Riding the waves

The ups and downs of capnography and pulse plethysmography

Dr Ellie Drynan
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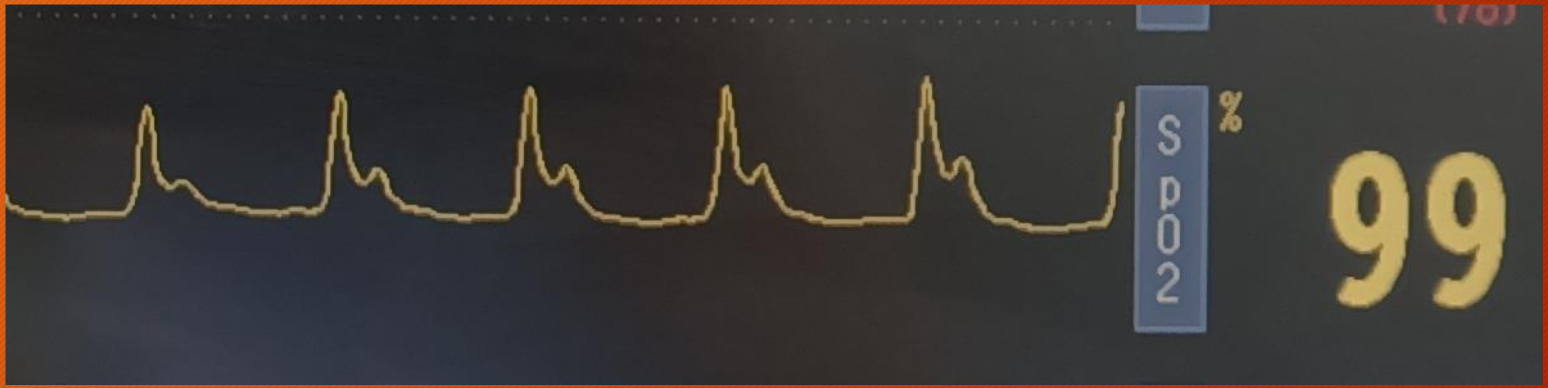
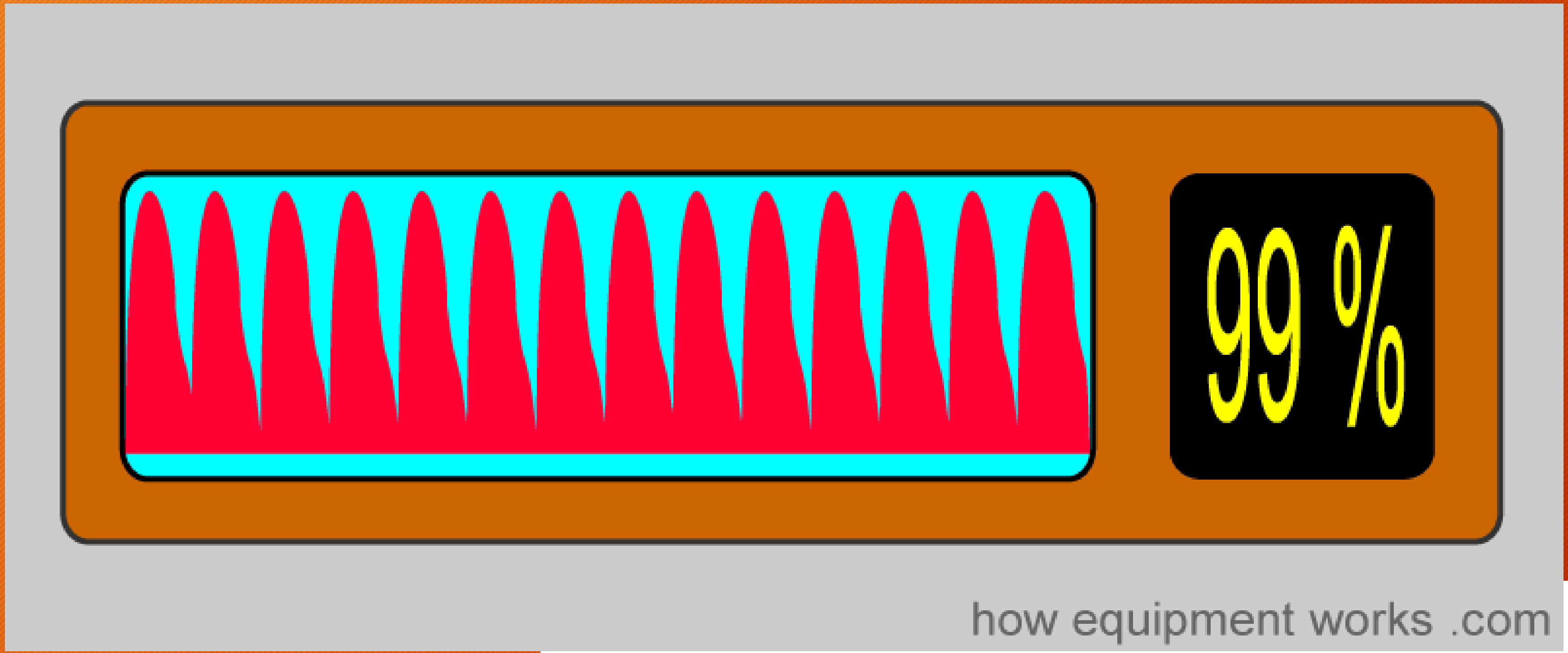
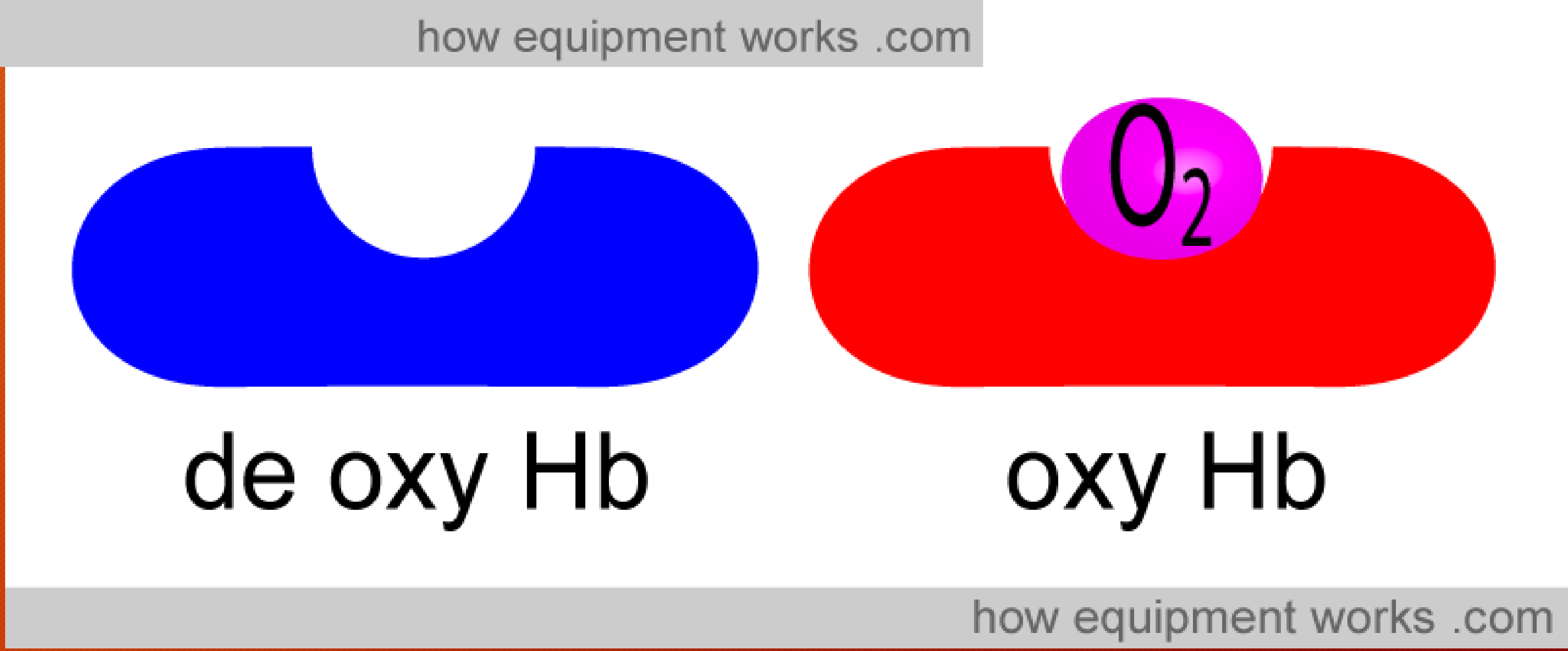
Specialist in Anaesthesia

zoetis

Pulse Oximetry




99 %
how equipment works .com

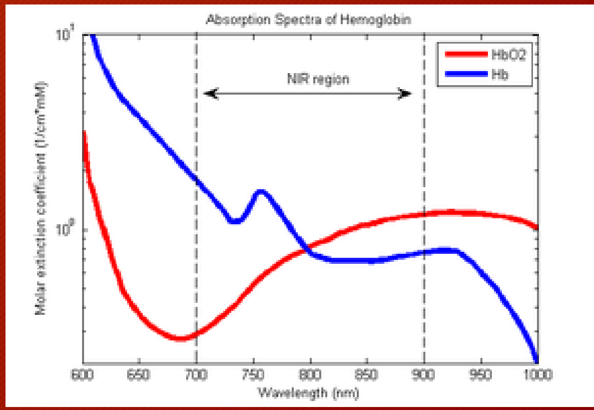

O_2
de oxy Hb
oxy Hb
how equipment works .com

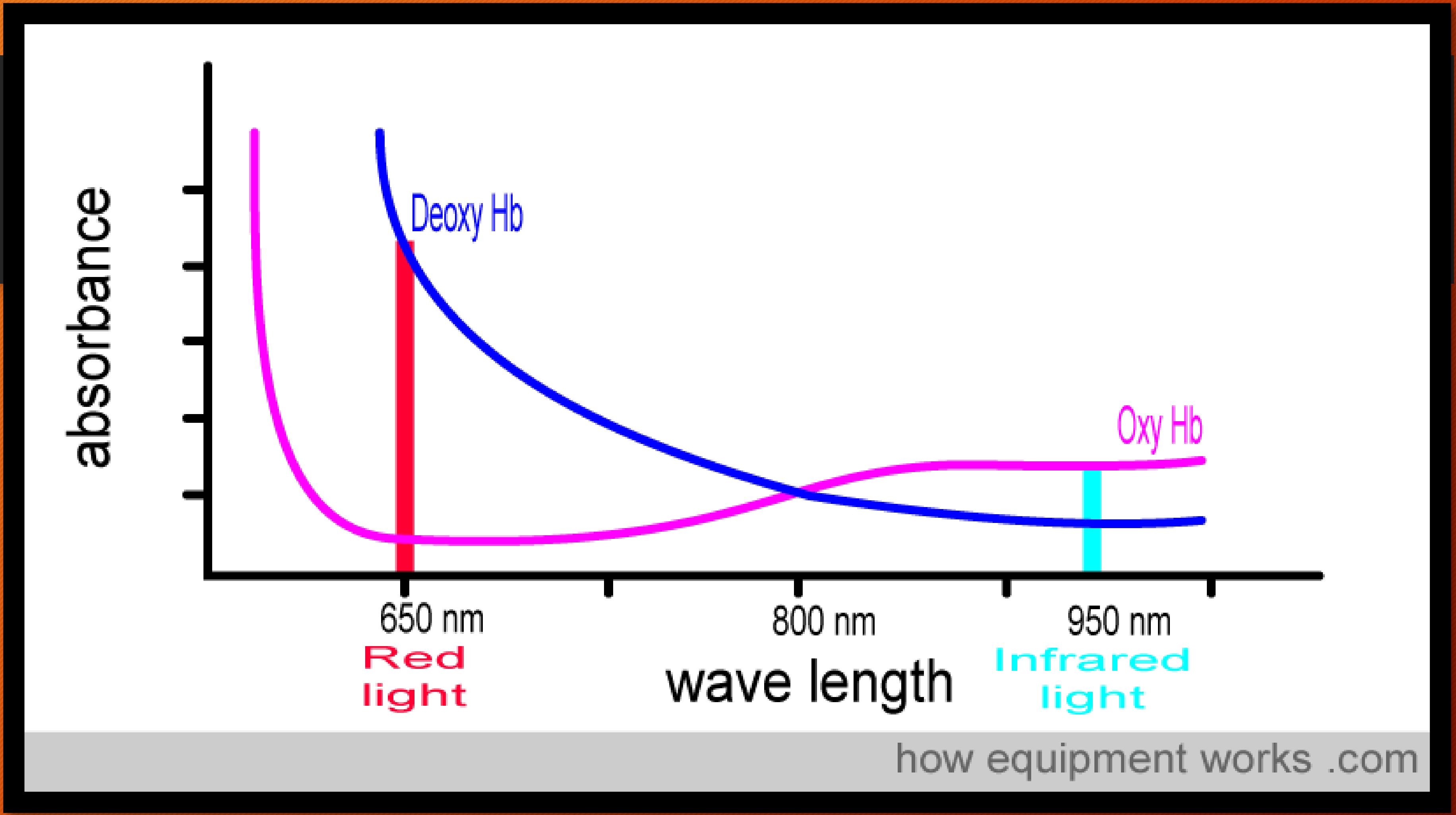
Pulse Oximetry

- Based on 2 principles:
  - pulse photoplethysmography
  - spectrophotometric oximetry

