Capnography

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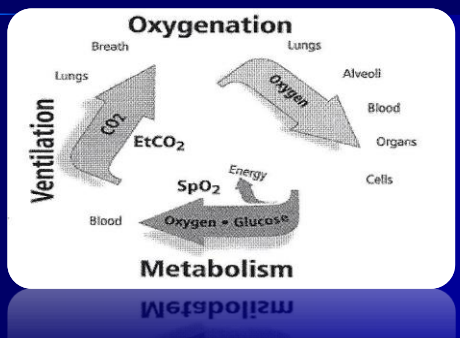
Capnography

- non invasive monitor for ventilation
  - measures end tidal CO2
- early detection
  - hyperventilation ⇨ hypoventilation
  - airway obstruction ⇨ apnea
  - correct ET tube placement
  - MH rise in CO2

Physiology of Ventilation



Physiology of Ventilation

- at end of inspiration
  - airway & lungs are filled with CO2 free gas
- CO2 diffuses from blood into the lungs
  - concentration depends upon alveolar V/Q
  - alveoli with high V/Q will have less CO2
    - most exhaled during early Phase II
  - alveoli with low V/Q will have high CO2
    - exhaled during late Phase III

Terminology

- Capnography
  - graphic display of respiratory CO_2 concentration or partial pressure versus time or volume
- Capnogram
  - CO_2 waveform
- Capnometry
  - measurement & numerical display of CO_2 concentration by a capnometer

Capnography Technology

- infrared spectroscopy
  - most commonly used in clinical practice
- Raman spectroscopy ⇨ argon laser
- Mass spectroscopy
- Photoacoustic gas
- Colorimetric

Capnography Technology

- infrared (IR)
  - CO_2 molecules absorb IR at wavelength of 4.26 μm
  - water vapor & nitrous oxide absorb near this wavelength
    - use filters to prevent interference
  - IR absorption is proportional to the concentration of CO_2 in the sample

Capnography Technology

- water traps for IR units
  - eliminate water vapor from the sample
    - water can absorb IR ⇨ get erroneous result
    - ↓ $ETCO_2$ reading
  - water in sample is at body temperature (37^0) while the unit is at lower temperature (25^0)
    - can overestimate CO_2 number by ~ 1.13 mm of Hg
  - disposable item that must be maintained

Capnography Technology

- Colorimetric Disposable Devices
  - used to verify ET tube placement
  - chemically treated foam inside a plastic housing
  - color change if CO2 present
  - single use item

Mainstream Capnograph

- CO2 sampling sensor is attached directly to the ET tube
  - IR sensor
  - no gas sampling back to monitor
- sensors are heated to 40^0 C to eliminate water vapor
- faster response time than sidestream
- sensor is hot & can burn the patient

Sidestream Capnograph

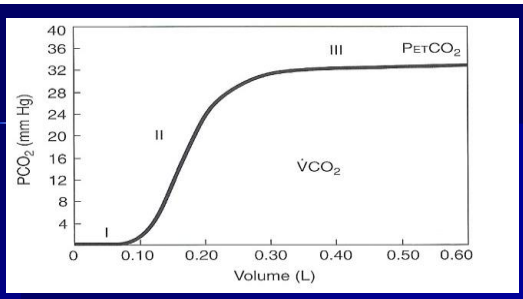
- CO2 sensor is in the monitor
- pump aspirates a gas sample to unit
  - optimal rate ⇨ 50 to 200 ml/min
- sample size exceeds expired gas flow
  - contaminate sample ⇨ PETCO2 ↓
- delay of 1 to 4 seconds to see
  - PETCO2 waveform & number
- can use on intubated & nonintubated
- tracing is more rounded than mainstream

Volume Capnogram

- PCO2 versus Volume in liters
- Phase I: anatomical & instrument dead space ⇨ no CO2
- Phase II: see a steep S wave ⇨ mix of deadspace gas + alveolar gas
- Phase III: CO2 rich alveolar gas

Volume Capnogram

- measures the volume of expired CO2
  - no inspiratory volume monitoring
- determine volumes for
  - airway (anatomic), physiologic, & alveolar dead spaces



