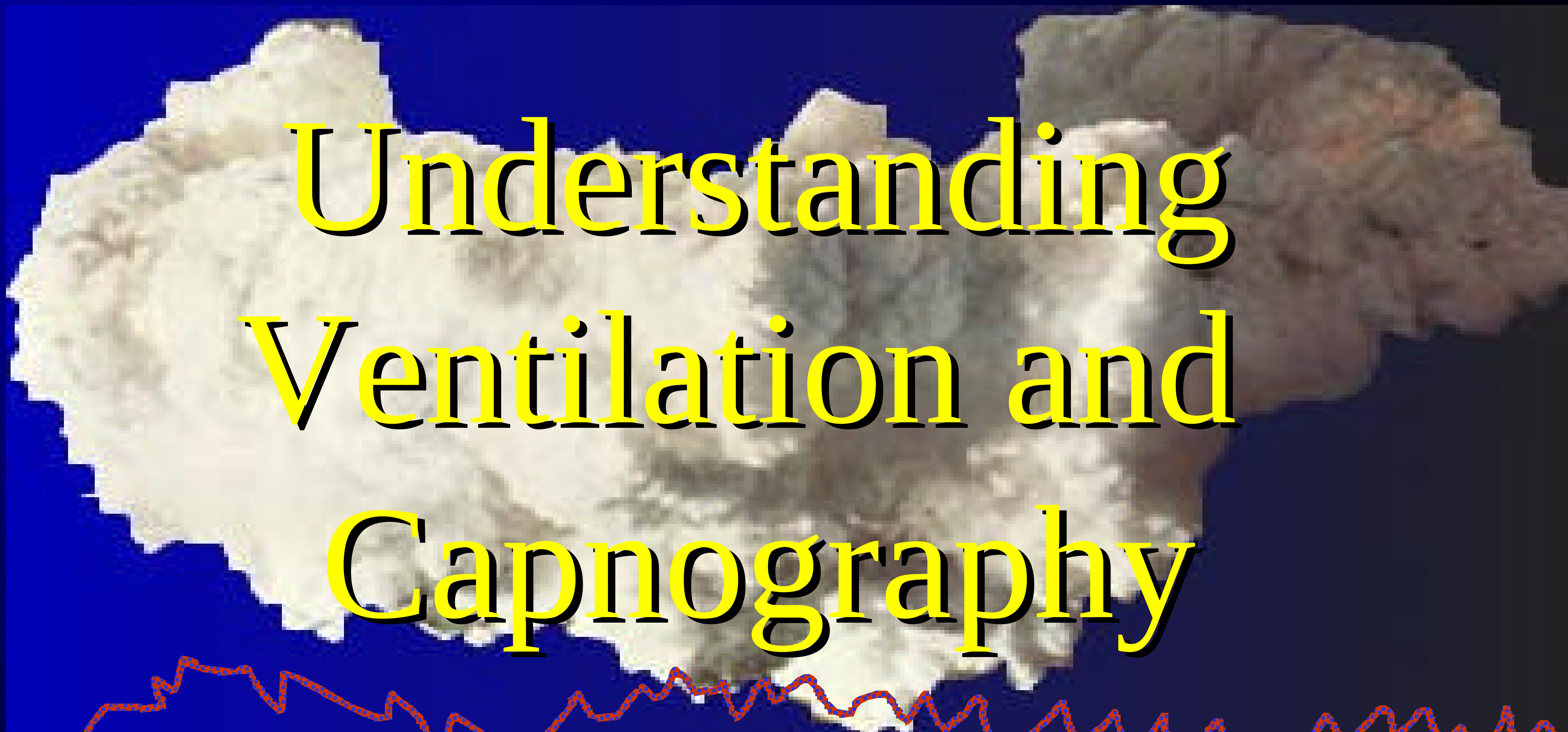

Understanding Ventilation and Capnography

Advanced concepts in the ventilation of the acutely ill patient

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The University of Texas Southwestern

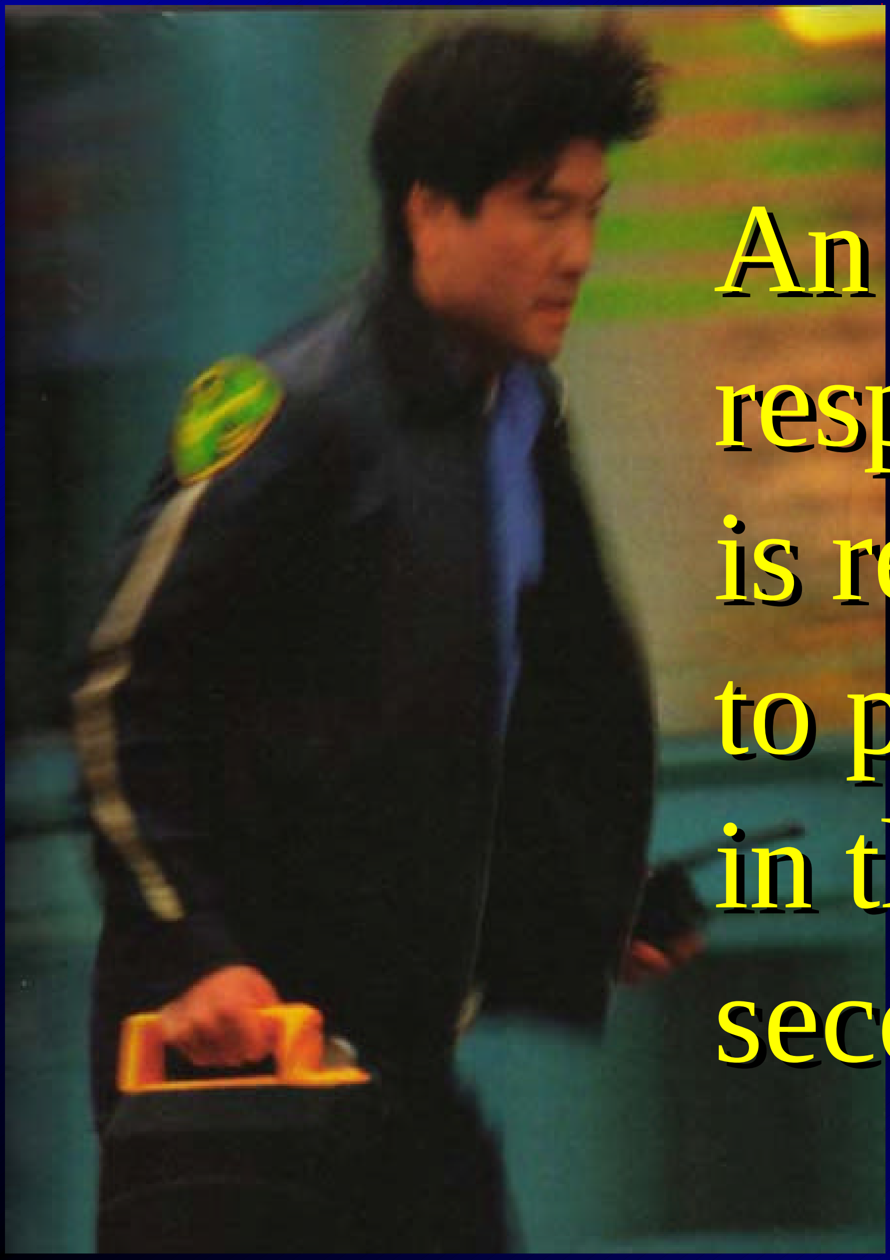
Associate EMS Medical Director

for Operations

Dallas Metro Area BioTel EMS System

www.doctorfowler.com

The acutely ill patient
is a helpless example
of the lives
that we have
sworn to serve.



An immediate
response
is required
to problems found
in the primary and
secondary survey

For example, an obstructed airway can bring death in a matter of a couple of minutes

This session will present important issues regarding the use of ventilation techniques for the acutely ill patient


CPR

As we assess patients,
we must quickly determine
fundamental parameters
of their respiratory
and circulatory status.

Oxygenation vs. Ventilation

Saturating Red Cells

vs.

Clearing CO_2

Minute Ventilation

Tidal Volume

x

Respiratory Rate

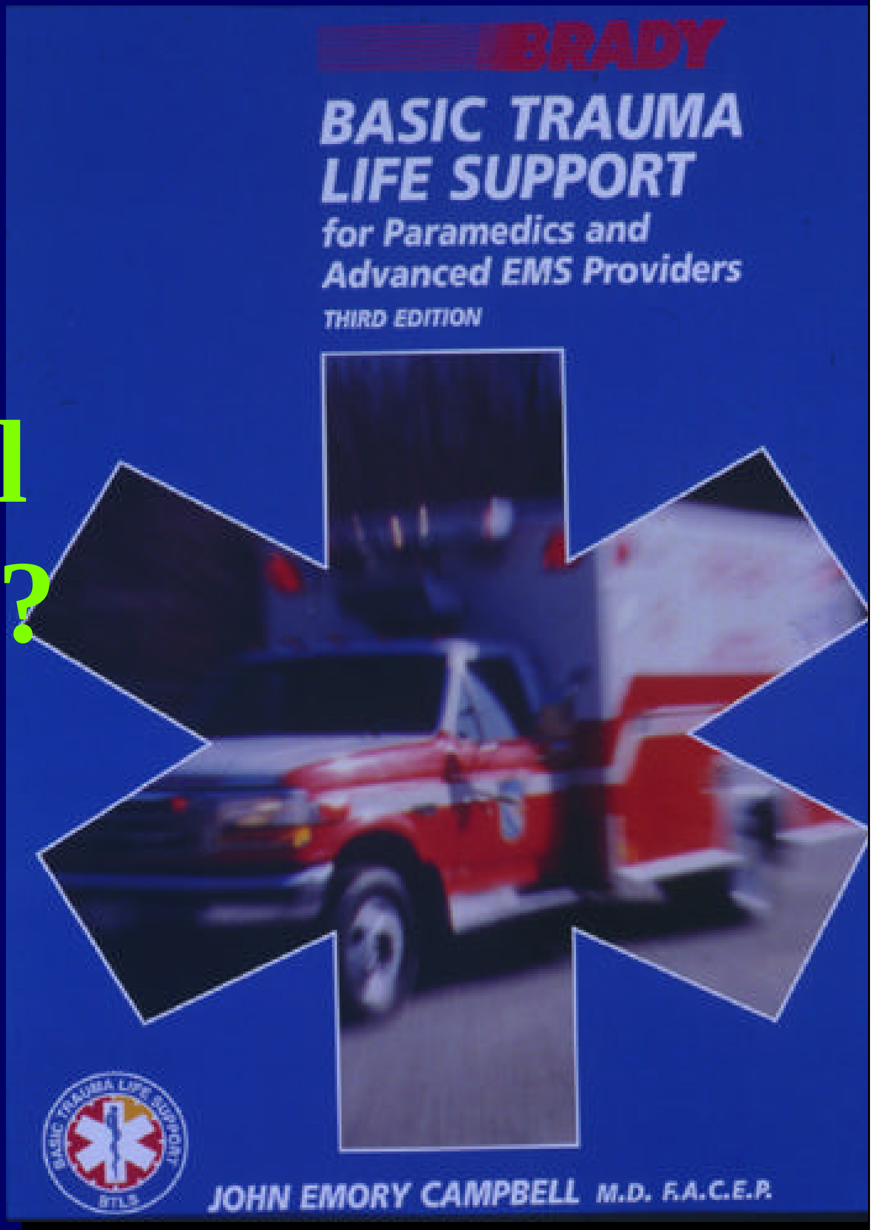
Adequate Lung Inflation*

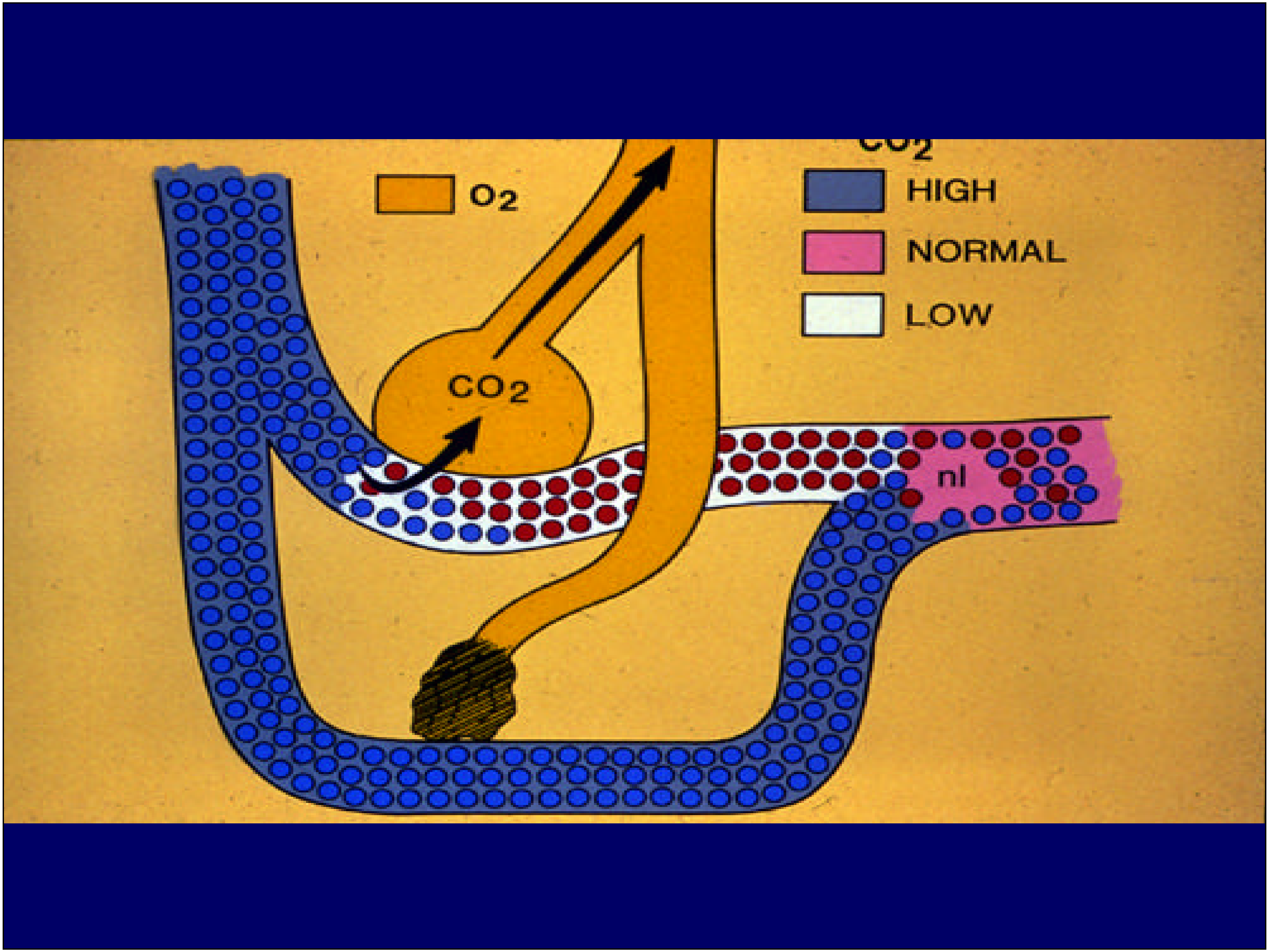
10- 15 ml/kg

** Assumes ET Tube & Positive Pressure Breaths*

Q: **What are the Typical Teachings & Current National Protocol Standards?**

A: **10-15 ml/kg Tidal Volume & 15-20 breaths/min.**





CO_2
HIGH
NORMAL
LOW
O_2
CO_2
nl

Oxygen Consumption

Largely Dependent on Oxygen Delivery...

...in low flow states

Oxygenation

- Adequate Lung Inflation
- Supplemental O_2

Oxygenation Strategy

- FiO_2 = 1.0 (100%)
- Select Adequate Tidal Volume
- Titrate RR as Needed

Need to Ventilate

- CO_2 Production

  (O_2 Consumption
  & Venous Return)

- Dead Space

  (wasted ventilation)

CO_2 Production

Largely Dependent on Oxygen Consumption

What is Carbon Dioxide?

