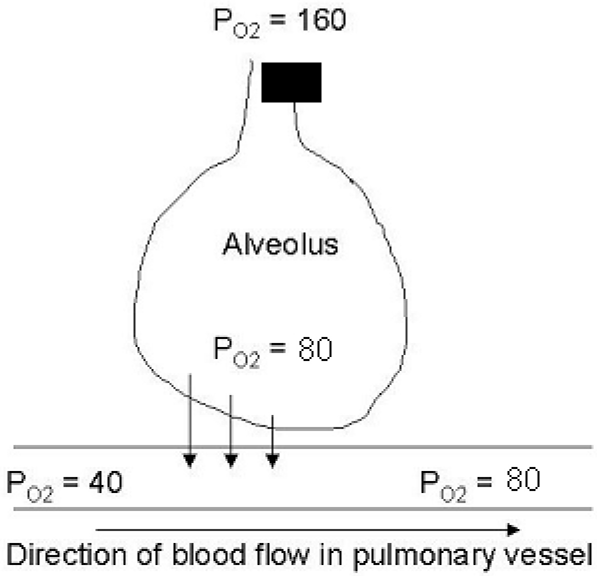
- Dead Space
  - Areas ventilated but not perfused
  - Anatomical, Physiological, and Mechanical
  - Lead to decreased PCO_2 in respiratory tree
- Shunt (V/Q mismatch)
  - Areas perfused but not well ventilated
  - Lead to increased PCO_2 in respiratory tree

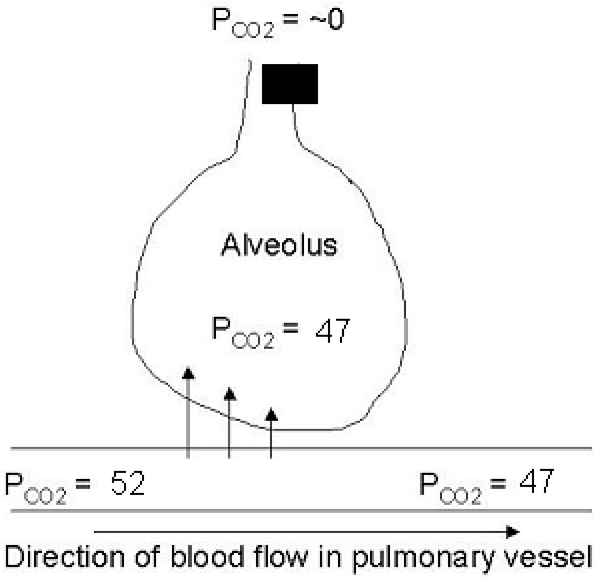
Dead Space

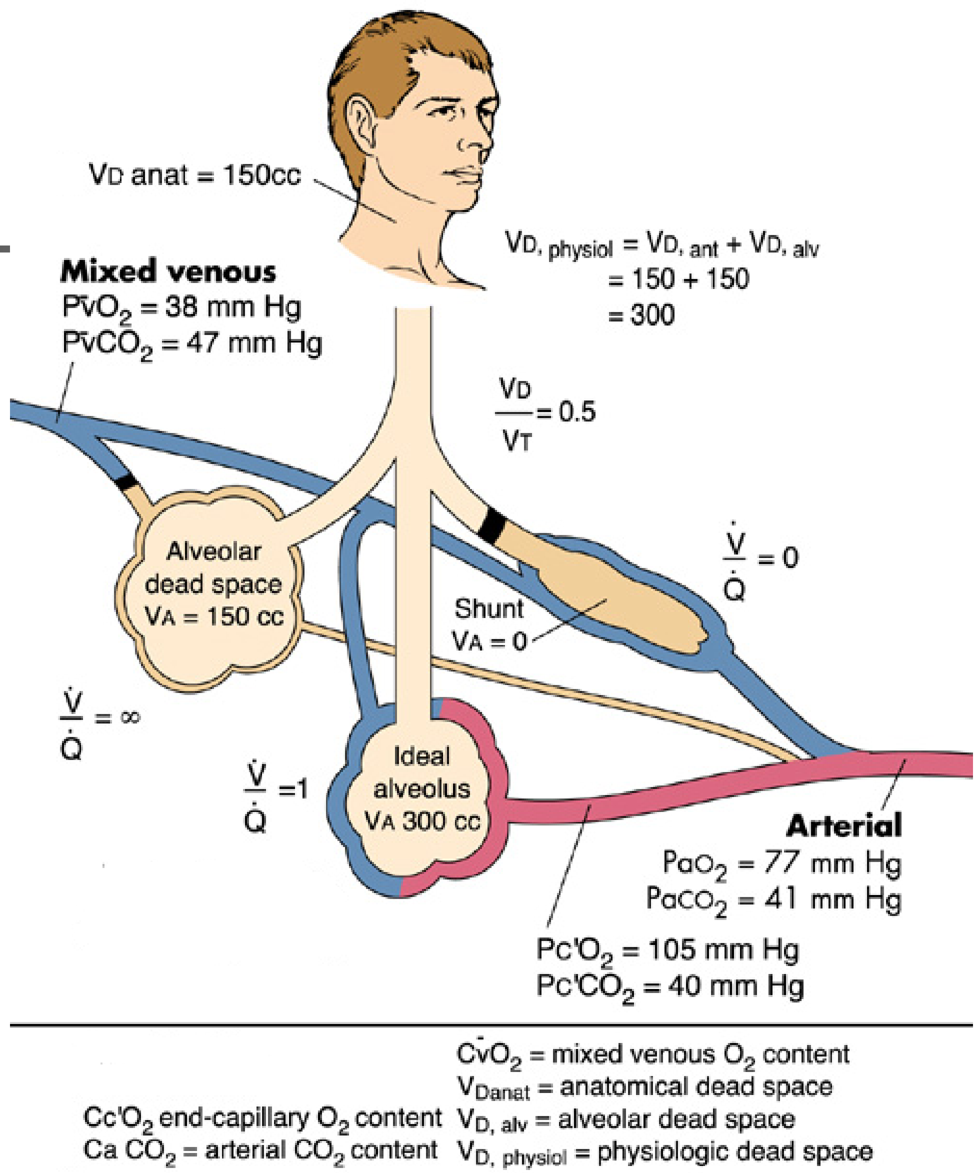




V/Q Mismatch (shunt)







http://80-www.images.md.ezp.miner.rochester.edu/users/image_show.asp

Shunt and Dead Space Math

- Total exhaled CO_2 is an average of the CO_2 from all alveoli
- More ventilated (less perfused) **V**/Q
  - less CO_2 produced
  - lower average
- More perfused (less ventilated) v/**Q**
  - more CO_2 produced
  - higher average

Shunt and Dead Space Math

- Ideal
  - 40 40 40 40 40 → 40
- Dead Space (lack of perfusion)
  - 40 0 0 40 40 → 24
- Shunt (diminished ventilation)
  - 40 50 50 40 40 → 44

Remember for capnography:

- These are the values for **<u>LUNG</u>** PCO_2
- These are not arterial PCO_2 values

- Dead space has no effect on blood PO_2 or blood PCO_2
- V/Q mismatch decreases blood PO_2 while increasing blood PCO_2
  - and pure shunt (V/Q = 0) has no direct effect on end tidal PCO_2

Capnography and Capnometry

- Non-invasive measurement of the PCO_2 in a patient’s airway
- Can be used on all patients – don’t have to be intubated or have assisted ventilations
- Provides insight into patient’s cardiovascular, respiratory, and metabolic status

Definitions

- $PETCO_2$
  - Partial pressure of end tidal CO_2
    - Pressure of CO_2 in airway at end of exhalation
- $PACO_2$
  - Partial pressure of CO_2 in the alveoli
  - Equivalent to $PETCO_2$ in most circumstances
- $PaCO_2$
  - Partial pressure of CO_2 in arterial blood

Definitions

- a-ADCO_2 gradient
  - The difference between arterial and alveolar PCO_2
  - Under normal physiologic conditions 2-5 mmHg

Physiology and $PETCO_2$

$PETCO_2$ Values and Changes in:	Elevated $PETCO_2$	Decreased $PETCO_2$
Metabolism	• Pain • Hyperthermia • Malignant hyperthermia • Shivering	• Hypothermia • Analgesia/sedation
Respiration	• Respiratory insufficiency • Respiratory depression • Obstructive lung disease	• Alveolar hyperventilation • Bronchospasm • Mucous plugging
Circulatory System	• Increased cardiac output (assuming constant ventilation)	• Cardiac arrest • Sudden hypovolemia/ hypotension • Embolism
Equipment	• Exhausted CO_2 absorber • Defective exhalation value	• Leak in airway system • Partial airway obstruction • ET tube in hypopharynx

Capnography concepts, page 12

Dead Space and a-ADCO$_2$

- Dead Space ventilation (**V**/Q) leads to a widened a-ADCO$_2$ gradient
- Low perfusion states mimic dead space
  - Pulmonary Embolism
  - Hypovolemia
  - Cardiac arrest
  - Increased Pulmonary Vascular resistance
  - High PEEP
  - Lateral decubitus position

Dead Space and $PETCO_2$

- As a result of large a-$ADCO_2$ gradient, dead space ventilation leads to decreased $PETCO_2$ values

Shunt and a-ADCO$_2$

- Lower v/**Q** ratio leads to hypoxemia
- a-ADCO$_2$ ratio is not effected as alveoli are well perfused
  - Atelectasis
  - Mucous plugging
  - Kinked endotracheal tube
  - Right mainstem bronchial intubation
  - Pneumonia
  - Bronchospasm

Shunt and $PETCO_2$

- Shunt physiology (v/**Q**) is much more complicated than dead space
- Shunt will cause an increase in $PaCO_2$
- Also see an increase in $PACO_2$ at shunt
- $ETCO_2$ values depend on response
  - Hyperventilation → lower $PETCO_2$
  - Hypoventilation → higher $PETCO_2$
- $PETCO_2 \neq PACO_2$ in shunt physiology

Capnometry vs. Capnography

- Capnometry
  - Instantaneous measurement
  - Determines a specific numerical value
  - Does not show trends
- Capnography
  - Continuous measurement
  - Measures continuous numerical values
  - Graphs trends and shows a waveform

* Next 17 slides courtesy of Jonnathan Busko MD, EMT-P

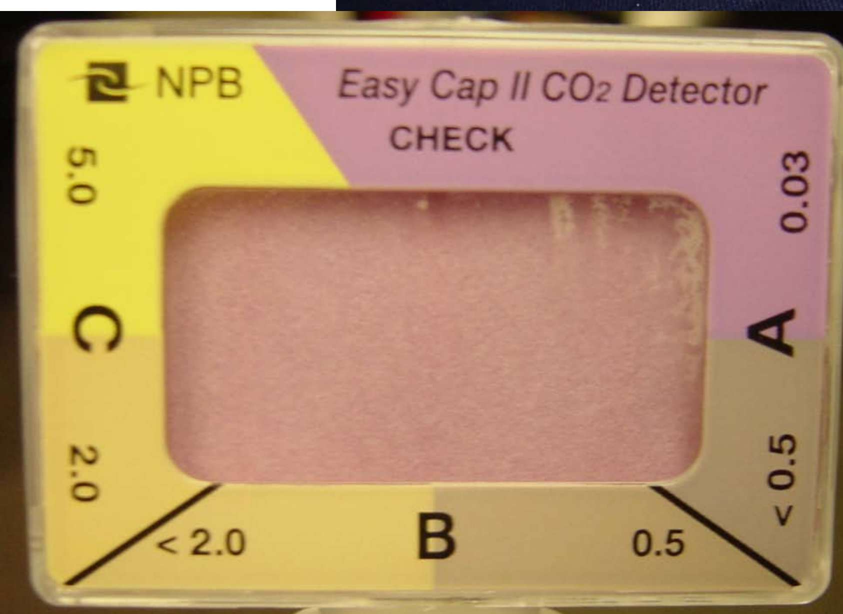
Capnometry

- Usually less expensive than capnography
- Commonly used to obtain a single value or confirmation of tube placement
- Can be either colorimetric or infrared

Colorimetric Capnometry

- Typically a disposable device
- pH sensitive filter paper (sulfonephthalein impregnated)
- Exhaled breath passes through or over paper
- Color changes from purple to yellow
- Key on device for value


CO2 Check


NPB
Easy Cap II CO2 Detector
CHECK
5.0
0.03
C
A
2.0
< 0.5
< 2.0
B
0.5


NPB
Easy Cap II CO2 Detector
CHECK
5.0
0.03
C
A
2.0
< 0.5
< 2.0
B
0.5

Colorimetric Capnometry

- Advantages
  - Rapid—Breath by Breath Analysis
  - Cheap—Disposable
  - Easy—Pops in-line / built into BVM
  - Can be read by red-green colorblind individuals