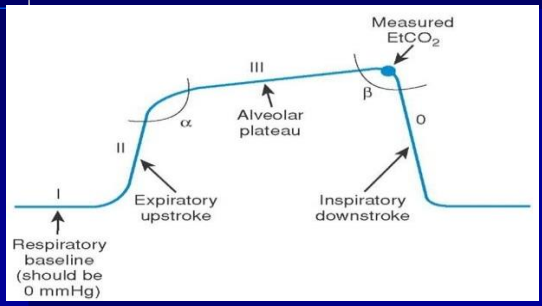
- Phase II & III analysis
  - analyze obstruction & V/Q abnormalities

Gravenstein. Capnography. 2nd edition

Time Capnogram

- PCO2 versus time (seconds)
- most common capnograph in clinical practice
- continuous tracings ⇨ changes in waveform describe ventilatory status
- inspiratory segment: Phase 0
- expiratory segments: Phase I, II, III, IV

Time Capnogram



Internet images

Time Capnogram

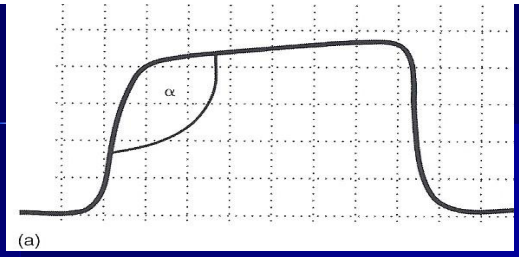
- Phase I
  - starts at end of inspiratory phase 0
  - little to no CO2 in external air PCO2 = 0
  - beginning of expiratory phase ⇨ PCO2 still is 0
    - anatomical dead space
    - not involved in gas exchange

Time Capnogram

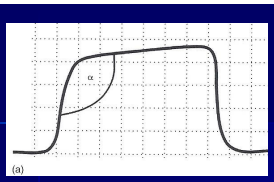
- Phase II
  - see a sharp rise in PETCO2
  - mixture of dead space gas + alveolar gas
- Phase III
  - CO2 rich alveolar gas
  - graph is a rising slope = alveolar plateau
  - if all alveoli had equal amounts of CO2
    - Phase III would be a flat line

Time Capnogram

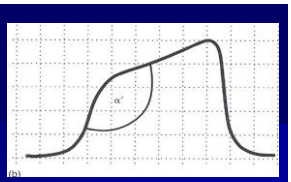
- alveolar plateau
  - near the end of expiration the volume of gas is less than at the beginning
  - CO2 in that low volume is now more concentrated
  - slope of the curve rises upward
- V/Q also involved
  - low V/Q = under ventilated alveoli
  - ↑ PETCO2



- α angle
  - angle between Phase II & III
  - normally 110^0
    - gets more obtuse as slope of Phase III rises
  - angle depends upon V/Q in lungs



Normal α



↑ α angle

- Phase II slope is less steep
- Phase III slope is rising
- V/Q is altered
- Acute asthma capnograph

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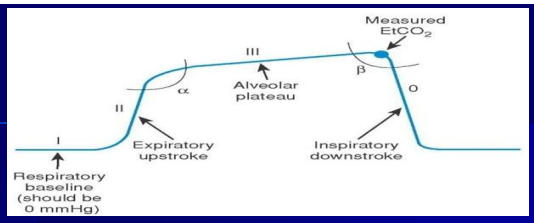
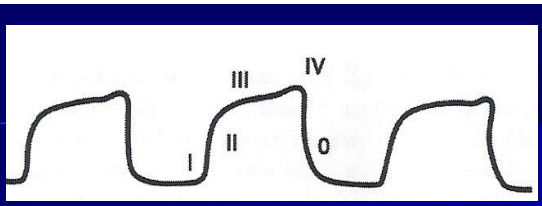


- β angle is between Phase III & inspiration
  - normally 90^0
- β used to assess rebreathing
  - angle increases due to presence of CO2 in the inspired gas



- Phase IV
  - occasionally seen
  - children, pregnant or obese patients

Anesthesiology. 2013;118:192

$PaCO_2 – P_{ET}CO_2$ Gradient

- healthy patients ⇨ ~ 5 mm Hg
- due to V/Q mismatch in lungs
  - alveolar dead space
- infants & children $P_{ET}CO_2 \sim PaCO_2$
- obese & pregnant patients
  - $P_{ET}CO_2 > PaCO_2$
- most patients: change in $P_{ET}CO_2$ correlates to a change in $PaCO_2$

