045 Anesthesiology Course

Fall 2021-2022

Anesthetic Monitoring

September 29, 2021

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Anesthetic Monitoring

Disclaimer and legal notice

Kindly, this lecture had been designed to fit the requirement of the Anesthesiology 045 course for the Medical students at the King Saud University. It is intended to be used solely for teaching purposes within the KSU and Anesthesiology 045 course.

We greatly appreciate your understanding

Anesthetic Monitoring

OBJECTIVES

At the end of the lecture you will be able to know the basics of anesthetic monitoring as follows:

- Definition
- What , When, How to monitor
- The policies that govern modern monitoring (Standards I and Standards II)

- The **basic monitors** and the **advanced monitors**
  - Arterial Oxygen Saturation- SpO_2
  - Expired CO_2 - $ETCO_2$
  - Awareness under anesthesia
    - Means to monitor the wakeful state of the brain
  - Other somatosensory and motor monitoring
  - Brief introduction about invasive hemodynamic monitoring and oxygenation of the brain
  - The neuromuscular junction relaxation monitoring

Anesthetic Monitoring

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Anesthetic Monitoring

Definition

What is ***Monitoring*** ?

Anesthetic Monitoring

Definition

What is ***Monitoring*** ?

- To observe and check the progress or quality of (something) over a period of time;
- Keep under systematic review.

Anesthetic Monitoring

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Anesthetic Monitoring

What do you **Monitor** in a patient?

- Vitals
  - Blood pressure
  - Heart rate
  - Respiratory rate
  - Temperature
- Color / skin
- Wakefulness state

Anesthetic Monitoring

What do you **Monitor** in a patient?

- Vitals
  - Q?: What vital sign had nowadays been measured very frequently ?
  - A: temperature in public areas during the pandemic

Anesthetic Monitoring

How do you **Monitor** in a patient?

- Physical exam
- Equipments (advances in technology)

Anesthetic Monitoring

Where do you monitor a patient?

- Hospital vs Out-of-Hospital setting
- Safe vs Dangerous place
  - (biologic, electric , chemical hazards, radioactive, etc…)

Anesthetic Monitoring

What **determines** the **Standards of Care** for **monitoring** a patient

What are you responsible for

Depends on

- **Patient/ illness**
- **Equipments/ technology**
- **Rules/ legislation**
  - Every institution or hospital may have its own policies that are based on evidence. Or adopted other national and international policies.
- **Place**
  - In-hospital Vs Out-of Hospital

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Anesthetic Monitoring

Standards for Intraoperative Monitoring

https://www.asahq.org/standards-and-guidelines/standards-for-basic-anesthetic-monitoring

American Society of Anesthesiologists

STANDARDS FOR BASIC ANESTHETIC MONITORING

Committee of Origin: Standards and Practice Parameters

(Approved by the ASA House of Delegates on October 21, 1986, last amended on October 20, 2010, and last affirmed on October 28, 2015)

These standards apply to all anesthesia care although, in emergency circumstances, appropriate life support measures take precedence. These standards may be exceeded at any time based on the judgment of the responsible anesthesiologist. They are intended to encourage quality patient care, but observing them cannot guarantee any specific patient outcome. They are subject to revision from time to time, as warranted by the evolution of technology and practice. They apply to all general anesthetics, regional anesthetics and monitored anesthesia care. This set of standards addresses only the issue of basic anesthetic monitoring, which is one component of anesthesia care. In certain rare or unusual circumstances, 1) some of these methods of monitoring may be clinically impractical, and 2) appropriate use of the described monitoring methods may fail to detect untoward clinical developments. Brief interruptions of continual† monitoring may be unavoidable. These standards are not intended for application to the care of the obstetrical patient in labor or in the conduct of pain management.

1. STANDARD I

Qualified anesthesia personnel shall be present in the room throughout the conduct of all general anesthetics, regional anesthetics and monitored anesthesia care.

1.1 Objective –

Because of the rapid changes in patient status during anesthesia, qualified anesthesia personnel shall be continuously present to monitor the patient and provide anesthesia

Anesthetic Monitoring

ASA Standards for Anesthetic Monitoring

Standard I

Anesthetic Monitoring

ASA Standards for Anesthetic Monitoring

Standard I

Standard II

Anesthetic Monitoring

ASA Standards for Anesthetic Monitoring

Standard I

Qualified anesthesia personnel shall be present in the room throughout the conduct of all general anesthetics, regional anesthetics and monitored anesthesia care.

Standard II

During all anesthetics, the patient's **oxygenation, ventilation, circulation and temperature** shall be continually evaluated

Anesthetic Monitoring

Standards for Anesthetic Monitoring

These standards

- apply to all anesthesia care

Anesthetic Monitoring

Standards for Anesthetic Monitoring

These standards

•apply to all anesthesia care although, In emergency circumstances, **appropriate life support measures take precedence.**

Anesthetic Monitoring

Standards for Anesthetic Monitoring

These standards

- apply to all anesthesia care although, In emergency circumstances, **appropriate life support measures take precedence.**

  - **So for example you may skip the temperature monitoring during the initial phases of ACLS or PALS**

Anesthetic Monitoring

Standards for Anesthetic Monitoring

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Anesthetic Monitoring

Standards for Monitoring Anesthetic

Brief **interruptions** of monitoring may be unavoidable.

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So you many **not be able** to monitor and document **"continuously at every second interval"**

Anesthetic Monitoring

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Hence the term **“Continual”** instead of **“Continuous”**

Anesthetic Monitoring

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"**continual**" is defined as "repeated regularly and frequently in steady rapid succession"

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So how frequent should it be? (as stated in Standard II)

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On the general ward, documenting vitals routinely would be every 8 hrs or every nursing team shift.

Anesthetic Monitoring

Standards for Monitoring Anesthetic

Brief **interruptions** of monitoring may be unavoidable.

So how frequent should it be? (as stated in Standard II)

On the general ward, documenting vitals routinely would be every 8 hrs or every nursing team shift.

In closed observation units (intensive care units) documenting patient's status would be at least every one hour or more frequently as per patient's condition.

Anesthetic Monitoring

Standards for Monitoring Anesthetic

Brief **interruptions** of monitoring may be unavoidable.

So how frequent should it be? (as stated in Standard II)

Frequency of mandatory monitoring varies between each category,

but **never exceeds five minutes.**

Otherwise, a reason should be documented on the patient's record (for medico-legal purposes)

Anesthetic Monitoring

Standards for Anesthetic Monitoring

Why should the frequency of mandatory monitoring should never exceeds five minutes.

Standard I

Qualified anesthesia personnel shall be present in the room throughout the conduct of all general anesthetics, regional anesthetics and monitored anesthesia care.

• Due to the rapidity of occurrence of physiologic derangement during surgical interference

- Neurodepression/respiratory depression
- Cardiodepression/ alterations in BP, C.O.
- Vasodilation
  - Low BP affects perfusion to vital organs
  - Low Oxygen affects metabolism of organs
- Bleeding
- Acid and blood gases, Fluid and electrolytes imbalance
- Hypothermia
- Myocardial infarction, acute heart failure and arrhythmias
- Brain ischemia
- Hypoperfusion to vital organs
- Anaphylaxis
- Etc…..

Anesthetic Monitoring

Standards for Anesthetic Monitoring

Standard I

Qualified anesthesia personnel shall be present in the room throughout the conduct of all general anesthetics, regional anesthetics and monitored anesthesia care.

- If there is a direct known hazard,
  - e.g., **radiation, to the anesthesia** personnel
  - which might require intermittent remote observation of the patient,

  - some provision for monitoring the patient must be made, via tele monitoring (cameras to the patient and monitor or satellite monitor out of the radiation area)

Anesthetic Monitoring

Standards for Anesthetic Monitoring

Standard I

In the event that an **emergency** requires the temporary absence of the person primarily responsible for the anesthetic,

the best judgment of the anesthesiologist will be exercised in **comparing the emergency with the anesthetized patient's condition**

and in the selection of the person left responsible for the anesthetic during the temporary absence.

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Anesthetic Monitoring

Standards for Anesthetic Monitoring

Standard II

As stated previously

During all anesthetics, the patient's **oxygenation, ventilation, circulation and temperature** shall be continually evaluated

Anesthetic Monitoring

Standards for Anesthetic Monitoring

Basic Monitors

Standard II

The following are all specifically mandated.