Colorimetric Capnometry

- Disadvantages
  - Does not give precise number
  - Does not trend over time / does not measure RR
  - With in-line devices, once paper wet → inactivated

Infrared Capnometry / Capnography

- CO_2 absorbs light at 4.26 micrometers
- Shoot light through gas sample
- Measure light absorption in CO_2 range
- Compare to sample with no CO_2
- Can calculate percentage in sample with CO_2

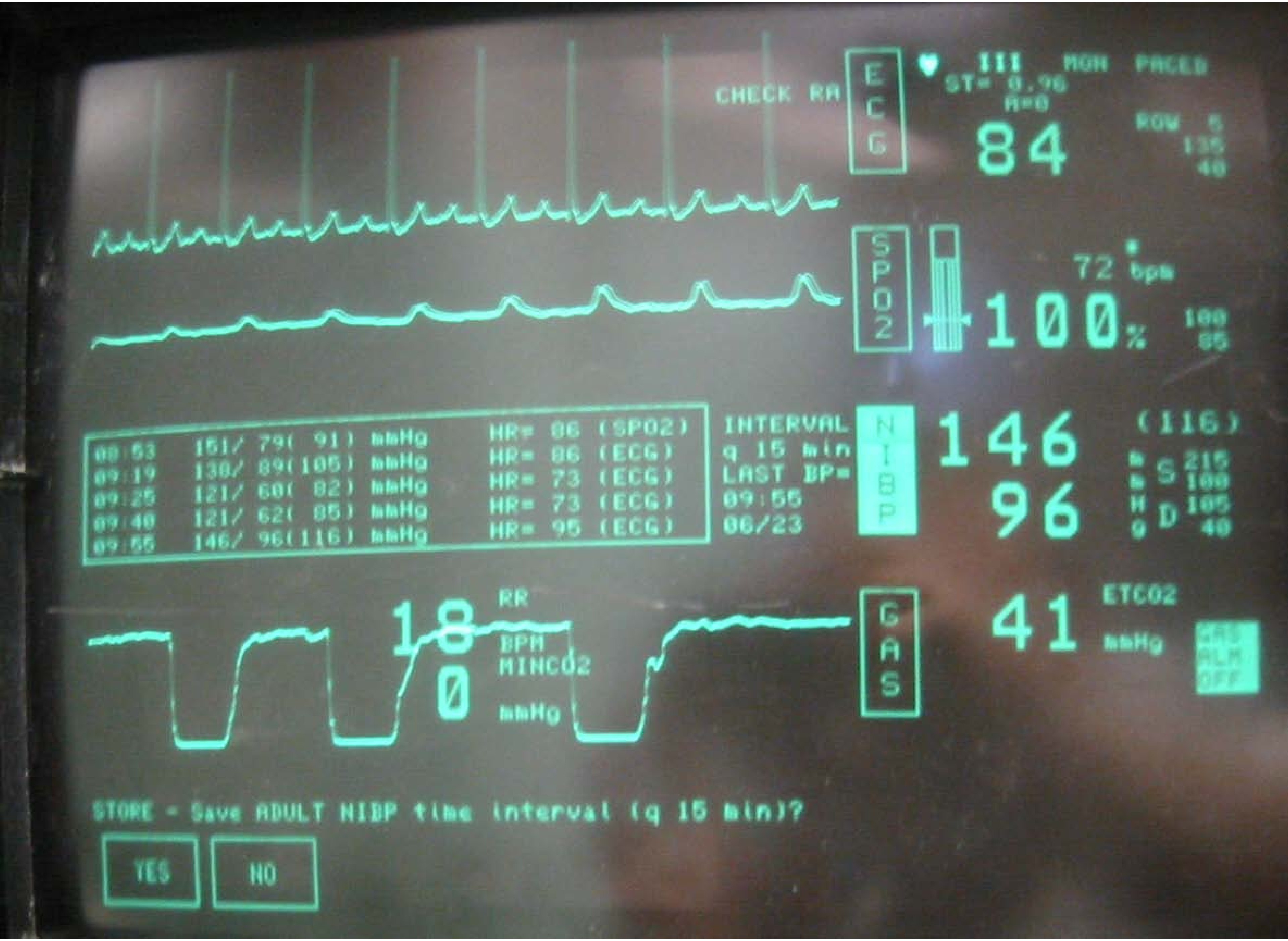
Infrared Capnometry

- Advantages
  - Gives numerical value for CO_2
  - Tracks respirations
  - Apnea alarm
- Disadvantages
  - Expensive (though less than most capnographs)
  - Does not trend over time
  - Typically not certified for “Continuous Monitoring”

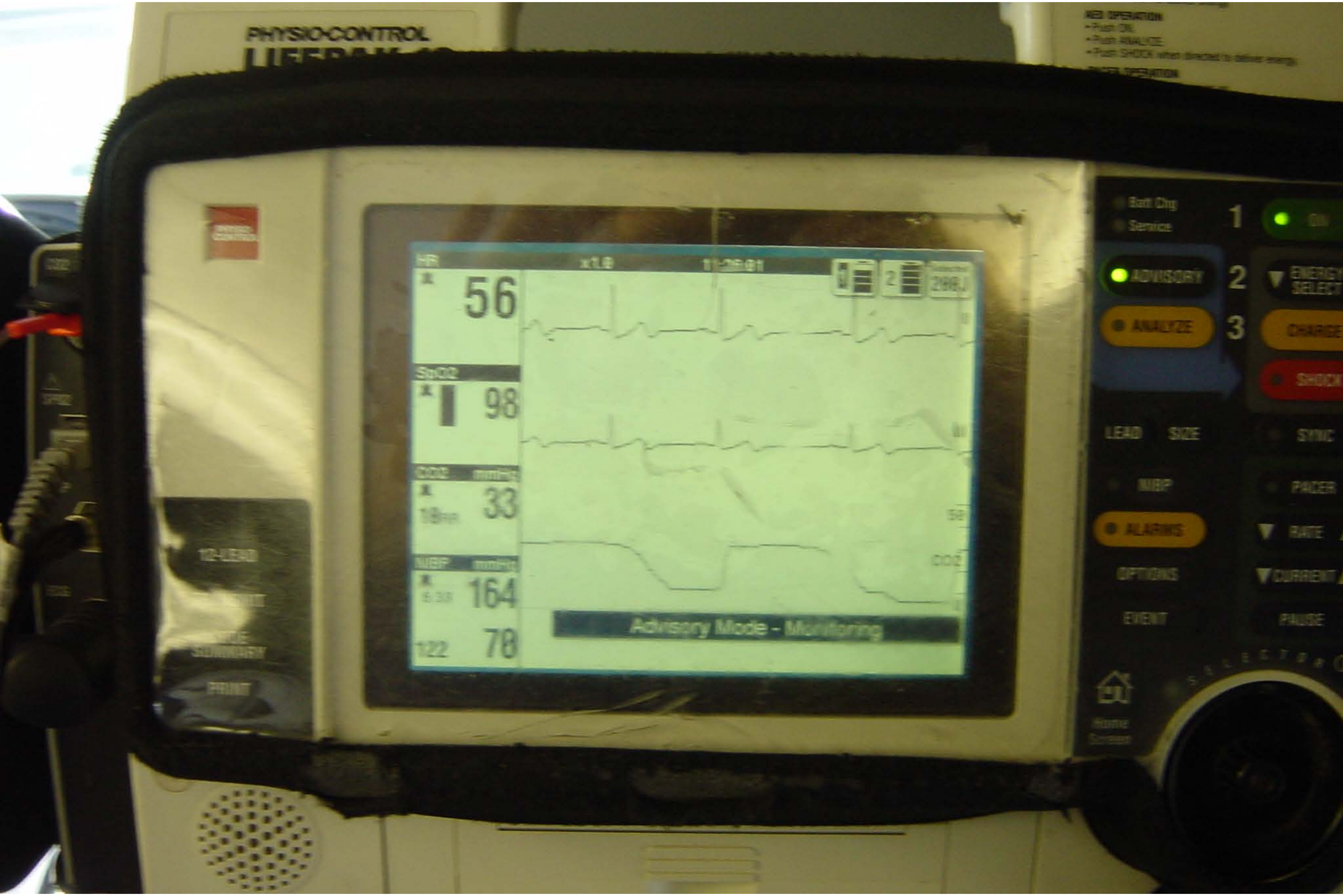

NONIN
%SpO2
ΔCO2
98
93
mmHg
75
50
30
20
10
6
2
10
7
4
2.6
1.3
0.8
0.3
kPa
On/Off
Advance
Setup/Print
NONIN
Model 9843

Infrared Capnography

- Continuous monitoring of CO_2
- Shows numerical value and graph
- Trends over time
- Can sample gas in one of three ways
  - Mainstream
  - Sidestream
  - Microstream



III MON PACED
ST= 0.96
CHECK RA
ECG
84
SPO2
72 bpm
100%
100
85
INTERVAL
q 15 min
LAST BP=
09:55
06/23
NIBP
146
(116)
96
S 215
D 105
40
08:53 151/ 79(91) mmHg HR= 86 (SPO2)
09:19 138/ 89(105) mmHg HR= 86 (ECG)
09:25 121/ 60(82) mmHg HR= 73 (ECG)
09:40 121/ 62(85) mmHg HR= 73 (ECG)
09:55 146/ 96(116) mmHg HR= 95 (ECG)
RR
18
BPM
MINCO2
0
mmHg
GAS
ETCO2
41
mmHg
STORE - Save ADULT NIBP time interval (q 15 min)?
YES
NO


PHYSIO-CONTROL
HR
56
SpO2
98
CO2 mmHg
33
NIBP mmHg
164
122
78
Advisory Mode - Monitoring
Batt Chg
Service
1
2
3
ADVISORY
ANALYZE
ENERGY SELECT
CHARGE
SHOCK
LEAD
SIZE
SYNC
NIBP
PACER
ALARMS
RATE
OPTIONS
CURRENT
EVENT
PAUSE
Home Screen
12-LEAD
PRINT