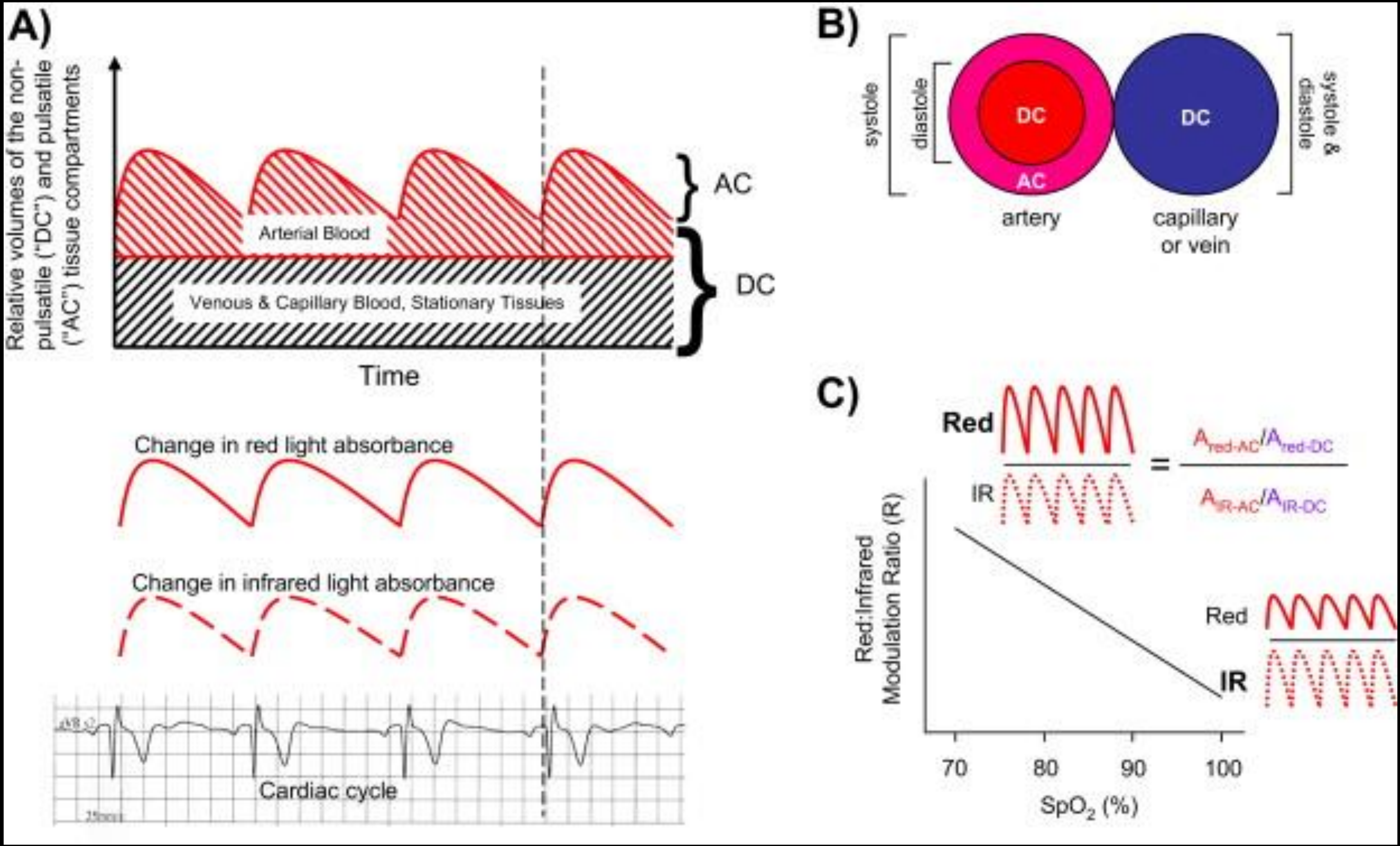
- Light transmitted through tissues is absorbed

- Variation in light absorption with each pulse

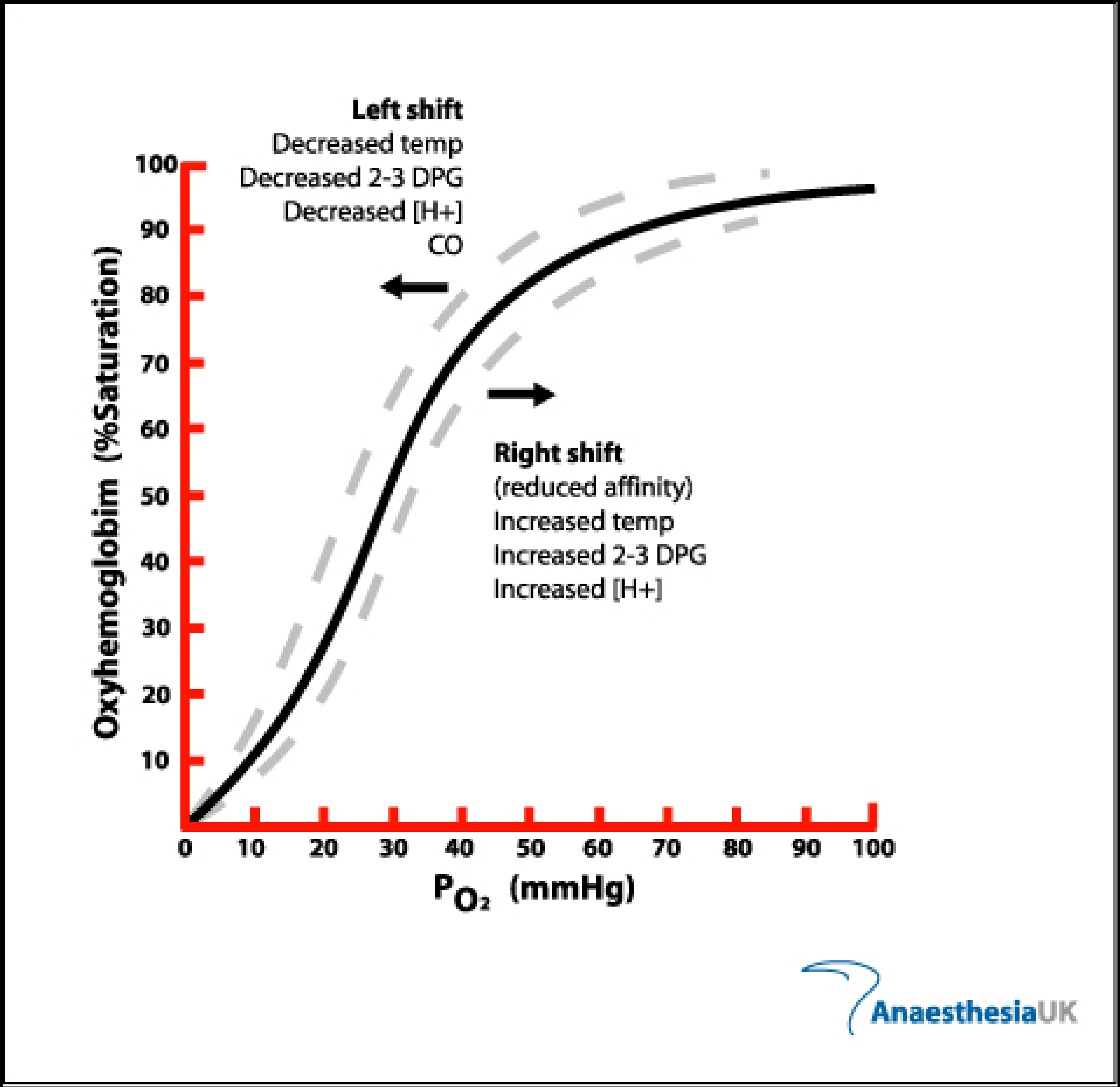




Uses Red and Infrared light: absorbed differently by oxygenated and deoxygenated haemoglobin


A)
Relative volumes of the non-pulsatile ("DC") and pulsatile ("AC") tissue compartments
Arterial Blood
Venous & Capillary Blood, Stationary Tissues
AC
DC
Time
Change in red light absorbance
Change in infrared light absorbance
Cardiac cycle
B)
systole
diastole
DC
AC
artery
DC
systole & diastole
capillary or vein
C)
Red
IR
= A red-AC/A red-DC / A IR-AC/A IR-DC
Red:Infrared Modulation Ratio (R)
Red
IR
70
80
90
100
SpO2 (%)

Clinically…



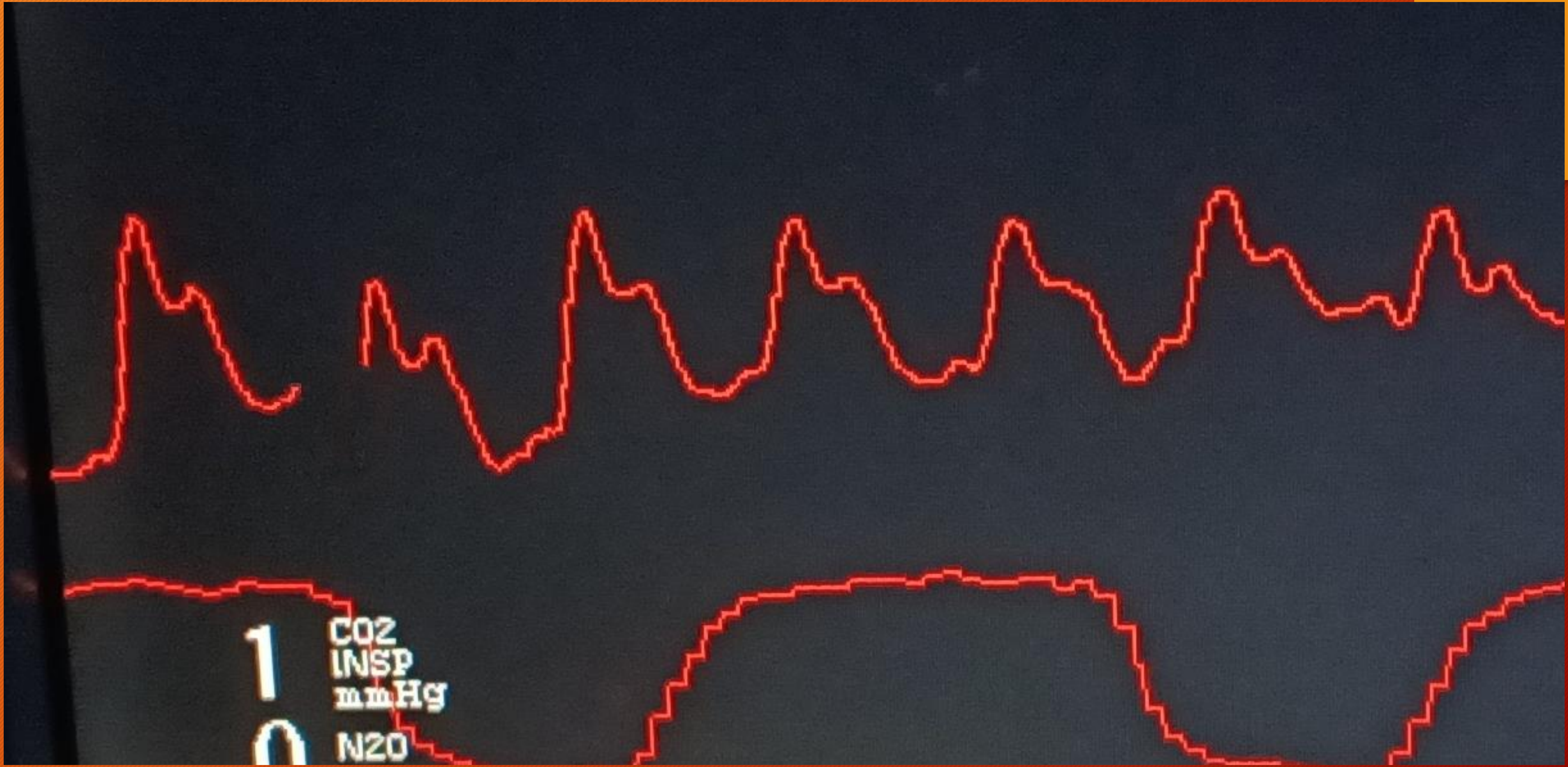
Left shift
Decreased temp
Decreased 2-3 DPG
Decreased [H+]
CO
Right shift
(reduced affinity)
Increased temp
Increased 2-3 DPG
Increased [H+]
Oxyhemoglobim (%Saturation)
100
90
80
70
60
50
40
30
20
10
0
10
20
30
40
50
60
70
80
90
100
P_{O_2} (mmHg)
AnaesthesiaUK