Anesthetic Monitoring

Standards for Anesthetic Monitoring

Basic Monitors

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1. Oxygen analyzer with a low inspired concentration limit alarm during general anesthesia

Anesthetic Monitoring

Standards for Anesthetic Monitoring

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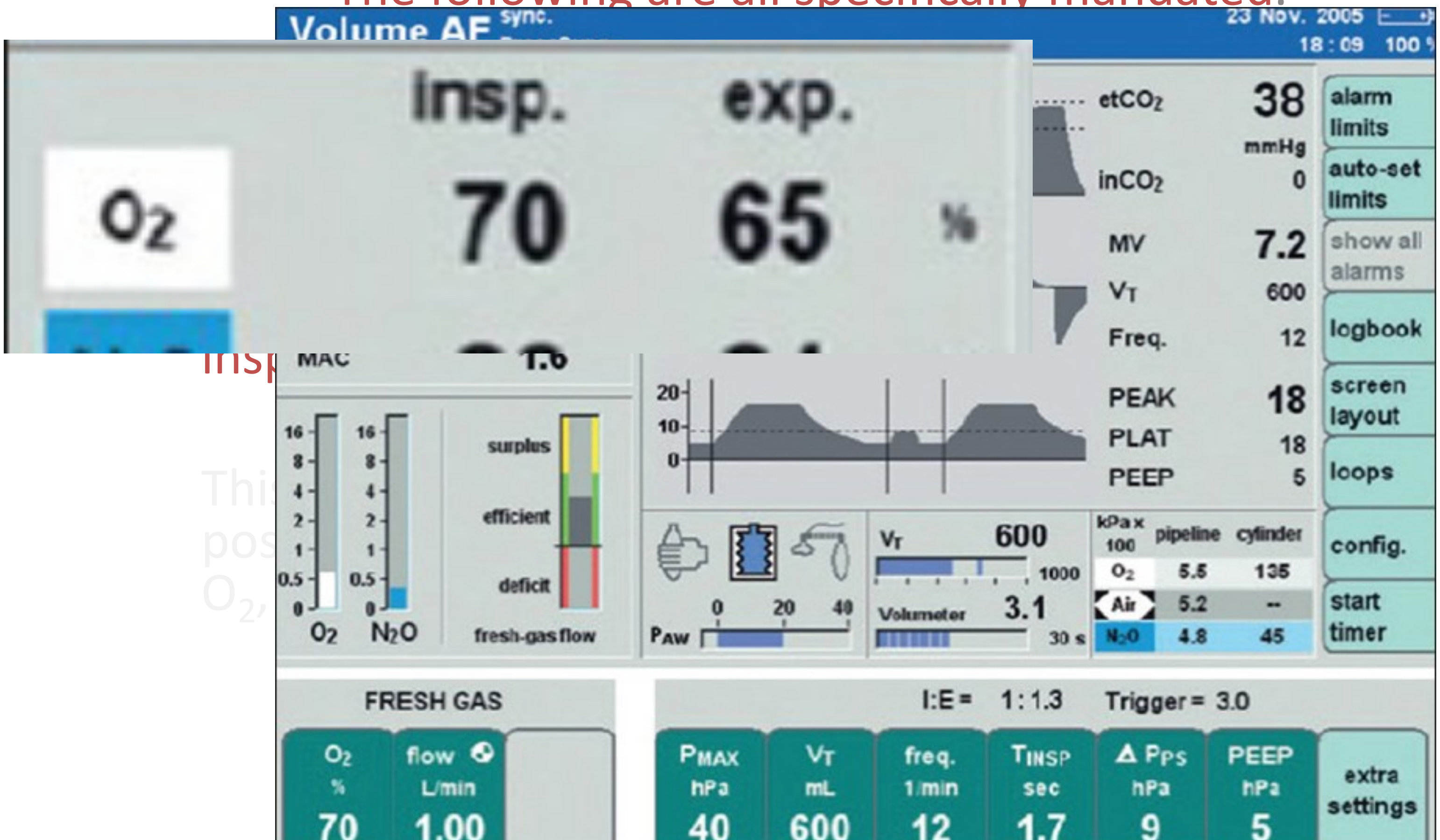

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Anesthetic Monitoring

Standards for Anesthetic Monitoring

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The following are all specifically mandated.

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Most modern anesthesia machines monitor both inspired and expired concentrations of O2

This is essential during anesthesia because it is possible to deliver a hypoxic gas mixture when mixing O_2, air, nitrous oxide, and/or volatile anesthetic agents.

Anesthetic Monitoring

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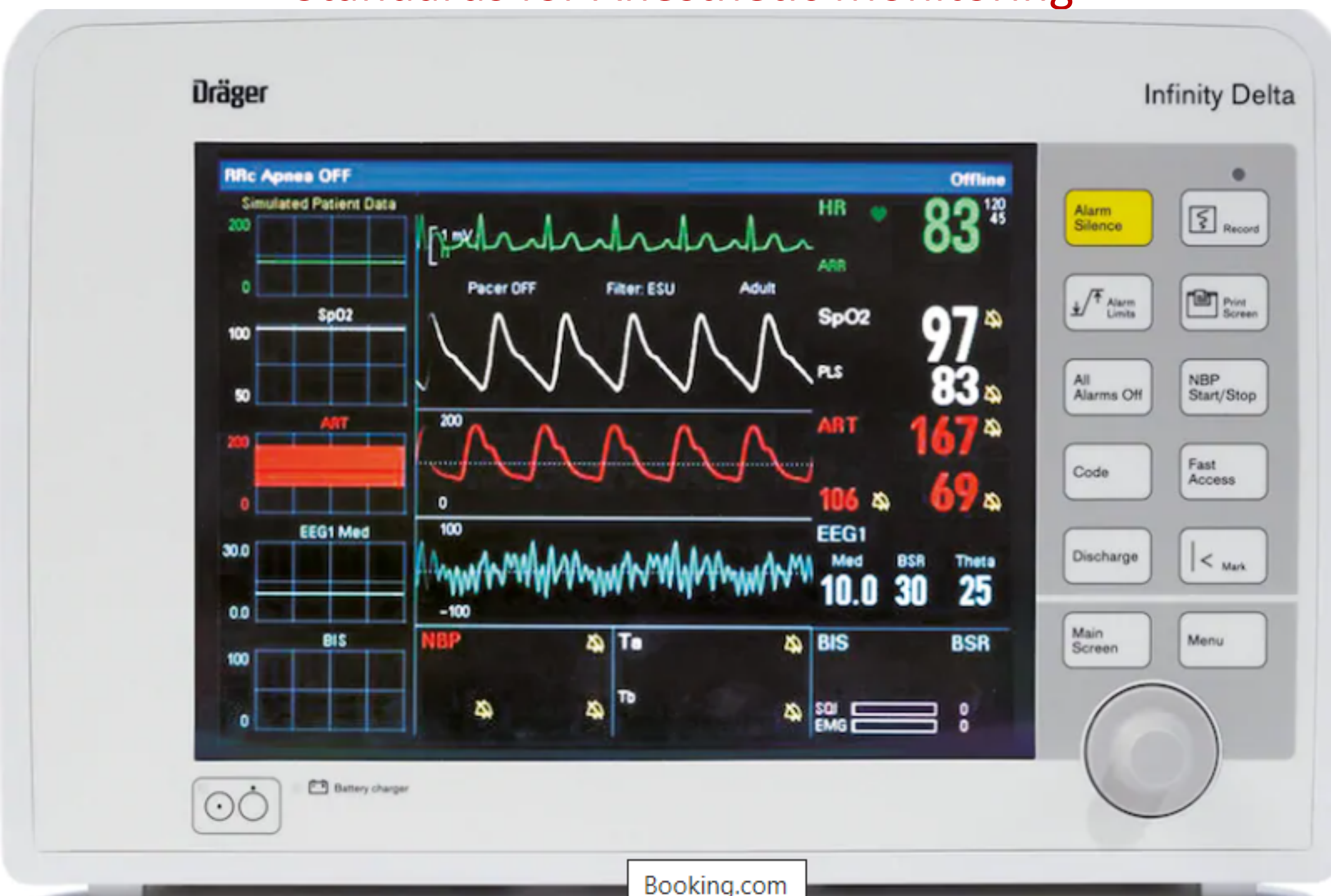
2. Quantitative assessment of blood oxygenation

Anesthetic Monitoring

Standards for Anesthetic Monitoring



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Anesthetic Monitoring

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Pulse Oximetry

- Provides quantitative analysis of the patient's saturation of hemoglobin with O_2.