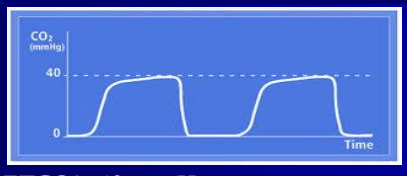
$PaCO_2 – P_{ET}CO_2$ Gradient

- ↑ gradient with
  - hypovolemia, anesthesia, and decreased CO
  - ↑ in age, pulmonary disease, & PE
- ↓ gradient with
  - large tidal volumes & hypoventilation

Normal Values

Parameter	Adult Range
Respiratory Rate	10 - 15 breath/min
Tidal Volume	6 – 10 ml/kg
Minute Ventilation	4 – 10 L/min
$P_{ET}CO_2$	35 to 45 mm Hg

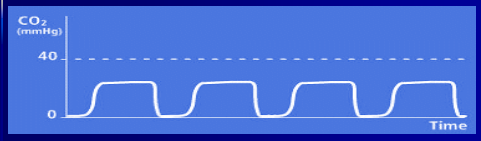
Normal Capnograph



- PETCO2 40 mm Hg
- normal Phase I, II, III
- normal α and β angles

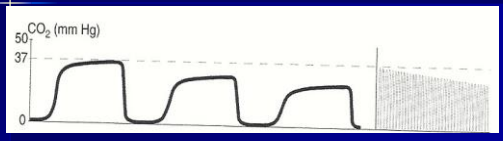
Internet Bing Images

Hyperventilation



- PETCO2 ↓
- waveform ⇨ low amplitude & narrow
- respiratory rate ↑
- baseline is at zero

Hyperventilation



- as hyperventilate
  - blow off CO2
  - amplitude of waveform = PETCO2
  - width of waveform = respiratory rate

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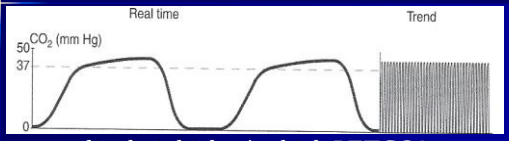
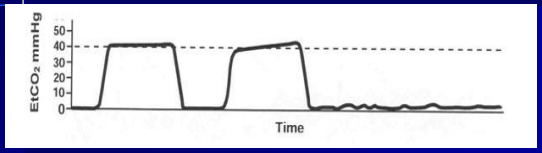
Hypoventilation



- amplitude is high ⇨ high PETCO2
- width is wide ⇨ slow respiratory rate
- arterial hypercarbia

Apnea



- loss of waveform
  - in intubated patient = apnea or dislodged ET
  - non intubated patient
    - complete laryngospasm ⇨ immediate onset
    - complete airway obstruction, apnea, mouth breathing

Shark Fin Waveform

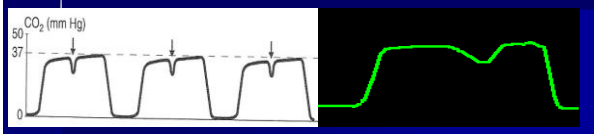
- Phase III slope has steep rise
- acute bronchospasm

Internet Bing Images

Rebreath CO2

- CO2 is not completely washed out
- causes
  - additional instrument dead space between ET tube and sidestream sampling device
  - malfunctioning exhalation valve
  - exhausted CO2 absorbent
  - **CO2 trapped by rubber dam?**

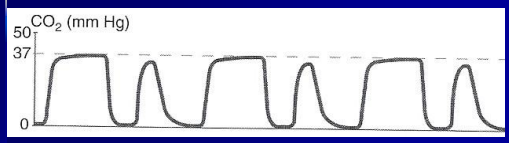
Curare Cleft



- patient is not completely paralyzed
- initiates a breath on his own against ventilator
- most likely due to diaphragm
- in a spontaneous breathing patient
  - a hiccup, rebreathing, response to pain

http://www.capnography.com

Mechanical Ventilation



- waves 1, 3, 5 are from the ventilator
- waves 2, 4, 6 are from spontaneous breaths with large enough tidal volume to get tracing

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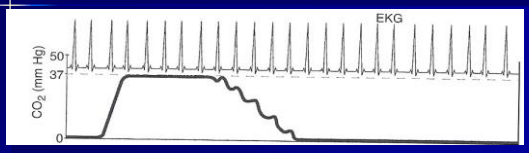
Cardiac Oscillations