- **Capnos comes from the Greek word for "smoke"**

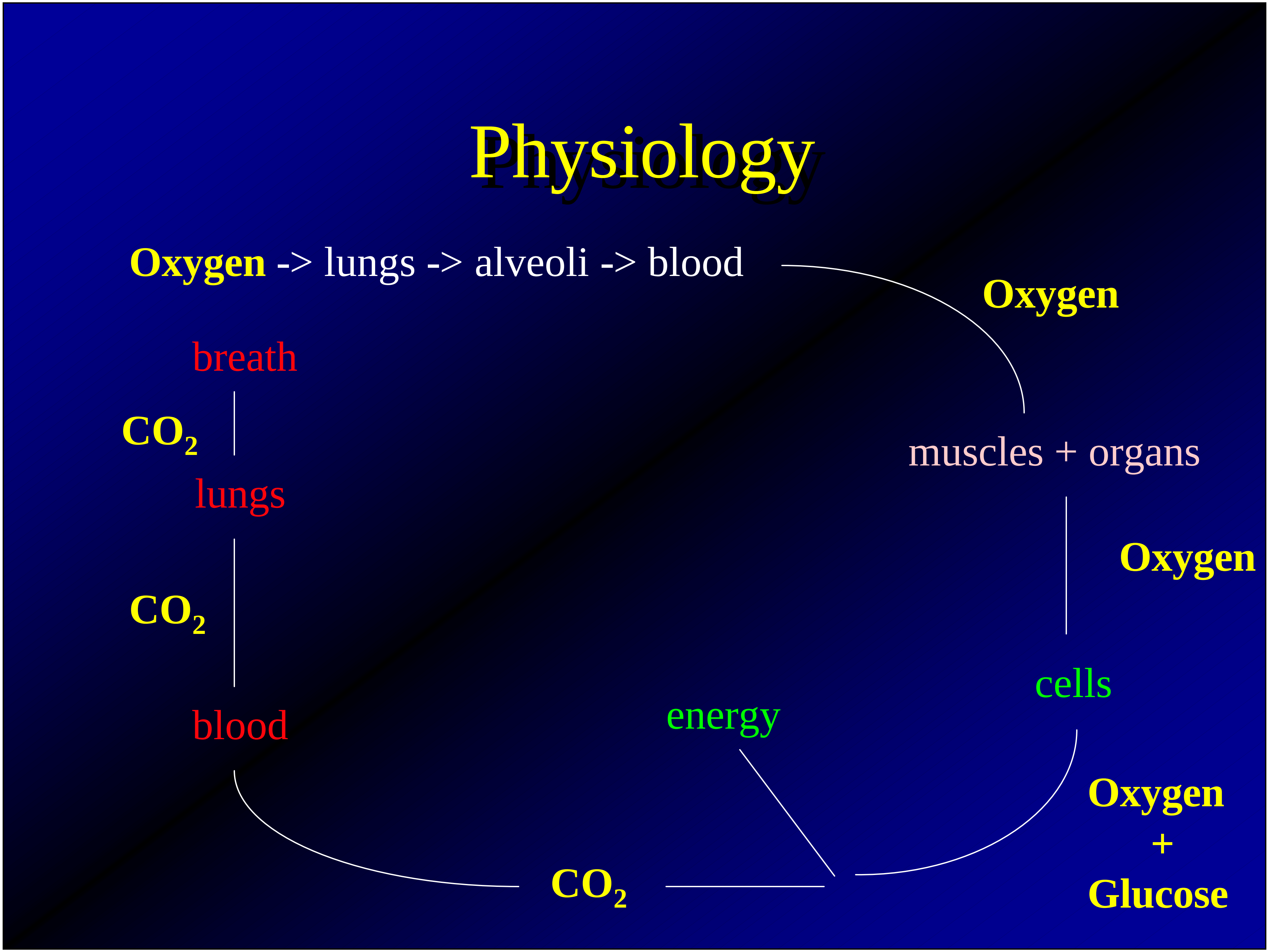
  - smoke from the fire of metabolism
  - a natural waste product of cellular activity
- **CO_2 is a compound molecule**
  - 2 elements of oxygen and 1 element of carbon
  - colorless and heavier than air
  - green plants clean up after our exhaled CO_2

Carbon dioxide physiology

- 0.03% concentration in air
- Resting adult produces 2.5 mg/kg/min

Carbon dioxide physiology

- **Transported in blood**
  - 60-70% bicarbonate ion after conversion in RBCs using carbonic anhydrase
  - 20-30% bound to proteins (e.g., Hb)
  - 5-10% in physical solution (PCO_2)
- **Cleared by alveolar ventilation**


Physiology
Oxygen -> lungs -> alveoli -> blood
Oxygen
breath
CO2
muscles + organs
lungs
Oxygen
CO2
cells
energy
blood
Oxygen
+
Glucose
CO2

Alveoli:

The Place Where Gas Exchange Happens

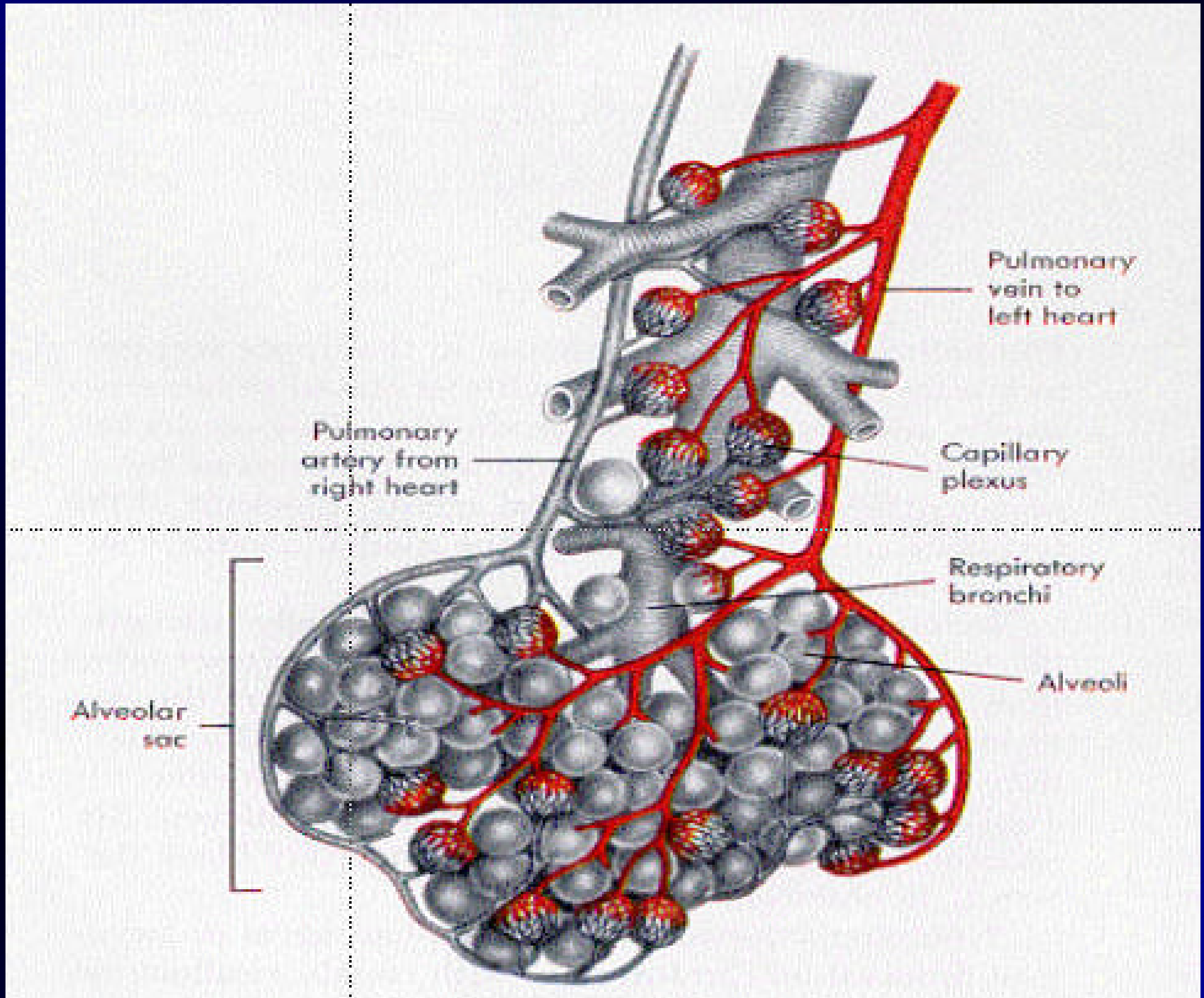


FIGURE 1-9
Structure of an acinus.

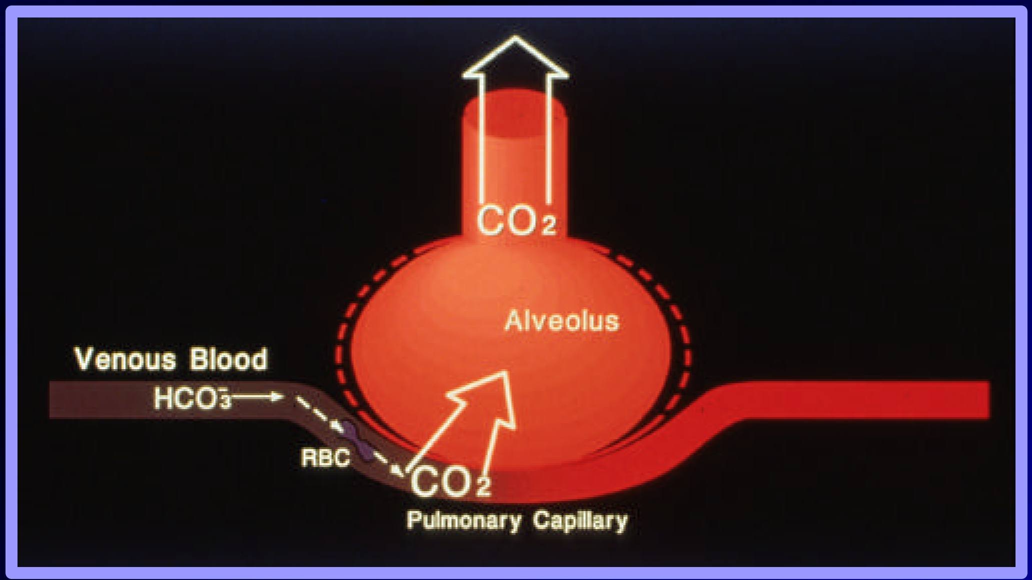
Respiratory Cycle

Phases of Expiration

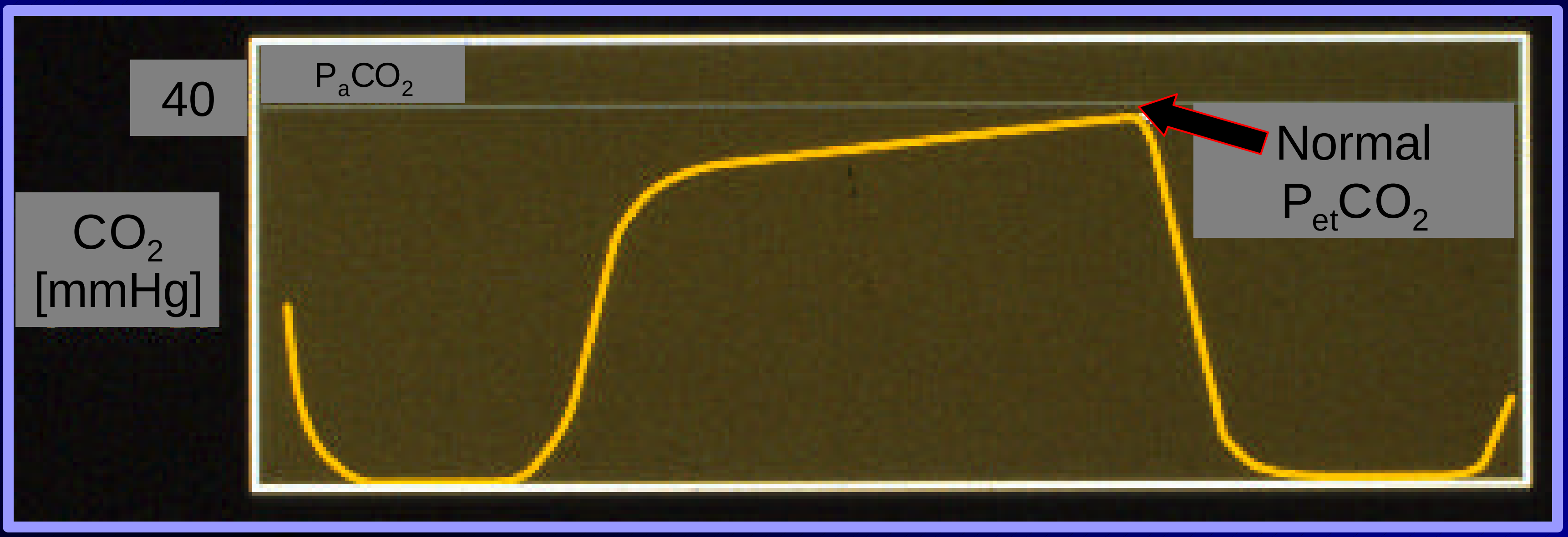
- Beginning expiration (DS_{vent}) - trachea
- Middle expiration - mixing proximal and distal airways
- End expiration - pure alveolar

Driving pressure for CO_2 elimination in the lung

- Partial pressure difference between CO_2 in pulmonary capillary and alveolar air
- Equilibration reached in <0.5 sec



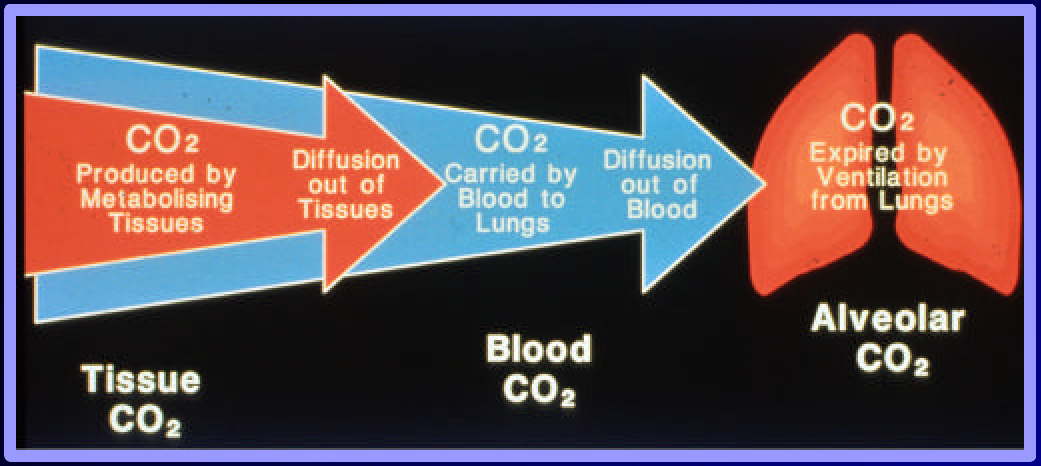
Normally the $P_{et}CO_2$ approximates the P_aCO_2



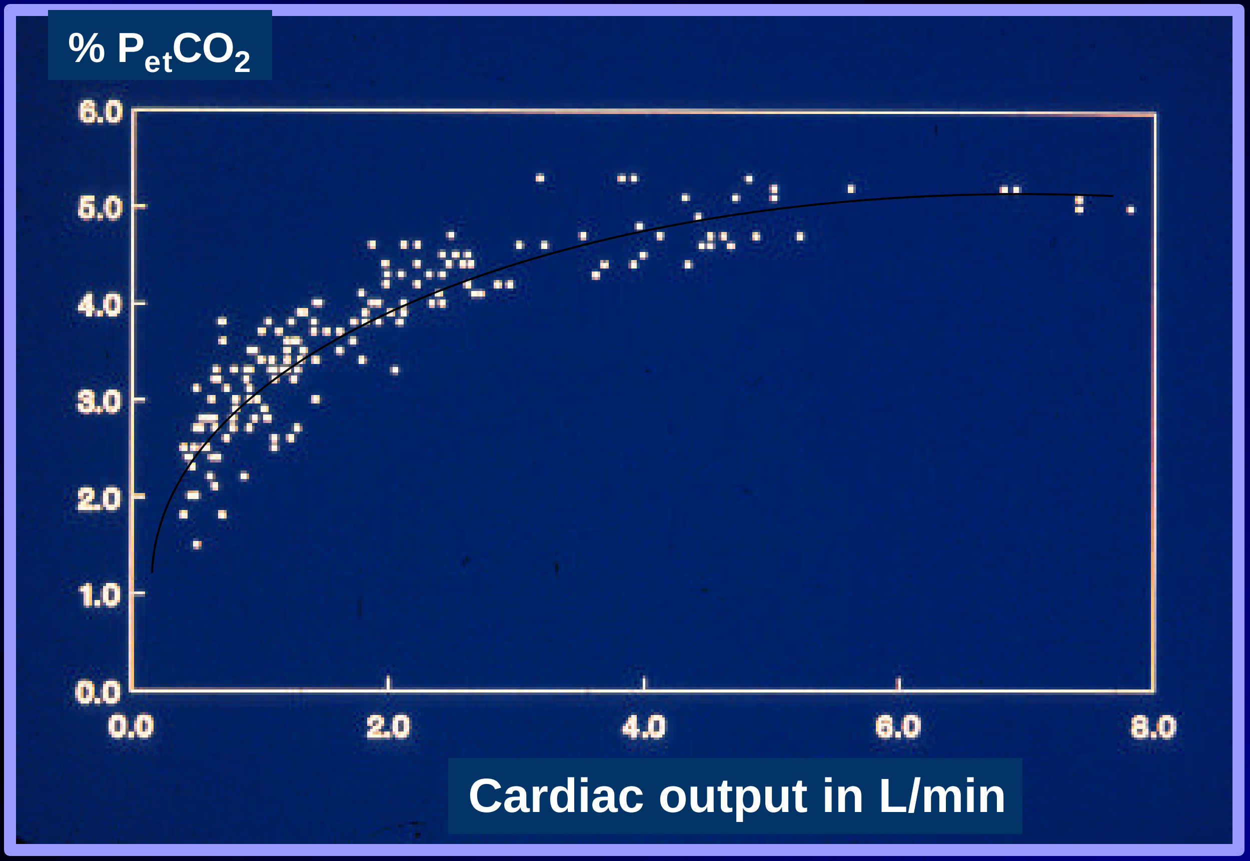
a-A $DCO_2 \leq 3$ mmHg

Factors affecting $P_{et}CO_2$

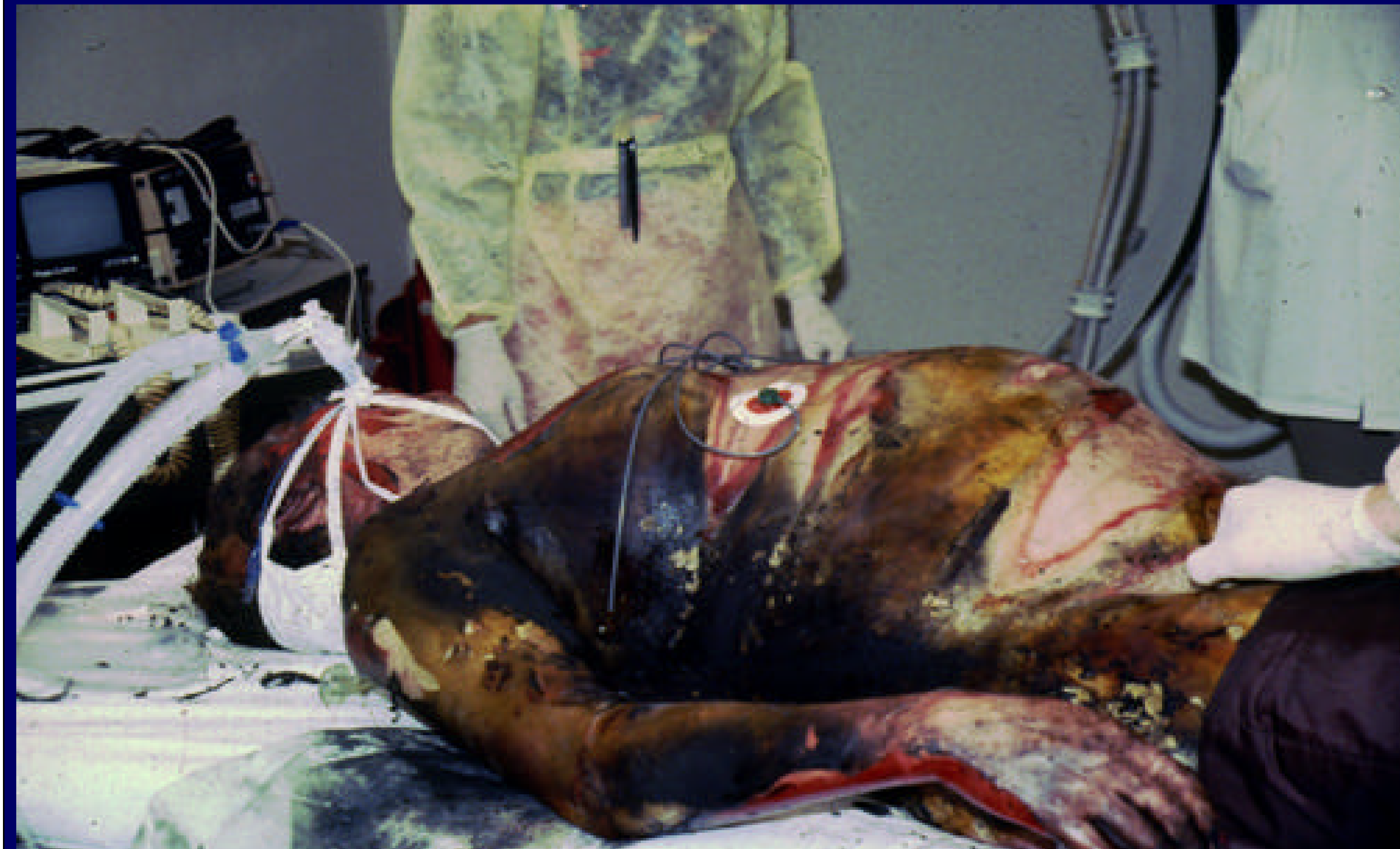
- Production (metabolism)
- Delivery (blood flow)
- Elimination (ventilation)



Relationship between cardiac output and $P_{et}CO_2$



Ornato JP, Garnett AR, Glauser FL. Ann Emerg Med 1990; 19:1104-6



Cardiac Arrest

- **Little O_2 Delivery & Consumption**
- **Little CO_2 Production & Venous Return**

...Little Need to Ventilate!!