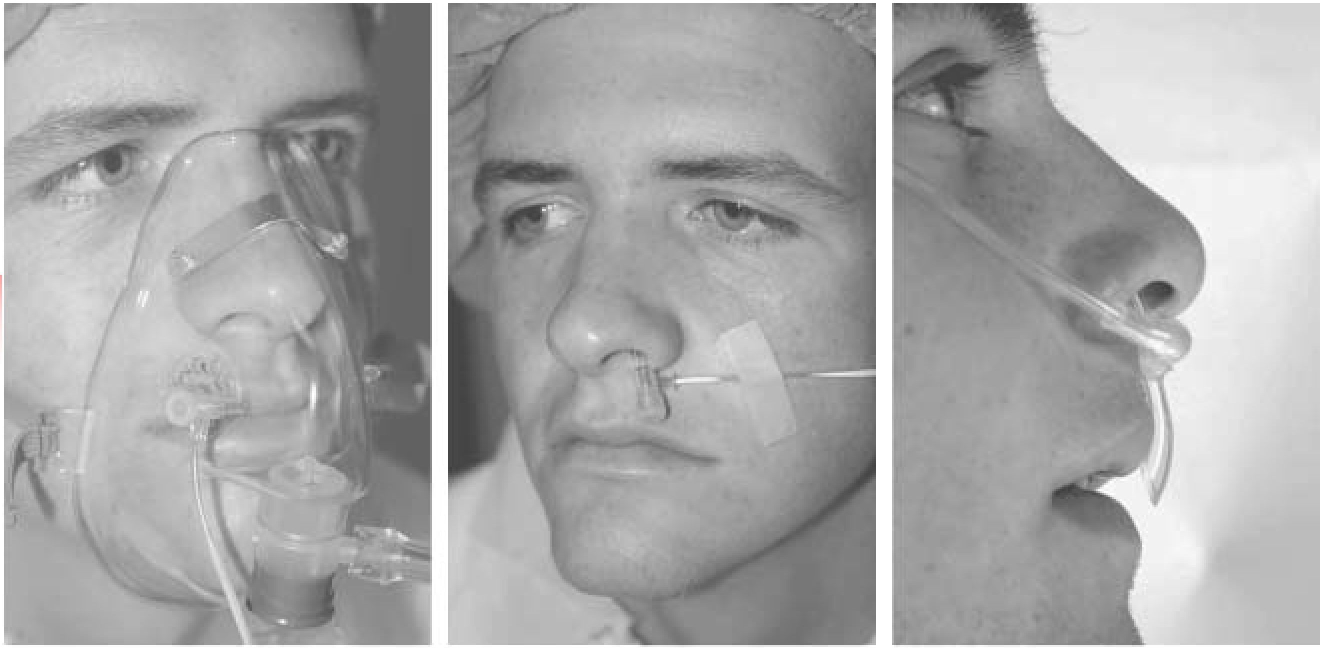
Mainstream Capnography

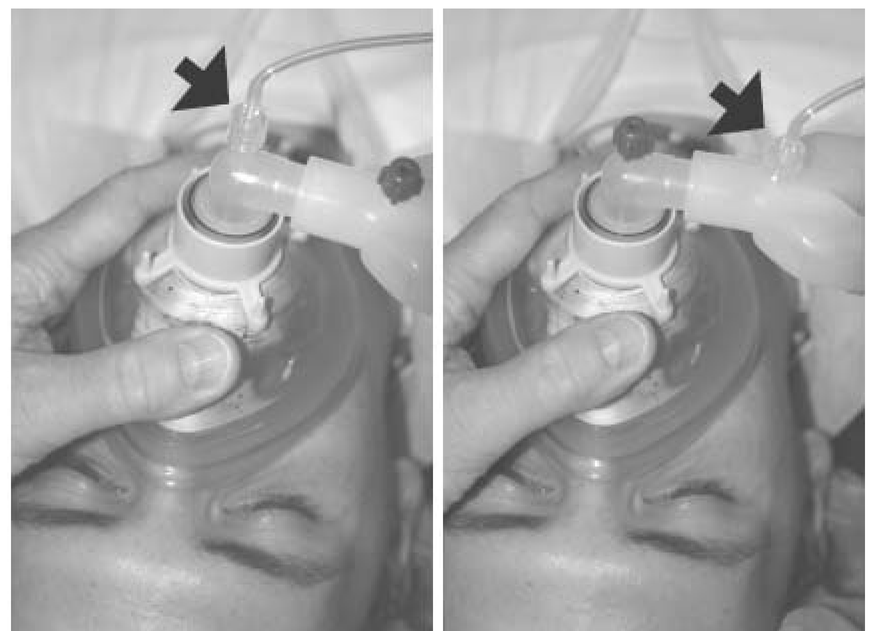
- Heated sensor
- Part of airway circuit
- Instantaneous measurements
- Usually only for intubated patients
- Sensor attached to end of ETT
- Easy to break
- Expensive to replace


TALL
REGULAR
PUSH TO LOCK
Made in U.S.A.
STIFNECK
SELECT

Sidestream Capnography

- Pump aspirates sample
- Sample subjected to spectroscopy
- Not part of ventilation circuit
  - Intubated and Nonintubated patients
- Small delay in analysis (< 1 s)
- Subject to gas leak / contamination
- Line can plug
- Poor detection in low volume / high RR (neonate)
- Harder to break unit / cheaper





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Microstream Capnography

- Similar to sidestream capnography
- Microbeam infrared sensor specific to CO_2
- Can be used in intubated and nonintubated patients
- Low flow rates needed
  - Can be used in neonates

Capnometry – The numbers

- “Normal” $PETCO_2$ is 40 mmHg
- Goal for ventilated patients = 35-45
- $PETCO_2$ is affected by metabolism, respiration, the cardiac system, and the sampling equipment
- Much more powerful tool when combined with waveform in capnography

Physiology and Capnometry

$PETCO_2$ Values and Changes in:	Elevated $PETCO_2$	Decreased $PETCO_2$
Metabolism	• Pain • Hyperthermia • Malignant hyperthermia • Shivering	• Hypothermia • Analgesia/sedation
Respiration	• Respiratory insufficiency • Respiratory depression • Obstructive lung disease	• Alveolar hyperventilation • Bronchospasm • Mucous plugging
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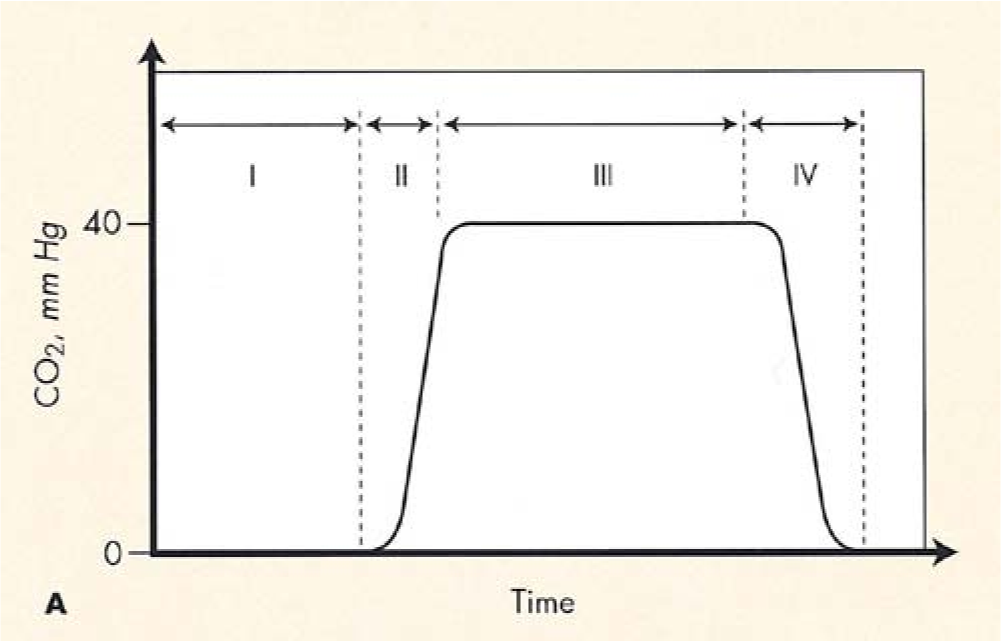
Capnography concepts, page 12

Capnography – Basics

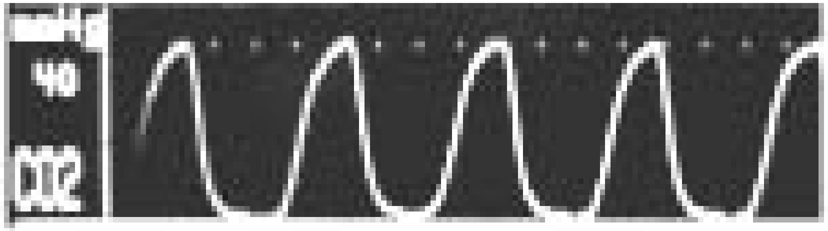


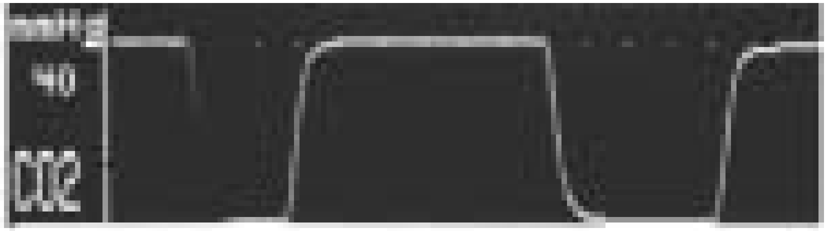
http://80-www.images.md.ezp.miner.rochester.edu/users/image_show.asp?imgid=ACA0301-08-008A

Four phases of waveform

- I = inspiration
- II = CO_2 appears at the beginning of expiration
- III = the plateau phase with or without a respiratory pause
- IV = descending portion with clearing of the airway of CO_2 from the previous expiration

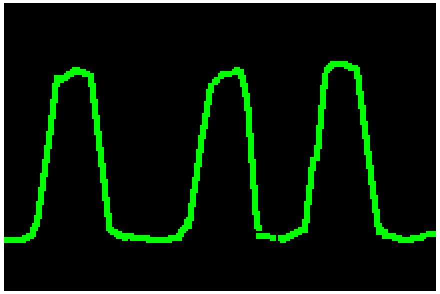
Waveform – “Normal”





Spontaneous breathing

Mechanical Ventilation



Miller: Miller's Anesthesia, 6th ed., Copyright © 2005 Elsevier
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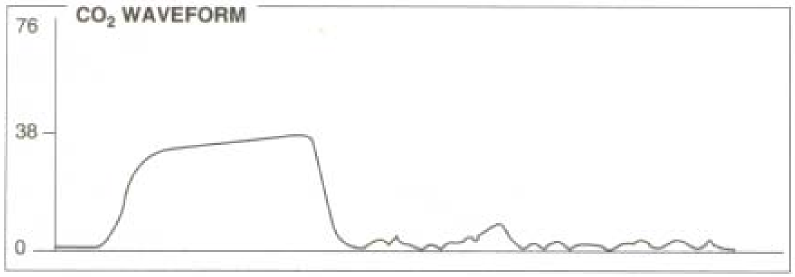
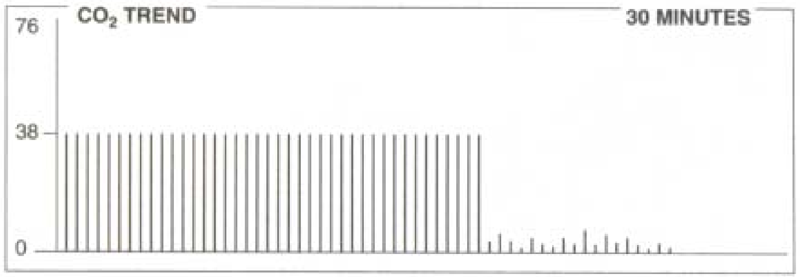
Sudden loss $PETCO_2$





IMMEDIATE DANGER!!! – NO RESPIRATIONS DETECTED

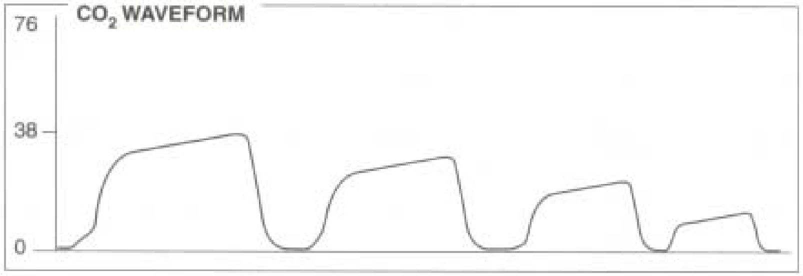
Esophageal Intubation

Complete Disconnect from ventilator

Complete ventilatory malfunction

Totally obstructed/kinked endotracheal tube

Exponential decrease $PETCO_2$



Catastrophic event in patient's cardiopulmonary system

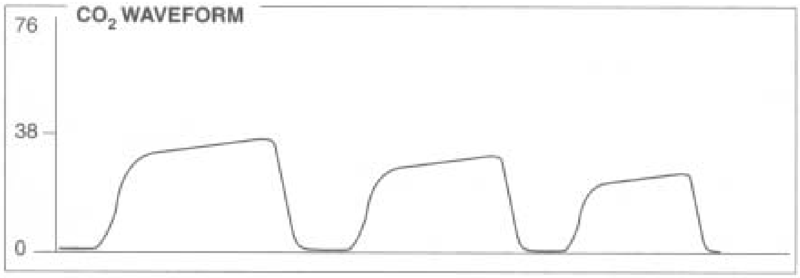
Sudden hypotension/massive blood loss

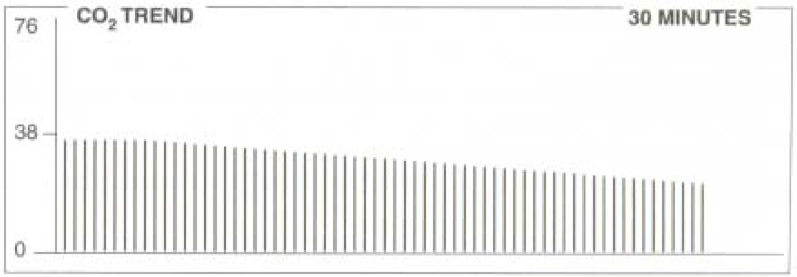
Circulatory arrest with continued pulmonary ventilation