- secondary peaks at end of waveform
  - caused by beating of heart against lungs
  - only seen if respiratory rate is very slow or tidal volume is small
  - indicate inadequate respirations

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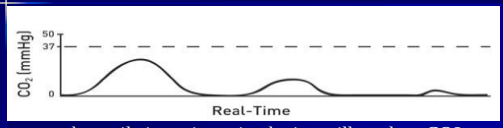
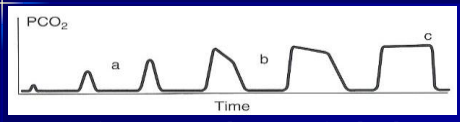
Esophageal Intubation



- mask ventilation prior to intubation will produce CO2 levels in esophagus
- place tube in esophagus ⇨ see CO2 on capnograph
  - after few breaths ⇨ CO2 is back to zero
  - know you are not in trachea
- avoid mistake if give 6 breaths prior to adding capnograph

Blind Nasal



- "a" ⇨ naso/oropharynx ⇨ dead space + some expired CO2 ⇨ small waveform
- "b" ⇨ glottic opening ⇨ see wave similar to leakage at ET cuff
- "c" ⇨ in trachea now & see normal wave

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Obstruction

- ET tube
  - tube is kinked or obstructed by secretions
- Spontaneous breathing patient
  - beginning of airway obstruction

Anesthesia & Hypoventilation

- with opioids we expect respiratory depression
  - slow respiratory rate
  - decreased tidal volume
  - or both
- stethoscope will help with rate
  - not really helpful with tidal volume
- capnography has a significant role here

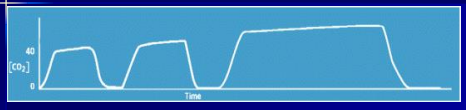
Types of Hypoventilation

- bradypneic hypoventilation
  - ↓ respiratory rate
  - normal tidal volume
  - ↓ alveolar ventilation
  - normal dead space fraction
  - ↑ $PaCO_2$
  - normal $P(a\text{-}et)CO_2$

  Result
  ↑ $ETCO_2$ PETCO2 > 50 mm Hg

Ann Emerg Med. 2007

Bradypneic Hypoventilation



- bradypneic hypoventilation
  - commonly associated with opioids
- very slow respiratory rate
- waveform ⇨ amplitude ↑ width ↑
- if untreated ⇨ get respiratory failure & apnea see PETCO2 ~ 80 mm Hg

Hypopneic Hypoventilation

Hypopneic Hypoventilation
- normal respiratory rate
- ↓ tidal volume
- ↓ alveolar ventilation
- ↑ dead space fraction
- ↑ $PaCO_2$
- ↑ $P(a\text{-}et)CO_2$

Result
normal, or ↓ $ETCO_2$

Ann Emerg Med. 2007; 50(2)

PETCO2 < 30 mm Hg

Hypopneic Hypoventilation

- anatomic dead space is normal
  - 150 ml
- tidal volume is decreasing more than respiratory rate
  - get an ↑ in dead space volume to tidal volume ratio
- waveforms ⇨ low amplitude & narrow width

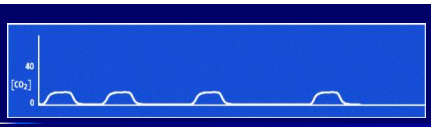
Hypopneic Hypoventilation

- differentiate from hyperventilation
  - need to use respiratory rate
  - hypopneic hypoventilation = slow rate
  - hyperventilation = fast rate
  - both have ↓ PETCO2
- usually due to sedative – hypnotics used in anesthesia

Hypopneic Hypoventilation

- variable anesthetic course
  - low tidal volume may resolve as drug redistributes from CNS
  - could cause periodic episodes of apnea
  - could progress to central apnea
    - no respiratory drive
- SpO_2 will take at least 2 to 3 mins to see a decrease
  - one study: average of 3.7 mins

Pediatric Emerg Care. 2011;27(5): 394



- hypopneic hypoventilation with pauses
- treatment
  - reduce dose of agent
  - assess for airway obstruction
  - increase oxygen flow
  - may need to assist ventilations