Anesthetic Monitoring

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The following are all specifically mandated.

1. Oxygen analyzer with a low inspired concentration limit alarm during general anesthesia

2. Quantitative assessment of blood oxygenation

3. Ensuring adequate ventilation during all anesthetic care including verification of
   - expired oxygen (when possible),
   - tidal volume, quantitative measurement of
   - capnography

   in all general anesthetics.

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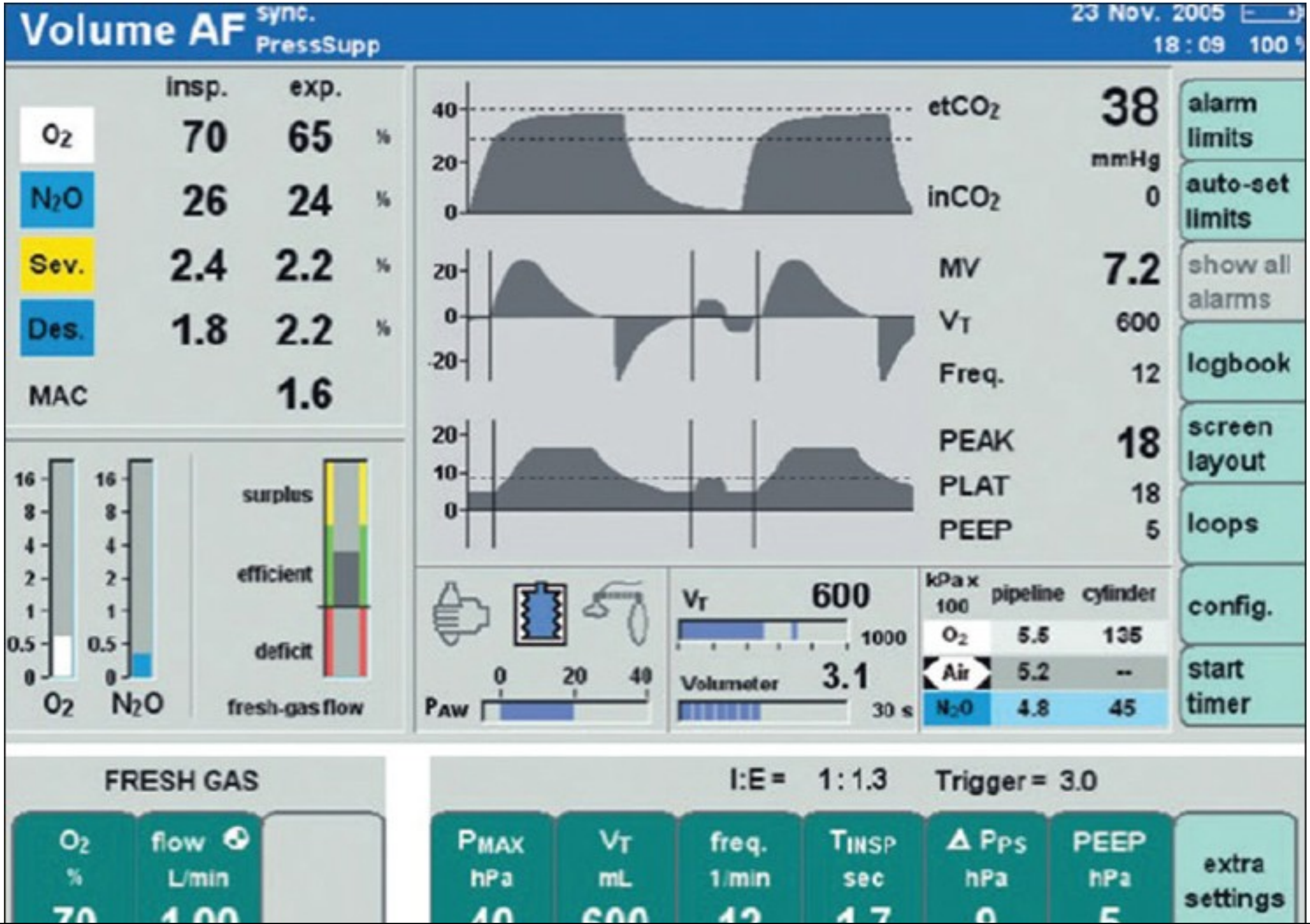

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Anesthetic Monitoring

Standards for Anesthetic Monitoring

Basic Monitors

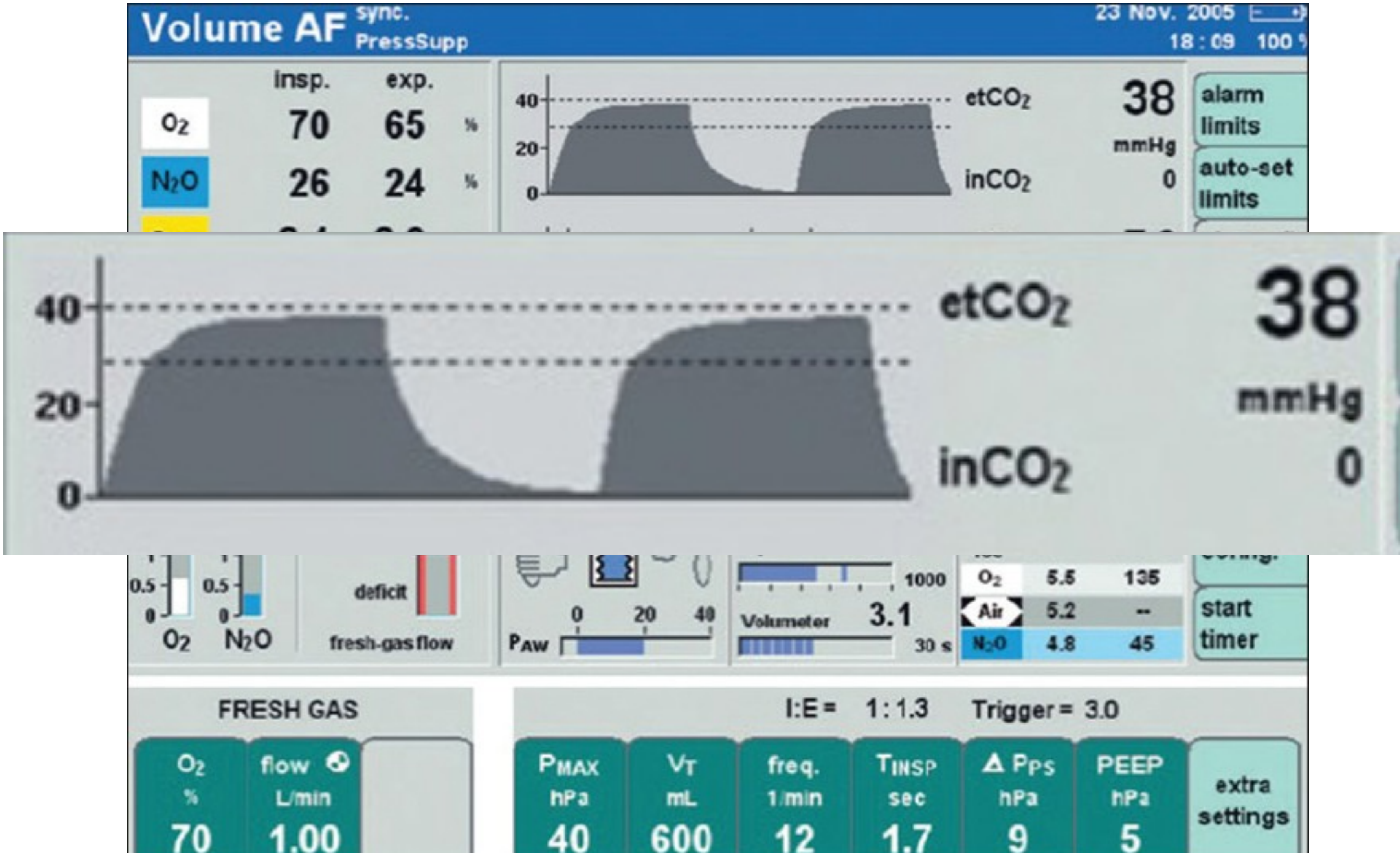
Standard II

The following are all specifically mandated.