Pulmonary embolism

Cardiopulmonary bypass

Gradual decrease $PETCO_2$

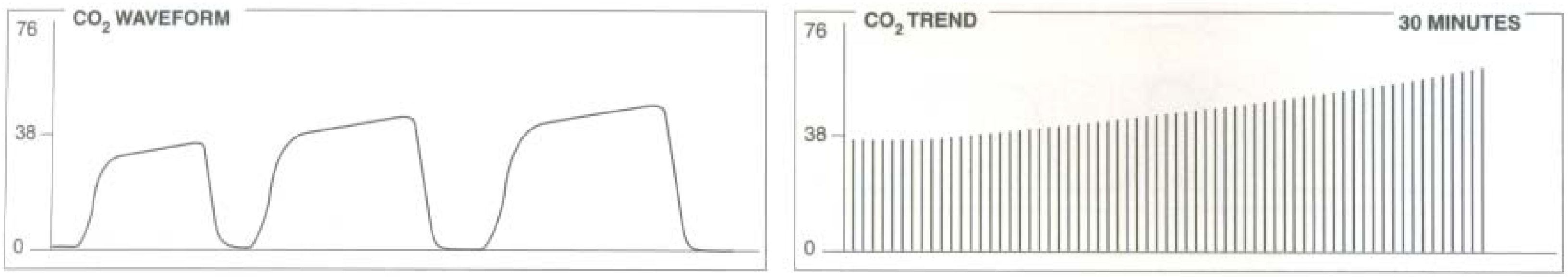




Indicates decreasing CO_2 production, hyperventilation, or poor perfusion

- Hypothermia
- Hyperventilation
- Decreasing cardiac output
- Sedation
- Hypovolemia

Gradual increase in $PETCO_2$

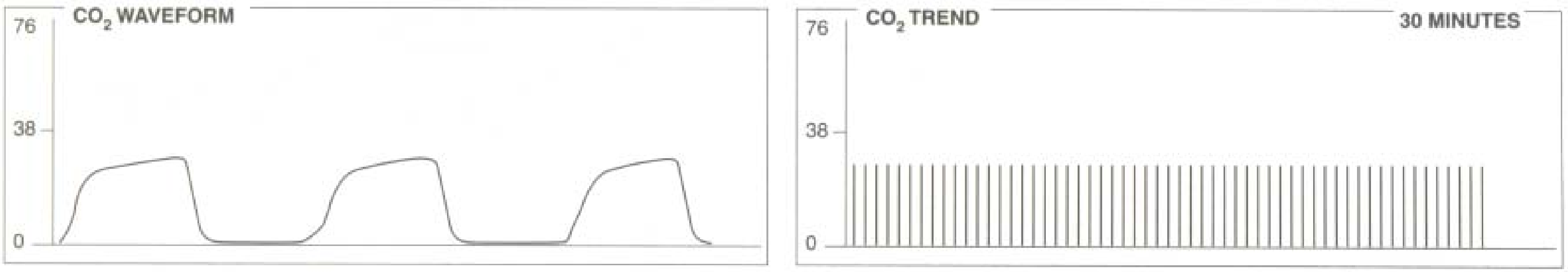


Rising Body Temperature

Hypoventilation

Absorption of CO_2 from exogenous source (i.e. laparoscopy)

Sustained low $PETCO_2$



If good plateau indicates hyperventilation or large dead space ventilation, causing a widened a-$ADCO_2$ gradient

Pulmonary embolism

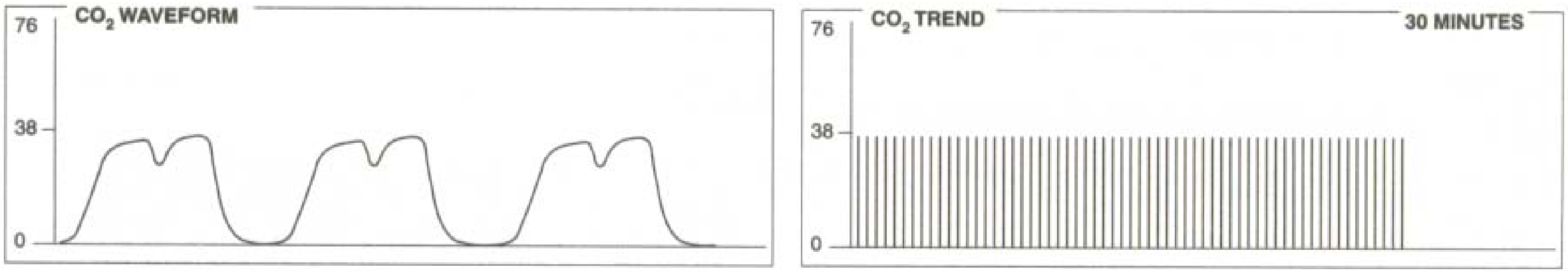
Hyperventilation

Excessive PEEP

Hypovolemia

COPD with distended alveoli

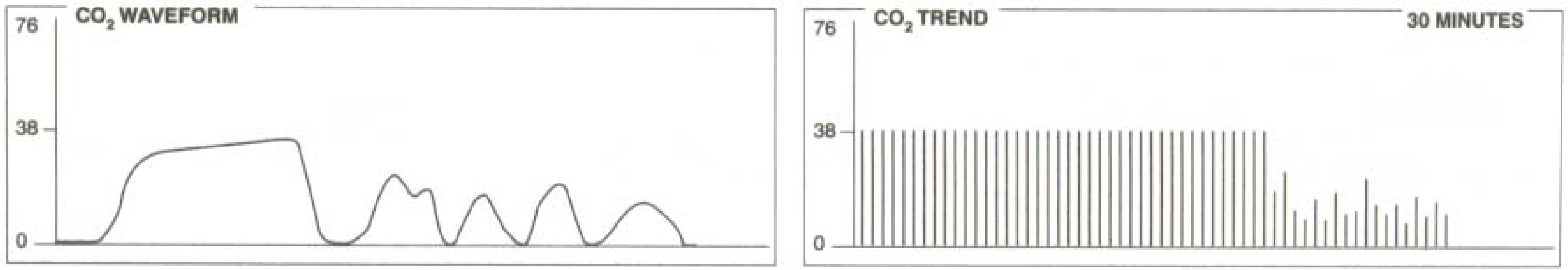
Cleft in alveolar plateau



Minimal spontaneous diaphragmatic movement

Partial recovery from neuromuscular blockade

Absent alveolar plateau



Incomplete alveolar emptying or loss of endotracheal airway integrity

Bronchospasm

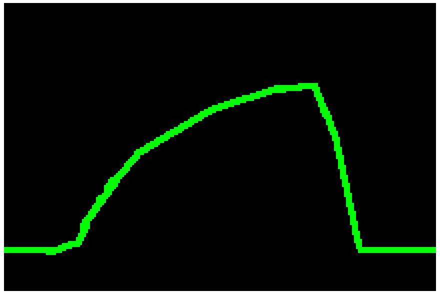
Endotracheal tube in hypopharynx

Leak in airway system

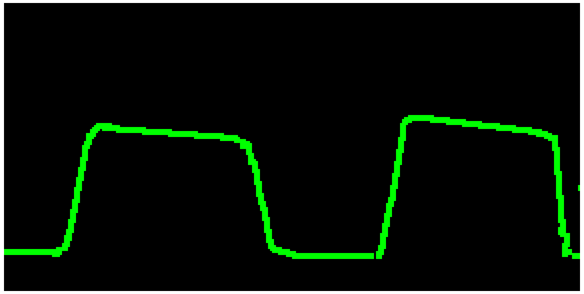
Partial disconnect from ventilator

Partial airway obstruction from secretions

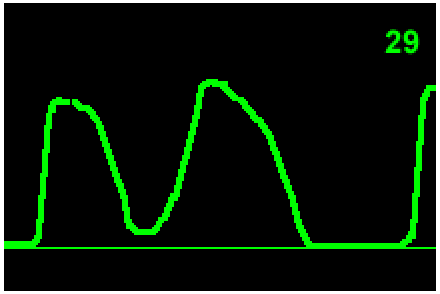
Other abnormal slopes



Incomplete alveolar emptying or abnormal airflow through upper airways – asthma, COPD, bronchospasm

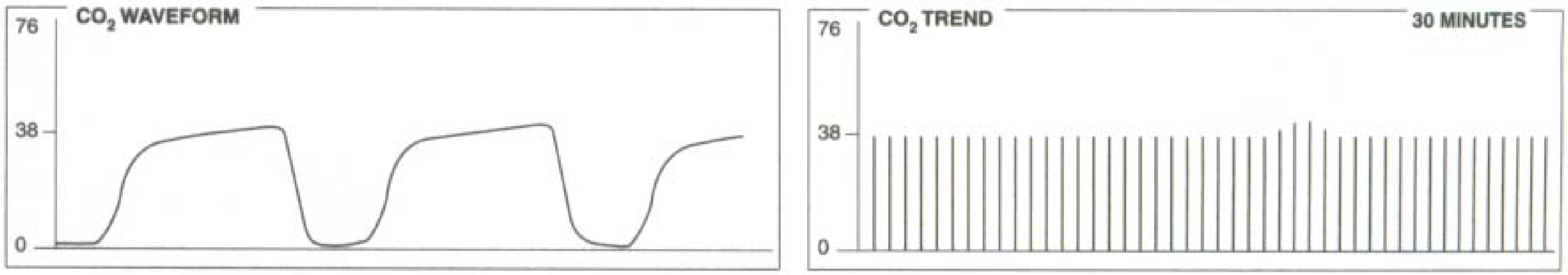


Reverse plateau from emphysema – alveolar dead space ventilation from damaged alveolar epithelium