Ann Emergency Med. 2007;50(2):176

Hypoventilation & Shallow Breathing

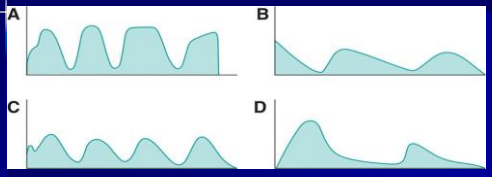
- normal wave followed by hypopneic hypoventilation
  - ↓ resp rate & ↓ tidal volume
- stimulate patient to take a deep breath
  - now get alveolar CO2 ⇨ ↑ CO2 level

Open Airway Techniques

- why use capnography?
- respiratory depression from sedation
  - 17 times more likely to be detected early with capnography than without
- ↓ in PetCO2 in pediatric sedation with ketamine in ER
  - occurred on average 3.7 minutes before SpO2 changes

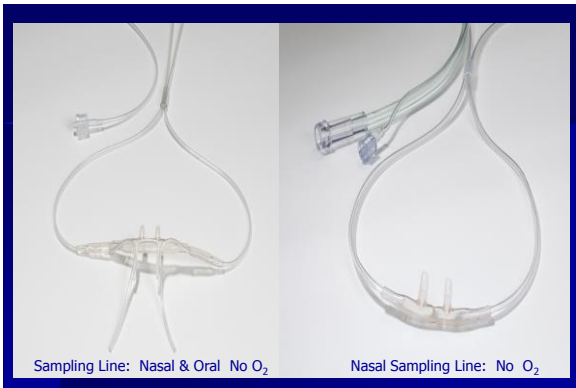
J. Clin Anesth. 2011; 23:189 Ped Emerg Care. 2011; 27(5): 394

Open Airway Techniques

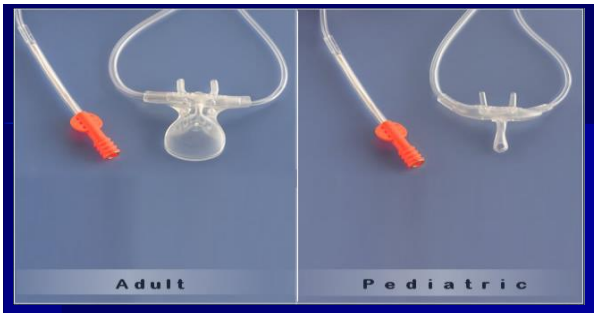


- do not expect to see classic waveforms in open airway techniques
  - PetCO2 diluted by O_2 or air
  - patient may be mouth breathing

Anesthesiology. 2013;118:192



Sampling Line: Nasal & Oral No O_2 Nasal Sampling Line: No O_2



- Sample both nasal & oral
- Oxygen flows through 1 nasal opening

Sidestream Face Mask: 1 port O_2 the other port PetCO2

- Capno2 Mask on right (Respironics)
  - mainstream unit

Nasal Cannula Monitoring

- Factors that may ↓ accuracy PetCO2
  - patient secretions & vapor clogging line
  - small tidal volumes
  - tachypnea
  - large volume of sampling line
  - high sampling rates
  - dilution by supplemental oxygen
  - mouth breathing

Nasal Cannula Monitoring

- PaCO2 – PetCO2 gradient accuracy
  - multiple studies in children & adults show correlation to intubated patients

Ann J Emerg Med. 1995; 13: 30
Crit Care Med. 1997; 25: 1242
Minerva Anesth. 2001; 67:161
Anaesth. 2000;17: 622

Nasal Cannula Monitoring

- non intubated deep sedation for cerebral angiography
  - nasopharyngeal airway
  - 1 group ⇨ stick sampling tube down airway
  - 1 group ⇨ use dual sampling nasal cannula
- results
  - PetCO2 correlated to PaCO2
    - difference between nose & pharynx 1.31 ± 1.25 mm Hg

J Neurosurg Anesthesiol. 2013;25(2): 191

Nasal Cannula Monitoring

- Problems with dental anesthesia
  - mouth is not closed
    - dilution from mouth breathing
  - supplemental oxygen
    - recommend flow rates of **< 3 L/min nasal**
  - can not use full face mask
  - nasal airway can be used
    - exceed moderate sedation level

Dental Anesthesia

- do not expect typical intubated waveforms
  - apply cannula prior to sedation to see baseline waveform and numbers
  - diagnosis is based upon changes in baseline
- not unusual to see no waveform but the patient is breathing