4. Quantitative evaluation of ventilation is required during all other care.

Anesthetic Monitoring

Standards for Anesthetic Monitoring



Anesthetic Monitoring

Standards for Anesthetic Monitoring

Basic Monitors

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4. Quantitative evaluation of ventilation is required during all other care.

   - Inspired and expired CO_2
   - Expired CO2 is frequently **displayed** through **capnography** with a displayed value correlating to the **peak expired CO_2** of each breath

Anesthetic Monitoring

Standards for Anesthetic Monitoring

Basic Monitors

Standard II

The following are all specifically mandated.

4. Quantitative evaluation of ventilation is required during all other care.
5. Ensure **correct placement** of **endotracheal tube** or **laryngeal mask airway** via expired carbon dioxide ($EtCO_2$)

Anesthetic Monitoring

Standards for Anesthetic Monitoring

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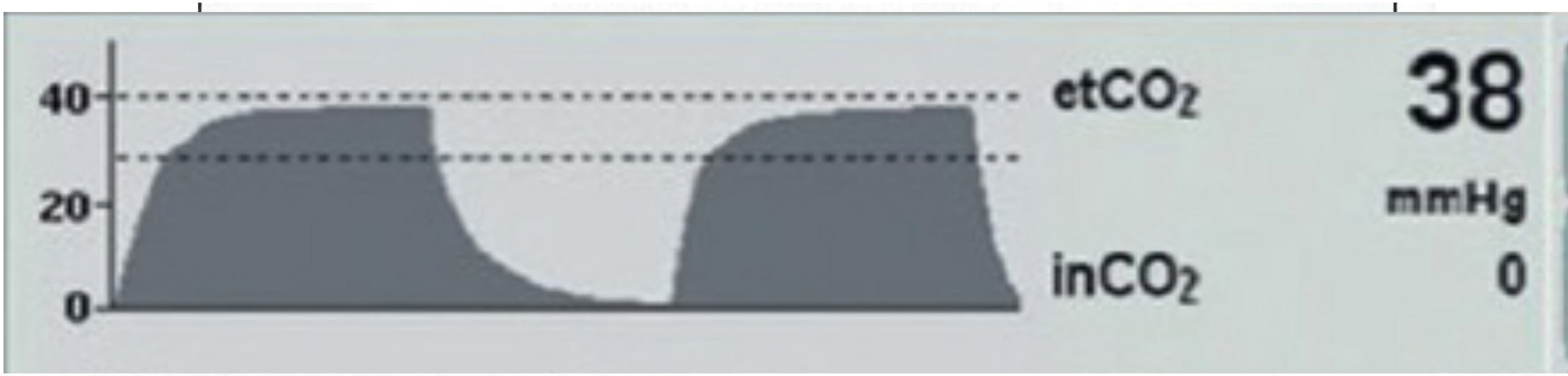
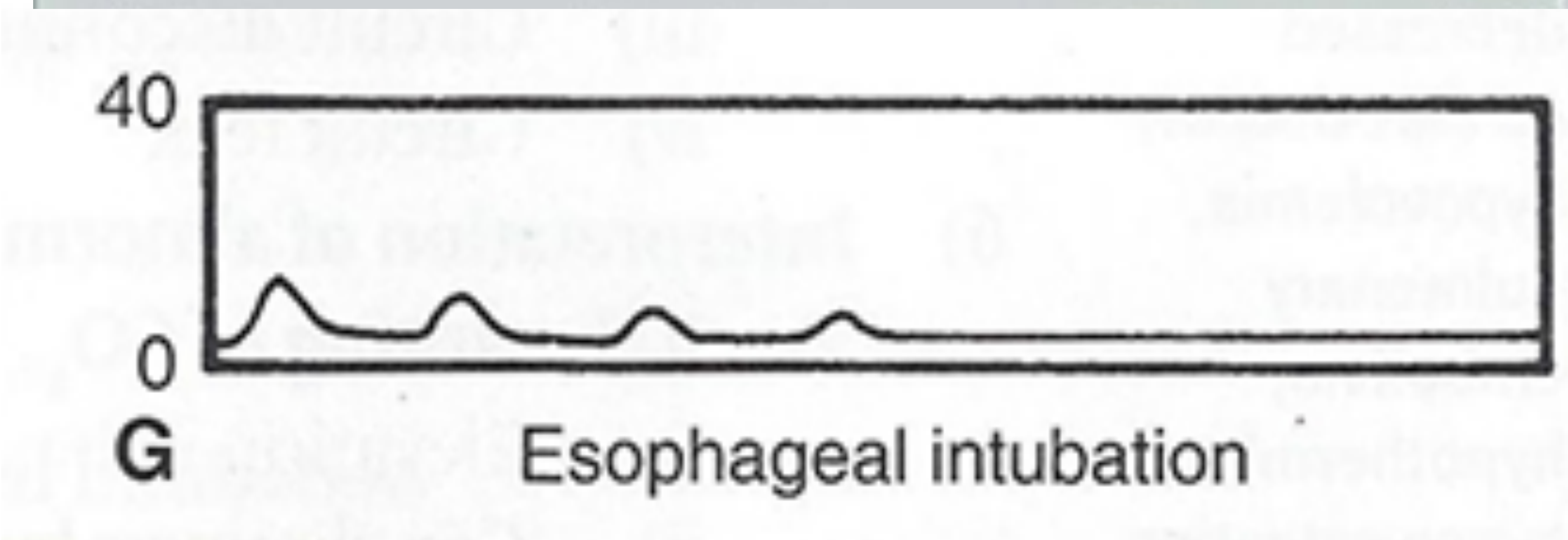
4. Quantitative evaluation of ventilation is required during all other care.
5. Ensure **correct placement** of **endotracheal tube** or **laryngeal mask airway** via expired carbon dioxide ($EtCO_2$)
    - Observation of bilateral chest movement and air entry, as well as auscultation of the chest is also necessary.

Anesthetic Monitoring

Standards for Anesthetic Monitoring





Anesthetic Monitoring

Standards for Anesthetic Monitoring

Basic Monitors

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4. Quantitative evaluation of ventilation is required during all other care.
5. Ensure **correct placement** of **endotracheal tube** or **laryngeal mask airway** via expired carbon dioxide ($EtCO_2$).
6. **Alarms** for breathing circuit disconnection or leak when a mechanical ventilator is used

Anesthetic Monitoring

Standards for Anesthetic Monitoring

Basic Monitors

Standard II

The following are all specifically mandated.

7. Continuous display of ECG

Anesthetic Monitoring

Standards for Anesthetic Monitoring

Basic Monitors

Standard II

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7. Continuous display of ECG
8. Determination of arterial **BP and heart rate at least every 5 minutes.**

Anesthetic Monitoring

Standards for Anesthetic Monitoring

Basic Monitors

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7. Continuous display of ECG
8. Determination of arterial **BP and heart rate at least every 5 minutes.**
9. Adequacy of circulation is to be determined by quality of pulse (either electronically, through palpation, or auscultation)

Anesthetic Monitoring

Standards for Anesthetic Monitoring

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7. Continuous display of ECG
8. Determination of arterial **BP and heart rate at least every 5 minutes.**
9. Adequacy of circulation is to be determined by quality of pulse either electronically, through palpation, or auscultation
10. The means to determine temperature must be available and should be employed when changes in temperature are anticipated or intended.