Endobronchial (right mainstem) intubation or COPD

Sudden transient rise $PETCO_2$

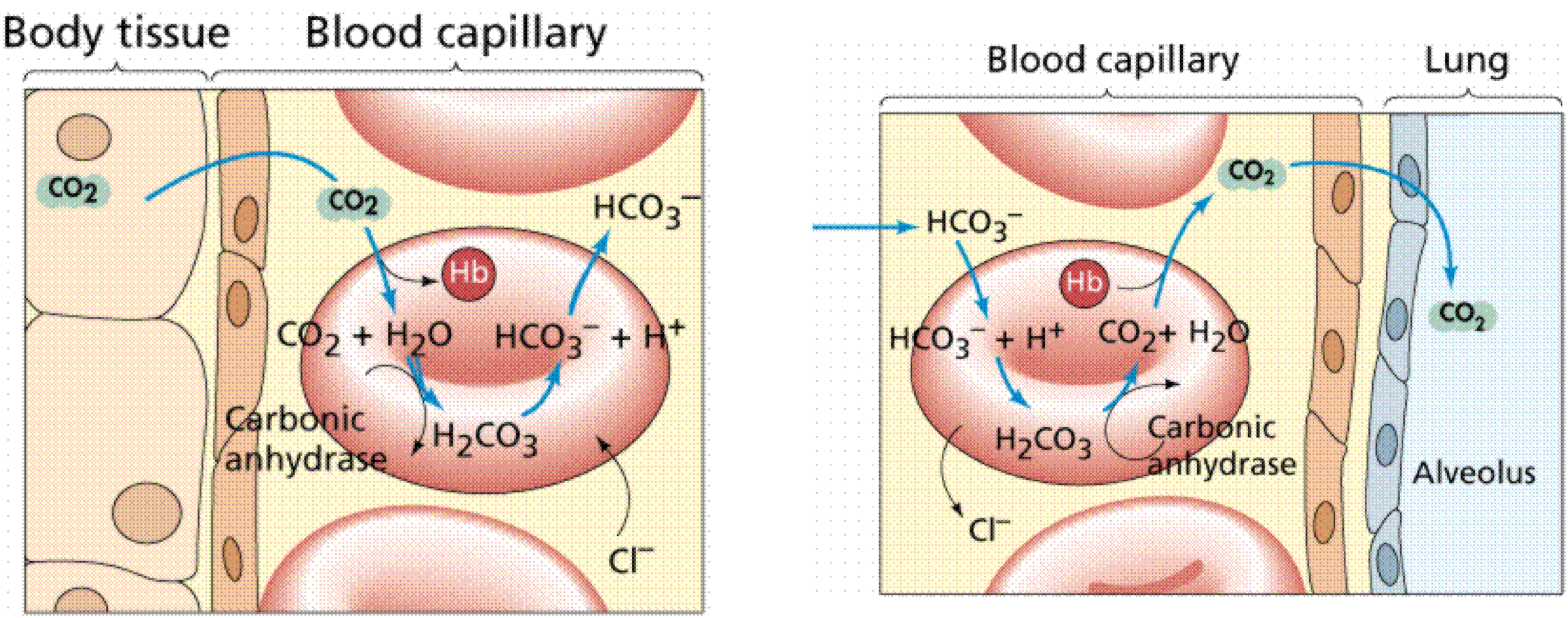


Anything that acutely increases delivery of CO_2 to pulmonary circulation

Injection of sodium bicarbonate

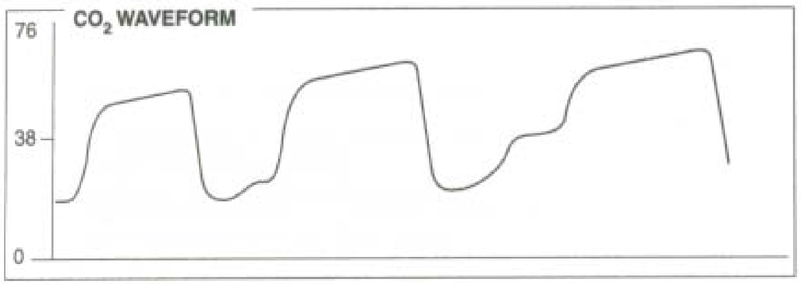
Release of limb tourniquet

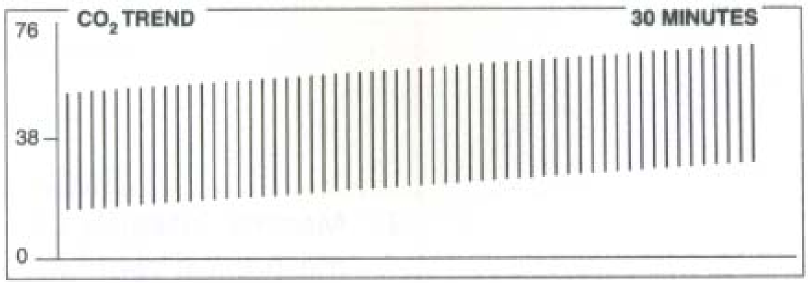
Sudden transient rise $PETCO_2$



http://www.emc.maricopa.edu/faculty/farabee/BIOBK/BioBookRESPSYS.html

Rise in baseline CO_2





Indicates rebreathing of CO_2

Exhaustion of soda-lime CO_2 absorber in closed circuit anesthesia machines

Addition of mechanical dead space in ventilator circuit

Case #1 – Am I keeping pace?

- Patient found down apneic with no palpable pulses and a severely bradycardic rhythm
- Patient intubated on scene
- No response to atropine
- Pacing started in conjunction with CPR

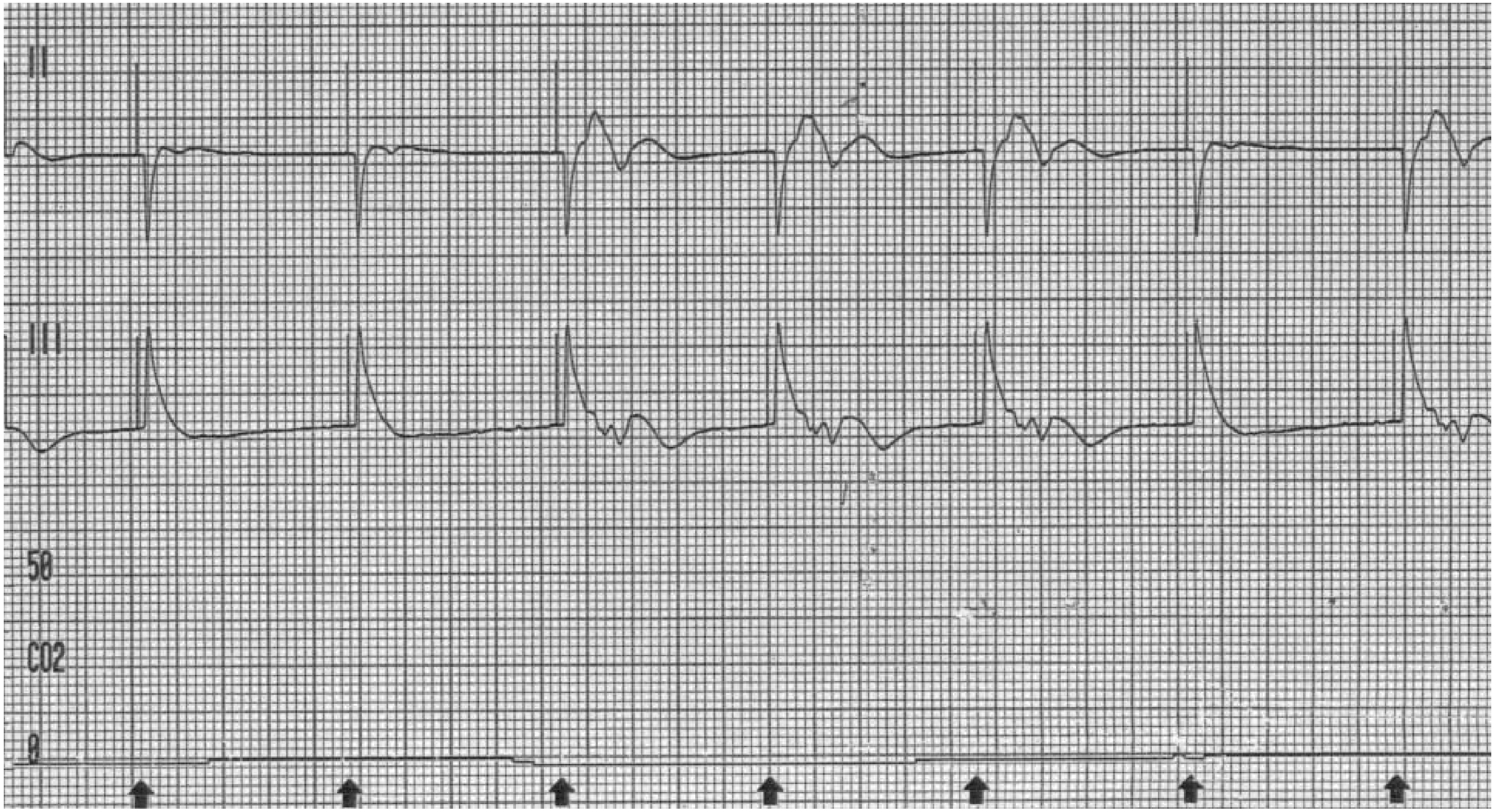
Thanks to Ray Hughes from CEMS for these cases!

Case #1 – Am I keeping pace?

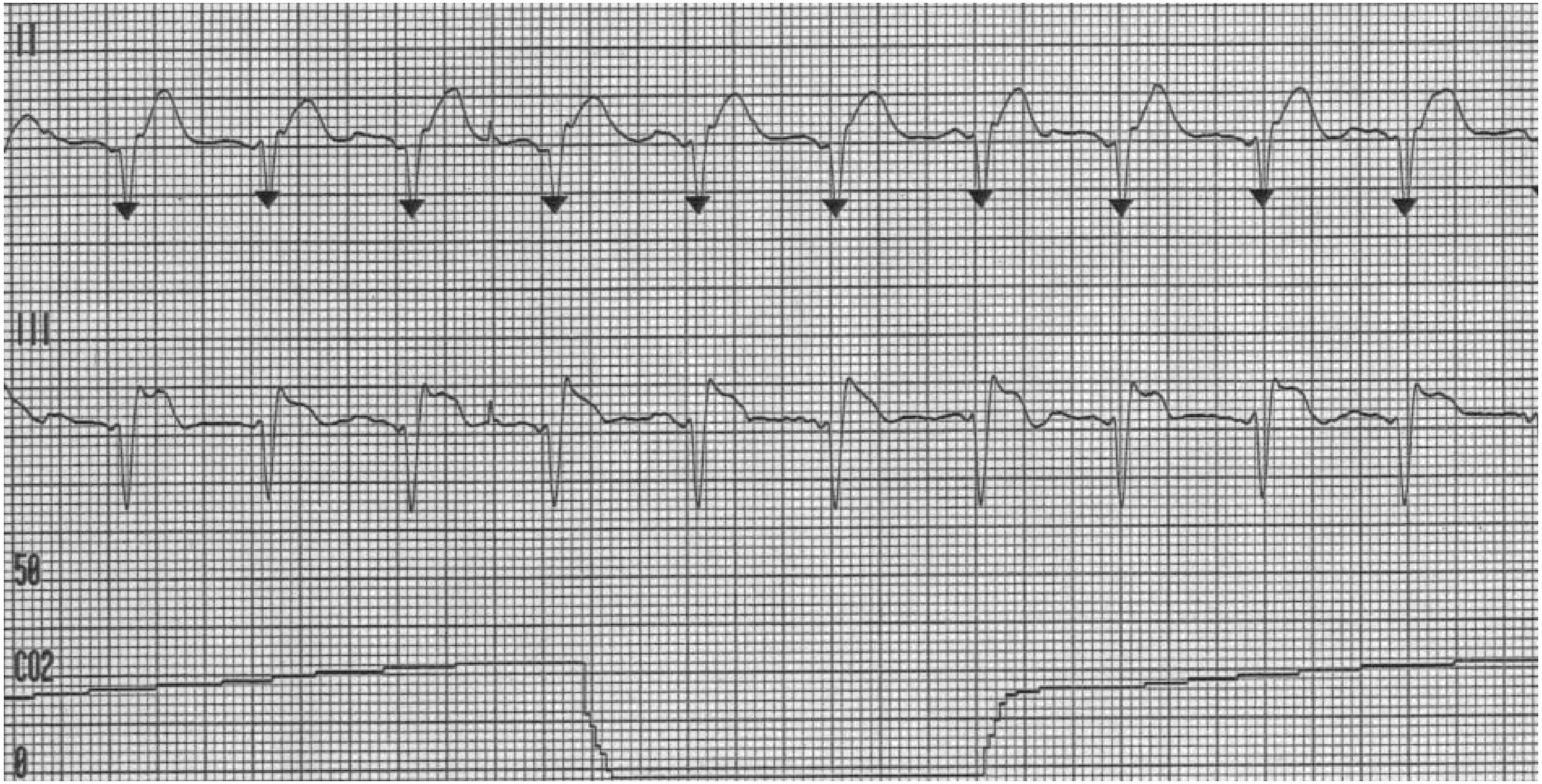
Time	Event	HR	EtCO2(mmHg)•RR
18:16:43	Power On		
18:16:43	Advisory Mode		
18:17:19	Analysis 1		
18:17:20	Motion		
18:17:22	Initial Rhythm		
18:17:29	No Shock Advised	---	
18:19:08	Check Patient	---	
18:20:01	Check Patient	---	
18:20:09	Check Patient	---	---•---
18:20:14	Analysis 2	---	---•---
18:20:16	Motion		
18:20:36	Analysis Stopped	---	9•0
18:20:47	Check Patient	---	9•0
18:20:48	Alarm Apnea	---	9•0
18:21:11	Manual Mode	---	4•0
18:21:41	Vital Signs	---	4•0
18:21:49	Check Patient	26	4•0
18:22:21	Check Patient	---	3•0
18:24:33	Check Patient	113	4•0

Time	Event	HR	EtCO2(mmHg)
18:25:08	Check Patient	---	---•---
18:26:41	Vital Signs	---	9•13
18:26:47	Check Patient	---	9•13
18:27:43	Alarm Apnea	53	8•13
18:28:32	Check Patient	---	5•0
18:30:03	Print 1	27	5•0
18:30:12	Pacing 1 Changed	---	4•0
18:30:19	Pacing 2 Started	---	4•0
18:30:32	Pacing 3 Set	---	4•0
18:30:35	Pacing 4 Changed	---	4•0
18:31:15	Pacing 5 Changed	---	3•0
18:31:41	Vital Signs	---	3•0
18:35:23	Alarm Apnea	---	8•12
18:36:41	Vital Signs	---	---•---
18:40:42	Print 2	---	29•12
18:41:41	Vital Signs	---	38•12
18:46:41	Vital Signs	---	41•12
18:47:11	Print 3	---	40•16
18:51:41	Vital Signs	---	40•32