Apnea

- Loss of capnogram
  - no waveform on monitor
- No chest wall movement
  - ECG impedence tracing = no waveforms
- No breath sounds detected
- Airway maneuvers → fail to reestablish breathing

UAO Incomplete

- Capnograph waveforms
  - loss of definition: ↓ in amplitude & width
    - waveforms are more rounded
- See chest wall movement
- Hear breath sounds → noisy, snoring
- ECG impedence tracing → see waves
- Initiate airway maneuvers

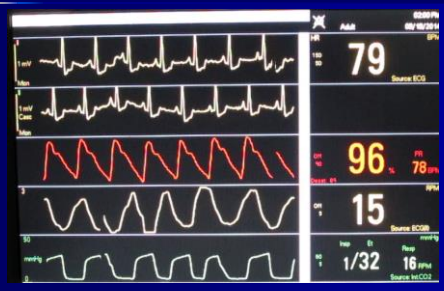
UAO Complete

- Capnograph → loss of waveform
- Chest wall movement
- ECG impedence tracing
  - tracing shows waveforms
- No breath sounds
- Initiate airway maneuvers to reestablish the airway
  - failed maneuvers → may be laryngospasm

Complete Laryngospasm

- Capnograph → loss of waveform
- Chest wall movement
- No breath sounds
- ECG impedence tracing
  - see waveforms
- Airway maneuvers do not reestablish ventilations

Strip #1



Strip #2 2 Liter flow

Strip #3 4 Liter flow

Strip #4 6 Liter flow

Strip #5

Strip #6

Strip #7

Identify

Strip #8

Strip #9

Strip #10

What is the third complex

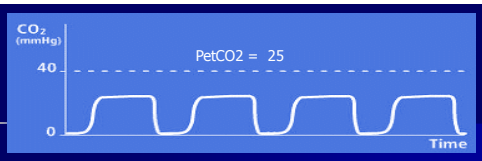
- Rebreathing during exhalation
- Hiccup
- Patient response to pain

- Is this bradypneic hypoventilation?
- Is this hypopneic hypoventilation ?
- Is this partial airway obstruction?
- Diagnosis: obstruction causing low tidal volume breathing.

- obstructed ⇨ open airway ⇨ get back to normal

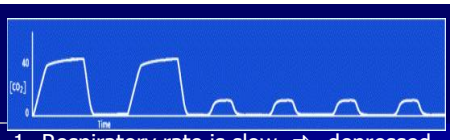
- obstruction
- open airway ⇨ expect to see ↑ PetCO2 for few breaths
- then back to normal

- Diagnosis: Obstruction
  - PetCO2 = 0 SpO2 = 99



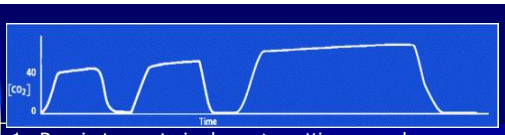
1. Fast respiratory rate
2. Waveform shows normal Phases
3. Low value for PetCO2

- Hyperventilation



1. Respiratory rate is slow ⇨ depressed
2. PetCO2 wave ⇨ low amplitude & width
3. Blood gas ⇨ PaCO2 is high
4. Shallow breathing

- Hypopneic hypoventilation
- small tidal volume = shallow breathing, low amplitude and wave width
  - dead space breathing ⇨ no alveolar gas ⇨ low PetCO2

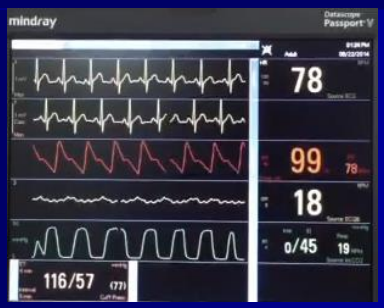


1. Respiratory rate is slow ⇨ getting very slow
2. Breathing is not shallow
3. Blood gas ⇨ PaCO2 is high
4. Waveform ⇨ wide & high amplitue

- Bradypneic hypoventilation
- Hypercarbic due to slow respiratory rate
  - alveolar gas filled with CO2
- Tidal volume is unaffected for now
  - as depression continues apnea will occur

Low amplitude waves?

General Anesthesia



General Anesthesia

Waking Up

Interpretation

Interpretation

Interpretation

Thank you

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