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Anesthetic Monitoring

Standards for Anesthetic Monitoring

Basic Monitors

Standard II

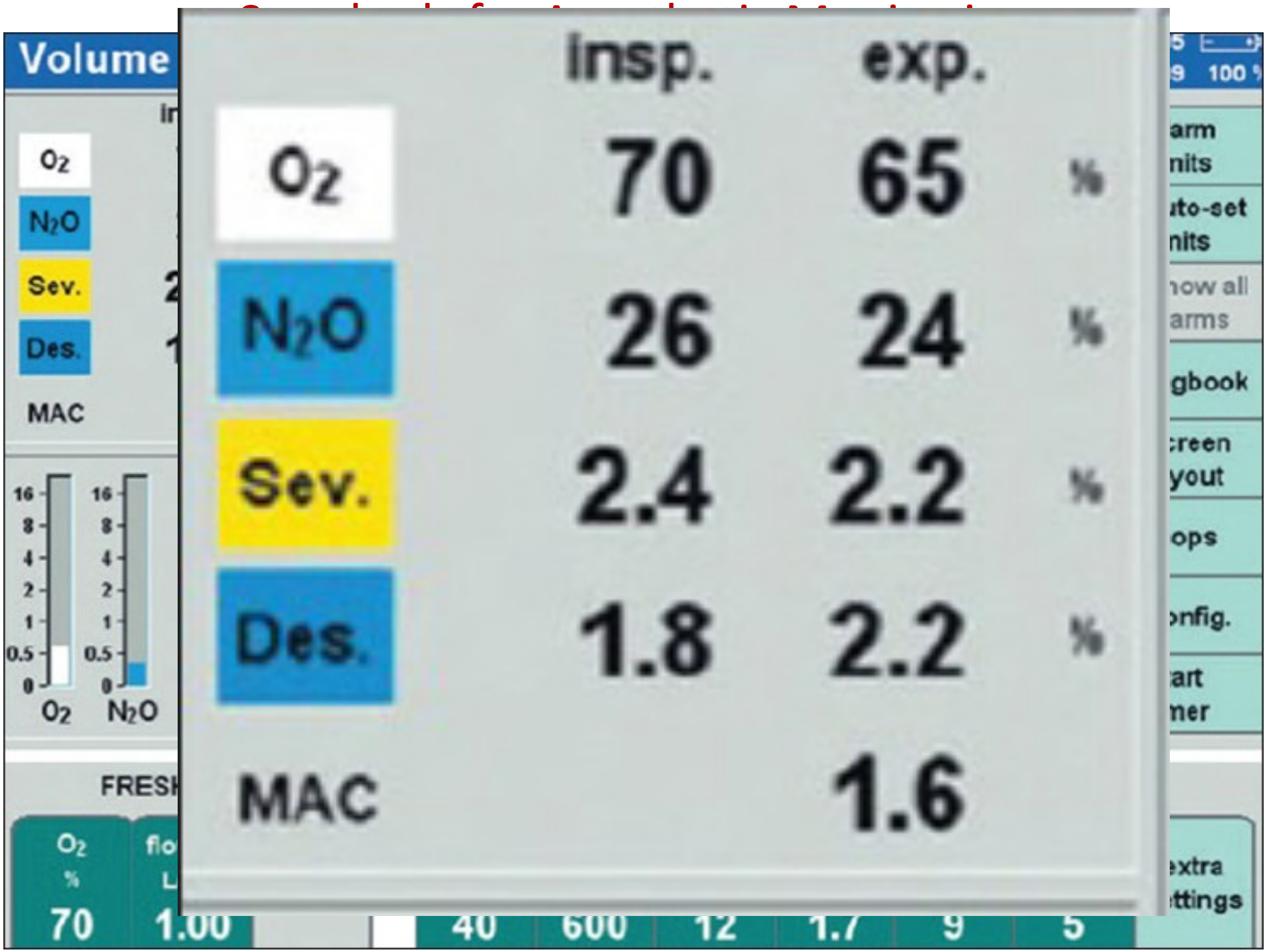
The following are all specifically mandated.

Multiple expired gas analysis

a) Allows determination of the **percent inspired and expired** of the volatile agents and nitrous oxide.

b) This allows the ability to better determine the **delivery of an adequate anesthetic without over or under dose.**

Anesthetic Monitoring



Anesthetic Monitoring

Standards for Anesthetic Monitoring

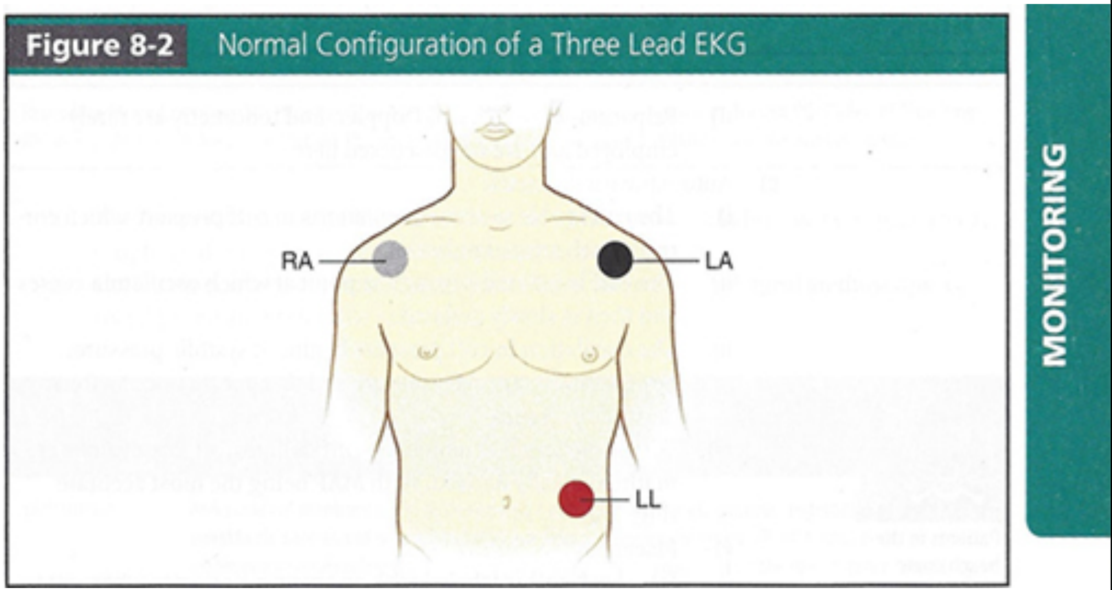
Basic Monitors

Standard II

The following are all specifically mandated

ECG

- The minimum



Anesthetic Monitoring

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Basic Monitors

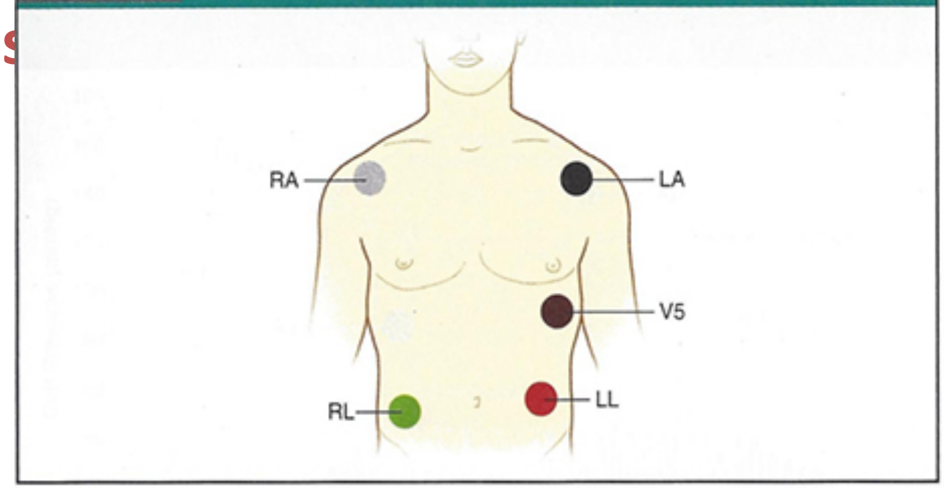
Standard II

The following are all specifically mandated

ECG

- The minimum of **three leads** is to be used although **five leads** adults.

Figure 8-1 Normal Five Lead ECG Lead Placement



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The following are all specifically mandated.

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- The minimum of three leads is to be used, although **five leads** are used for most adults.
- Consideration must be taken for the surgical field and patient positioning.