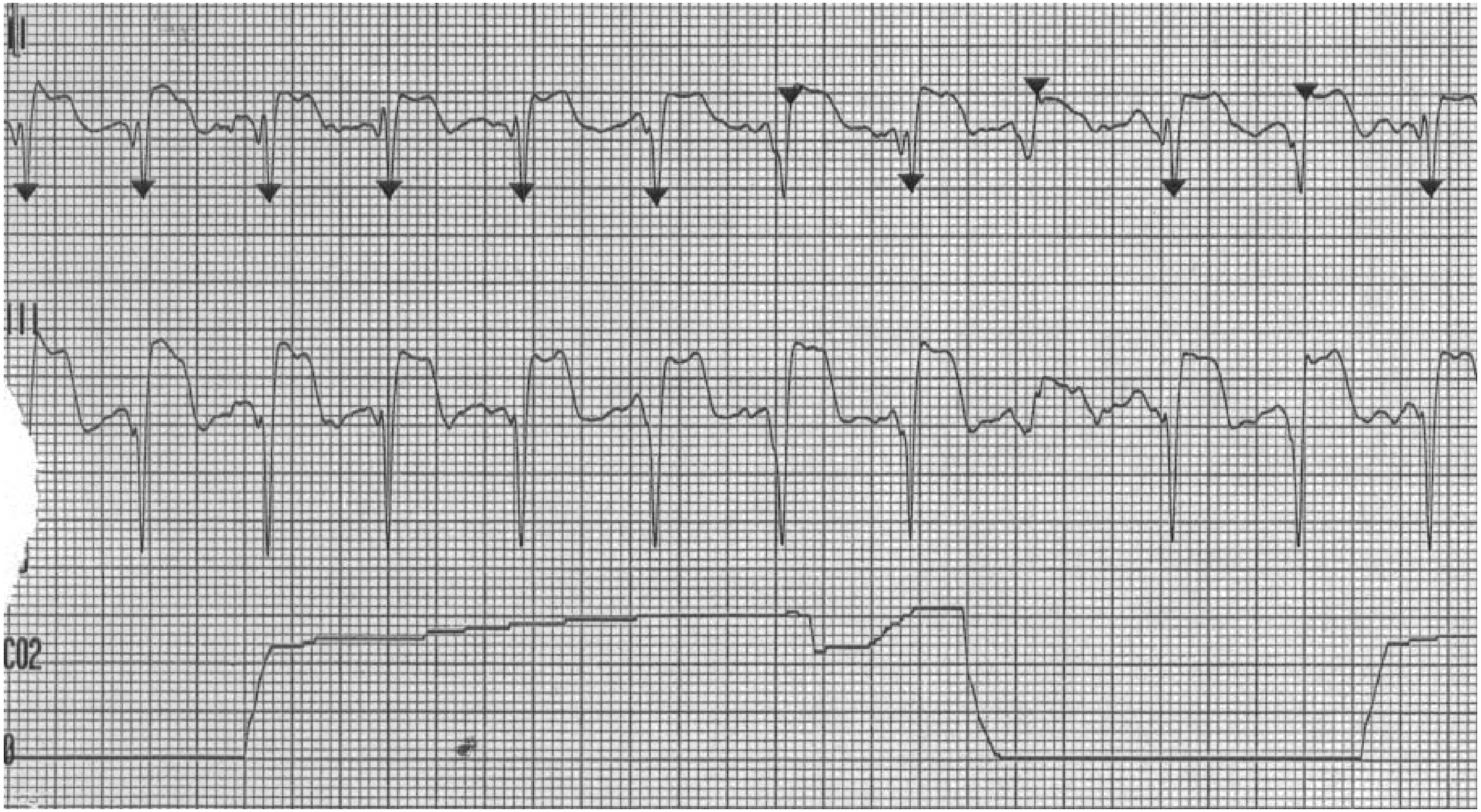
Case #1 – Am I keeping pace?



Case #1 – Am I keeping pace?



Case #1 – Am I keeping pace?



Case #1 – Am I keeping pace?

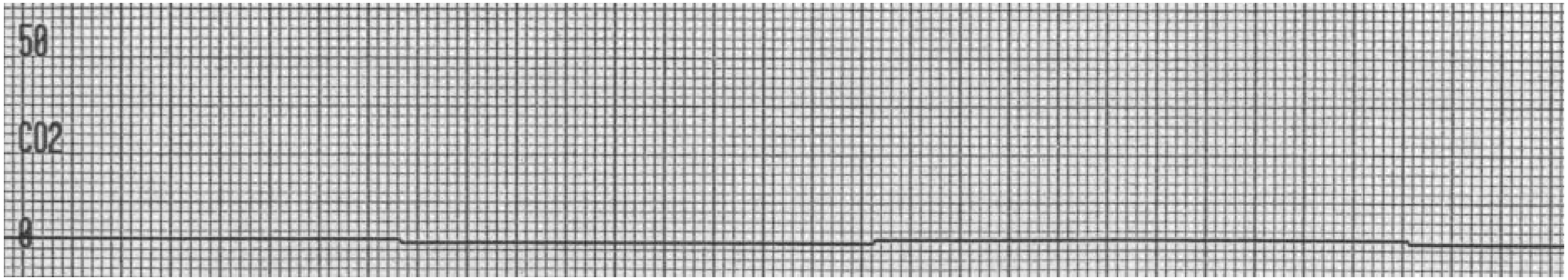
- Pulses never palpable in field but found by doppler and transthoracic ultrasound in ED
- Capnography waveform the key in identifying that the pacing was effective
- Consider pressor?

Case #2– What's gone wrong?

- Patient found down at home – prolonged downtime
- Patient intubated with good visualization of the cords, colormetric ETCO2 monitor turned yellow
- Patient is connected to monitor and the following is seen...

Case #2– What's gone wrong?

Time	Event	HR	EtCO2(mmHg)•RR
10:23:37	Check Patient	---	---•---
10:24:06	Analysis 1	---	---•---
10:24:12	No Shock Advised	---	---•---
10:24:35	Vital Signs	---	---•---
10:27:05	Manual Mode	---	---•---
10:29:34	Vital Signs	---	---•---
10:33:00	Print 3	103	---•---
10:34:35	Vital Signs	105	---•---
10:39:34	Vital Signs	---	---•---
10:44:01	Power Off		



Case #2– What's gone wrong?

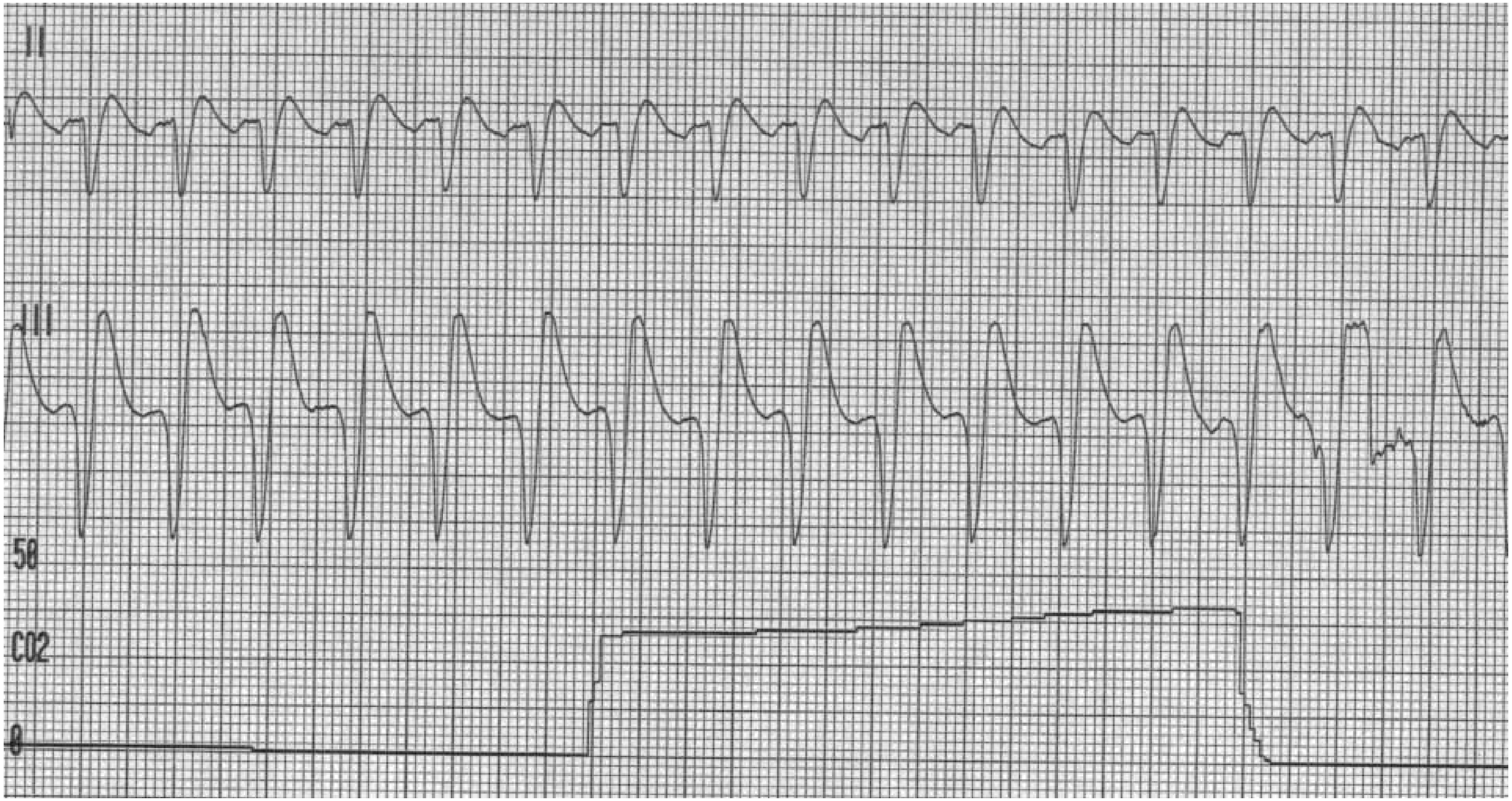
- Is the tube in place?
  - Yes

  - There is still a small waveform, there just is minimal CO_2 in the airway due to prolonged downtime

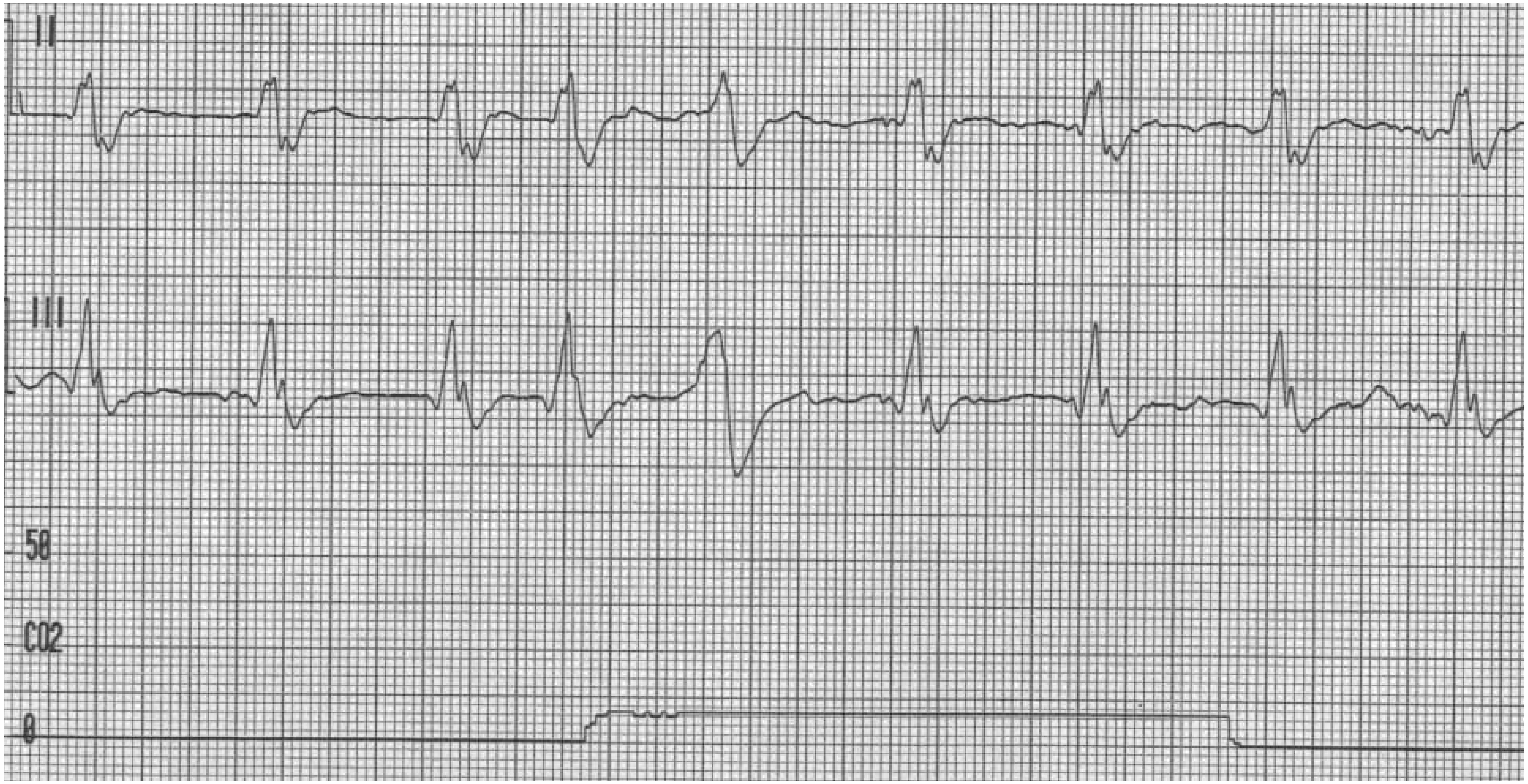
Case #2– What's gone wrong?