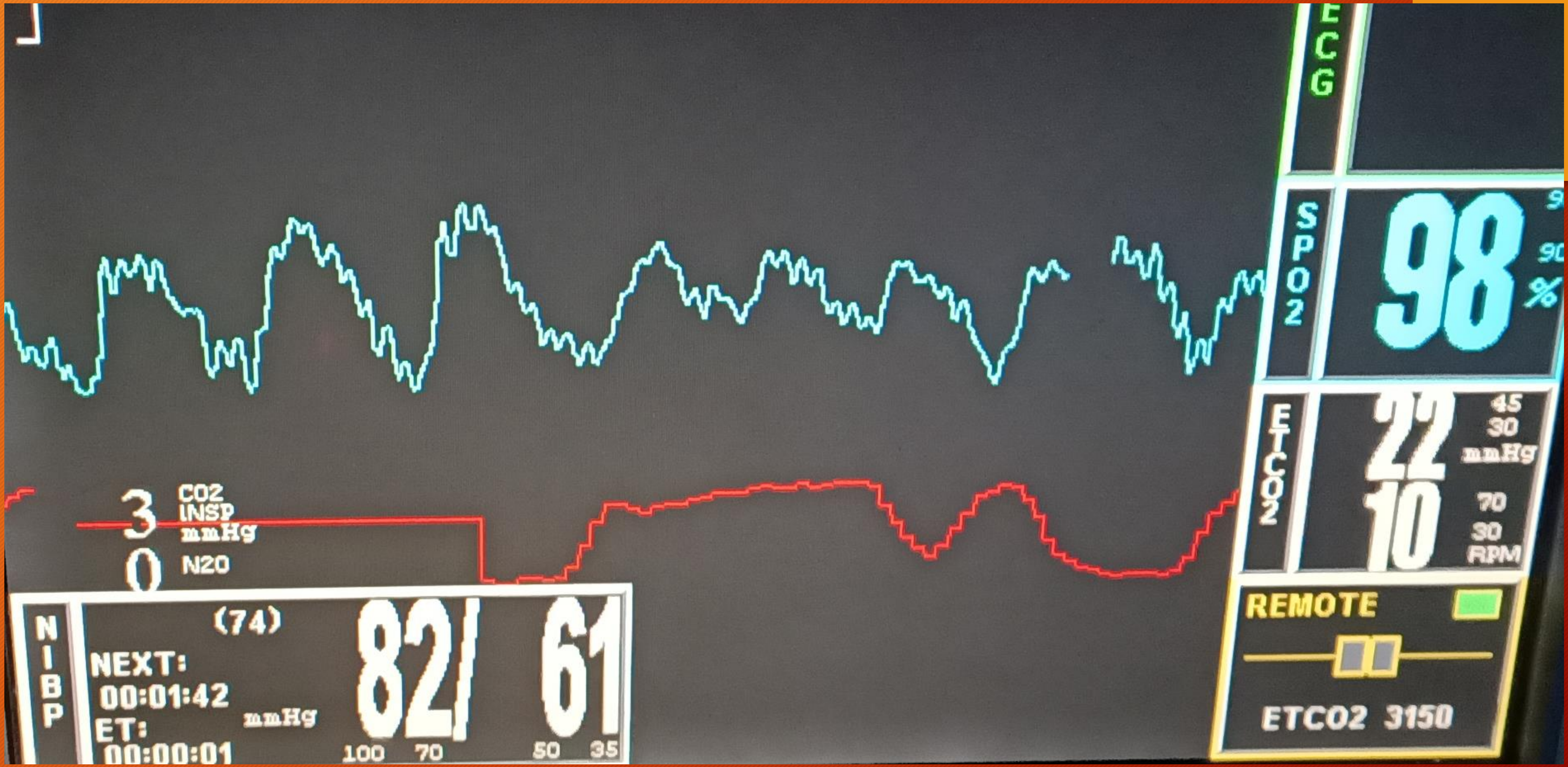
Transmission and Reflectance

- Transmission – emitter and photodetector are opposite each other
- Reflectance – emitter and photodetector are next to each other on top of the measuring site
  - the light bounces from the emitter to the site and back

Factors that may affect the reading

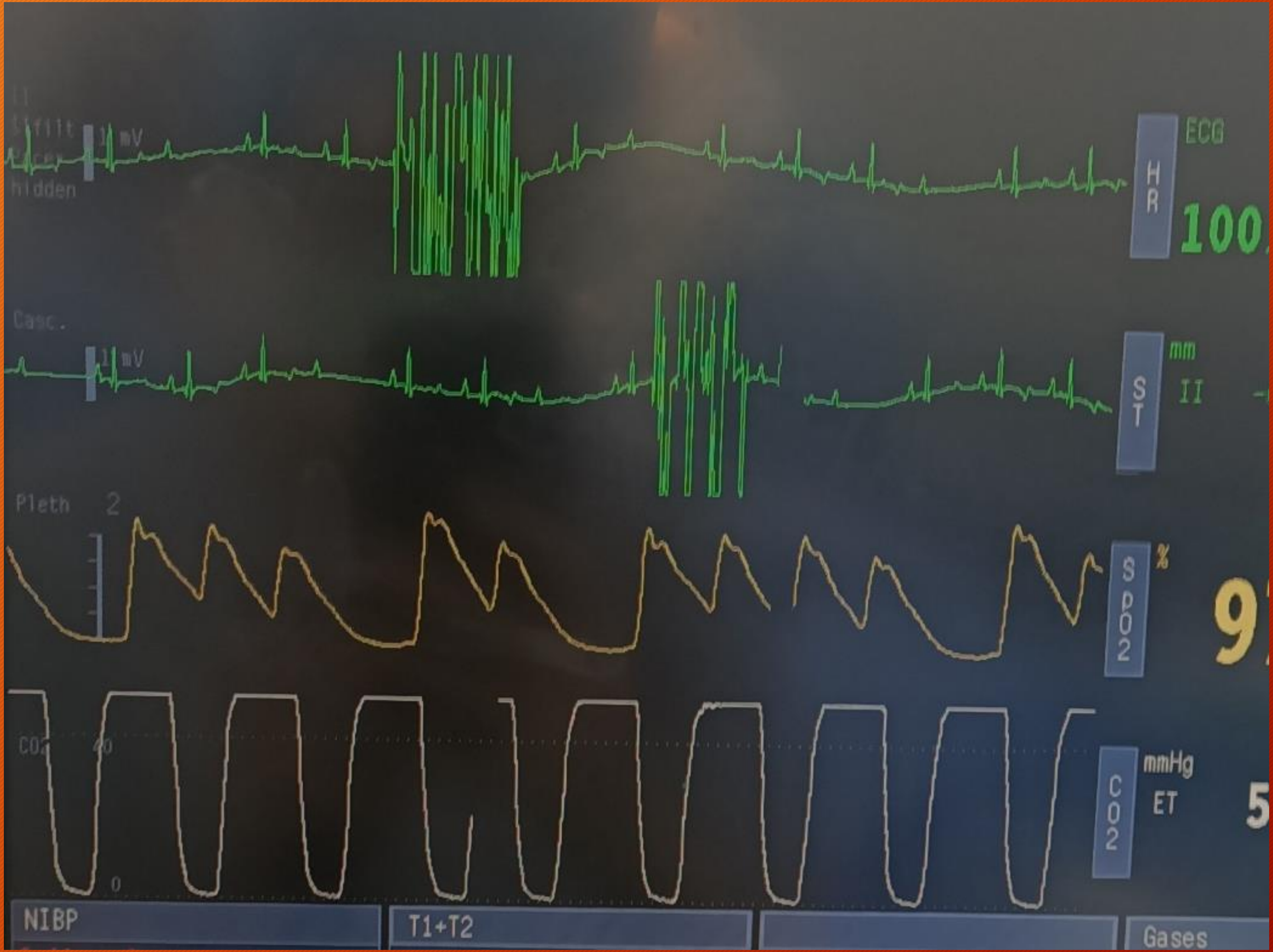
- Poor positioning
- Anaemia
- Hypotension/ hypovolaemia
- Peripheral vasoconstriction (hypovolaemia and hypothermia)
- Slow HR and/or arrhythmias
- Patient movement
- Extraneous light
- Pigments in skin
- Equipment


1
CO2
INSP
mmHg
0
N2O


ECG
SPO2
98
%
ETCO2
22
45
30
mmHg
10
70
30
RPM
3
CO2
INSP
mmHg
0
N2O
NIBP
(74)
NEXT:
00:01:42
ET:
00:00:01
mmHg
82/ 61
100 70
50 35
REMOTE
ETCO2 3150

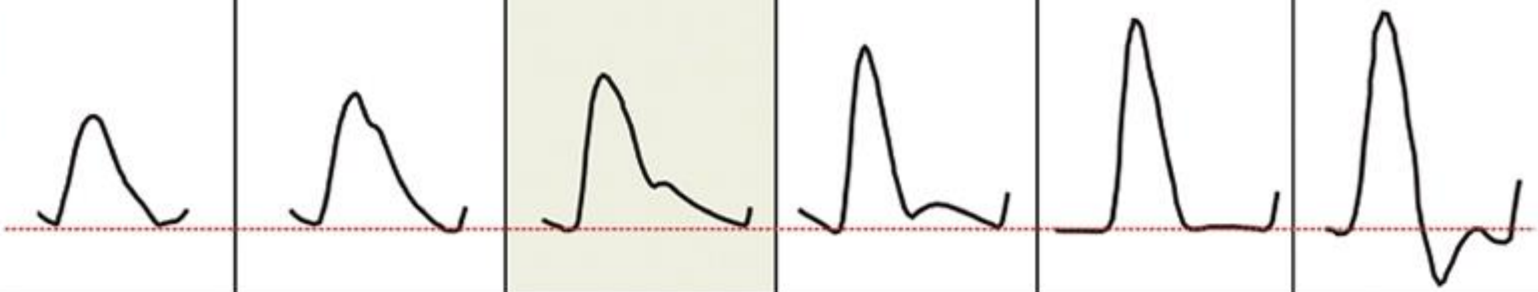
SpO2
%
9
CO2
40
0
mmHg
ET
5
NIBP
Cuff occlusion
---/---
Cuff 30 0 5 min
T1+T2
°C T2:
T1 ---
T2-T1
T2 36.5

Gases
% O2
ET 93
FI 100



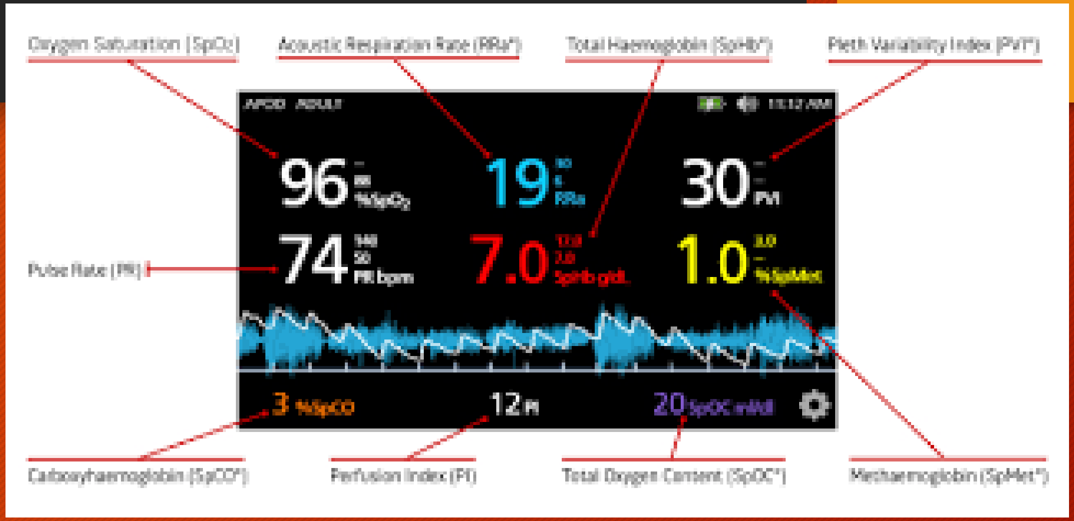
II
filt
1 mV
hidden
ECG
HR
100
Casc.
1 mV
mm
ST
II
Pleth
2
%
SpO2
9
CO2
40
0
mmHg
ET
CO2
5
NIBP
T1+T2
Gases

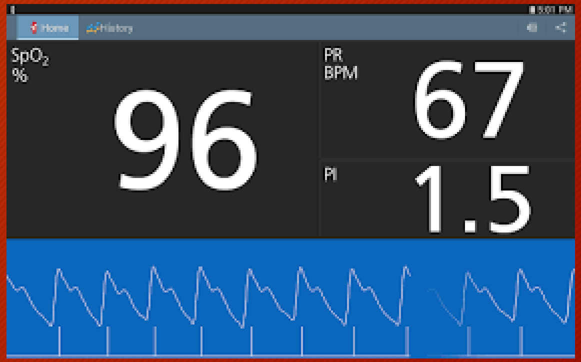
Pulse Shape

Vascular tone	Vasoconstriction		Normal	Vasodilation		
	severe	*moderate*		*slight*	*moderate*	*severe*
PPG waveform shape						
Amplitude	↓↓↓	↓↓	=	↑	↑↑	↑↑↑
Notch position	↑↑↑	↑↑	=	↓	↓↓	↓↓↓