Anesthetic Monitoring

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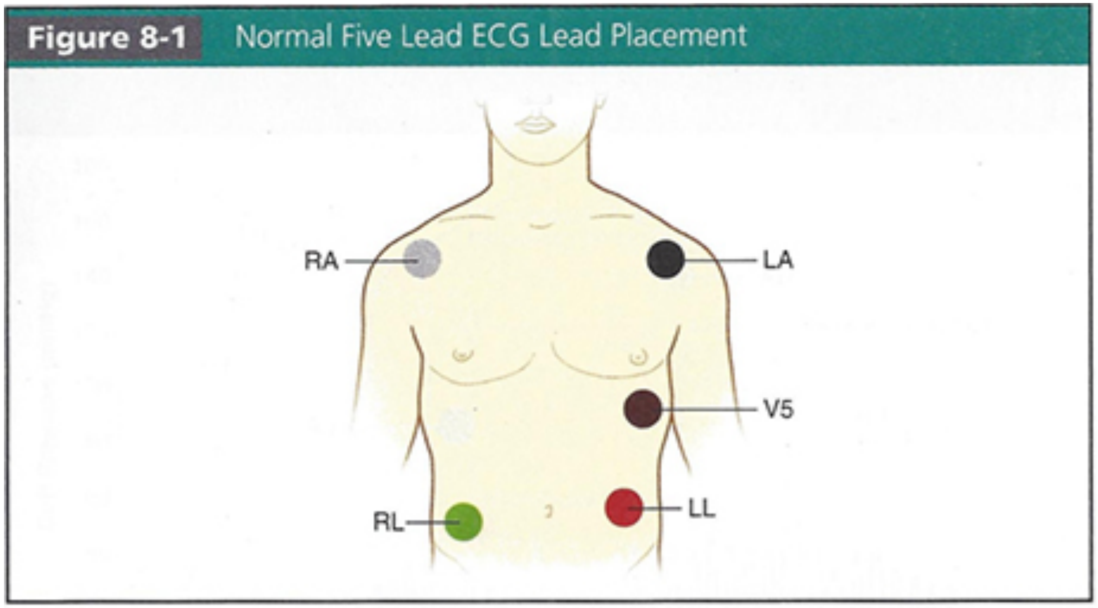
ECG

- The minimum of three leads is to be used, although **five leads** are used for most adults.
- Consideration must be taken for the surgical field and patient positioning.
  - Lead placement is commonly altered for cases involving the chest, shoulders, back, and neck.

Anesthetic Monitoring



nitoring

mandated.

- **Five Lead ECG**
  - Includes the right arm **(RA)**, **left arm (LA)**, **right leg (RL)**, **left leg (LL), and V.**
  - The five lead arrangement can be used to display **I, II, III, aVR, aVL, aVF, and/or V**

Anesthetic Monitoring

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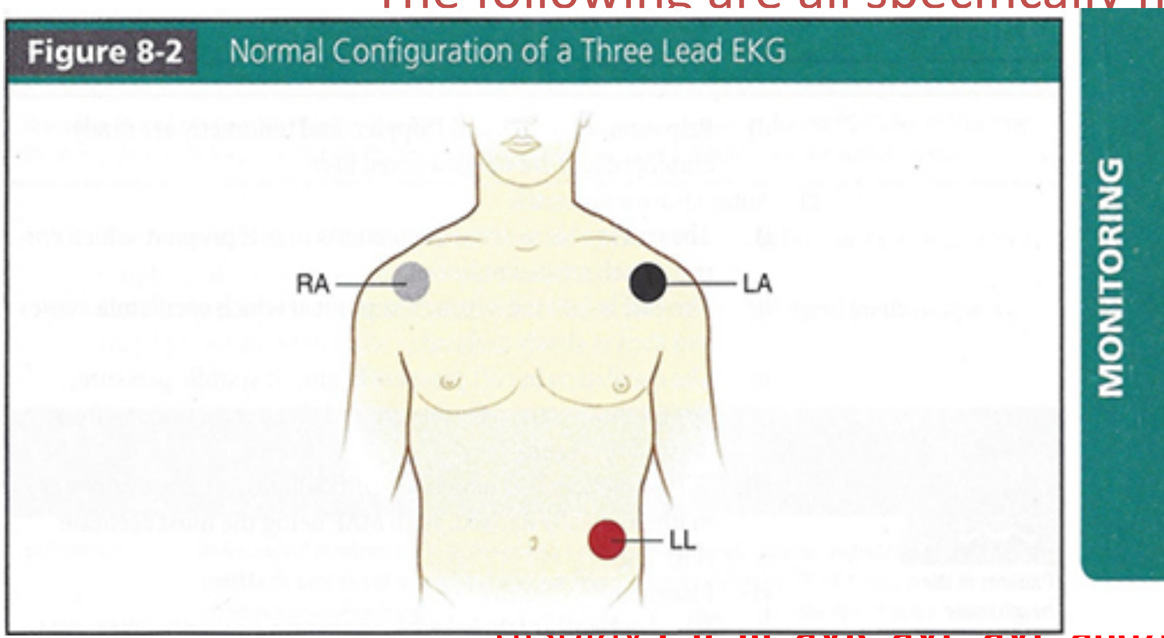


arm (LA), right

be used to

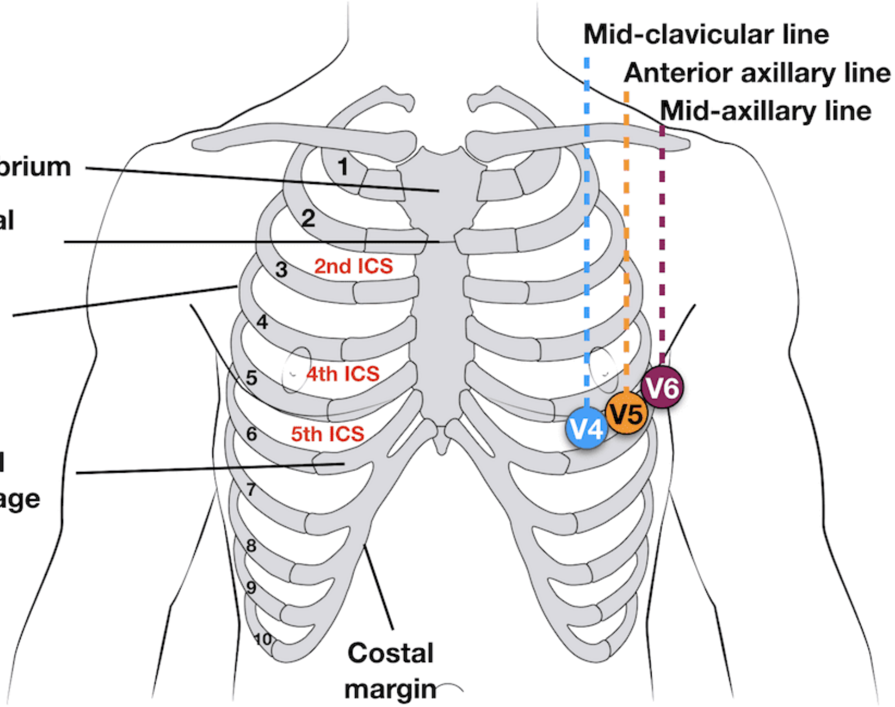
display I, II, III, aVR, aVL, aVF, and/or V

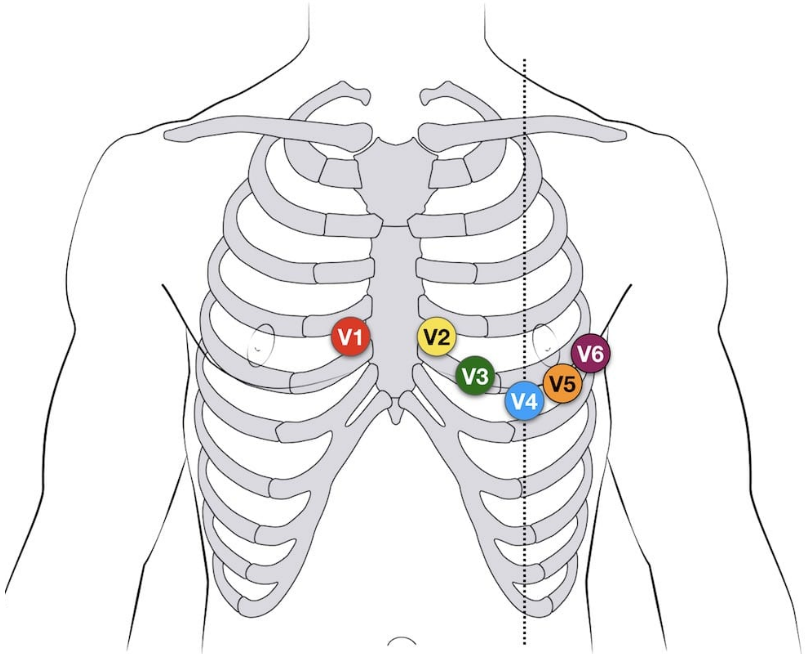
- **Three lead ECG**
  - Includes the **RA, LA, and LL leads**
  - **and can be used to display leads I, II,and/or III**