- "An end-tidal carbon dioxide level of 10 mm Hg or less measured 20 minutes after the initiation of advanced cardiac life support accurately predicts death in patients with cardiac arrest associated with electrical activity but no pulse. Cardiopulmonary resuscitation may reasonably be terminated in such patients."
- Excerpt from "End tidal carbon dioxide and outcome of Out of Hospital Cardiac Arrest."
- (N Engl J Med 1997;337:301-6.)

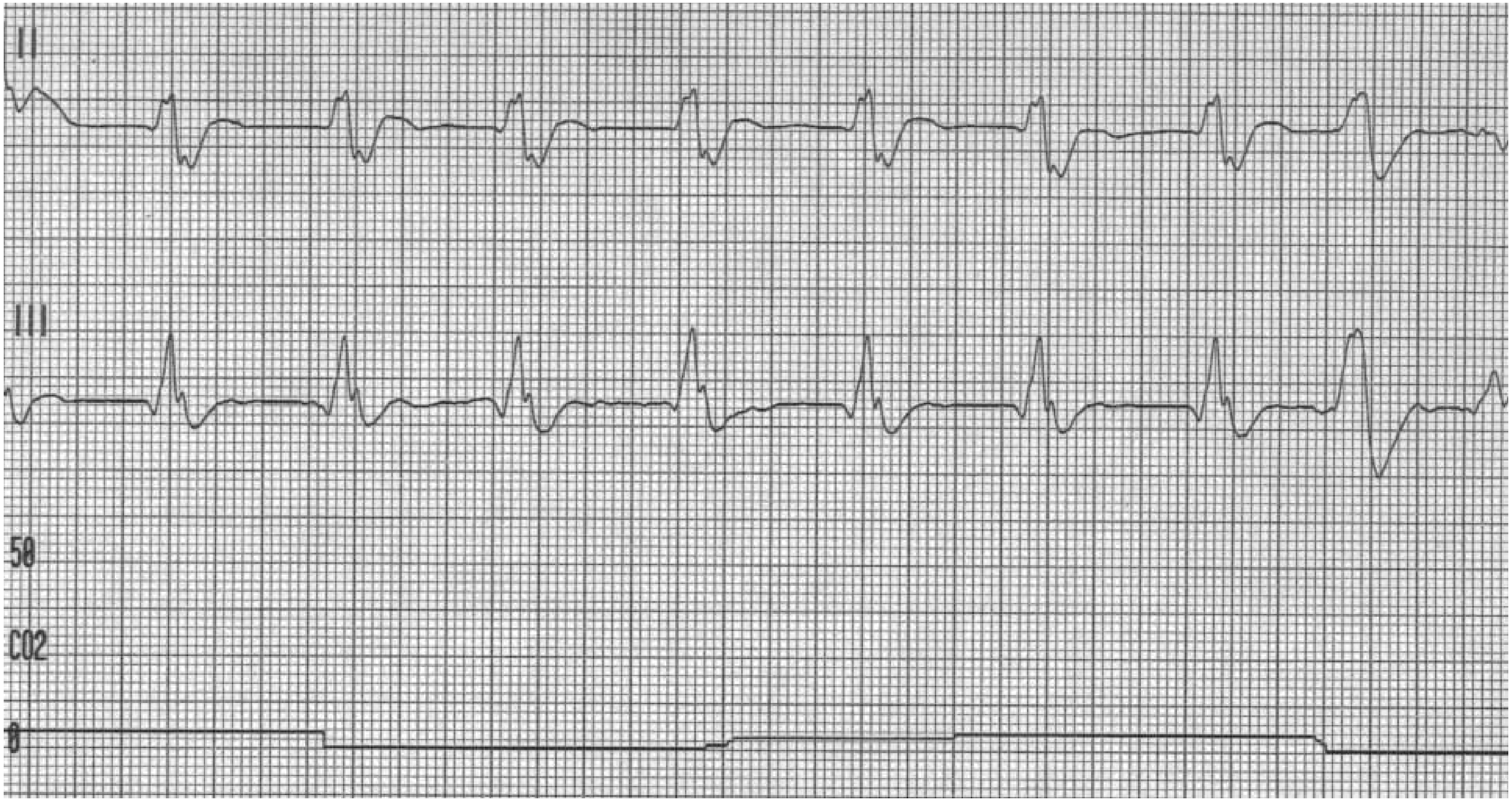
Case #3 – Arresting Developments



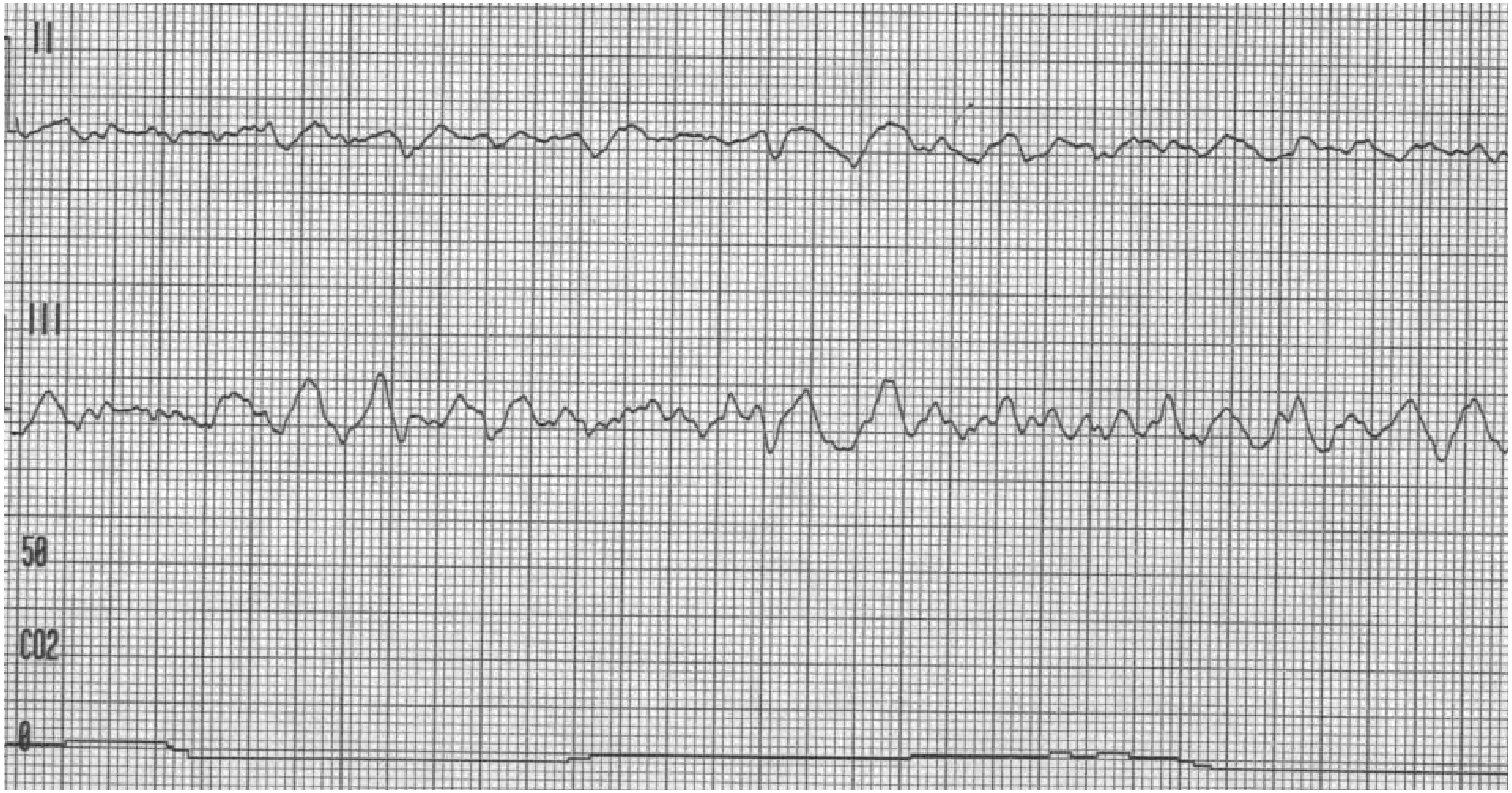
Case #3 – Arresting Developments



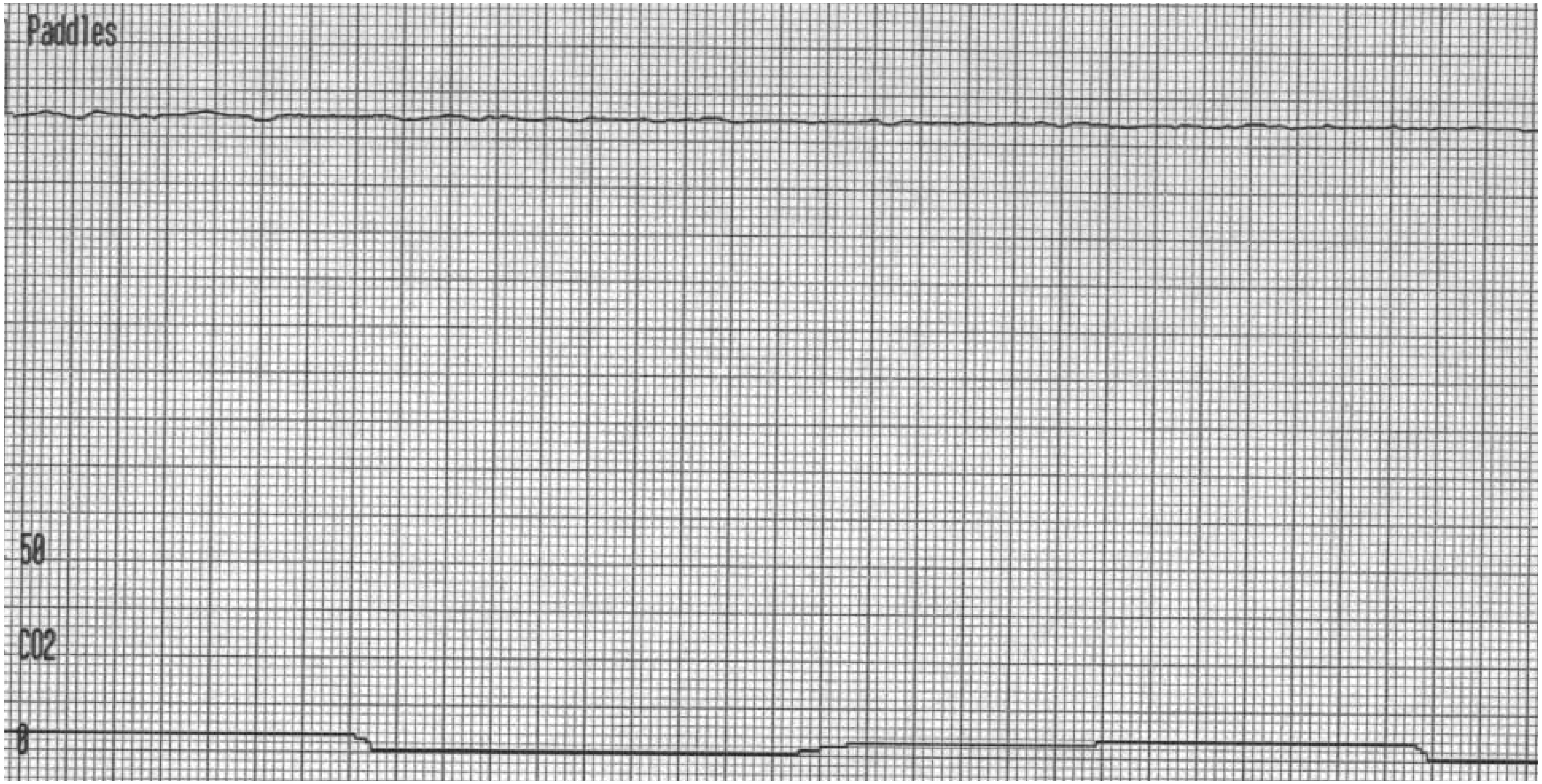
Case #3 – Arresting Developments



Case #3 – Arresting Developments



Case #3 – Arresting Developments



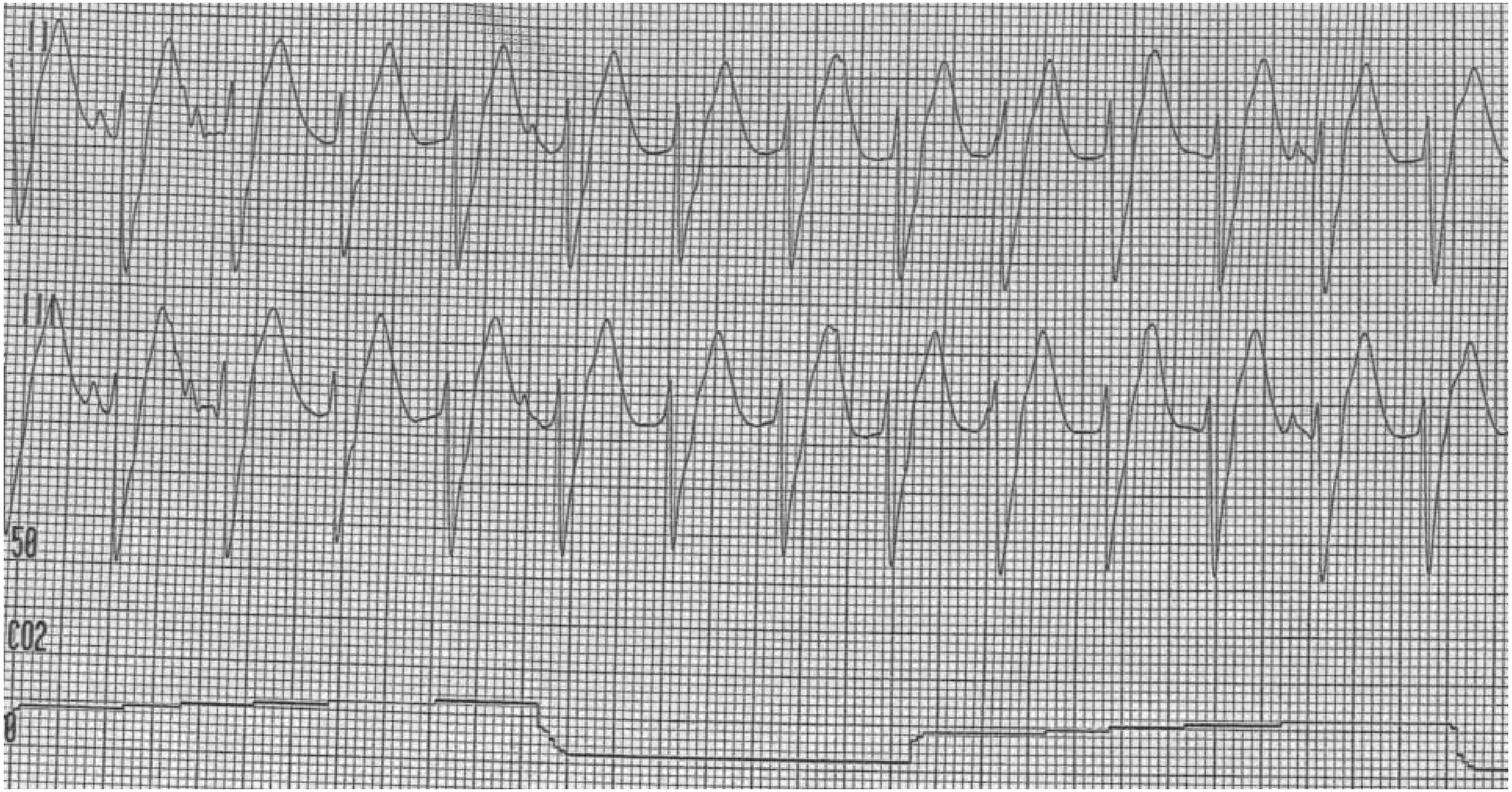
Case #3 – Arresting Developments

14:15:49	Alarm Apnea	107	---•---
14:16:50	Vital Signs	145	31•9
14:17:02	Alarm Apnea	139	31•9
14:18:48	NIBP	76	17•11
14:20:56	Alarm Apnea	70	8•0
14:21:01	NIBP	72	5•0
14:21:50	Vital Signs	78	8•13
14:22:06	Alarm Apnea	70	8•13
14:22:44	Alarm Apnea	87	8•13
14:24:13	Print 1	73	5•0
14:25:10	Alarm Apnea	---	4•0
14:25:10	NIBP	---	4•0
14:26:50	Vital Signs	37	4•0
14:28:40	Advisory Mode	---	4•0
14:28:41	Analysis 1	---	4•0
14:28:46	No Shock Advised	---	4•0
14:28:55	Manual Mode	---	4•0
14:29:11	Shock 4 360J	---	---•---

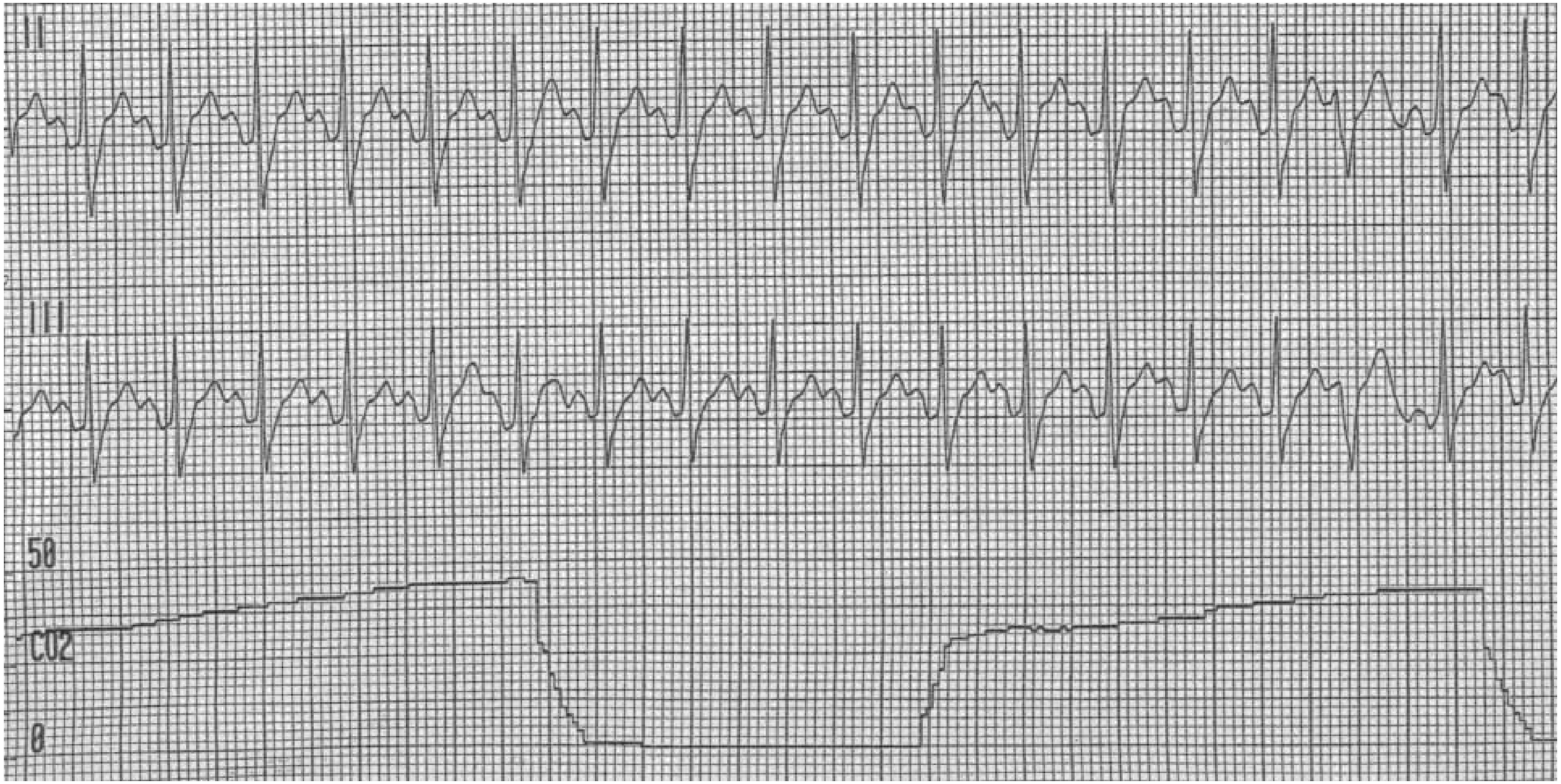
Case #3 – Arresting Developments

- Note as the rhythm deteriorates and perfusion decreases, so does the ETCO2

Case #4 – It's still PEA, right?



Case #4 – It’s still PEA, right?



Case #4 – It's still PEA, right?

- The sudden increase in $ETCO_2$ indicates a change to a perfusing rhythm
- May need pressors in order to augment BP
- Continue resuscitative efforts even if pulse is not palpable

Case #4 – It's still PEA, right?