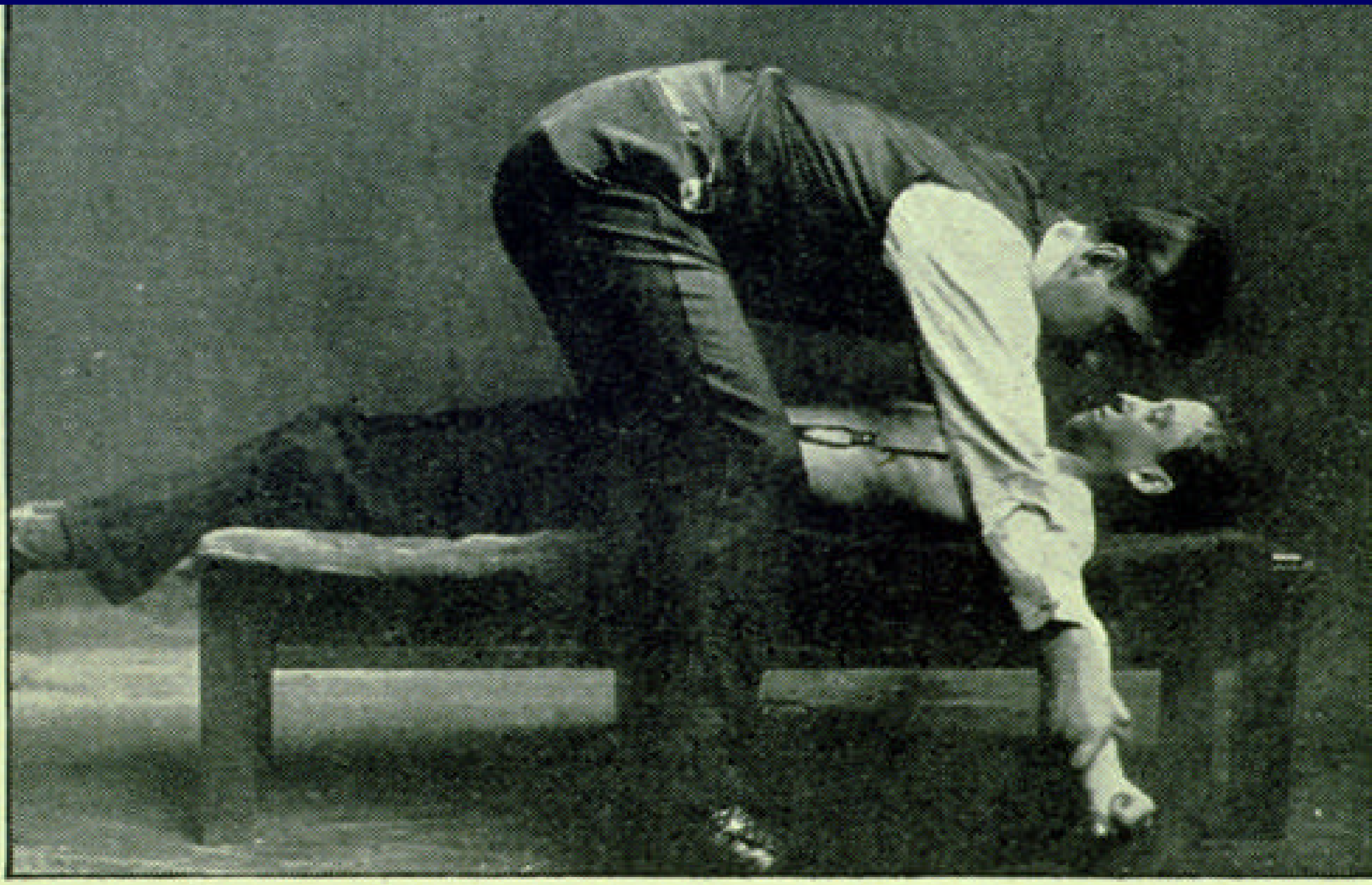


FIG. 105. ARTIFICIAL RESPIRATION.
Raising and lowering arms. Third Method.

Moribund Trauma Pt.

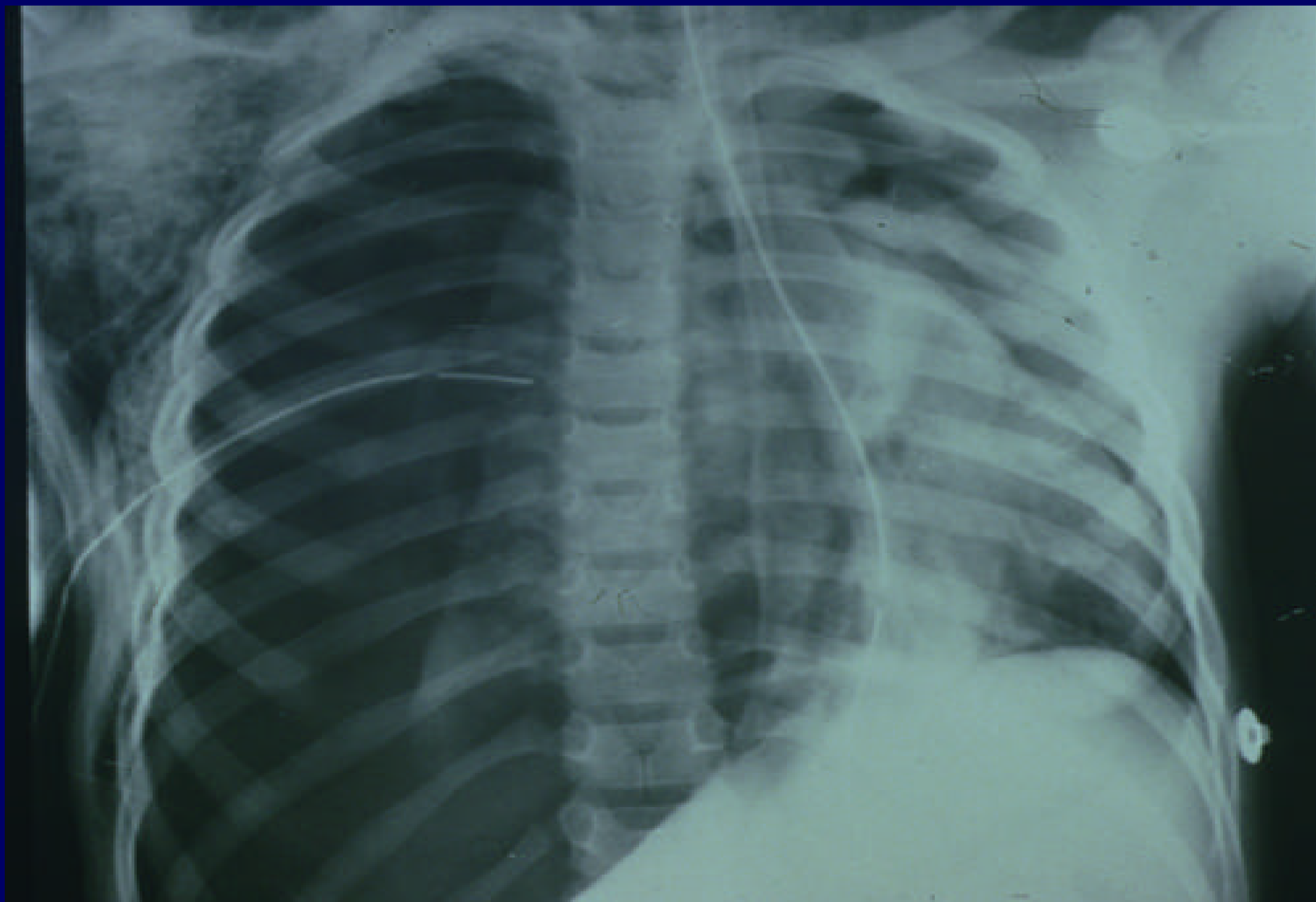
- Little O_2 Transport & Consumption
- Little CO_2 Production & Venous Return

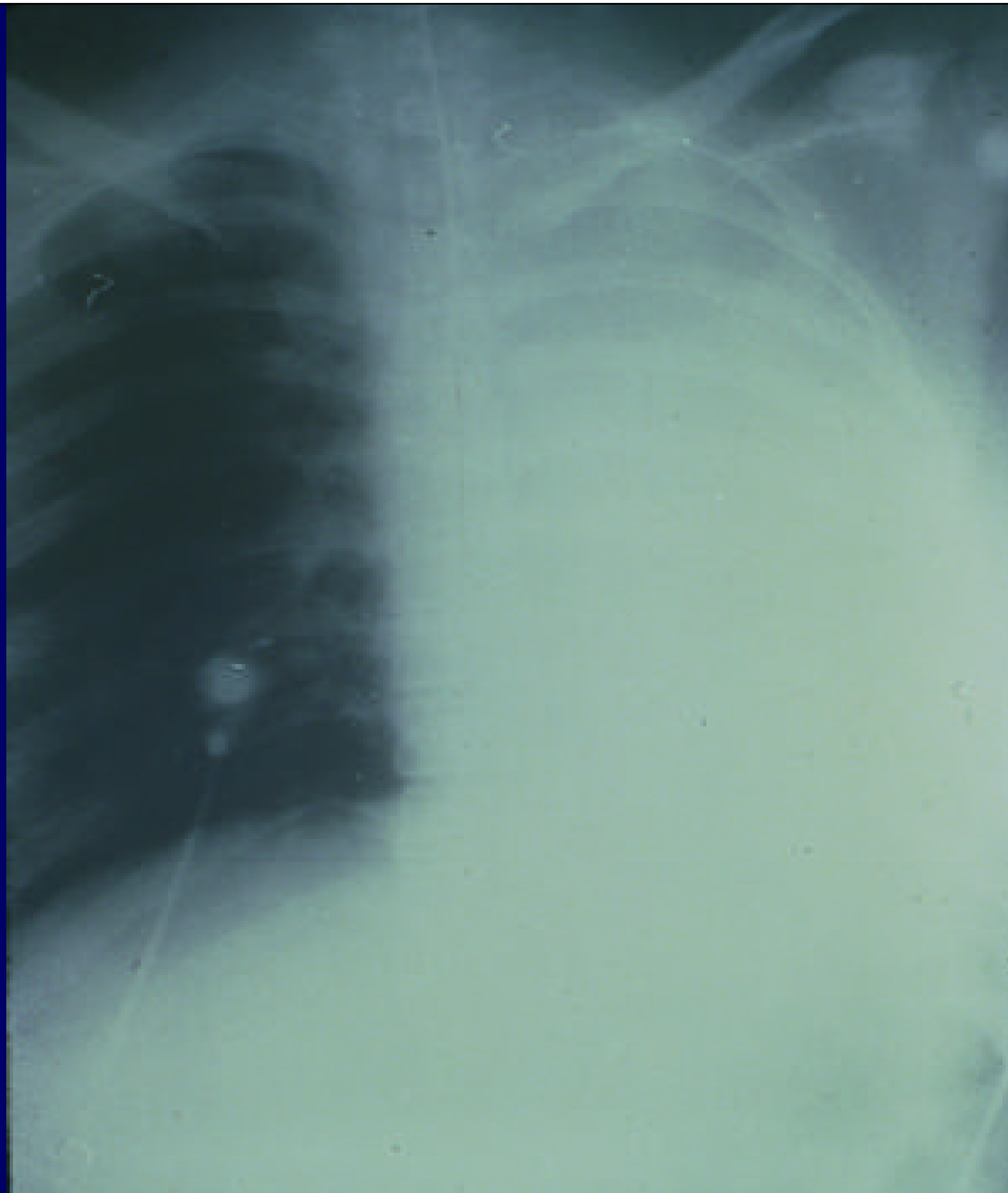
Little Need to Ventilate

And There's a Key Problem...

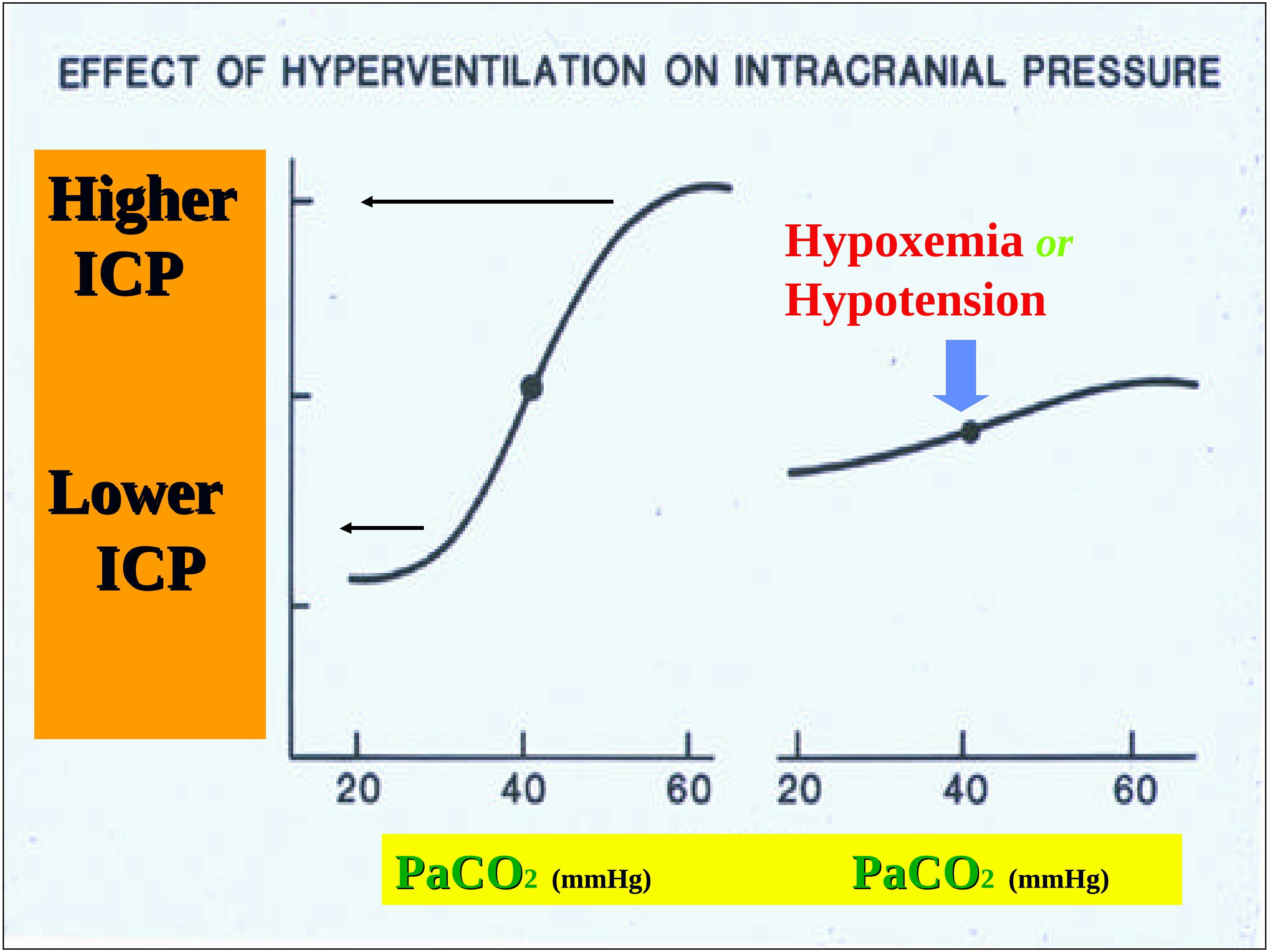
Positive Pressure Breaths *Can Impair Cardiac Output*...

...in the Face of Circulatory Compromise





The Response of Intracranial Pressure
to changes in carbon dioxide is
less when the patient is
in circulatory compromise


EFFECT OF HYPERVENTILATION ON INTRACRANIAL PRESSURE
Higher ICP
Lower ICP
Hypoxemia or Hypotension
20
40
60
20
40
60
PaCO2 (mmHg)
PaCO2 (mmHg)

Ventilation Decisions:

Tidal Volume = Lung inflation which equals oxygenation

Respiratory Rate = Amount of CO_2 which needs to be removed

Critical Decision:

Patients with tension pneumo or with poor venous return can have their venous return worsened by excessive respiratory rates

“Anyone who has
limited oxygen consumption
and CO_2 production
does NOT need that many breaths.

Assure oxygenation with
proper lung inflation but don’t
use overzealous respiratory rates
in circulatory compromise.”

Paul Pepe, M.D., FACEP, MPH
November, 2001

The

Tidal Volume

vs.

Rate

"Disconnect"

Tidal Volume = Oxygenation

Rate = CO_2

Depth of Lung Inflation = Oxygenation

Respiratory Rate = Tied to the amount of CO_2 to be removed

Adjust the respiratory rate based on:

1. Metabolism
2. Hemodynamics

Don't need to remove much CO_2 when little is being produced

OR

when little is being returned to the lungs (such as in deep hemodynamic compromise)

Warning Will Robinson!!!

Coronary perfusion MAY be diminished by overzealous ventilation!!