Anesthetic Monitoring

Standards for Anesthetic Monitoring

Chest External Landmarks for the V leads





https://www.litfl.com/ecg-lead-positioning/

Anesthetic Monitoring

Standards for Anesthetic Monitoring

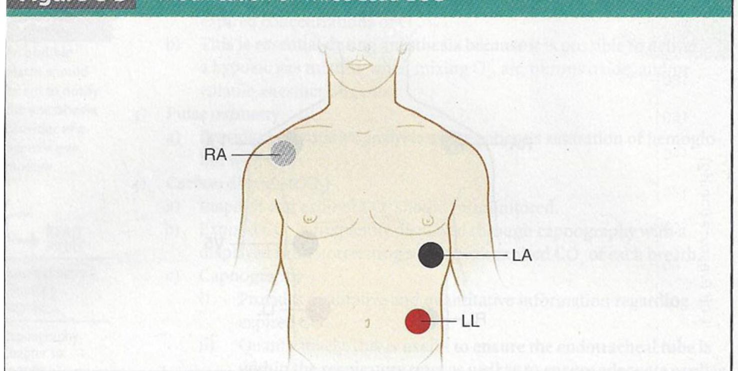
Basic Monitors

ECG

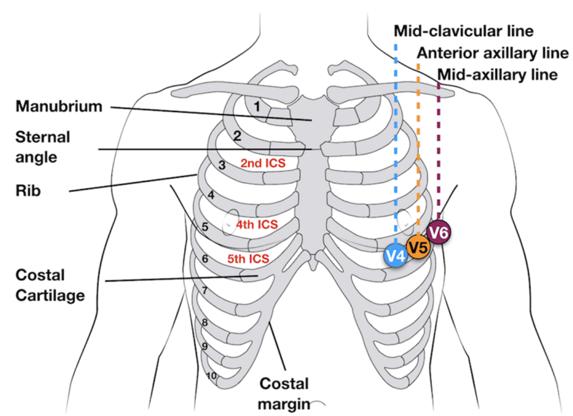
A three lead ECG can be modified to display V5

- by moving the LA lead to the V5 position in the fifth intercostal space at the anterior axillary line

Figure 8-3 Modification of Three Lead ECG



Modification of the three lead ECG allows display of both leads II and V_5. Lead V_5 is monitored through the display of lead I in this configuration.



Anesthetic Monitoring

Standards for Anesthetic Monitoring

Basic Monitors

ECG

The most commonly monitored leads are II and V5

- Lead II is best used to monitor rhythm because it provides the best visibility of the P wave

- Lead V5 monitors for anterior and lateral ischemic events

Anesthetic Monitoring

Standards for Anesthetic Monitoring

ECG

Sensitivity of Various Lead Combinations for Detecting Ischemia

London et al.		Landesberg et al.	
Single leads V_5, V_4, and V_3	75%, 61%, and 24%, respectively	Single leads V_5, V_4, and V_3	75%, 83%, and 75%, respectively

ischemic events

Anesthetic Monitoring

Standards for Anesthetic Monitoring

ECG

Anesthetic Monitoring

Standards for Anesthetic Monitoring

ECG

If an arrhythmia or ischemic event appears to be present, the ability to viewing all leads simultaneously may be helpful for diagnostic purposes.

Anesthetic Monitoring

Standards for Anesthetic Monitoring
Standard II
Arterial Blood Pressure

Arterial blood pressure (BP)

BP can be monitored **non-invasively**

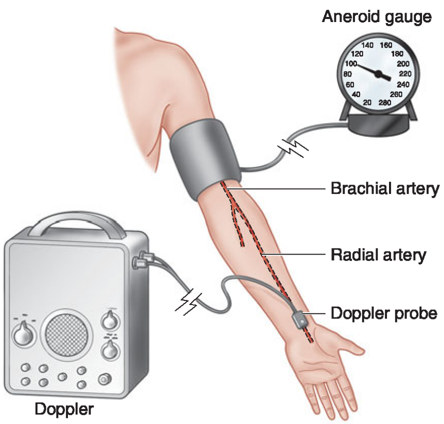


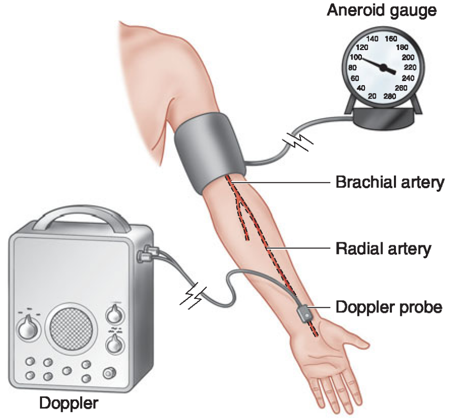
FIGURE 5–3 A Doppler probe secured over the radial artery will sense red blood cell movement as long as the blood pressure cuff is below systolic pressure. (Reproduced, with permission, from Parks Medical Electronics.)

Anesthetic Monitoring

Standards for Anesthetic Monitoring
Standard II
Arterial Blood Pressure

Arterial blood pressure (BP)

BP can be monitored **non-invasively** or **invasively**.



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Anesthetic Monitoring

Standards for Anesthetic Monitoring
Standard II
Arterial Blood Pressure

Arterial blood pressure (BP)

Automatic oscillometric

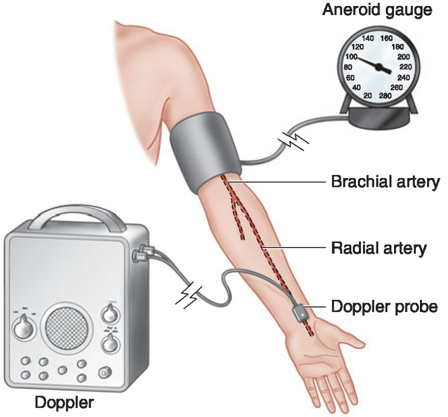
i. The cuff is able to sense oscillations in cuff pressure which correlate with arterial pulsation.

ii. Placement

   1. Each cuff is labeled with an arrow pointing to where arterial pulsation is felt best.
   2. The cuff is then placed on the arm over the brachial artery, forearm over the radial artery, or thigh/calf over the popliteal artery.

iii. Patient positioning

   1. When monitoring non-invasive pressure, consideration must be taken of patient position.



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Anesthetic Monitoring

Standards for Anesthetic Monitoring

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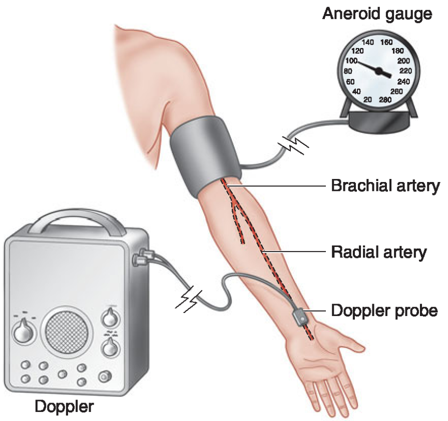

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Anesthetic Monitoring

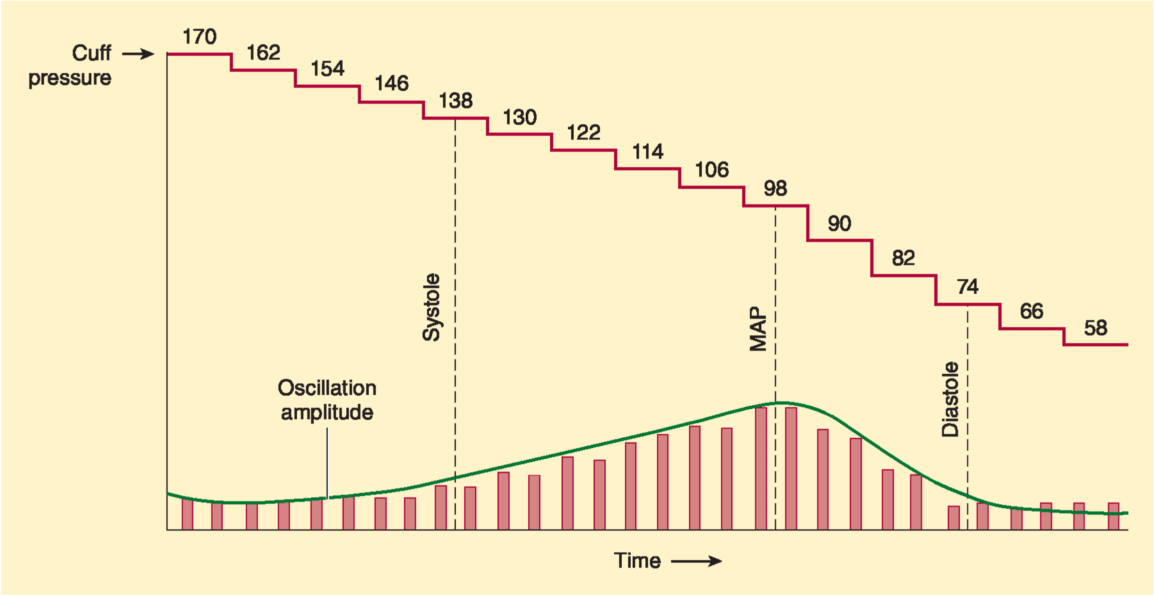


FIGURE 5–4 Oscillometric determination of blood pressure.