Perfusion Index (PI)

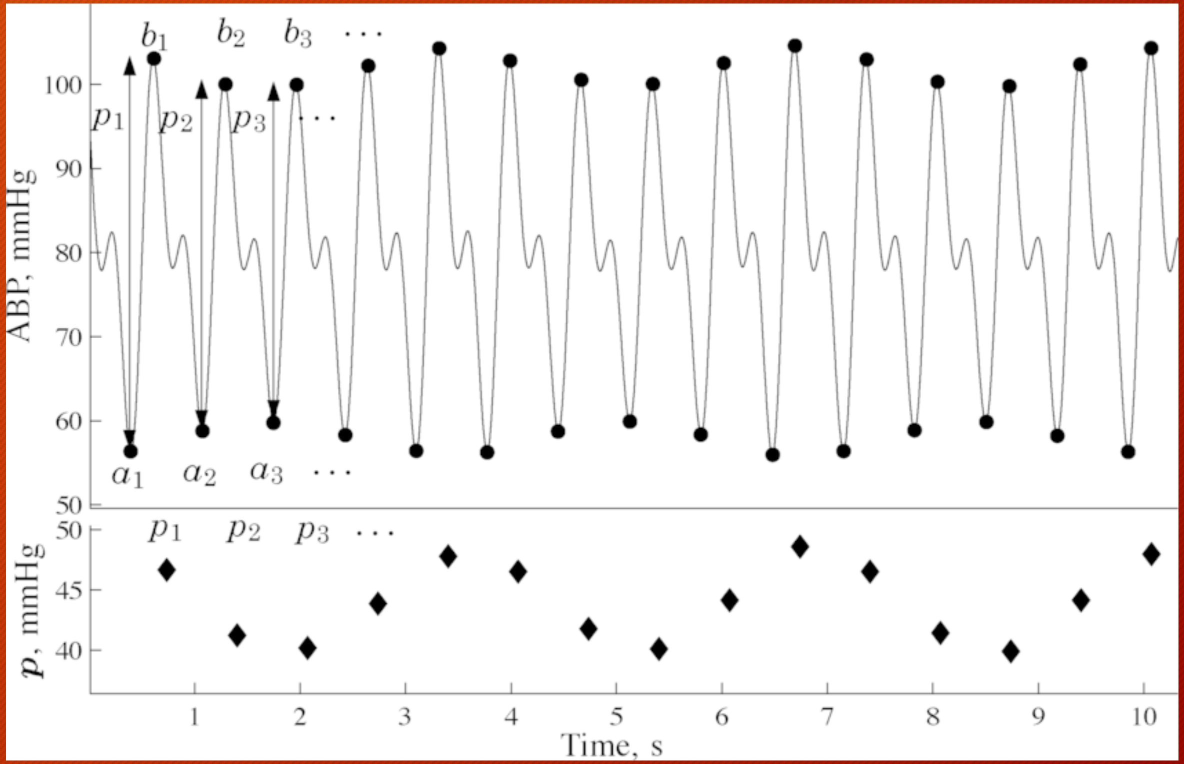
- Represents the strength of the pulse at that site
- Calculated by expressing the pulsatile flow as a percentage of the non-pulsatile flow at the wavelength of infrared light (940 nm)
- The perfusion index generally changes in association with peripheral perfusion
- Measurements range between 0.02 – 20





Pulse pressure variation (PPV)

- Arterial line
- Percentage variation between the PPmax, which is usually recorded during the inspiratory cycle of mechanical ventilation, and the PPmin, which is recorded between tidal breaths



mmHg
Art
104/53
(66)
Pleth
SpO2
%
98
CO2
mmHg
ET
42
FI
3
RR
11 /min

Pulse pressure variation

- In humans, PPVs > 12% to 13% are predictive of fluid responsiveness (ie, volume loading is expected to result in a substantial [> 15%] increase in stroke volume)
- Disadvantages: theoretically requires mechanical ventilation of the animal with a tidal volume of 8–10 mL/kg, and an arterial line

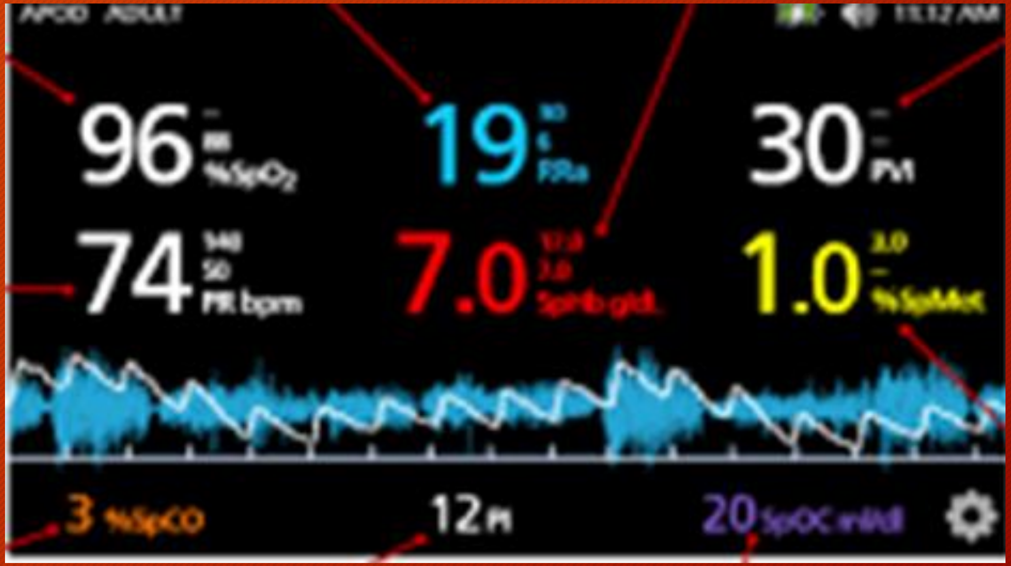
Plethysmographic Variability Index (PVI)

- Variation in amplitude of the plethysmograph in mechanically ventilated animals

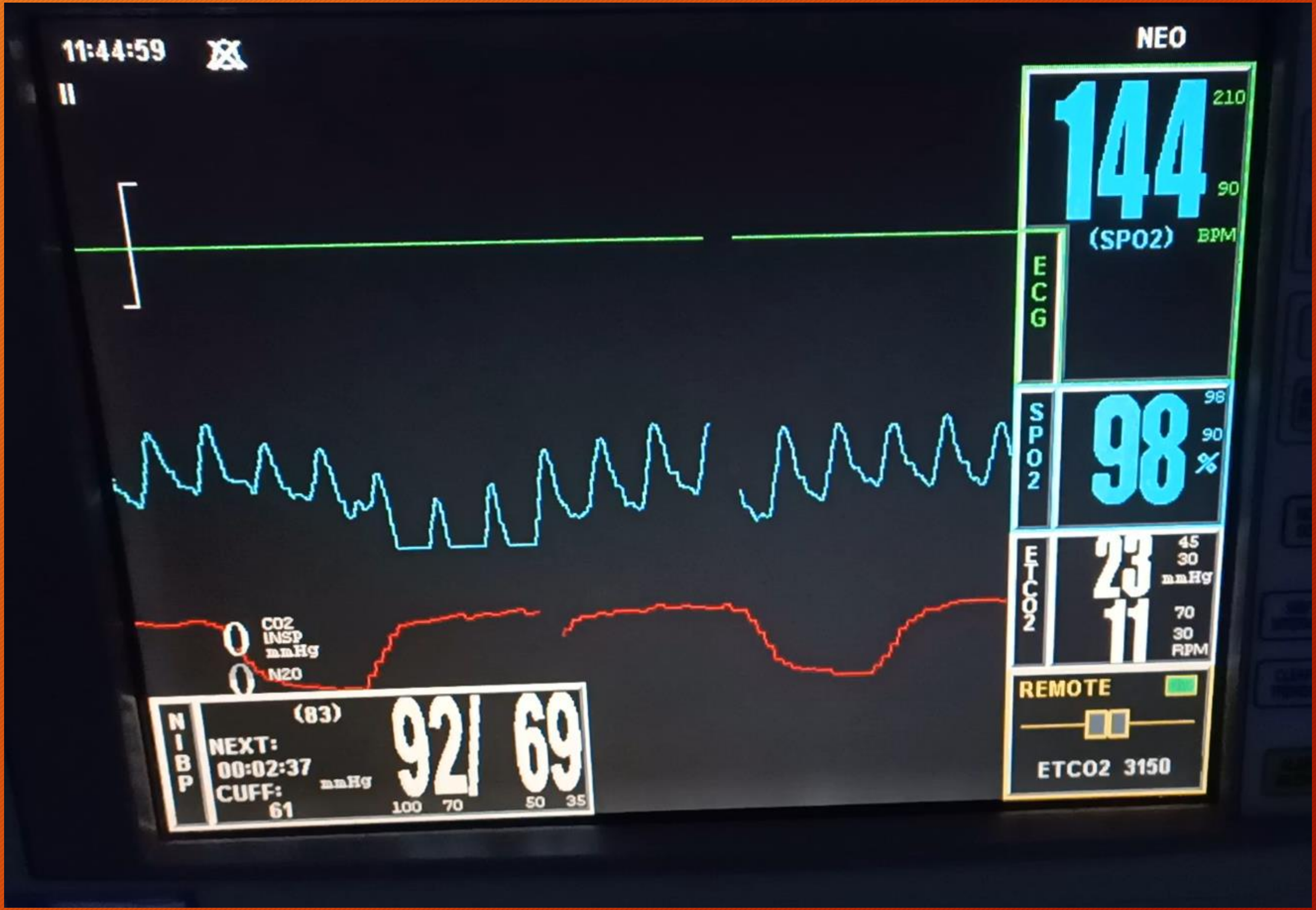
- Calculated from changes in the absorption of light during blood flow to the pulse oximeter probe

- PVI = (PImax – PI min)/ Pimax x 100%

- Lower the number = less variability over the resp cycle




V/C lead off
1 mV
ECG
HR
/min
Pleth
47 /min
1 mV
ST
mm
II OFF
V5 OFF
aVL OFF
II
OFF
Pleth 5
SpO2
%
97
CO2 40
0
CO2
mmHg
ET 45 FI 1
RR 13 /min
NIBP
mmHg Sys Dia
109/48
Mean (73) 0 3 min
T1+T2
°C T1:
T1 35.7 T2-T1
T2 --- ---
Gases
% O2 N2O Iso
ET 83 0 1.3
FI 89 0 1.6
Silence



11:44:59
NEO
144
210
90
(SPO2)
BPM
ECG
SPO2
98
98
90
%
ETCO2
23
45
30
mmHg
11
70
30
RPM
CO2
INSP
mmHg
0
0
N2O
NIBP
(83)
NEXT:
00:02:37
CUFF:
61
mmHg
92/ 69
100
70
50
35
REMOTE
ETCO2 3150

Pediatric Anesthesia

RESEARCH REPORT | Open Access

The predictive value of the Pleth Variability Index on fluid responsiveness in spontaneously breathing anaesthetized children—A prospective observational study

Frank Weber, Bharat K. Rashmi, Gülhan Karaoz-Bulut, Jaap Dogger, Iris J. de Heer, Christopher Prasser

First published: 07 August 2020 | https://doi.org/10.1111/pan.13991

SECTIONS PDF TOOLS SHARE

Abstract

Background

In children, the preoperative hydration status is an important part of the overall clinical assessment. The assumed preoperative fluid deficit is often routinely replaced during induction without knowing the child's actual fluid status.

Results

Only in fluid responsive patients, Pleth Variability Index values were higher before fluid administration than thereafter (21.4 ± 5.9% vs 15.0 ± 9.4%, 95% CI of difference 1.1 to 11.8%, *P* = .02). Pleth Variability Index values at baseline were higher in fluid responders (21.4 ± 5.9%) than in fluid nonresponders (15.3 ± 7.7%), 95% CI of difference 1.6 to 10.6%, *P* = .009. The area under the receiver operating curve indicating fluid responsiveness was 0.781 (95% CI 0.623 to 0.896, *P* = .0002), with the highest sensitivity (82%) and specificity (70%) at a Pleth Variability Index of >15% (Positive predictive value 2.71 (95% CI: 1.4 to 5.2)). Only in fluid responders, the Pleth Variability Index decreased during passive leg raising, while stroke volume increased.

Conclusions

The Pleth Variability Index may be of additional value to predict fluid responsiveness in spontaneously breathing anesthetized children. A significant overlap in baseline Pleth Variability Index values between fluid responsive and nonfluid responsive patients does not allow a reliable recommendation as to a cut off value.