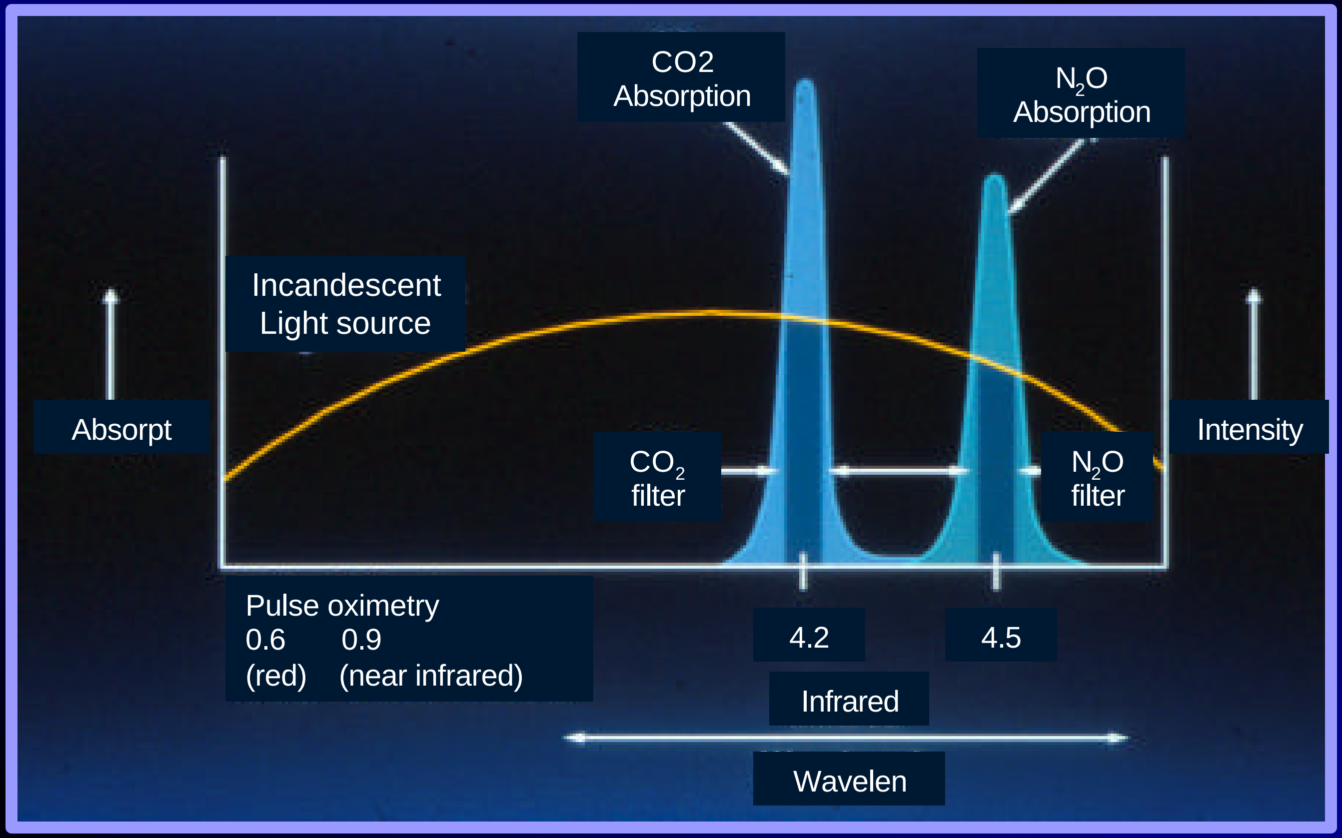
Capnography

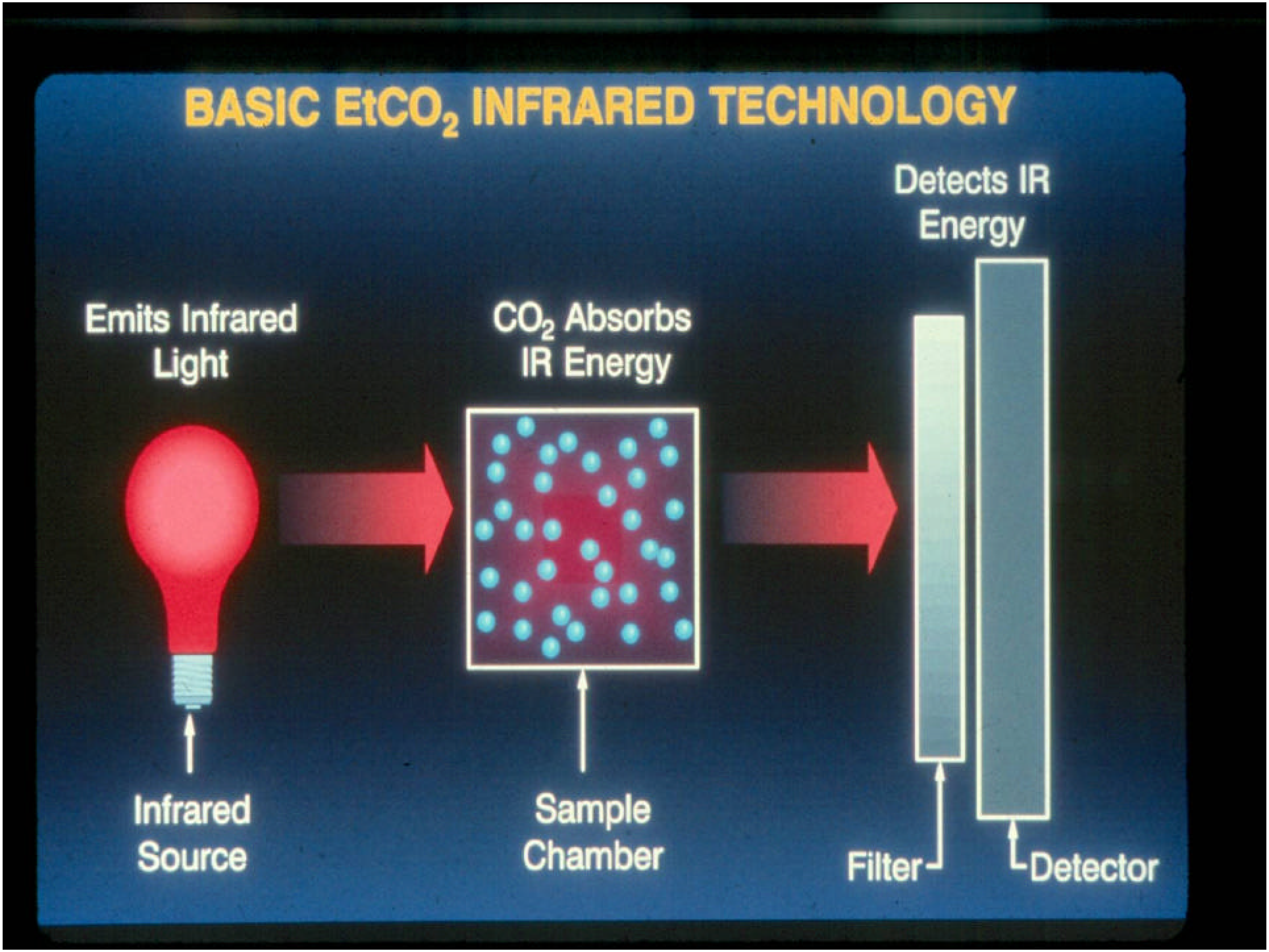
A New Art Form for the Field

Terminology

- Capnometry
  - Measurement of CO_2 in the airway during respiration
- Capnography
  - Graphic display of this measurement over time

Carbon dioxide measurement



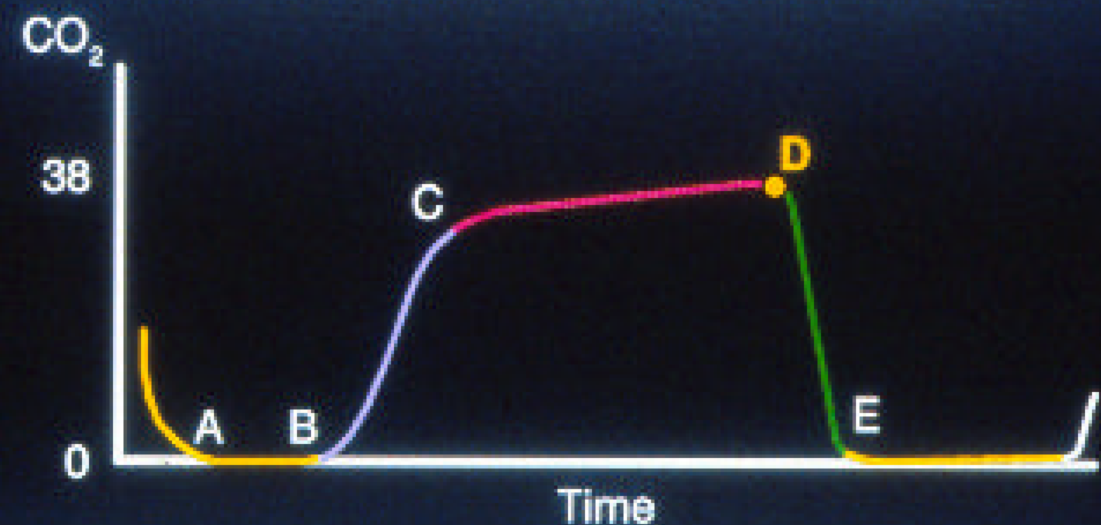

BASIC EtCO2 INFRARED TECHNOLOGY
Detects IR Energy
Emits Infrared Light
CO2 Absorbs IR Energy
Infrared Source
Sample Chamber
Filter
Detector

Methods for reporting $P_{et}CO_2$

- Partial pressure (mmHg)
- Percentage (%)

1% = 7.6 mmHg

Capnographic waveform



- Zero baseline (A-B)
- Rapid, sharp rise (B-C)
- Alveolar plateau (C-D)
- End tidal value (D)
- Rapid, sharp downstroke (D-E)

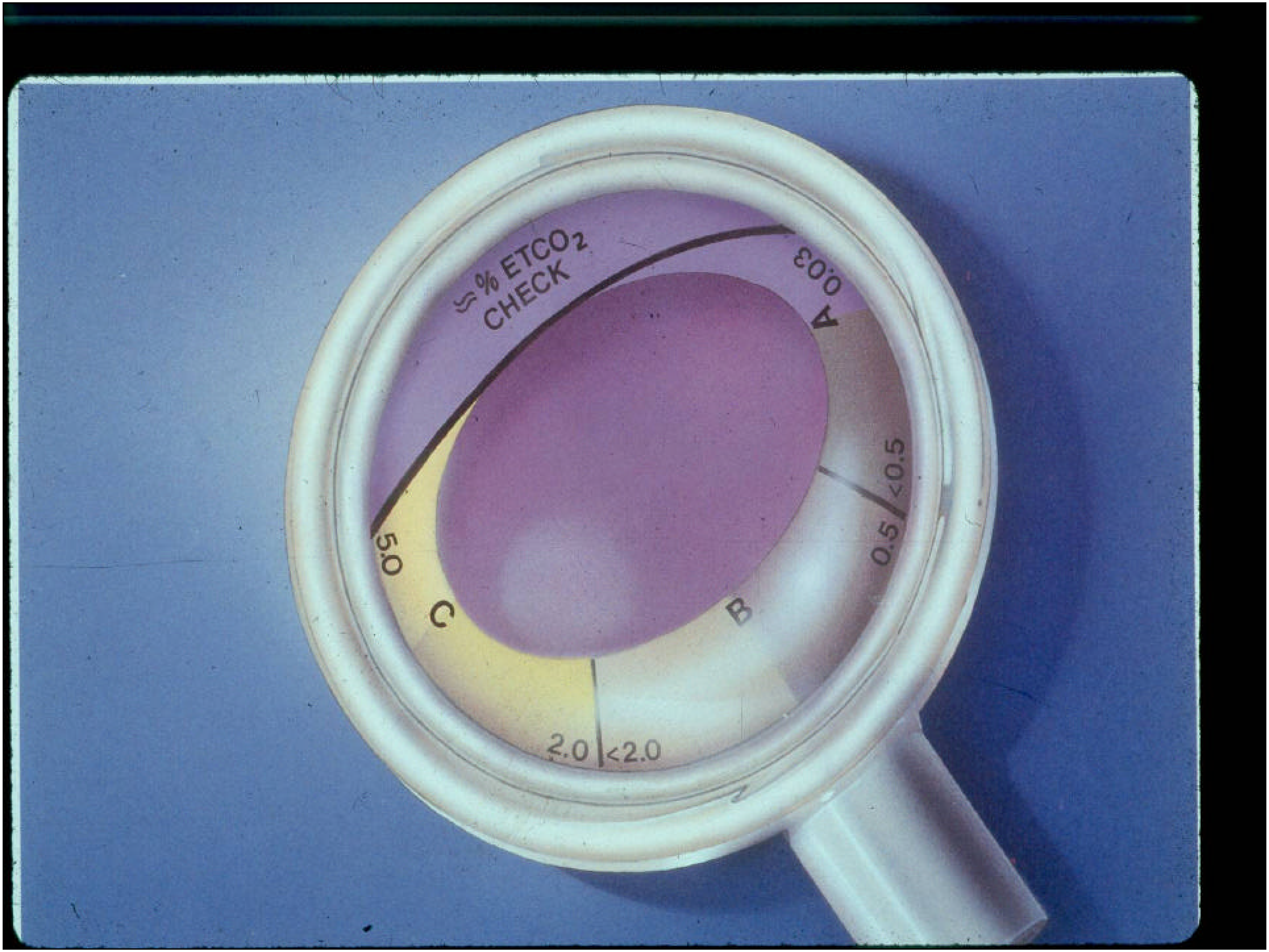
$P_{et}CO_2$ device types

- Sidestream
- Mainstream

Technology

Methods of CO2 dete

- Colorimetric
  - EZ-Cap
  - Capno-Flo
  - Spot Detection
- Non-CO_2 Specific
  - Broad Band
  - Side/Mainstream
- CO_2 Specific
  - Narrow Band
  - Microstream (both Side and Mainstream)


% ETCO2
CHECK
A
0.03
<0.5
0.5
B
<2.0
2.0
C
5.0

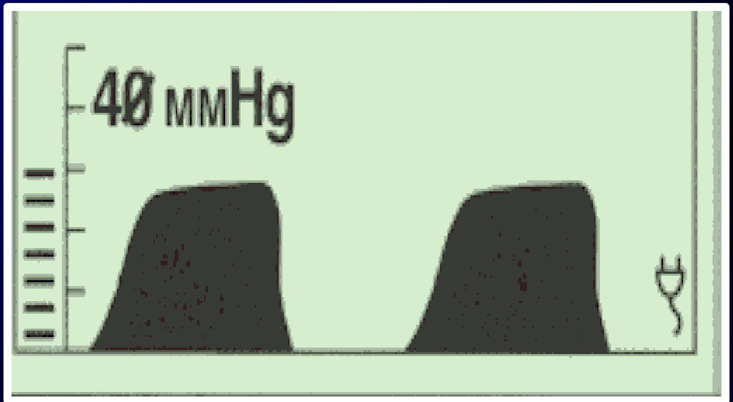
Colorimetric method

- A (purple) = < 4 mm Hg
- B (tan) = 4-15 mm Hg
- C (yellow) = > 15 mm Hg

Capnometer

- Capnometry: Provides only a numeric display of CO_2 concentration appearing at the patient's airway

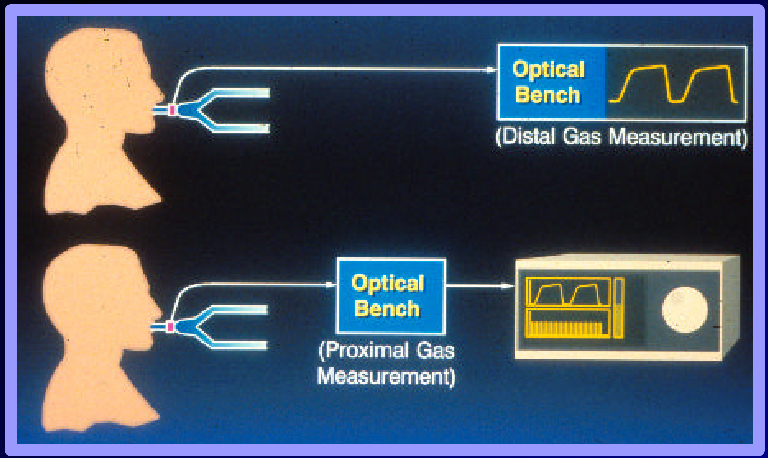
Capnogram



- Capnography: Provides graphic display of CO_2 concentration appearing at the patient's airway over time

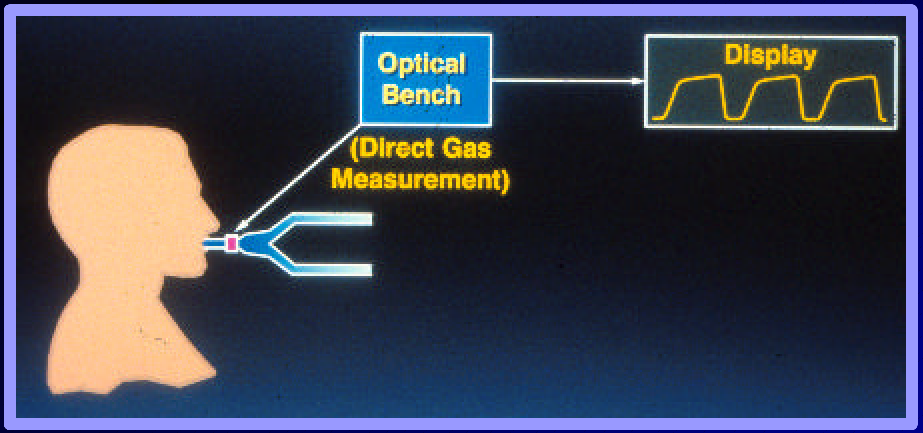
Sidestream analysis

- Aspirate gas from exhaled air column
- Lightweight port
- Easy to use on non-intubated patient
- Sample line easily plugged by secretions
- 2-3 sec delay
- Extraneous air leaks



Mainstream analysis

- Sensor part of airway
- Real-time measure
- No mixing of gases
- Sensor heated to prevent condensation
- Expense



Technology
Configuration

- Mainstream
  - Second generation
  - IR sensor is mounted to the patient's ETT
  - Limitations
    - Can only be used on intubated patients
    - Sensor adds weight to the end of ETT leading to kinked vent lines
    - Can be interfered with by condensation/moisture
    - Very expensive

Hand Held Technology

ET CO_2 is an easily
measurable reflection
of patients' $PaCO_2$,
and computerized measurement
of shape gives
significant evaluation of
bronchial obstruction.

Capnography provides a rapid
and reliable method
for detecting life-threatening conditions:

- malposition of tracheal tubes,
- unsuspected ventilatory failure
- circulatory failure
- defective breathing circuits
- to circumvent potentially
  irreversible patient injury

Capnography is an important non-invasive technique that provides information about CO_2 production, pulmonary perfusion and alveolar ventilation, respiratory patterns as well as elimination of CO_2 from the pulmonary circuit and/or ventilator.