- In the study from NEJM referenced below, in all 35 patients in whom spontaneous circulation was restored, end-tidal carbon dioxide rose to at least 18 mm Hg before the clinically detectable return of vital signs.
- "End tidal carbon dioxide and outcome of Out of Hospital Cardiac Arrest."
- (N Engl J Med 1997;337:301-6.)

Case #5 -ETCO2 and Sedation

- Parameters that should lead to immediate reassessment of patient status:
  - ETCO2 >50 mm Hg,
  - ETCO2 absolute change >10 mm Hg
  - Absent ETCO2 waveform
- “End-tidal Carbon Dioxide Monitoring during Procedural Sedation”
  - (Acad Emer Med 2002; 9:275–280)

Review – Changes in $PETCO_2$

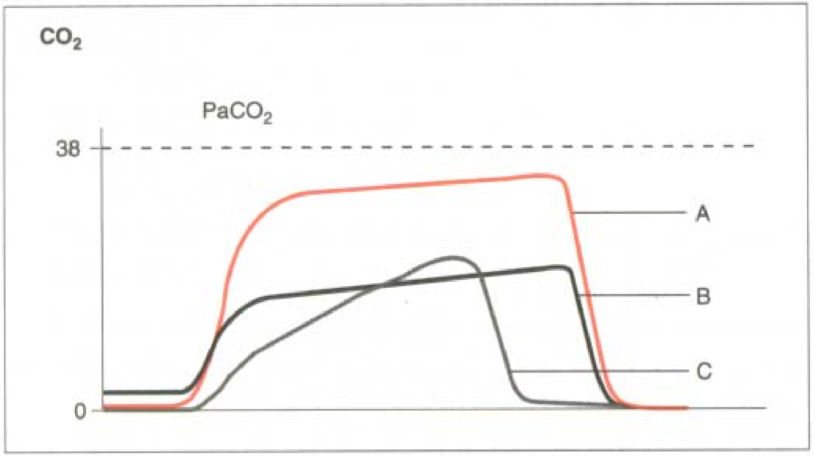
$PETCO_2$ Values and Changes in:	Elevated $PETCO_2$	Decreased $PETCO_2$
Metabolism	• Pain • Hyperthermia • Malignant hyperthermia • Shivering	• Hypothermia • Analgesia/sedation
Respiration	• Respiratory insufficiency • Respiratory depression • Obstructive lung disease	• Alveolar hyperventilation • Bronchospasm • Mucous plugging
Circulatory System	• Increased cardiac output (assuming constant ventilation)	• Cardiac arrest • Sudden hypovolemia/ hypotension • Embolism
Equipment	• Exhausted CO_2 absorber • Defective exhalation value	• Leak in airway system • Partial airway obstruction • ET tube in hypopharynx

Review – Waveforms

A. Normal capnogram configuration and normal $PETCO_2$.

B. Normal capnogram with decreased $PETCO_2$. This is caused by dead space ventilation or hypocarbia.

C. Abnormal capnogram with loss of alveolar plateau. Indicates either incomplete alveolar emptying or abnormal airflow through upper airways.



Sources

- Slides 48-59 and background for this presentation: Clinical Concepts in Capnography monograph by Mallinckrodt, 2000
- Further background from: www.capnography.com
- Thanks also to Jonnathan Busko, MD for the capnography background slides... and Ray Hughes, CEMS Assistant Chief for the Case Studies
- Picture sources noted on each slide