Pulsus paradoxus

- Cyclic respiratory changes in the arterial pulse are reflected by proportional changes in the pulse oximetry

- In patients with acute respiratory failure, PVI depends almost exclusively on the magnitude of changes in pleural pressure (i.e on the respiratory effort

Capnography

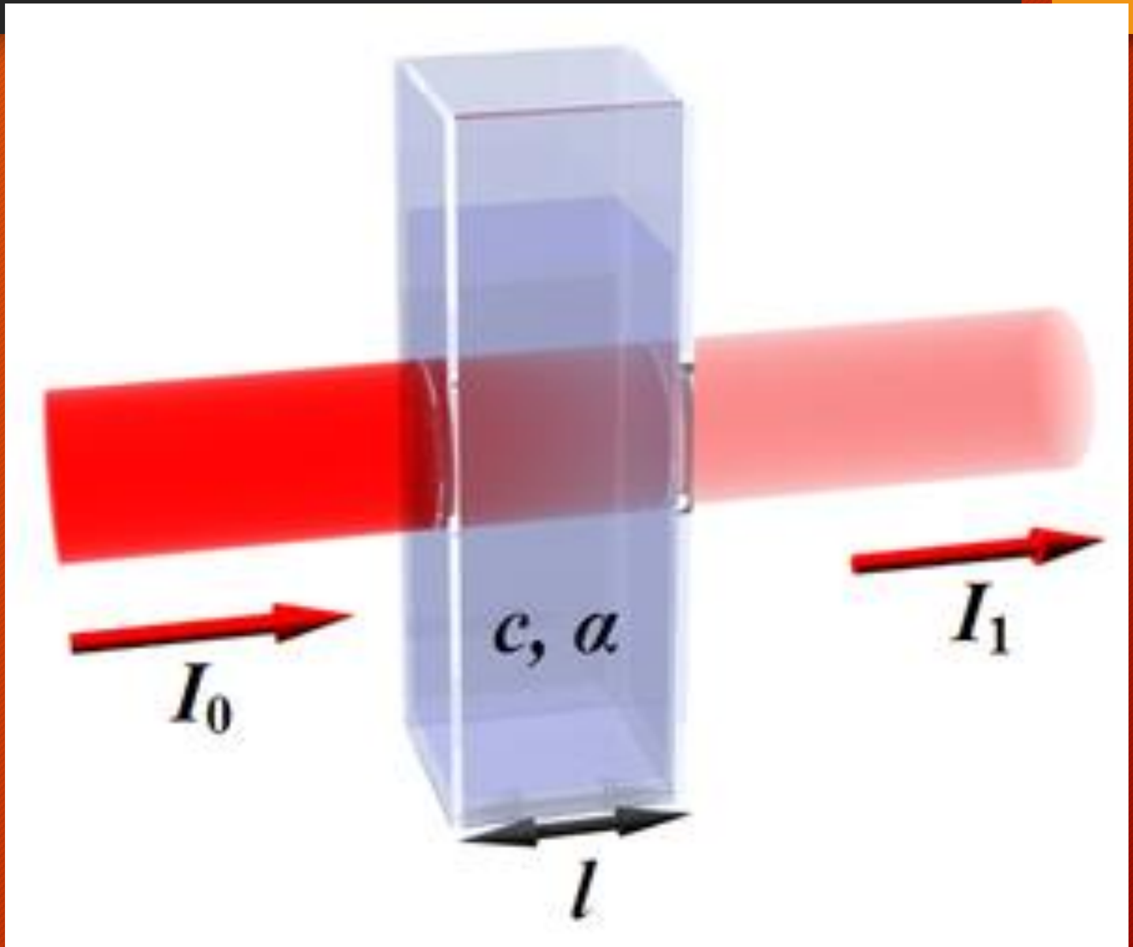
- Capnometry is the numerical assessment of $ETCO_2$ mmHg
- Capnography is the graphical and continuous representation of $ETCO_2$ (RR and $FiCO_2$)
- Capnogram is the graphical representation of $PACO_2$
- $ETCO_2 = PACO_2 = PaCO_2$
- 35 – 45 mmHG

ETCO2 affected by:

- Metabolism
- Circulation
- Ventilation

Beer-Lambert Law

- Amount of infrared light absorbed is proportional to the length and the concentration



Capnography

1) Mainstream

2) Sidestream

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Sidestream capnography

- Most common method
- Gas withdrawn from the circuit – 200 mls/min
- Gas goes to chamber
- Water vapour needs to be removed

Sidestream capnography

- Advantages:

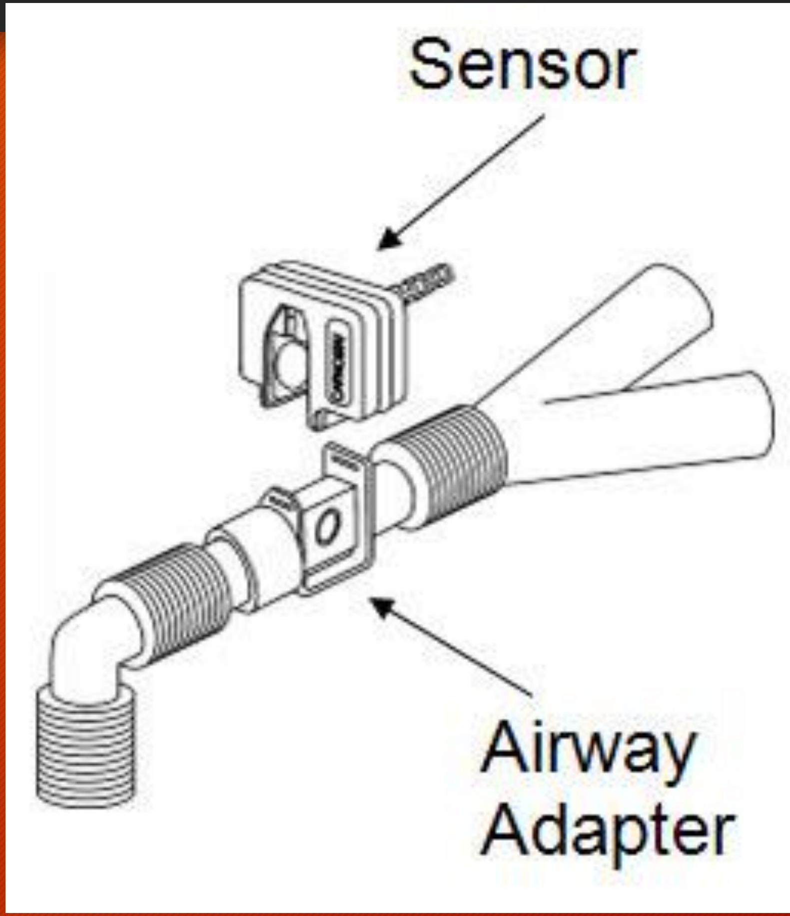
  Cheap lines, near patient, nasal measurement

- Disadvantages:

  Lag time, kinked tubing, water vapour, flow rate

Mainstream Capnography

- Sensing chamber is in a connector
- Placed within the circuit



Mainstream Capnography

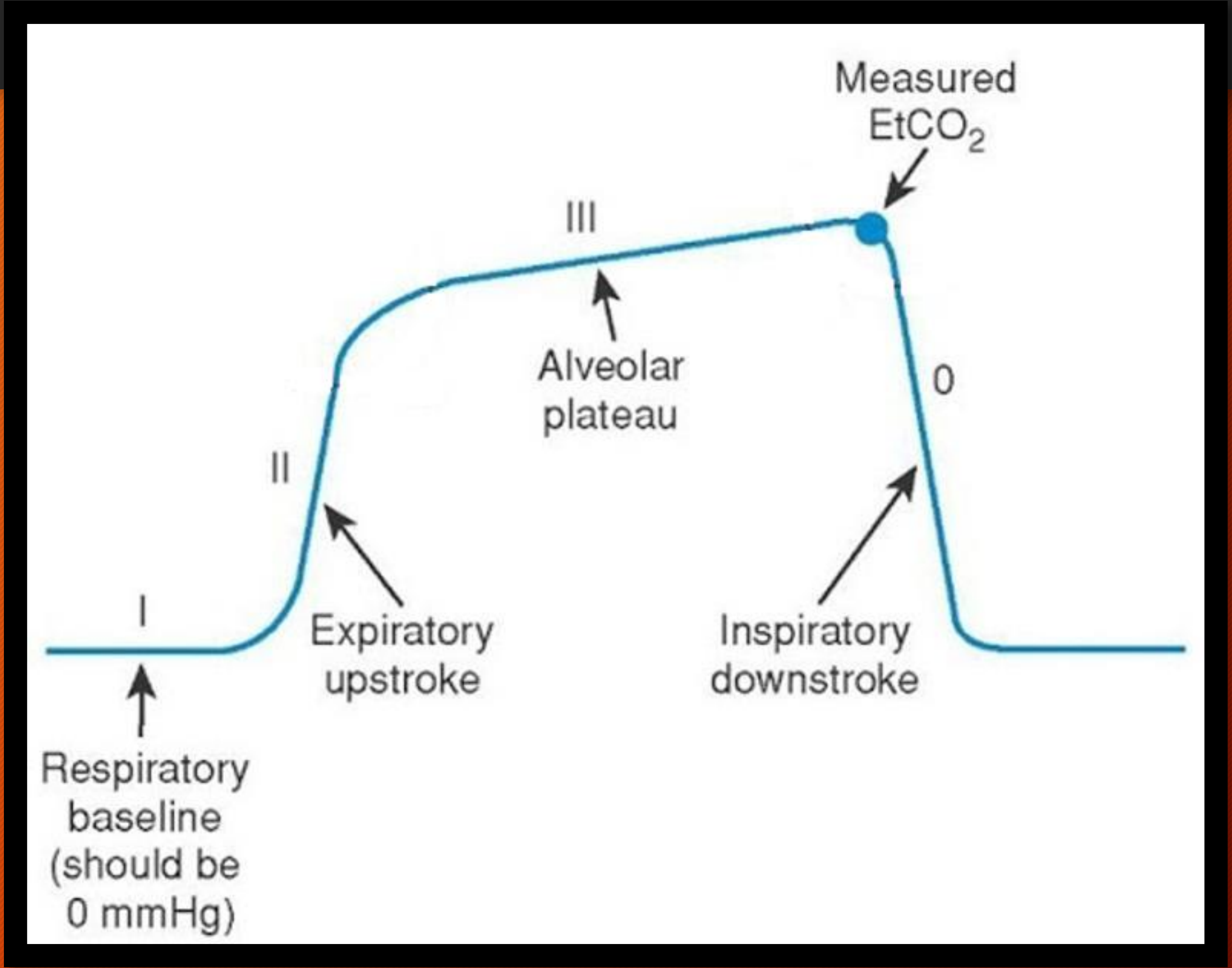
- Advantages:

  no lag time, direct sampling

- Disadvantages:

  increased dead space, added weight to the circuit, expensive, risk of thermal burns

Capnogram



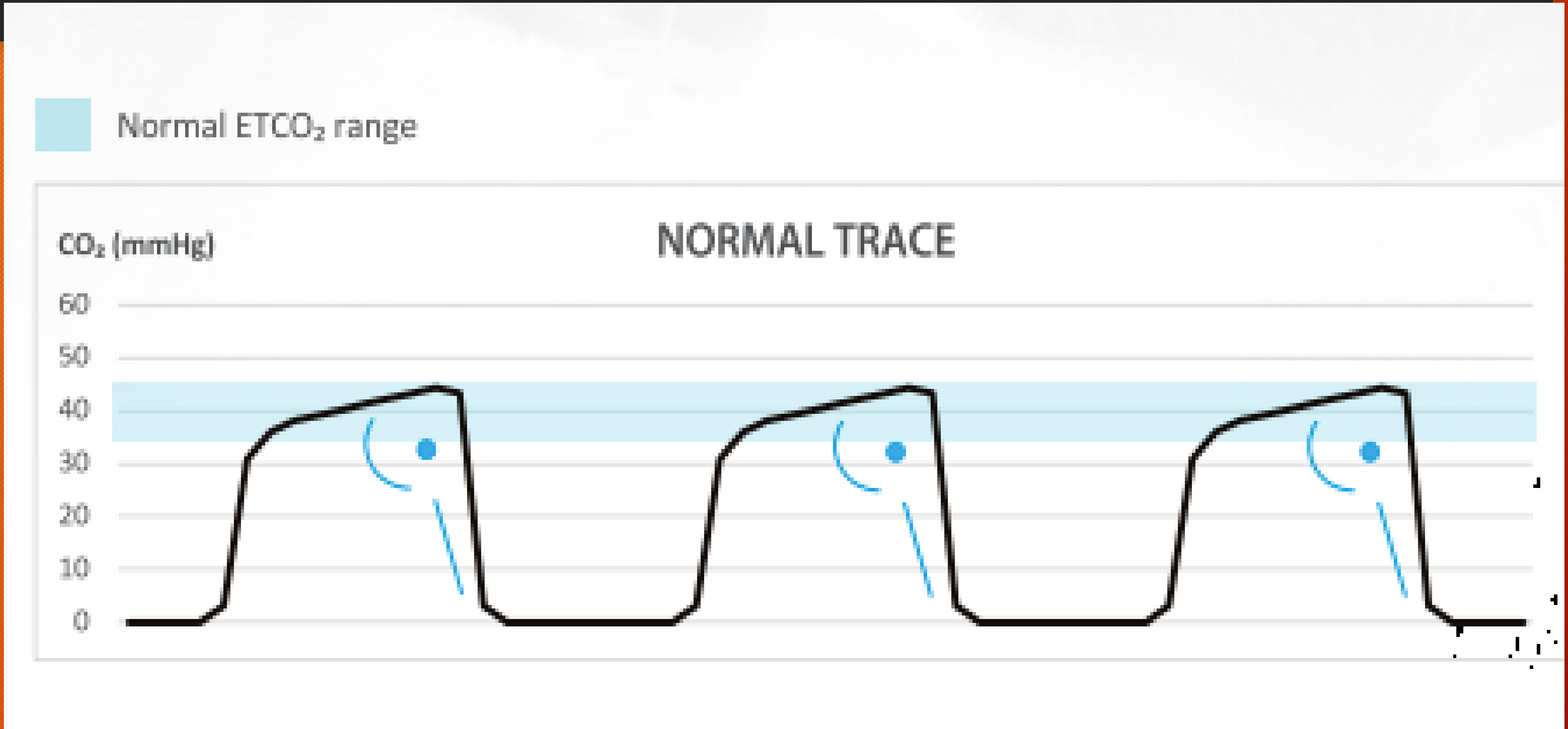
Measured
$EtCO_2$
III
Alveolar
plateau
0
II
Expiratory
upstroke
Inspiratory
downstroke
I
Respiratory
baseline
(should be
0 mmHg)