Capnography has been shown to be effective in the early detection of adverse respiratory events

Application of capnography and pulse oximetry together could have helped in the prevention of 93% of avoidable anesthesia mishaps (ASA closed claim study)

Capnography facilitates better detection of potentially life-threatening problems than clinical judgment alone (Cote et al)

1983 - Murray and Modell

- *Anesthesiology*
- First study to show utility of capnography
- Dog model

1983 - Murray and Modell

- Tracheal extubation into esophagus
- Retropharyngeal dislodgment
- Incremental obstruction of ETT using Fogerty catheter

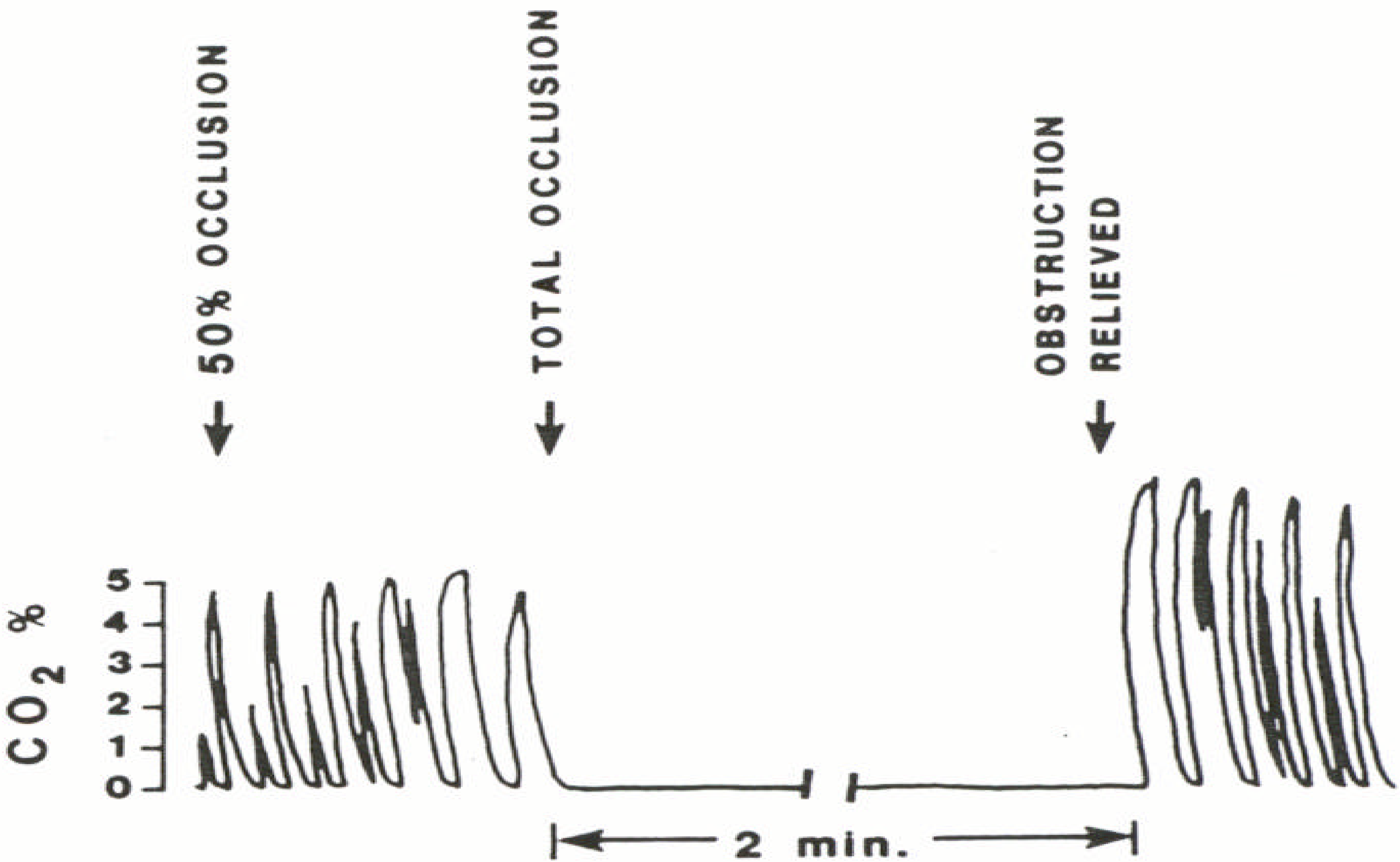


FIG. 3. Carbon dioxide tracing of tidal gas during a gradual decrease until total occlusion of the lumen of an endotracheal tube.

1986 - Birmingham et al

- Breath Sounds
  - “Normal” breath sounds present with esophageal ventilation
  - Review of 29 OR deaths due to esophageal intubation, 18/29 had documented breath sounds

1989 - Vaghadia et al

- *Can J Anesth*, Rat model
  - Comparison of $EtCO_2$, SpO_2 and clinical signs for detection of esophageal intubation
  - $EtCO_2$
    - 100% sensitivity and specificity
  - SpO_2
    - Poorer performance than most clinical signs
- $EtCO_2$ more reliable than SpO_2 and clinical signs

1987 - Garnett et al

- *JAMA*
  - Background: animal studies showed that $EtCO_2$ correlates with CO during and after CPR
  - First human study to demonstrate utility of $EtCO_2$ as a clinical indicator of ROSC
  - 23 patients, 10 ROSC
  - Computer-controlled CPR Thumper

1987 - Garnett et al

- Marked increase in $EtCO_2$ in patients with ROSC [1.7% (13) +/- 0.6 $\rightarrow$ 4.6% (34) +/- 1.4%]
- No difference in $EtCO_2$ of patients w/out ROSC (1.8% +/- 0.9) and $EtCO_2$ of patients before ROSC in those that had ROSC (1.7% +/- 0.6)

1988 - Falk et al

- *NEJM*
  - 10 ICU patients, 13 arrests, 7 ROSC
- Confirmed physiologic sequence
  - $EtCO_2$ decreased at onset of cardiac arrest
  - Increased during precordial compression
  - Markedly increased with ROSC
  - No change in $EtCO_2$ in patients without ROSC

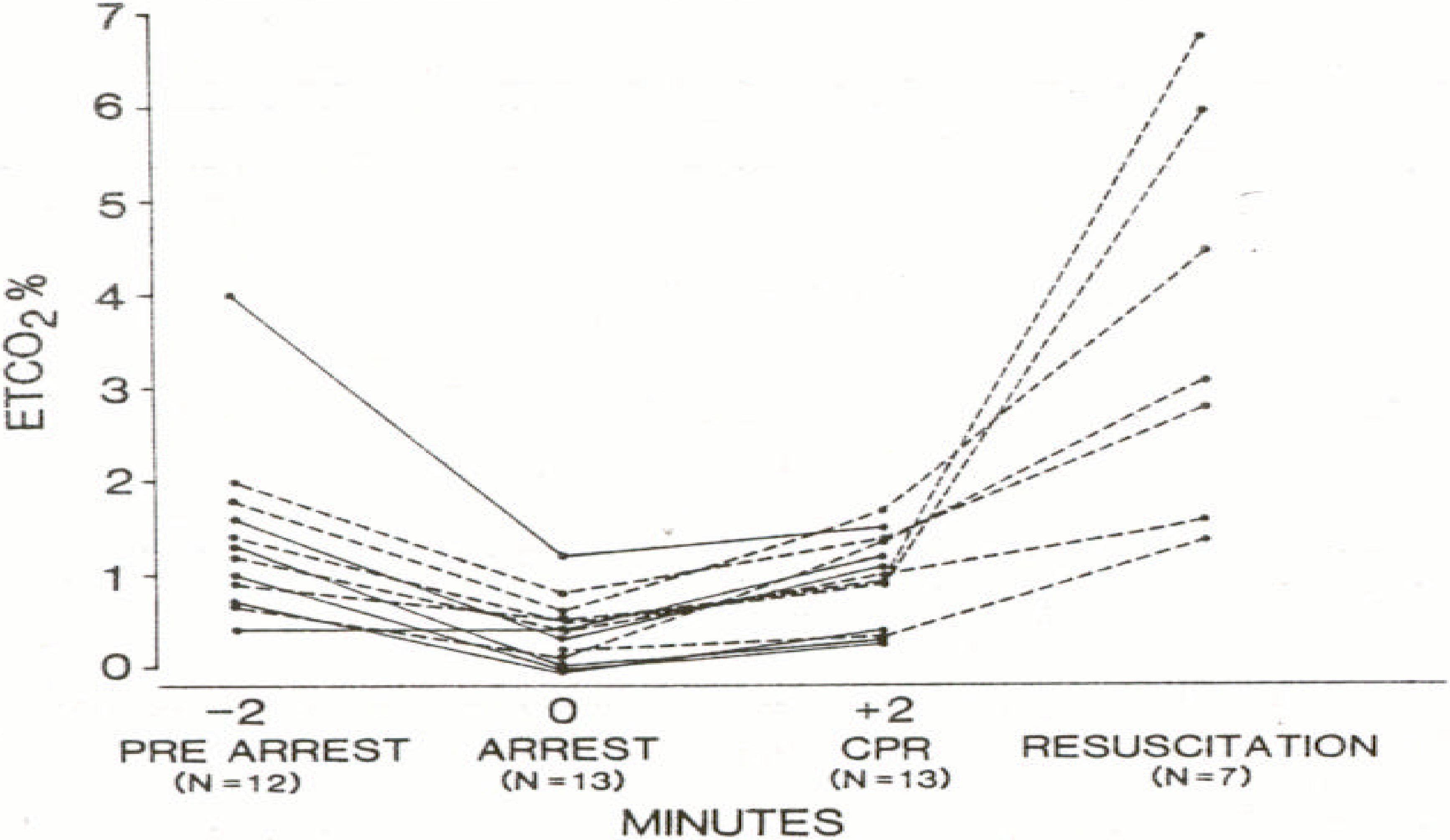


Figure 2. End-Tidal Carbon Dioxide Concentration ($ETCO_2$) before Cardiac Arrest, at the Onset of Arrest but before Precordial Compression, Two Minutes after the Start of CPR and Immediately after Successful Resuscitation in 10 Patients on 13 Occasions. Solid lines represent nonresuscitated patients, and broken lines resuscitated patients.

1989 - Sanders et al

- *JAMA*
  - Established threshold for survival ($EtCO_2$ >10 mm Hg)
  - 34 patients in cardiac arrest, 9 ROSC
  - Patients with ROSC had higher $EtCO_2$ (15 vs 7)
  - All patients with ROSC were above the threshold
  - All non-resuscitated patients were below the threshold

1995/1997 - Levine et al

- *Annals 1995, NEJM 1997*
  - $EtCO_2$ as predictor of death rather than survival
  - Wayne et al, 1995 *Annals* → 94 patients
  - 150 EMS patients, 35 ROSC
  - $EtCO_2$ below the threshold (<10 mm Hg) predicted death in 100% of cases

TABLE 1. END-TIDAL CARBON DIOXIDE VALUES IN PATIENTS WHO SURVIVED TO HOSPITAL ADMISSION AND IN THOSE WHO DID NOT.

VARIABLE	NONSURVIVORS (N=115)	SURVIVORS (N=35)	P VALUE*
	mean ±SD (range)		
Age (yr)	68.0±13.8 (31–95)	71.5±13.0 (27–90)	0.19
End-tidal carbon dioxide (mm Hg)†			
Initial	12.3±6.9 (2–50)	12.2±4.6 (5–22)	0.93
Final	4.4±2.9 (0–10)	32.8±7.4 (18–58)	<0.001

*P values were calculated with the Wilcoxon rank–sum statistic.

†Initial end-tidal carbon dioxide levels were determined immediately upon intubation. Final end-tidal carbon dioxide levels were determined after 20 minutes of advanced cardiac life support.

Roberts et al reported in 1995:

Mean time to detection of esophageal intubation

Clinical signs = 97 seconds (+/- 93)

Capnography = 1.6 seconds (+/- 2)

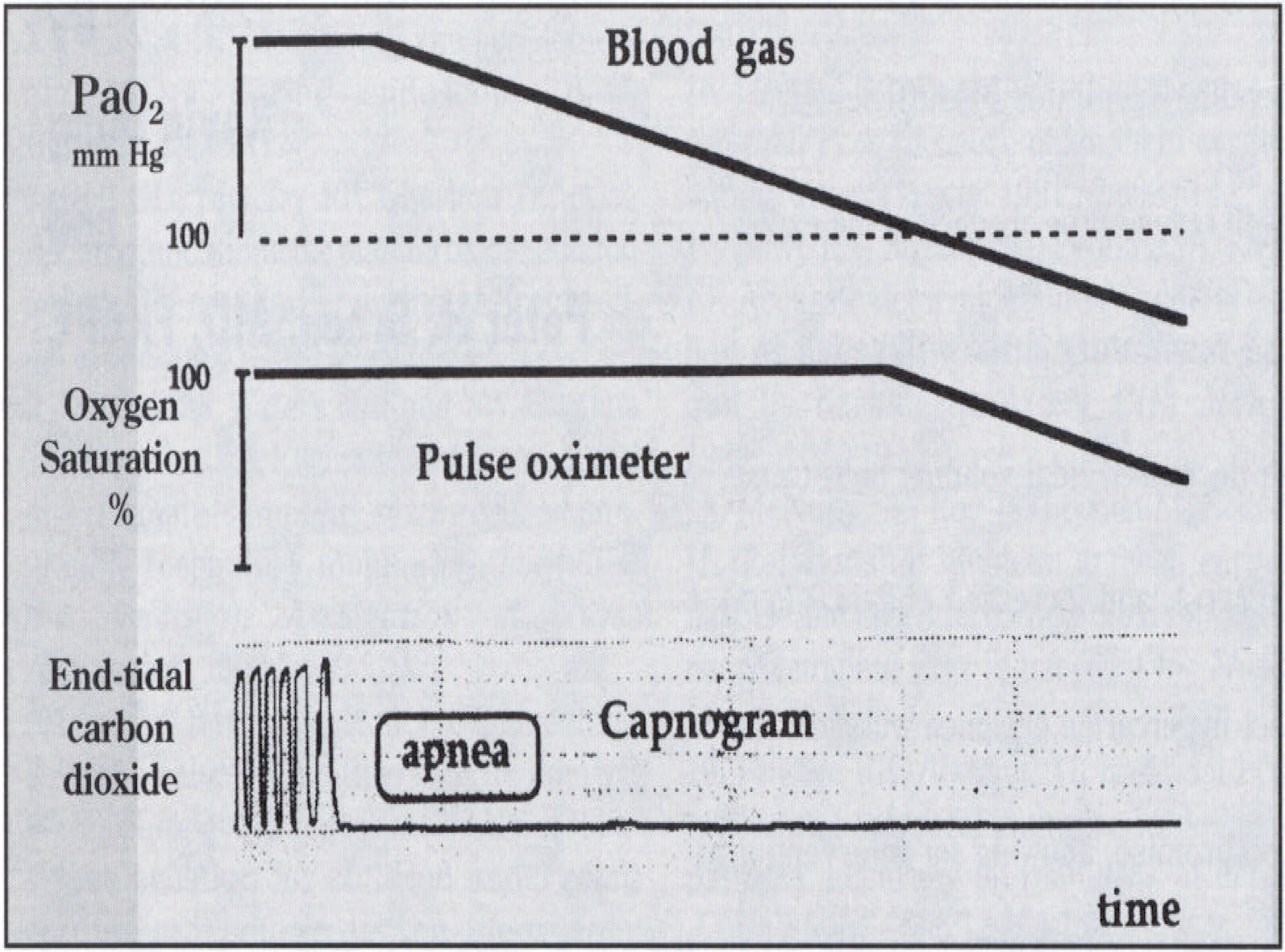
Poirier et al in 1998 found:

"Continuous end-tidal capnography detects acute airway obstruction and hypopharyngeal extubation more rapidly than does pulse oximetry or vital sign monitoring…"

Porcine model

Poirier et al in 1998 also found:

"… *capnography detects total occlusion of the airway rapidly, LONG BEFORE hypoxia or hemodynamic instability occurs*."



Blood gas
PaO2
mm Hg
100
100
Oxygen
Saturation
%
Pulse oximeter
End-tidal
carbon
dioxide
apnea
Capnogram
time

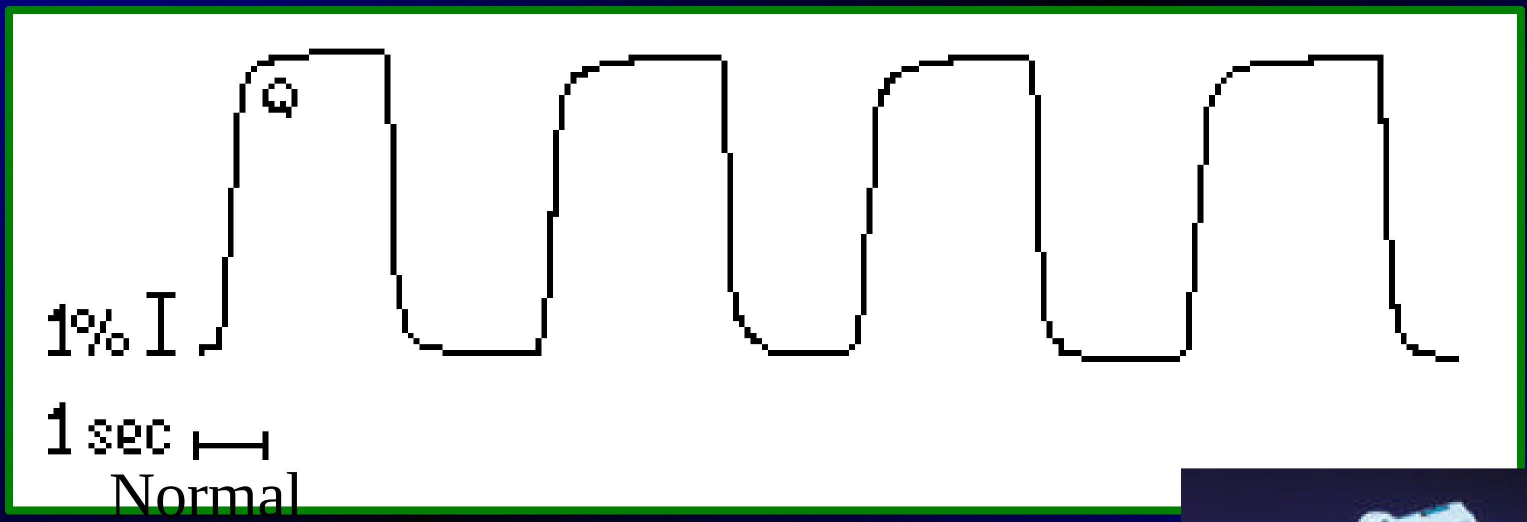
ACEP Policy on Expired CO_2 Monitoring

- *Approved 1994 - Reaffirmed 1998*
- "Carbon dioxide monitoring of tracheal intubation placement is desirable, but should not be mandated at this time for all emergency patients. "

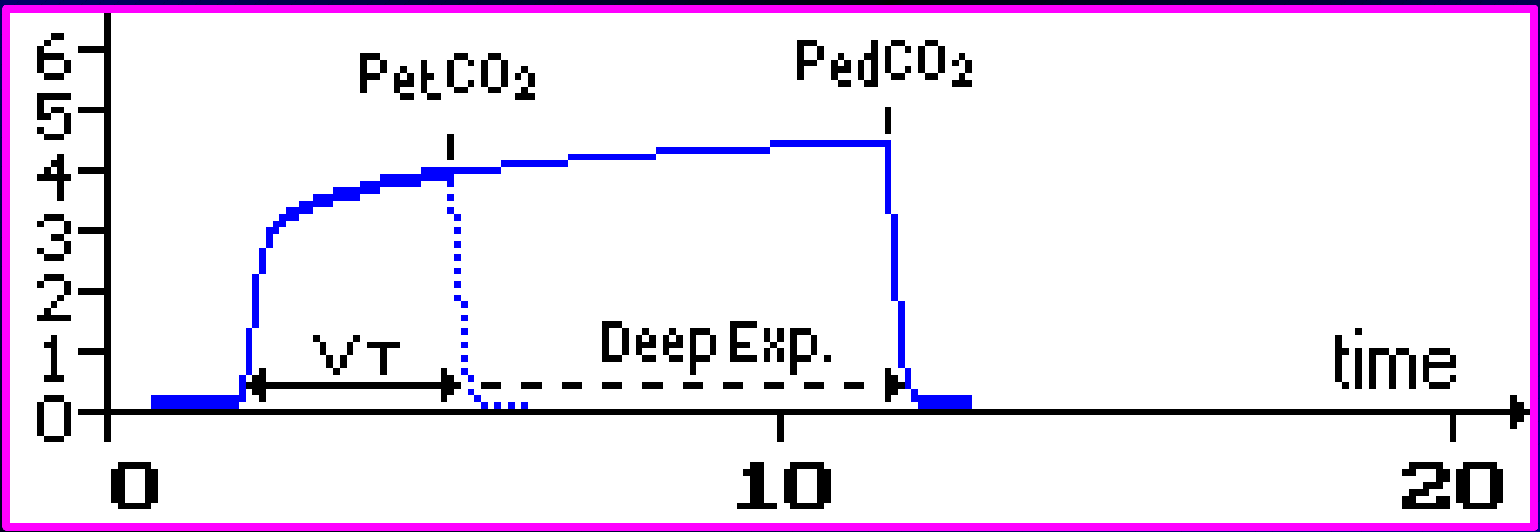
ACEP Policy on Expired CO_2 Monitoring

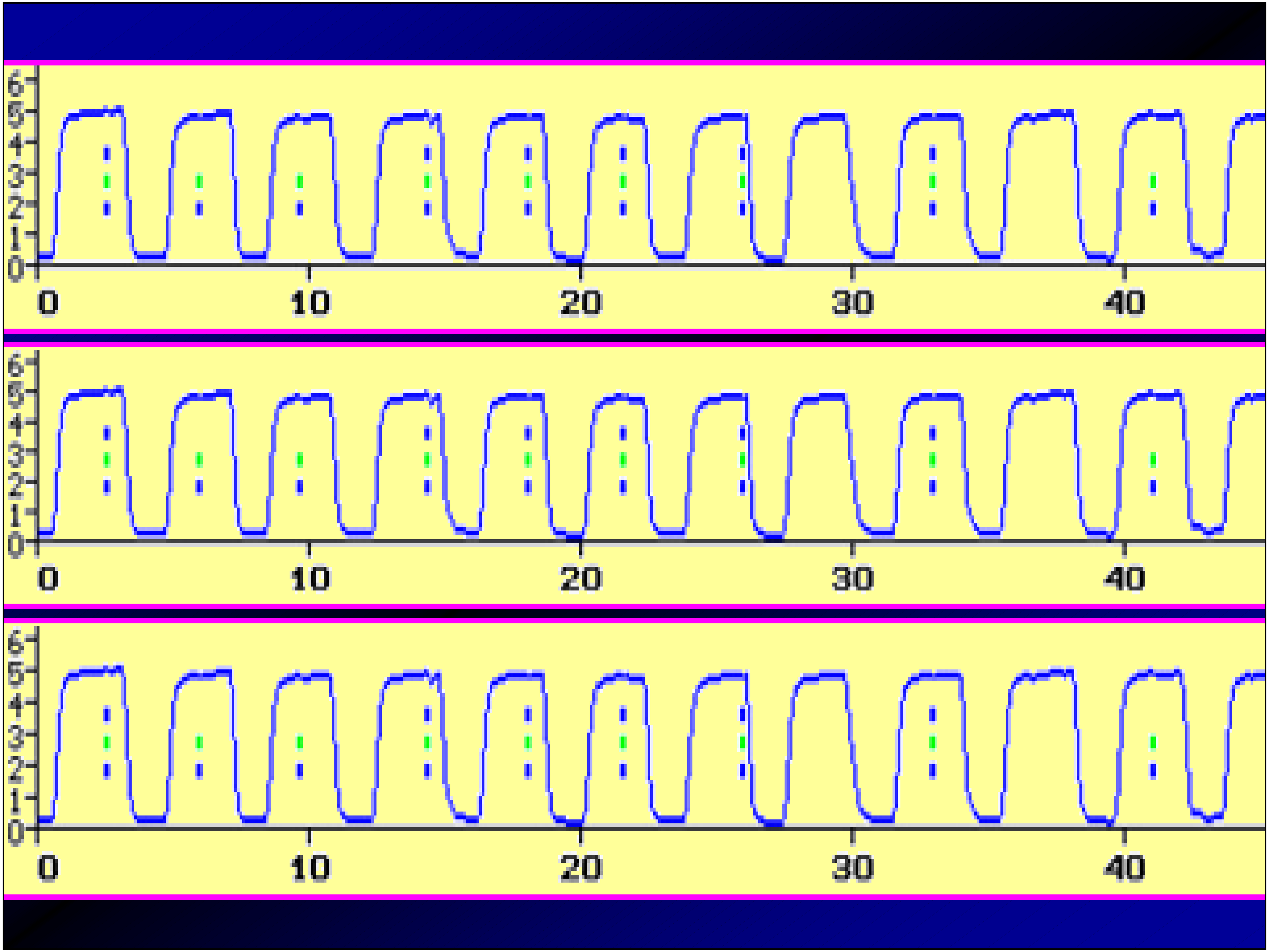
- “Carbon dioxide levels may be falsely low despite correct tracheal placement of the endotracheal tube in cardiac arrests, severe shock, and other clinical conditions with low cardiac outputs and inadequate tissue perfusion.”

Normal Capnogram

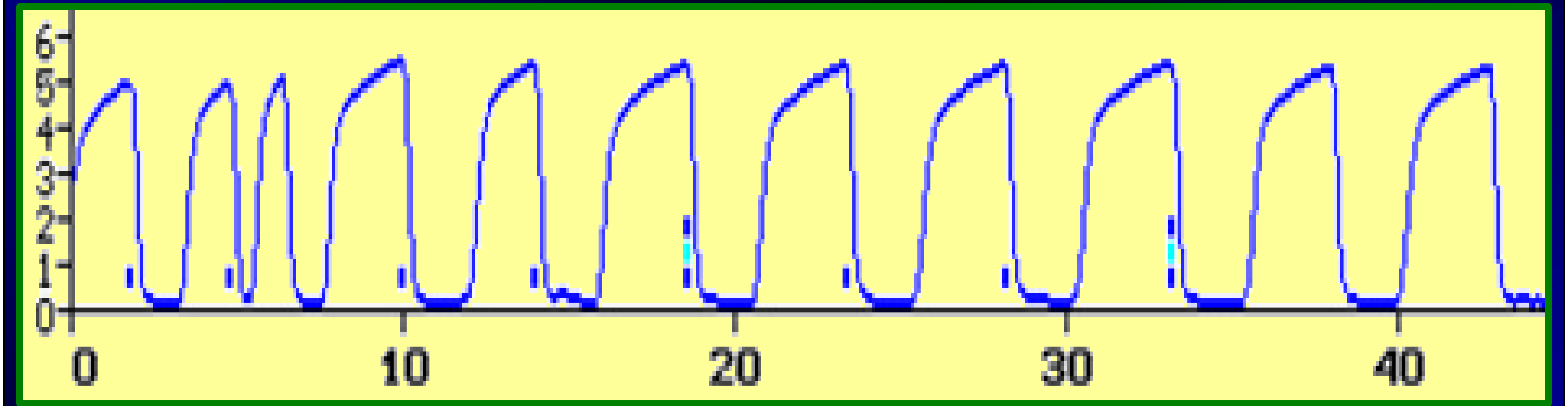


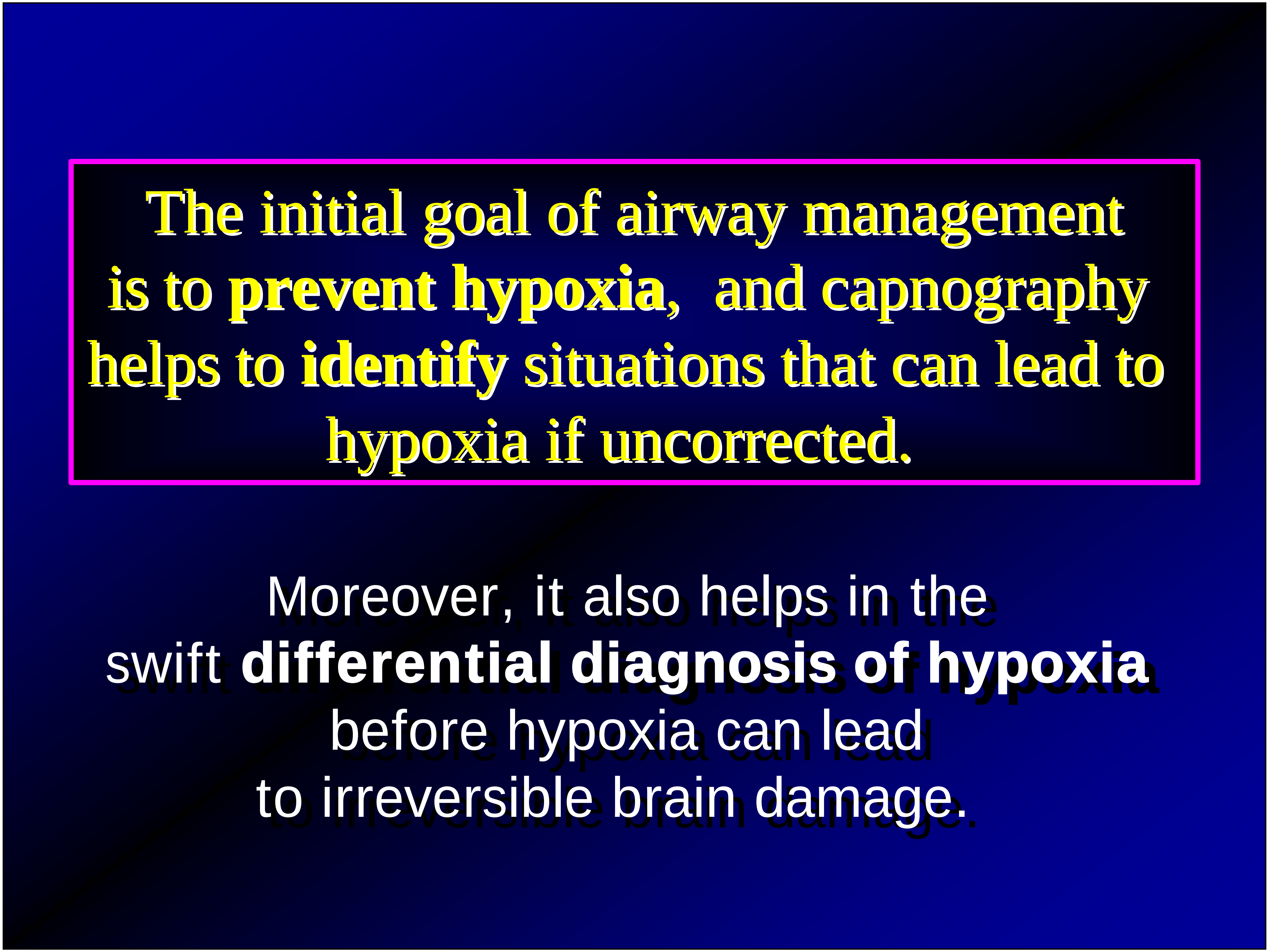
Prolonged Exhalation Capnogram




0 1 2 3 4 5 6
0 10 20 30 40
0 1 2 3 4 5 6
0 10 20 30 40
0 1 2 3 4 5 6
0 10 20 30 40

Marked bronchospasm

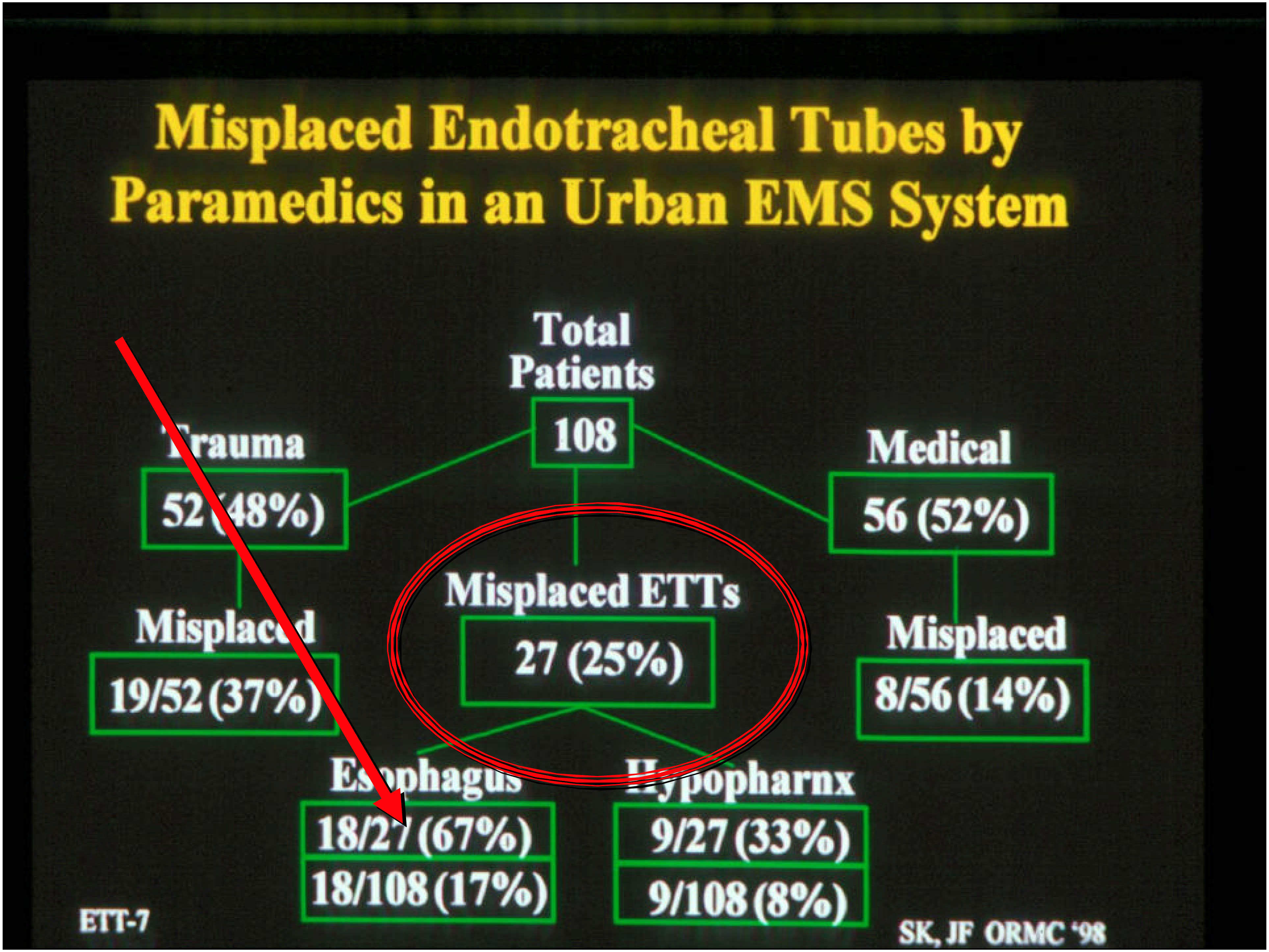



The initial goal of airway management is to prevent hypoxia, and capnography helps to identify situations that can lead to hypoxia if uncorrected.
Moreover, it also helps in the swift differential diagnosis of hypoxia before hypoxia can lead to irreversible brain damage.

Misplaced Endotracheal Tubes by Paramedics in an Urban EMS System

Steven H. Katz, M.D.
Jay L. Falk, M.D., FACEP, FCCM
Marybeth Wash, R.N.

Department of Emergency Medicine
Orlando Regional Medical Center
Orlando, FL

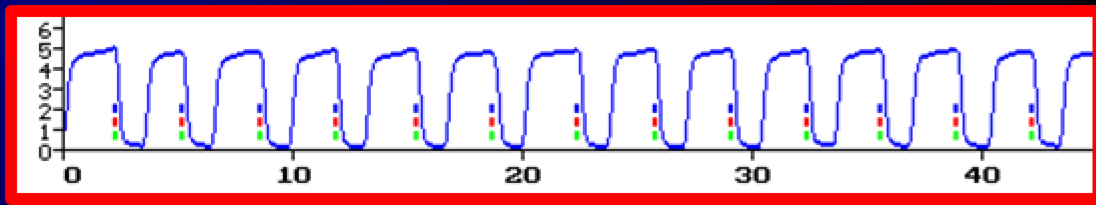

Misplaced Endotracheal Tubes by Paramedics in an Urban EMS System
Total Patients
108
Trauma
52 (48%)
Medical
56 (52%)
Misplaced
19/52 (37%)
Misplaced ETTs
27 (25%)
Misplaced
8/56 (14%)
Esophagus
18/27 (67%)
18/108 (17%)
Hypopharnx
9/27 (33%)
9/108 (8%)
ETT-7
SK, JF ORMC '98

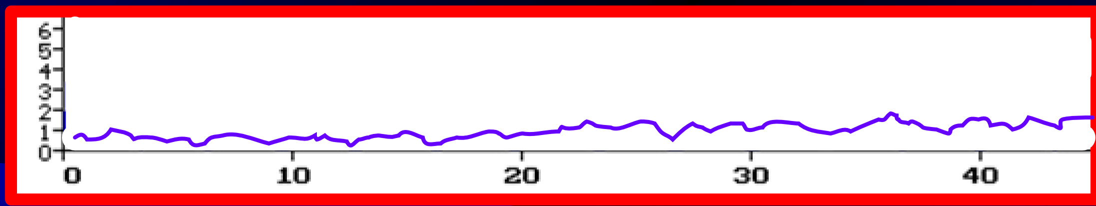
Misplaced Endotracheal Tubes by Paramedics in an Urban EMS System

CONCLUSION

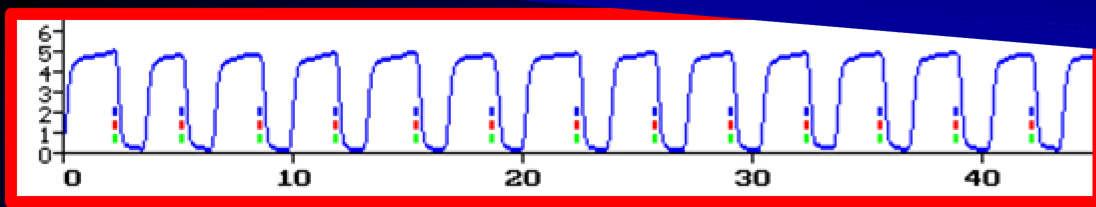
- Alarming rate of unrecognized, misplaced ETTs in the field
  - * misplaced
  - * dislodged
  - * role of confirmatory devices
- Unique to Orange County, Florida?
- Under reported national problem?