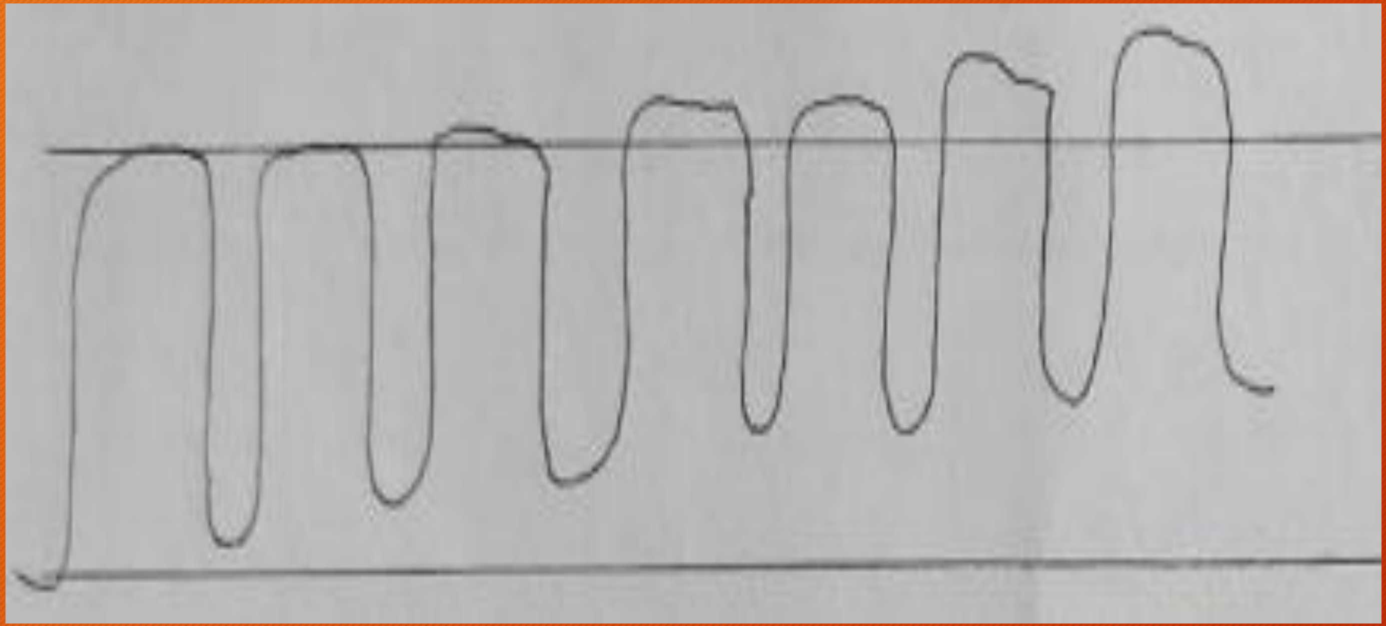
What can capnography tell us?

- Respiratory rate
- End-tidal carbon dioxide
- Inspired carbon dioxide
- ETT problem
- Indication of depth
- Hyperventilation
- Hypoventilation
- Arrest
- Adequacy of CPR

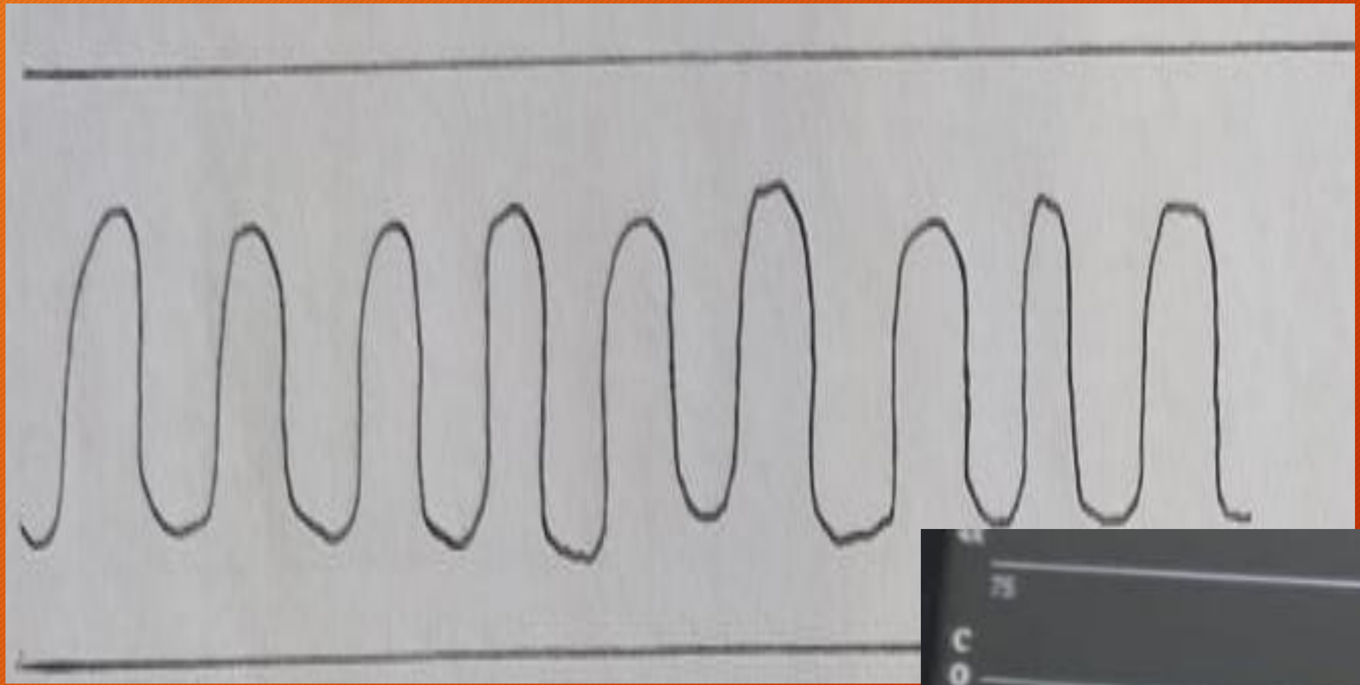
Abnormal waveforms…should we be worried?

Remember what is normal…

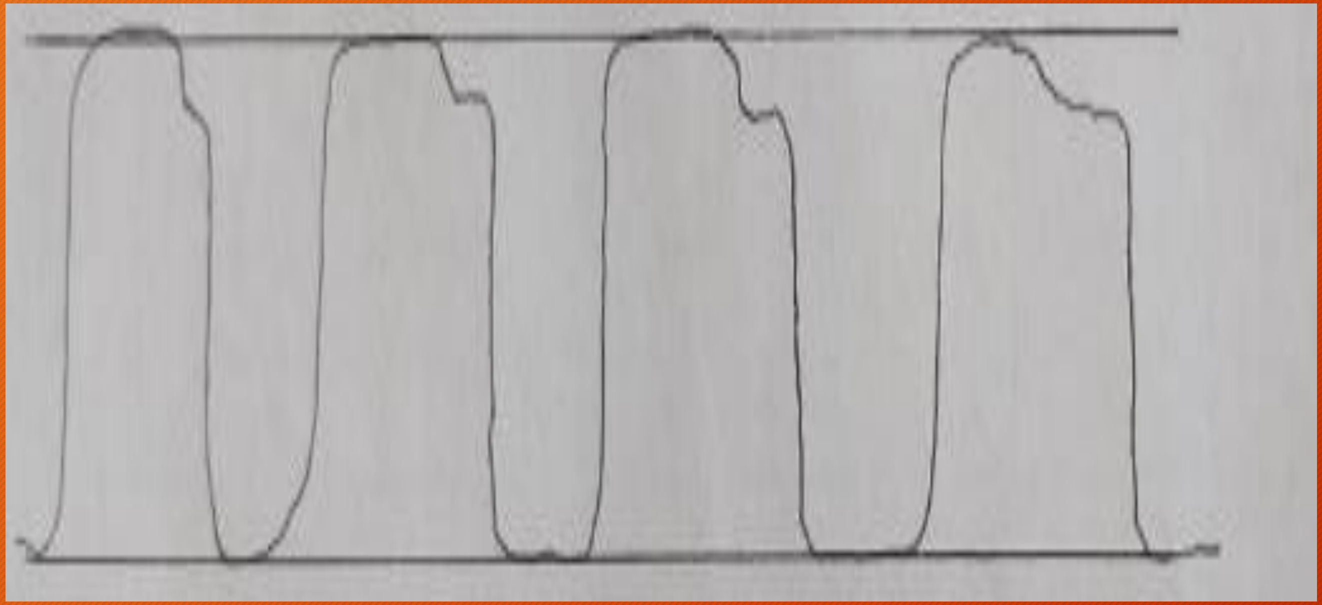




- Increasing inspired CO_2. Could be due to expired soda lime, faulty one-way valves, too low fresh gas flow rates in a non-rebreathing system

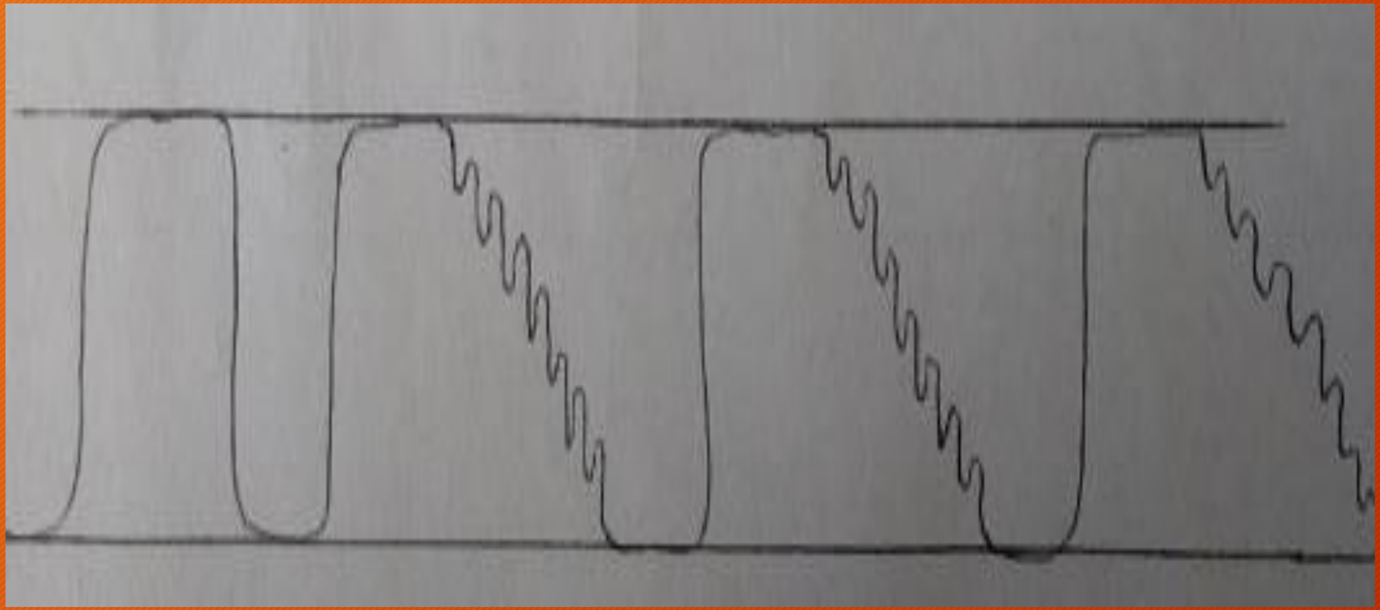


- High respiratory rate with low tidal volumes

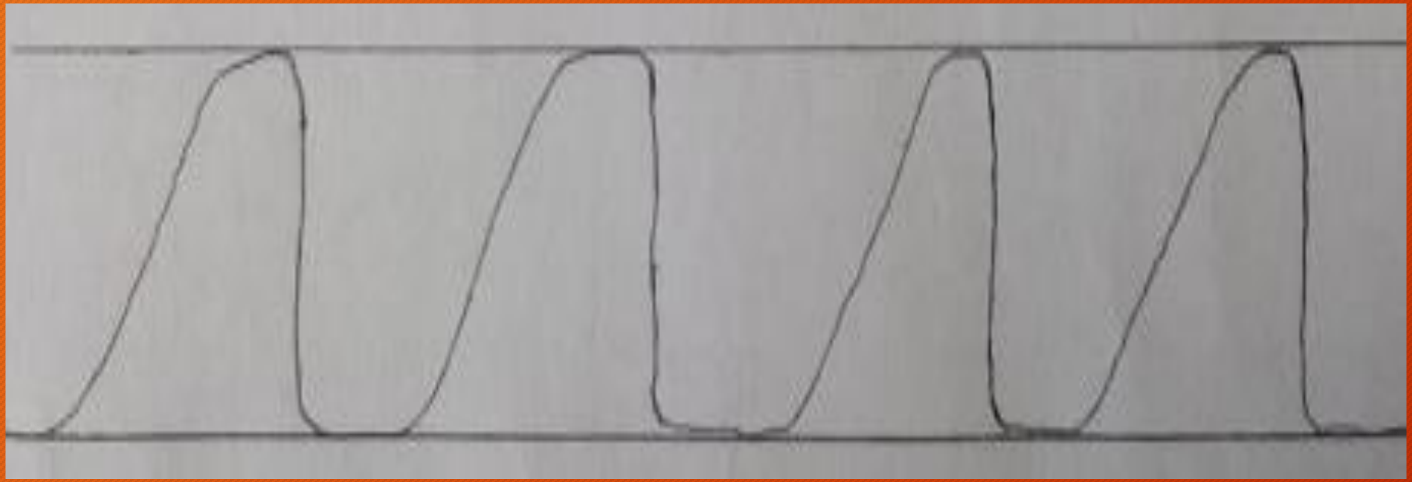


- Leak (in the cuff)

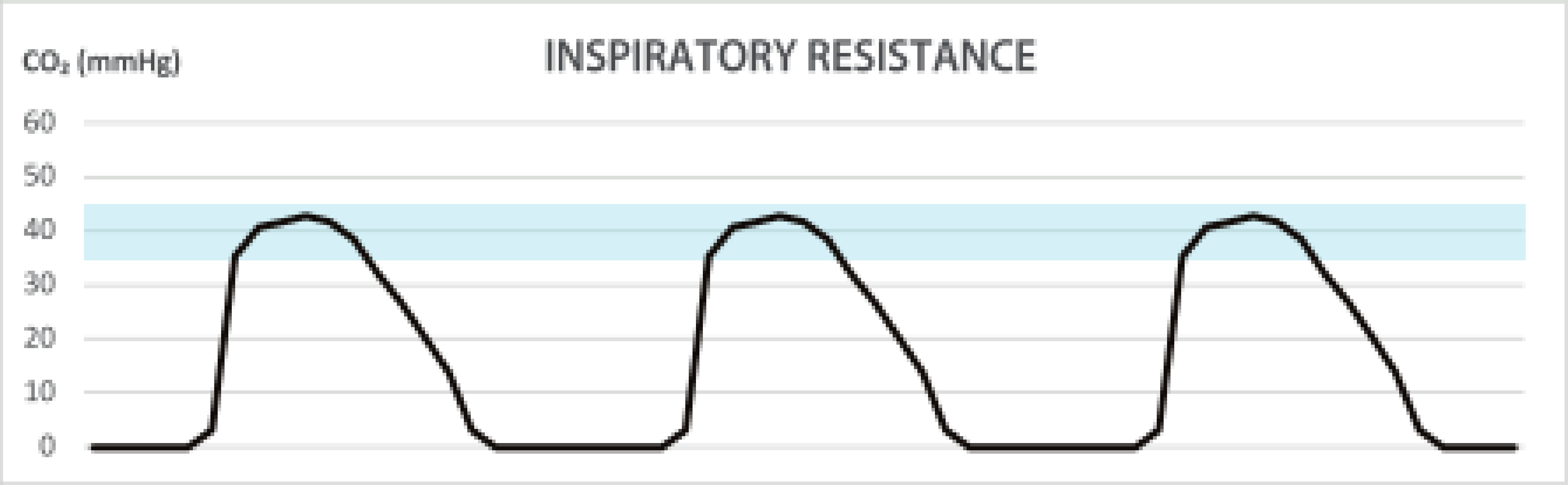

10:35:15
NEO
66
210
90
(SPO2)
BPM
ECG
SPO2
94
98
90
%
ETCO2
22
45
30
mmHg
10
70
30
RPM
CO2
INSP
mmHg
N2O
REMOTE
ETCO2 3150
NIBP
(98)
NEXT:
00:02:38
ET:
00:00:04
mmHg
111/ 80
100 70
50 35
NIBP INTERVAL
CLEAR TRENDS



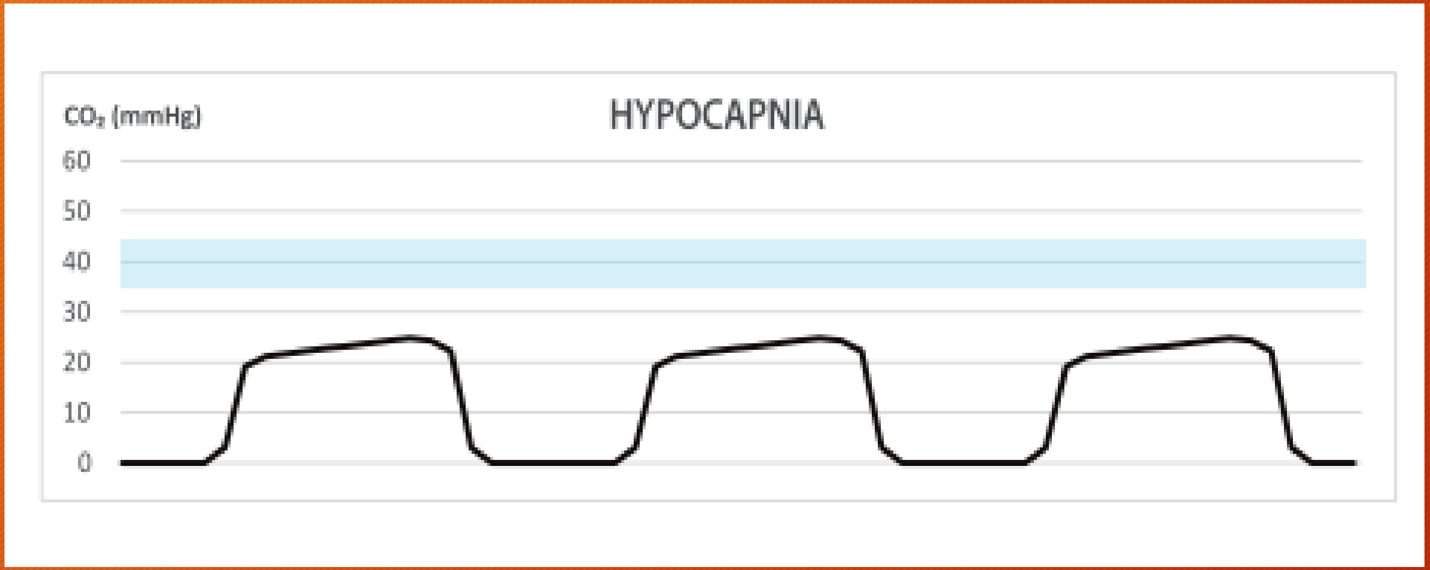
- “Cardiac” Oscillations



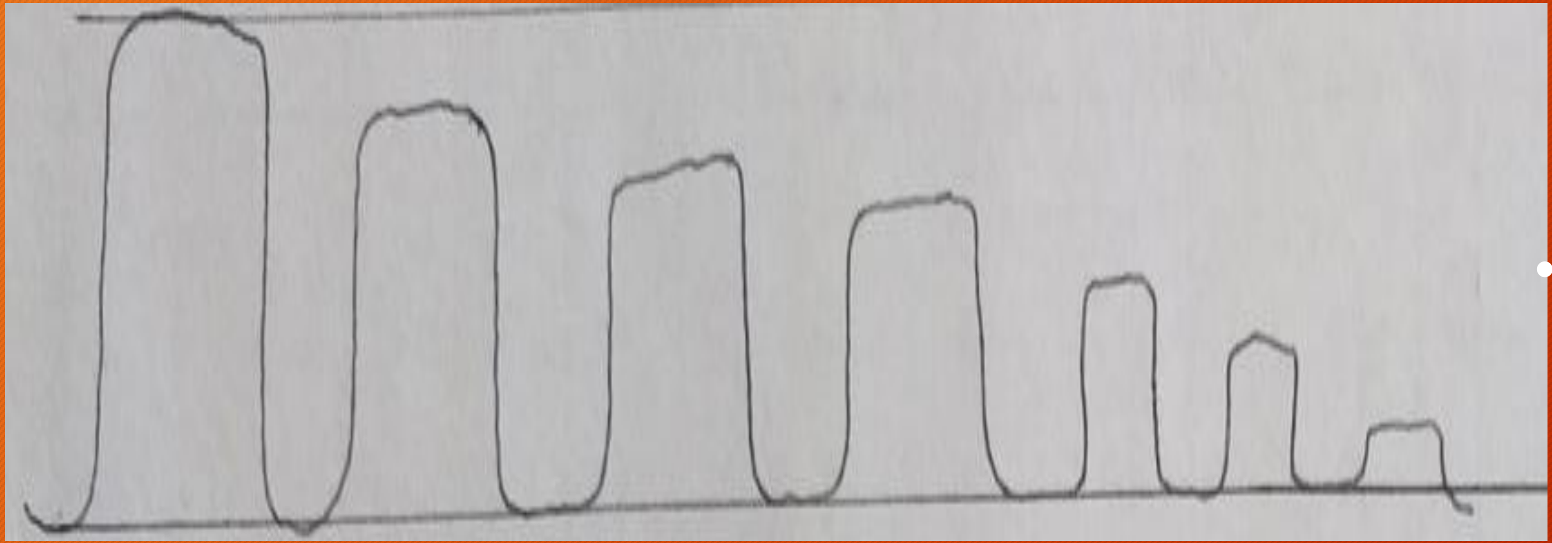
- Increased expiratory resistance to airflow e.g. cats with asthma