What Happened in Block 2?





The endotracheal tube became dislodged!



Quick Review of Causes of an Elevated $EtCO_2$

- Increased Metabolism
  - Pain
  - Hyperthermia
  - Malignant hyperthermia
  - Shivering
- Circulatory System
  - Increased cardiac output - with constant ventilation
- Respiratory System
  - Respiratory insufficiency
  - Respiratory depression
  - Obstructive lung disease
- Equipment
  - Defective exhalation valve
  - Exhausted CO_2 absorber

Quick Review of Causes of a Decreased $EtCO_2$

- Decreased Metabolism
  - Analgesia / sedation
  - Hypothermia
- Circulatory System
  - Cardiac arrest
  - Embolism
  - Sudden hypovolemia or hypotension
- Respiratory System
  - Alveolar hyperventilation
  - Bronchospasm
  - Mucus plugging
- Equipment
  - Leak in airway system
  - Partial airway obstruction
  - ETT in hypopharynx

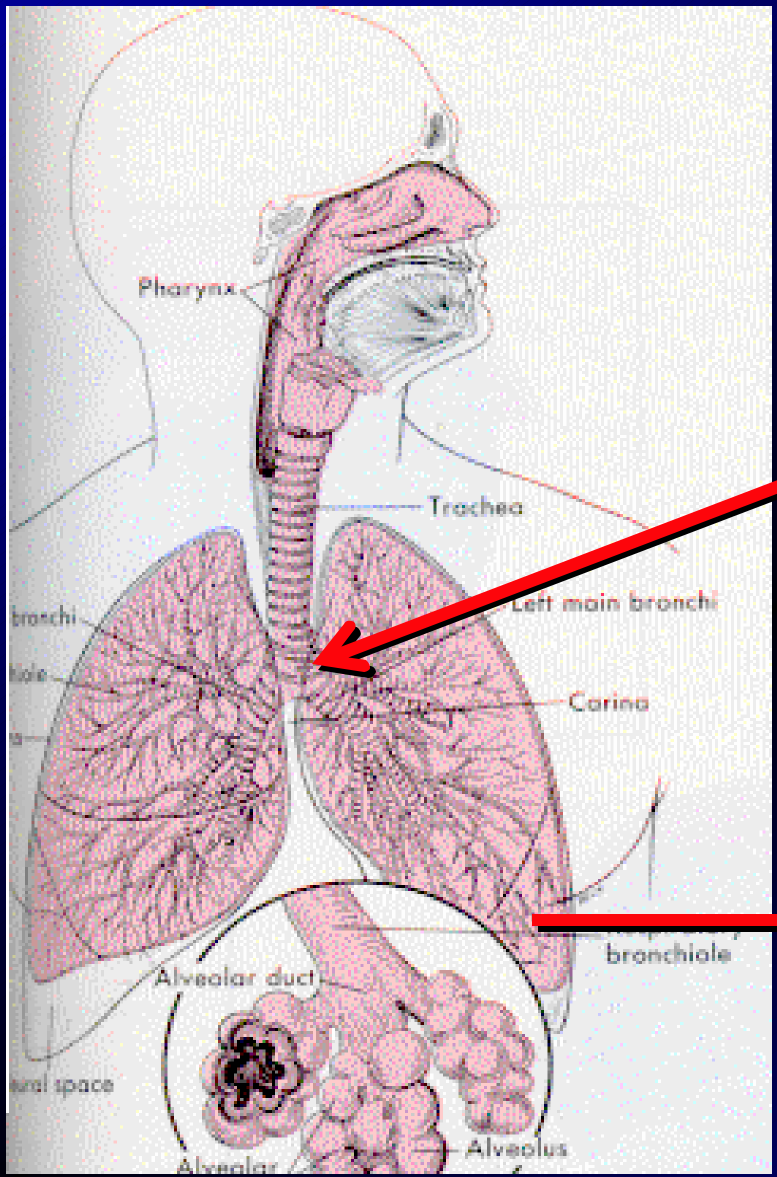
Waveforms

Waveforms are a window into your patient

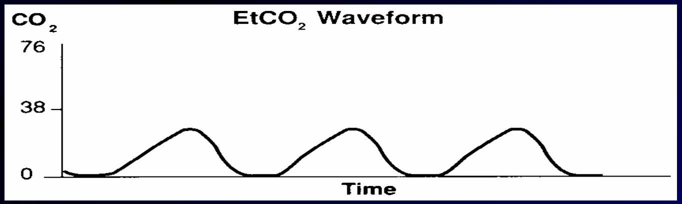
- Square vs. humped in appearance
- Waveform shape compared to numeric value (capnometer)
- Waveform shape, numeric value, compared to the patient’s clinical condition

Interpreting the waveform

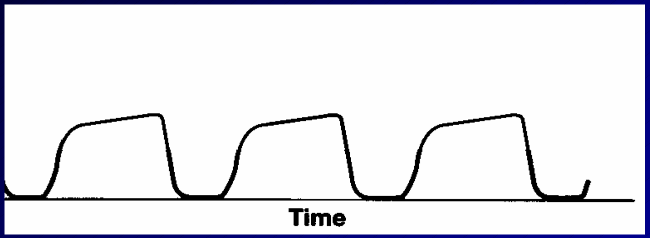
- Evaluate with a systematic approach
  - height
  - contour
  - baseline
  - frequency
  - rhythm



Pharynx
Trachea
Left main bronchi
Carina
bronchiole
Alveolar duct
Alveolus

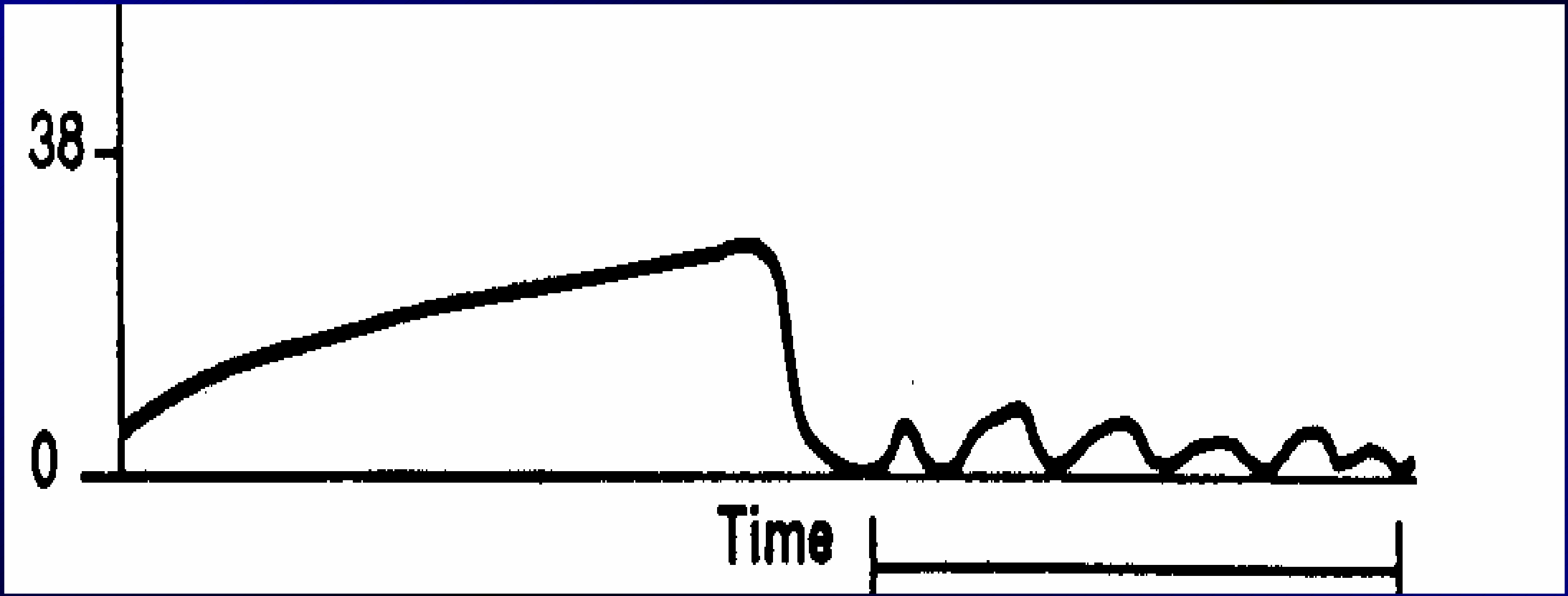


CO2
EtCO2 Waveform
76
38
0
Time



Time

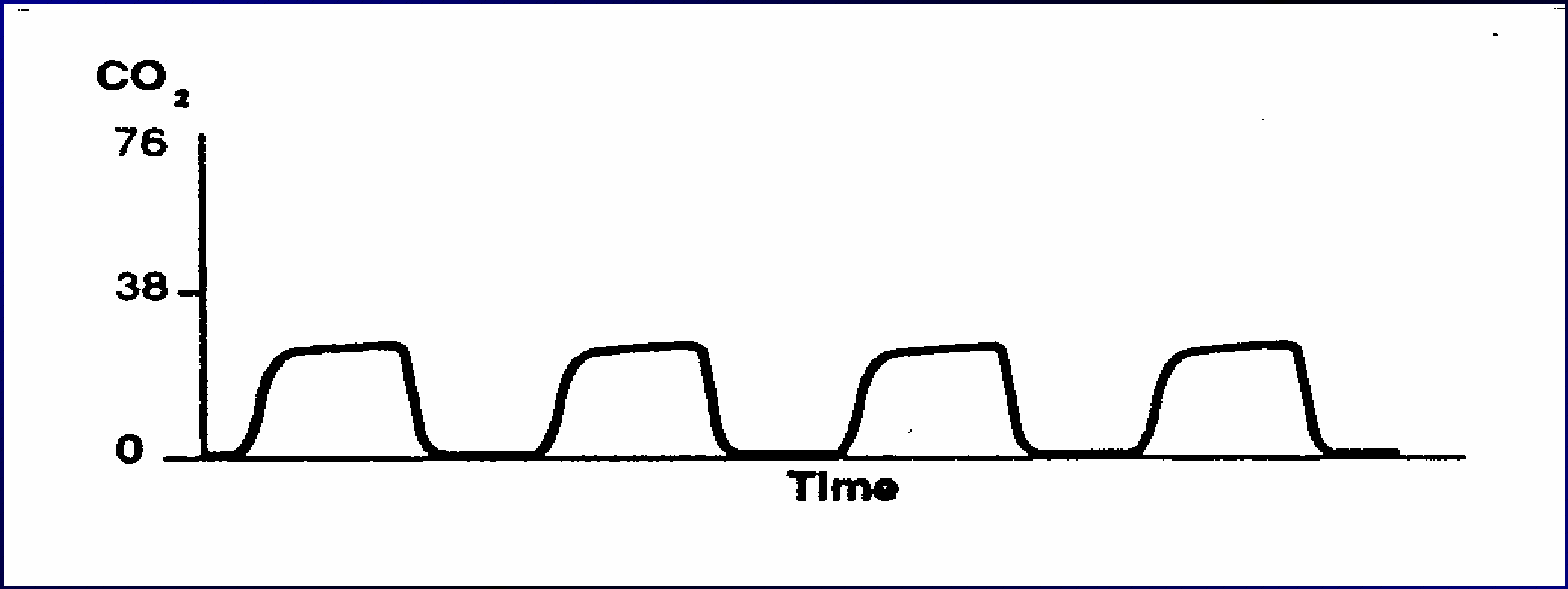
Abnormal Waveforms



Sudden Loss of $ETCO_2$ –

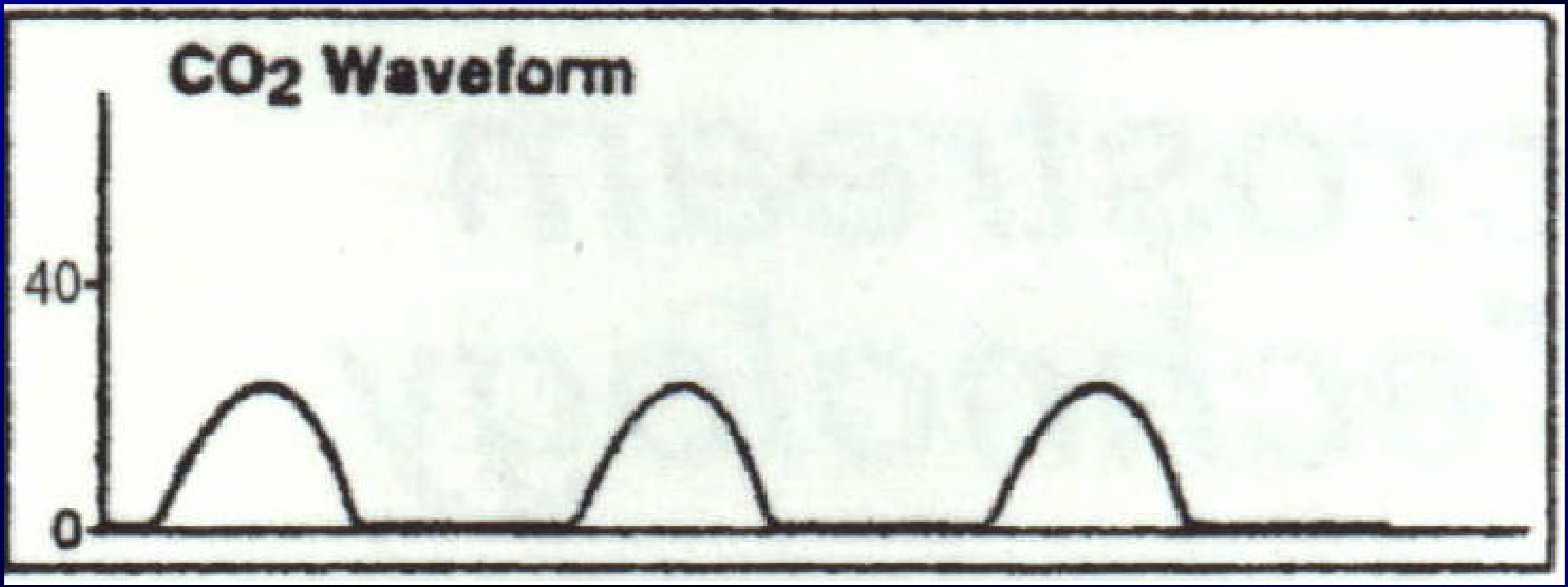
Cardiac arrest or tube out

Abnormal Waveforms



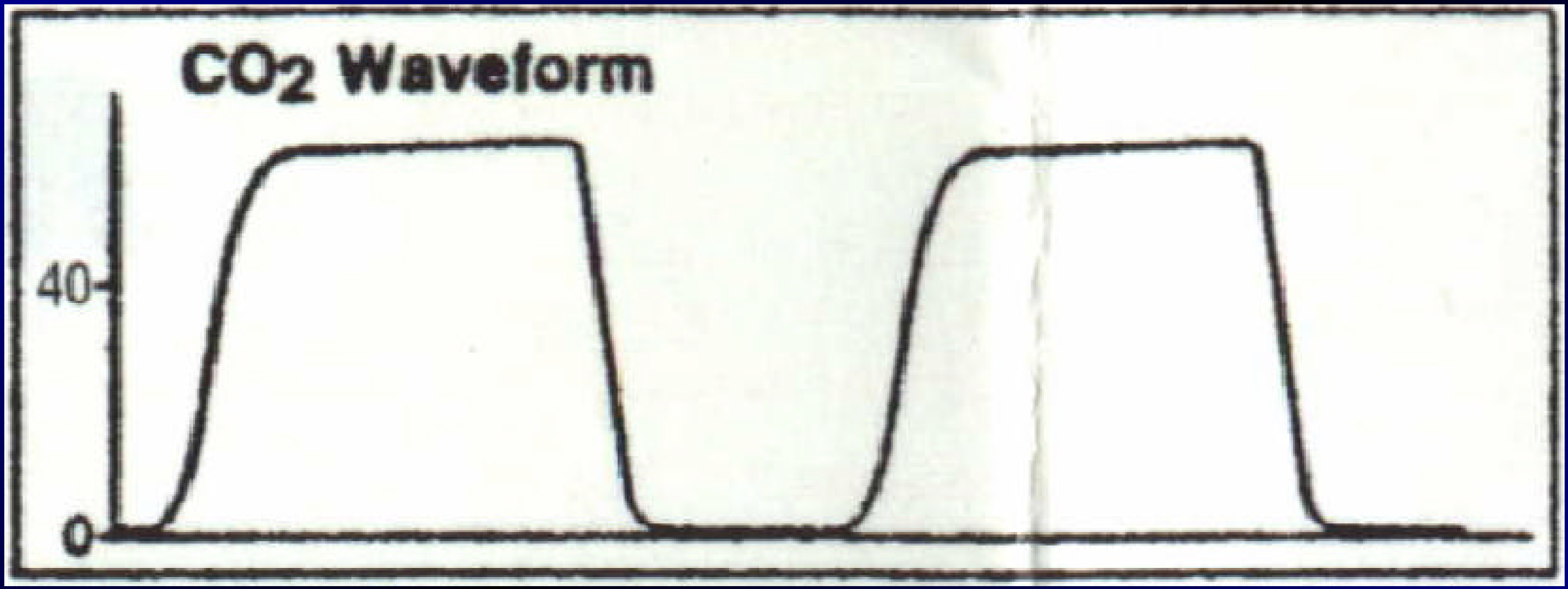
Sustained Low $ETCO_2$ With Good Plateau – Consider circulatory shock