INSPIRATORY RESISTANCE
CO₂ (mmHg)
60
50
40
30
20
10
0

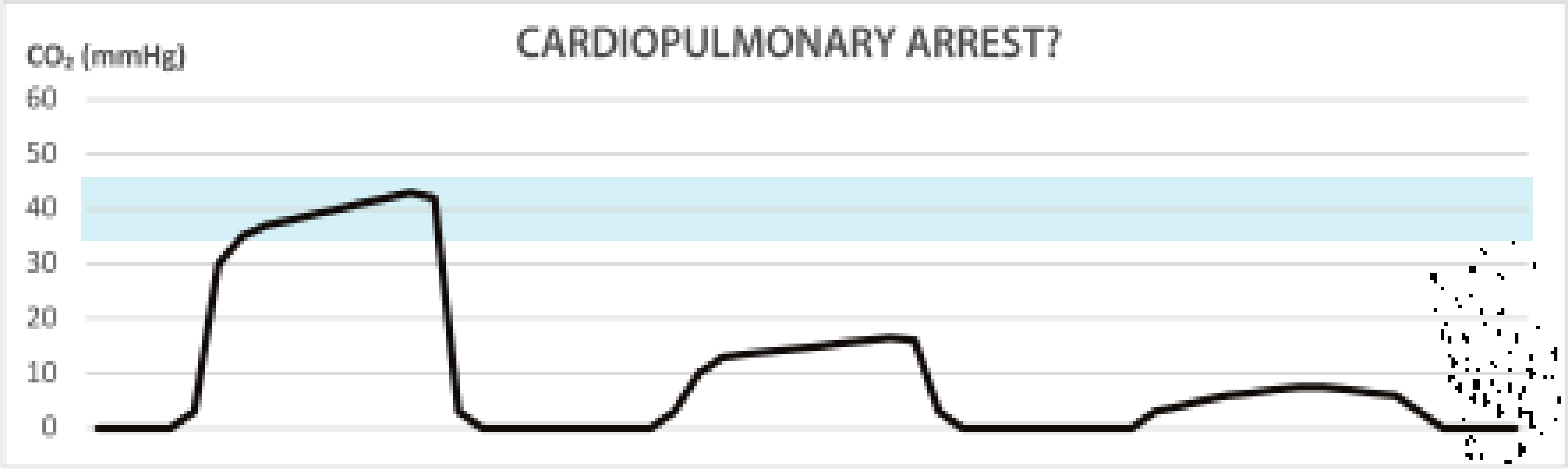
Decreased ETCO2



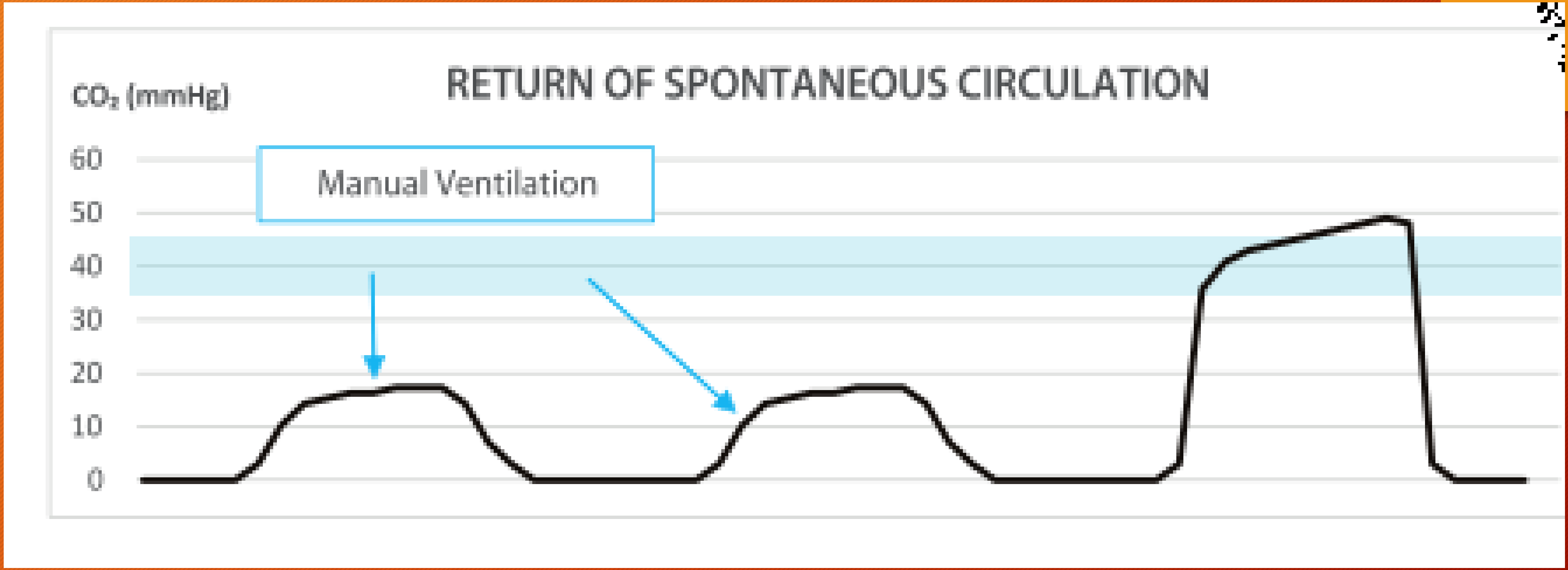
- Leak
- Too high FGF -> dilution
- Hyperventilation
- Decreased CO: hypotension, bradycardia, hypovolaemia, hypothermia, haemorrhage, imminent cardiac arrest



- Cardiac arrest with mechanical ventilation still being performed



CARDIOPULMONARY ARREST?
CO2 (mmHg)
60
50
40
30
20
10
0


RETURN OF SPONTANEOUS CIRCULATION
CO₂ (mmHg)
60
50
40
30
20
10
0
Manual Ventilation

No capnograph/ flat line capnograph??

- Oesophageal intubation
- Disconnection
- Kink
- Blocked ETT
- APL valve closed
- Arrest

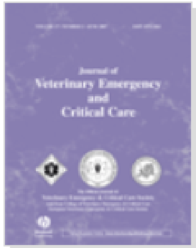
JOURNAL OF Veterinary Emergency AND Critical Care

Explore this journal >

Partial pressure of end-tidal CO_2 sampled via an intranasal catheter as a substitute for partial pressure of arterial CO_2 in dogs

D. Pang BVSc, J. Hethey, N. A. Caulkett DVM, MVetSc, DACVA,

T. Duke BVetMed, DVA, DACVA, DECVA



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Am score

Address correspondence and reprint requests to:
Dr. Tanya Duke, Department Small Animal Clinical Sciences, Western College of Veterinary Medicine, University of Saskatchewan, 52 Campus Dr., Saskatoon, SK, Canada, S7N 5B4.
E-mail: tanya.duke@usask.ca

Abstract

Objective: To demonstrate correlation and clinical usefulness of the partial pressure of end-tidal CO_2 ($ETCO_2$) measurement by nasal catheter placement in sedated dogs with and without concurrent nasal oxygen administration as a substitute for partial pressure of arterial CO_2 ($PaCO_2$).

Design: Prospective, cross-over trial.

Abstract

Objective: To demonstrate correlation and clinical usefulness of the partial pressure of end-tidal CO_2 ($ETCO_2$) measurement by nasal catheter placement in sedated dogs with and without concurrent nasal oxygen administration as a substitute for partial pressure of arterial CO_2 ($PaCO_2$).

Design: Prospective, cross-over trial.

Setting: University of Saskatchewan veterinary research laboratory.

Animals: Six cross-breed dogs with a mean (±SD) weight of 29.1±4.03 kg.

Interventions: All dogs were sedated with 5 μg/kg medetomidine intravenously (IV) and an arterial catheter was placed in a dorsal pedal artery for removal of blood for gas analysis. A nasal catheter was placed in the ventral meatus and connected to a capnometer for $ETCO_2$ measurements in all dogs. Dogs receiving supplemental nasal oxygen had a second nasal catheter placed in the contralateral naris.

Measurements and main results: In the group without nasal oxygen supplementation, the $ETCO_2$ measurement underestimated (negative bias) the $PaCO_2$ by −2.20 mmHg with limits of agreement (95% confidence interval) of −5.79, 1.39 mmHg. In the group receiving oxygen supplementation, $ETCO_2$ measurement underestimated (negative bias) the $PaCO_2$ by −2.46 mmHg with limits of agreement (95% confidence interval) of −6.42, 3.50 mmHg.

Conclusions: The results of this study demonstrate that $ETCO_2$ monitoring via a nasal catheter provides a clinically acceptable substitute to arterial blood gas analysis as a means of monitoring ventilation in healthy, sedated dogs. The limits of agreement were within acceptable limits with and without concurrent insufflation of oxygen.

ACADEMIC EMERGENCY MEDICINE • April 2002, Volume 9, Number 4 • www.aemj.org

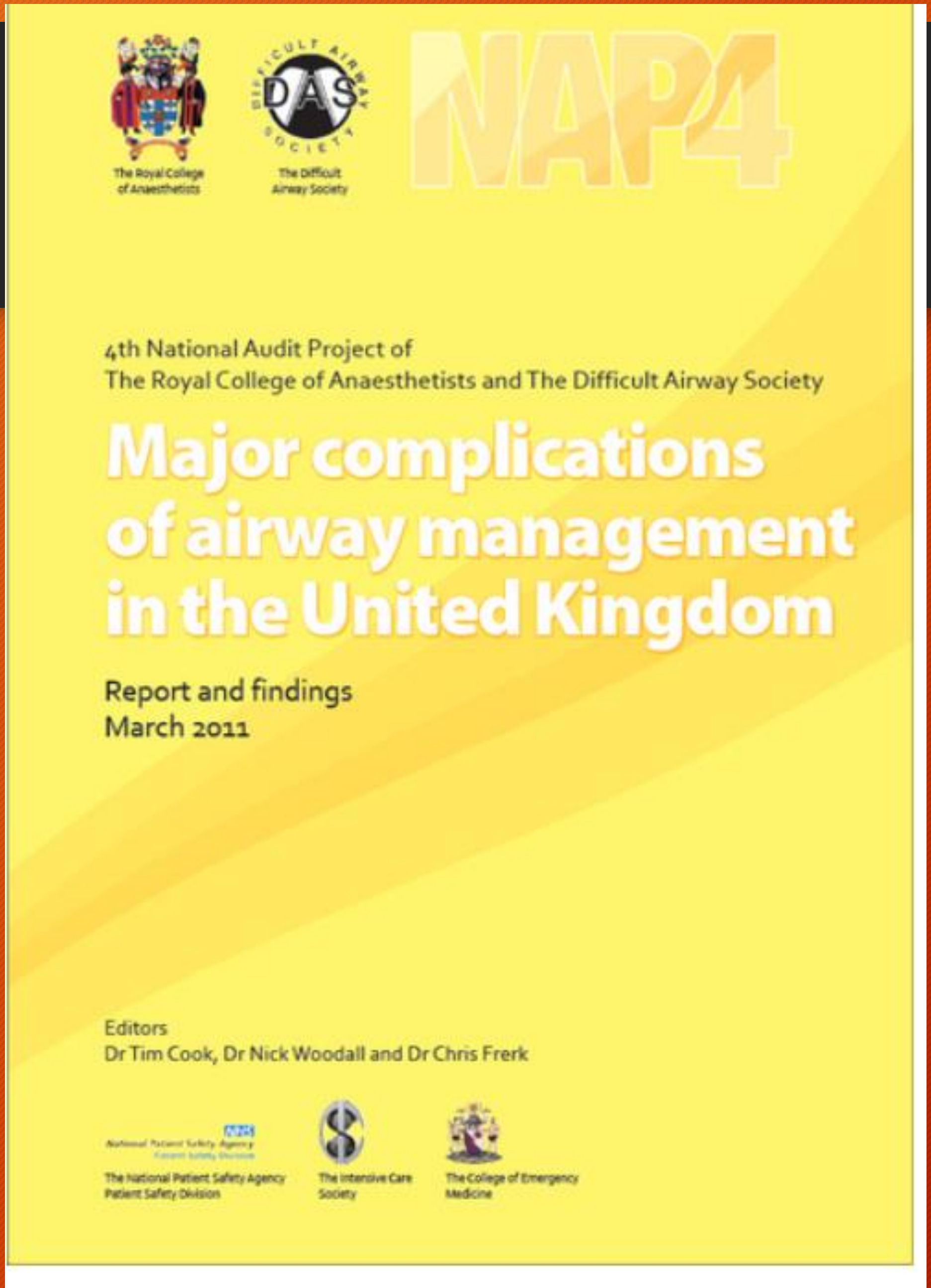
CLINICAL INVESTIGATIONS

End-tidal Carbon Dioxide Monitoring during Procedural Sedation

JAMES R. MINER, MD, WILLIAM HEEGAARD, MD, MPH, DAVID PLUMMER, MD

RD. Rising $ETCO_2$ indicates hypoventilation, whereas hypoxia is a relatively late finding, especially in a patient receiving supplemental oxygen. Detecting hypoventilation before hypoxia develops would allow the clinician to intervene by stimulating the patient, evaluating the airway, and/or withholding additional sedatives.

Nasal-cannula $ETCO_2$ values correlate well


The Royal College of Anaesthetists

The Difficult Airway Society

NAP4

4th National Audit Project of
The Royal College of Anaesthetists and The Difficult Airway Society

Major complications of airway management in the United Kingdom

Report and findings
March 2011

Editors
Dr Tim Cook, Dr Nick Woodall and Dr Chris Frerk

The National Patient Safety Agency Patient Safety Division

The Intensive Care Society

The College of Emergency Medicine

skilled staff and equipment to manage these events successfully, delayed recognition of events and failed rescue due to lack of or failure of interpretation of capnography. The project findings suggest avoidable deaths due to airway complications occur in ICU and the emergency department.

- **Failure to use capnography in ventilated patients likely contributed to more than 70% of ICU related deaths.** Increasing use of capnography on ICU is the single change with the greatest potential to prevent deaths such as those reported to NAP4.
- **Displaced tracheostomy**, and to a lesser extent displaced tracheal tubes, were the greatest cause of major morbidity and mortality in ICU. Obese patients were at particular risk of such events and adverse outcome from them. All patients on ICU should have an emergency re-intubation plan.
- **Most events in the emergency department were complications of rapid sequence induction.** This was also an area of concern in ICU. RSI outside the operating theatre requires the same level of equipment and support as is needed during anaesthesia. This includes capnography and access for equipment needed to manage routine and difficult airway problems.

- In a world of monitors and machines, ♪ ♪ Where science meets the human beings, ♪ ♪ There's a tale of two heroes, silent and wise, ♪ ♪ Capnography and pulse oximetry, they arise. ♪
- Pulse oximetry, a beacon of light, ♪ ♪ Clipping on our fingers, oh so slight, ♪ ♪ Measuring oxygen levels, strong and true, ♪ ♪ Keeping us healthy, seeing us through.
- Capnography whispers secrets untold, ♪ ♪ Revealing airway issues, a story unfold, ♪ ♪ From intubation to anesthesia deep, ♪ ♪ It paints a picture, our lives it keeps. ♪
- So let's celebrate these two unsung knights, ♪ ♪ Capnography and pulse oximetry's might, ♪ ♪ For in their quiet hum, they offer us peace, ♪ ♪ Ensuring our health, our worries they ease. ♪

THANK YOU FOR LISTENING ☺

QUESTIONS?

zoetis