Abnormal Waveforms



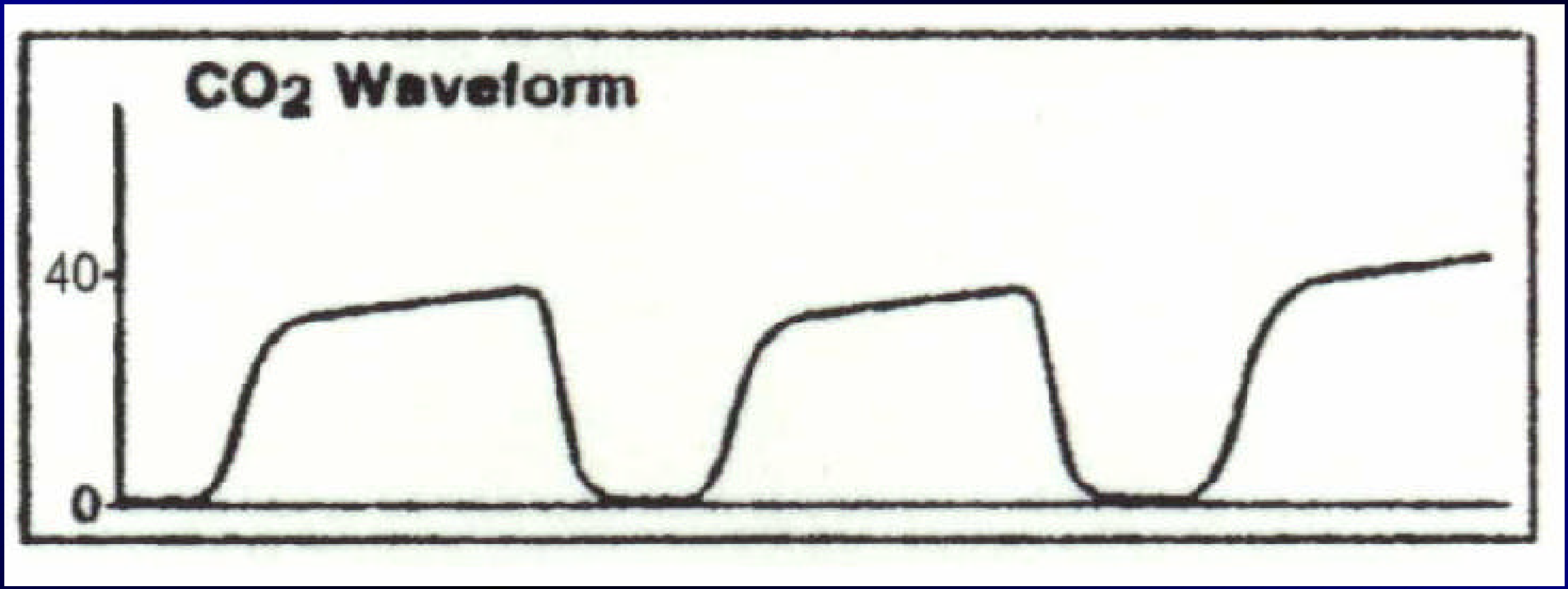
Sustained Low $ETCO_2$ With Poor Plateau – Worsening perfusion

Abnormal Waveforms



Sustained High $ETCO_2$ With Good Plateau – Increased CO_2 production

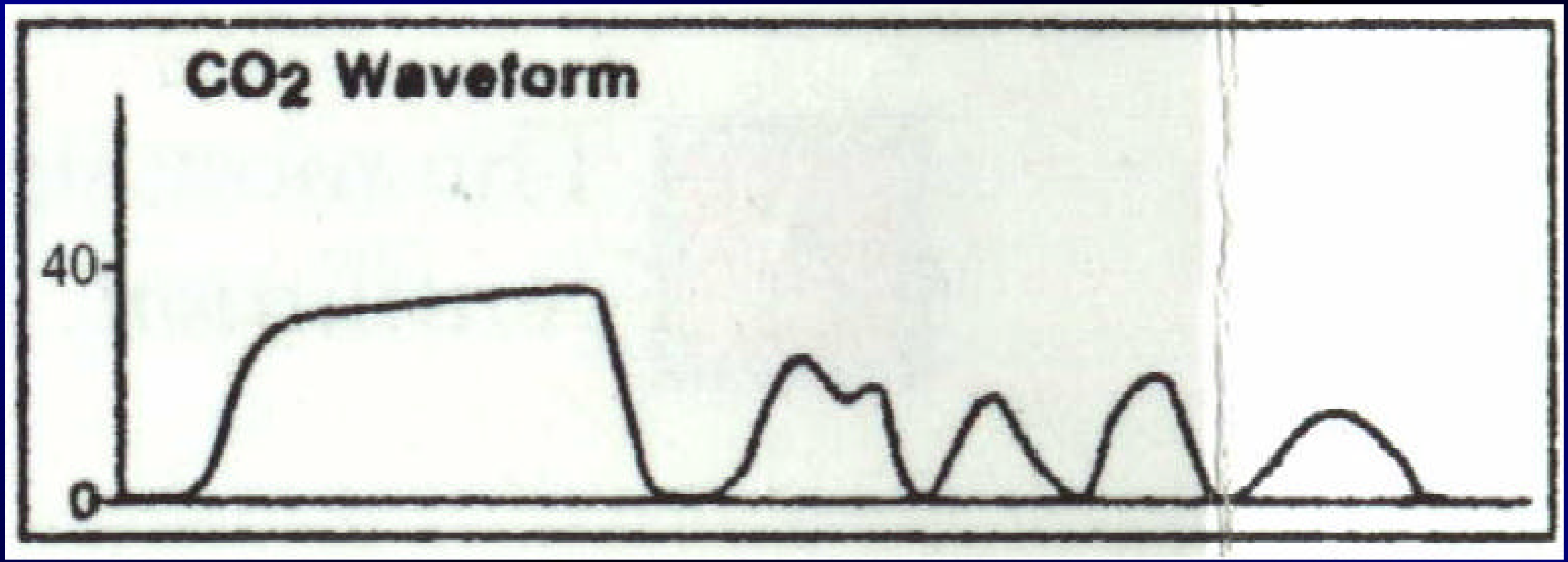
Abnormal Waveforms



Sudden Transient Rise in $ETCO_2$ –

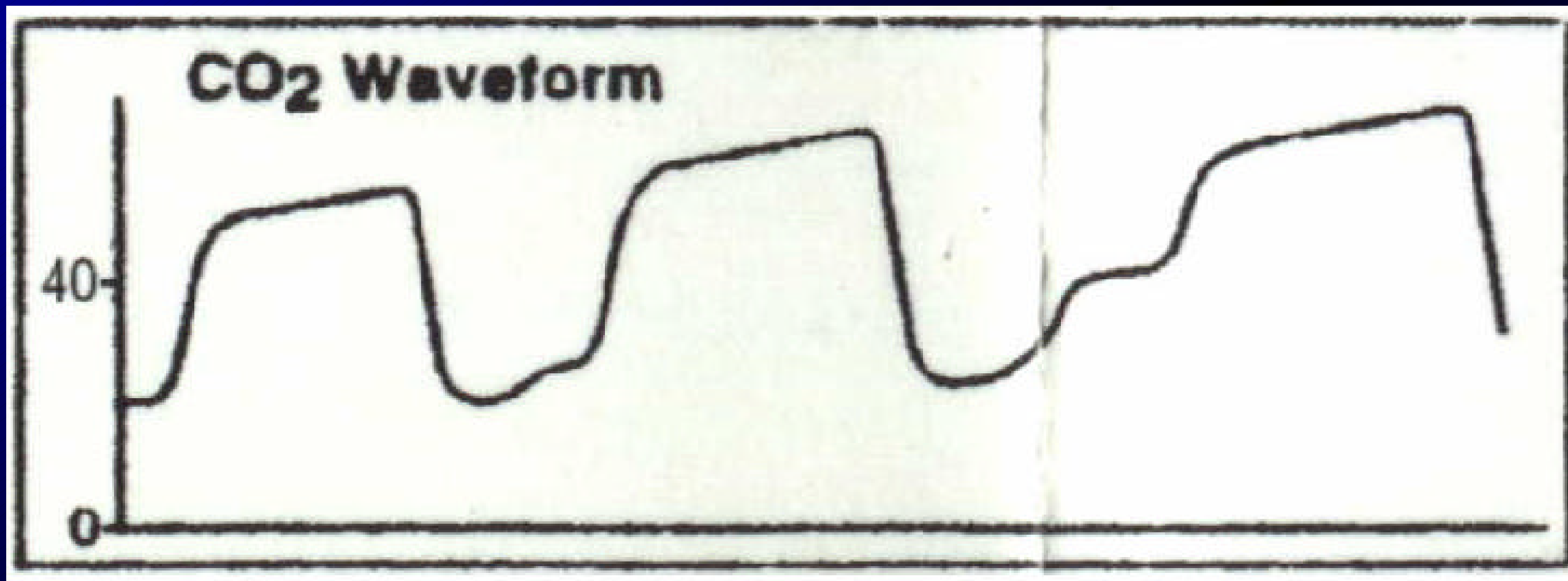
Consider sedation, other causes of increased CO2 production, worse COPD

Abnormal Waveforms



Sudden Loss of $ETCO_2$ to Zero or Near Zero –
Consider respiratory circuit failure or sudden shock state

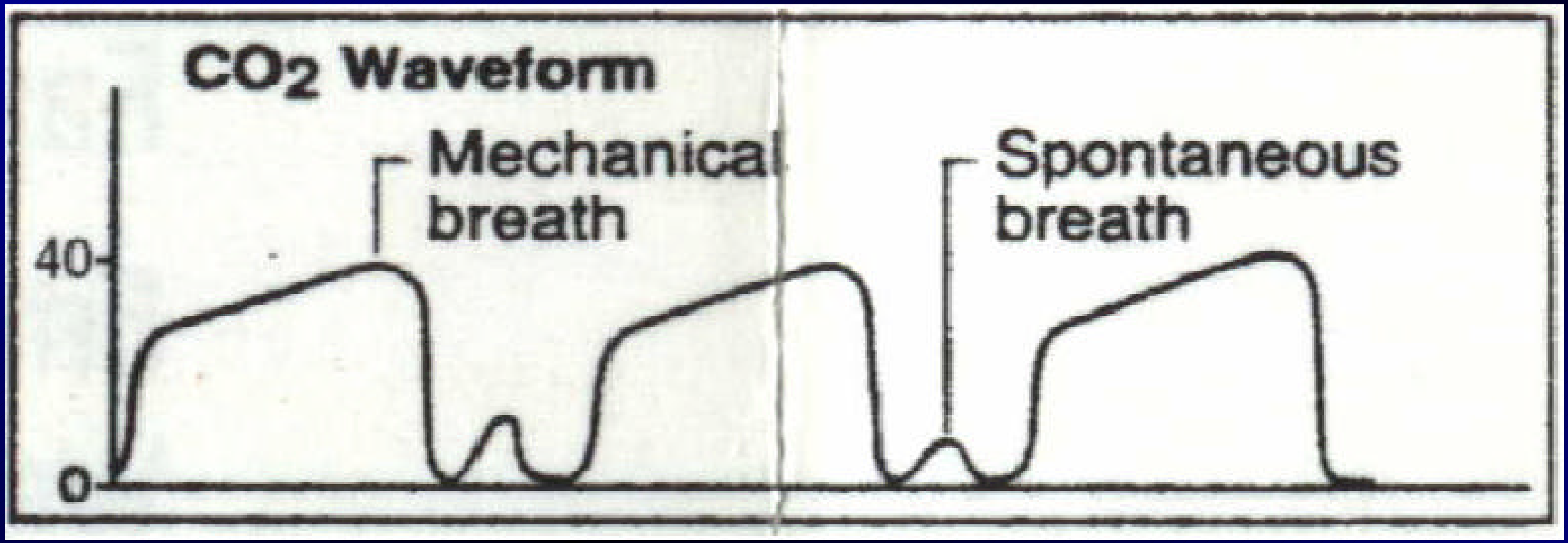
Abnormal Waveforms



Rise in Baseline and $ETCO_2$

Consider problems with the respiratory circuit, such as insufficient exhalation time

Abnormal Waveforms



Spontaneous breathing during mechanical ventilation

Critical Care Ventilation

Perform a Primary Survey

Determine Ventilation Status

What is the patient's ventilatory status

LOC
Airway
Resp Rate
Pulse
Color
Pulse Ox
ET CO_2

Tidal Volume

Choose the Route for Ventilation

Mouth to Mask
BVM
ET
NT
Surgical Airway

Compute Tidal Volume

Based on Need for Oxygen:

10-15 cc/kg
Big squeeze big folks, full bag

Little squeeze little folks
(1/3 bag for 12 y/o)

Tidal Volume

On the low side if using BVM

On the low side if tension pneumo

10-15 cc/kg

Big squeeze big folks
Little squeeze little folks

Compute Respiratory Rate

Based on Need to remove CO_2

Respiratory Rate

- Trauma Arrest = 6-8/min
- Cardiac Arrest = 8-10/min
- Altered LOC with unilateral blown pupil no circ comp = 15/min
- Head-injured trauma with circulatory compromise = 8-10/min
- Asthma = 8-10/min
- Hypovolemia = 8-10/min
- COPD = 8-10/min

Capnography

- If shock state and the reading is below 30, slow down the respiratory rate
- If cardiac arrest and the reading is below 30, slow down the respiratory rate
- If CO_2 continues to fall, keep rate low and try to keep airway pressures low
- Continued falling of CO_2 is a grim sign

NAEMSP recommends adoption of the following:

1. No single technique is 100% reliable under all circumstances.
2. EMS providers should receive training to use specific methods for the verification of endotracheal tube placement in conjunction with advanced airway training.
3. Each EMS system should implement endotracheal tube placement verification protocols and use ongoing performance improvement to assure compliance.
4. Clinical observation, as a sole means of verifying endotracheal tube placement, is not uniformly reliable. EMS services perform endotracheal intubation should be issued equipment for confirming proper tube placement.
5. In the patient with a perfusing rhythm, end-tidal CO2 detection is the best method for verification. In the absence of a perfusing rhythm, capnography may be extremely helpful, and may be superior to colorimetric methods.
6. The esophageal detector device may be unreliable in certain clinical setting and should be used as an adjunct to other confirmatory methods.
7. Tube verification should be performed by the EMT based upon accepted standards of practice while taking into account whether or not the patient has a perfusing rhythm. Verification methods should include a combination of clinical signs and the use of adjunctive devices such as the presence of exhaled carbon dioxide and esophageal detection devices.
8. Once placement has been confirmed, the endotracheal tube should be secured.
9. Confirmation of tube placement is a dynamic process requiring ongoing patient assessment.
10. Reconfirmation should be performed any time the patient is moved, or if tube dislodgment is suspected.

Carrollton Fire Department

Endotracheal Tube
Placement Check-Off

This form will be completed when an oral or nasal endotracheal tube is inserted. The checklist includes the different ways that the paramedic has to confirm ET placement is correct in the trachea. It is our goal to meet all of the following criteria:

- ❑ Visualized the ET tube pass through the vocal cords (if oral intubation); noting cords above and below the ET tube.*****
- ❑ Noted ET tube depth marking _______cm at front teeth (in oral intubation).*****
- ❑ Absence of epigastric sounds upon delivery of first ventilation.
- ❑ Ausculated bilateral breath sounds (below clavicles first).
- ❑ Visualized equal rise and fall of the chest wall.
- ❑ Visualized tidal condensation in the ET tube.
- ❑ Bulb aspirated syringe (Tube Check), showed free flow of air.
- ❑ Taped/secured ET tube in place, ensuring same depth of original front teeth marking.*****
- ❑ Capnography reading was appropriate for tracheal placement (rise and fall after 5 breaths).
- ❑ Applied a cervical collar on the patient to minimize movement of the ET tube.
- ❑ Pulse oximeter showed good saturation (>95% on 100% oxygen) in patients with full circulation.

*** Alternatives for Nasotracheal Intubation**

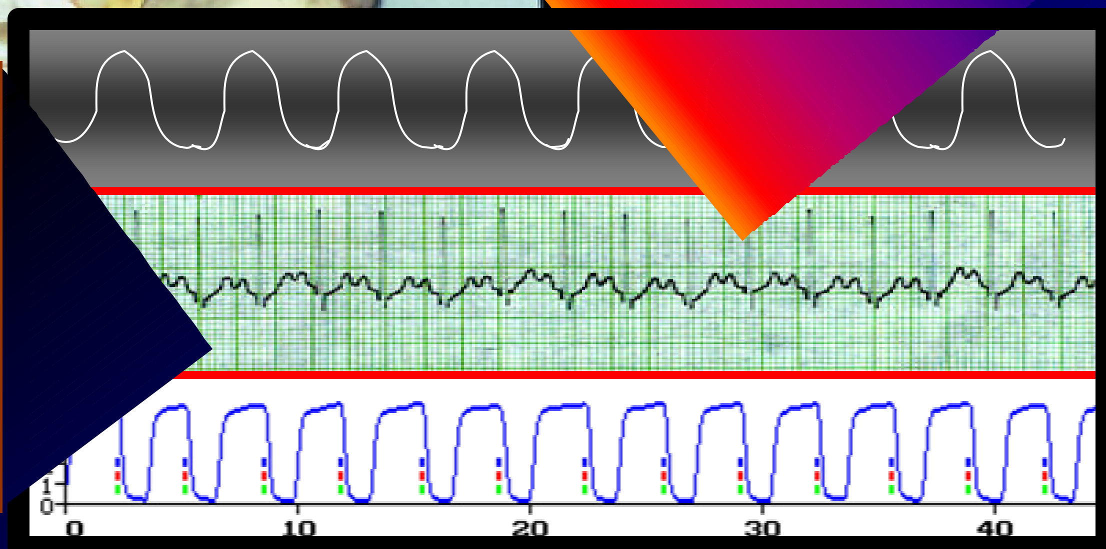
- ❑ In nasotracheal intubation, patient spontaneously breathed through the tube after mouth and nares closed off (recognizing false positive is tube sitting at the top of the cords.)
- ❑ Noted tube depth marking at nasal opening in nasotracheal intubation.
- ❑ Secured tube at the original depth noted at nares.

I have performed the above checklist and confirmed to the best of my ability that the endotracheal tube has properly been placed. This care was maintained up until the transfer of patient care to the hospital staff.

________________________________	________________________
Paramedic's Signature	**Date**
________________________________	________________________
Paramedic's Signature	**Date**

Synthesis

BP = 88/55
P = 160
Resp = 36
TV = 800
Glu = 425
Hgb = 9



The Medics of the Near Future will be "Out of Hospital Intensivists"

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