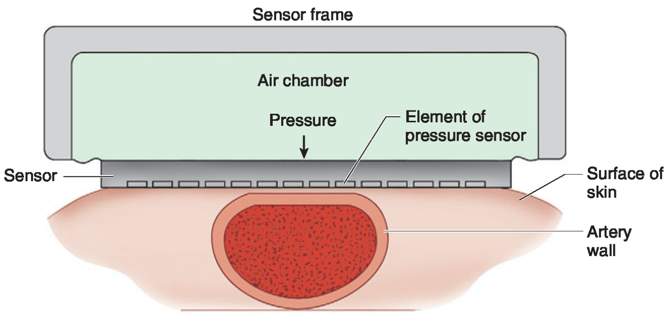


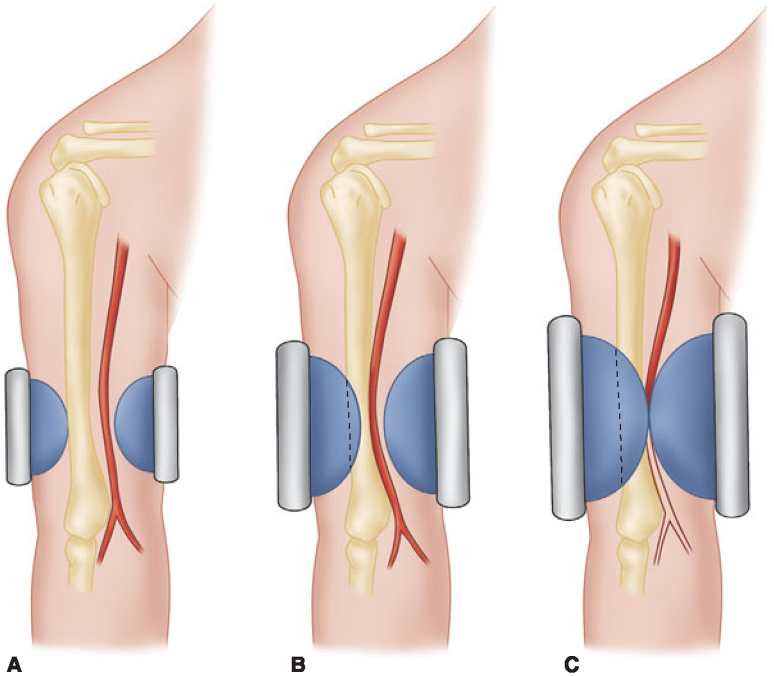
FIGURE 5–5 Tonometry is a method of continuous (beat-to-beat) arterial blood pressure determination. The sensors must be positioned directly over the artery.

Anesthetic Monitoring

Standards for Anesthetic Monitoring

Arterial blood pressure (BP)

FIGURE 5–6 Blood pressure cuff width influences the pressure readings. Three cuffs, all inflated to the same pressure, are shown. The narrowest cuff (**A**) will require more pressure, and the widest cuff (**C**) less pressure, to occlude the brachial artery for determination of systolic pressure. Too narrow a cuff may produce a large overestimation of systolic pressure. Whereas the wider cuff may underestimate the systolic pressure, the error with a cuff 20% too wide is not as significant as the error with a cuff 20% too narrow. (Reproduced, with permission, from Gravenstein JS, Paulus DA: *Clinical Monitoring Practice*, 2nd ed. Lippincott, Philadelphia, 1987.)



Anesthetic Monitoring

Modalities for Anesthetic Monitoring

Invasive pressure monitoring

allows for continuous beat to beat monitoring of arterial blood pressure displayed as a waveform

Anesthetic Monitoring

Modalities for Anesthetic Monitoring

Invasive pressure monitoring

allows for continuous beat to beat monitoring of arterial blood pressure displayed as a waveform and provides access for arterial sampling

Monitors Arterial Blood Gases and electrolytes, and Hemoglobin

Anesthetic Monitoring

Modalities for Anesthetic Monitoring

Invasive pressure monitoring

Cannulation technique

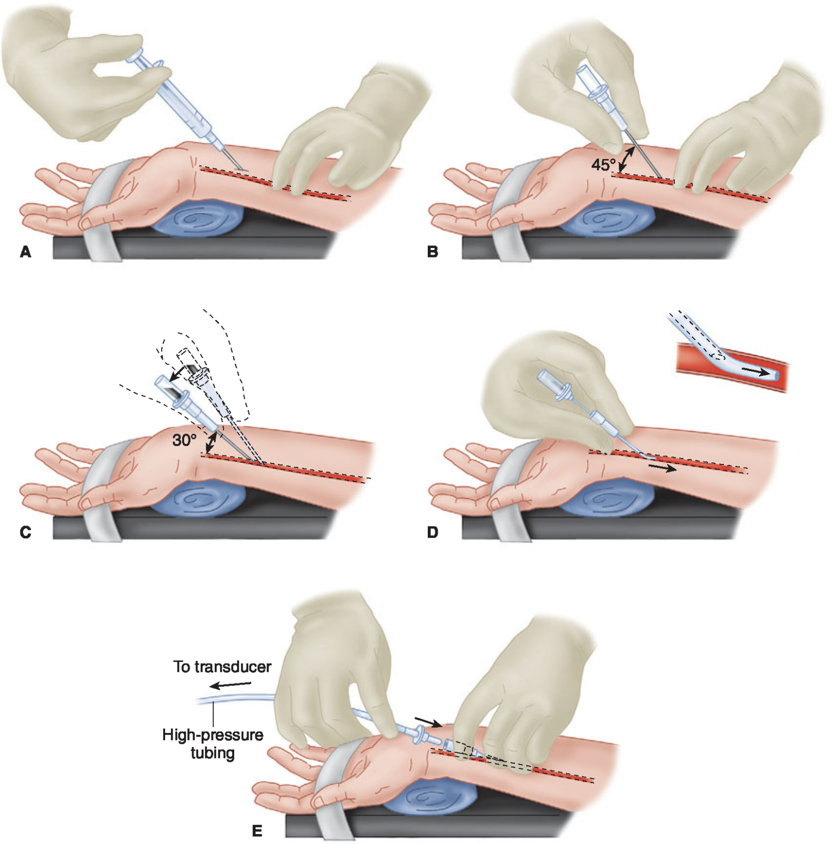


FIGURE 5–7 Cannulation of the radial artery. **A:** Proper positioning and palpation of the artery are crucial. After skin preparation, local anesthetic is infiltrated with a 25-gauge needle. **B:** A 20- or 22-gauge catheter is advanced through the skin at a 45° angle. **C:** Flashback of blood signals entry into the artery, and the catheter–needle assembly is lowered to a 30° angle and advanced 1–2 mm to ensure an intraluminal catheter position. **D:** The catheter is advanced over the needle, which is withdrawn. **E:** Proximal pressure with middle and ring fingers prevents blood loss, while the arterial tubing Luer-lock connector is secured to the intraarterial catheter.

Anesthetic Monitoring

Standards for Anesthetic Monitoring

Basic Monitors

Standard II

The following are all specifically mandated.

Temperature

a. Temperature changes should be anticipated and expected under any general anesthetic and therefore **any general anesthetic requires temperature measurement.**

- Very brief procedures may be an exception, but the availability of temperature monitoring should be recorded.

Anesthetic Monitoring

Standards for Anesthetic Monitoring

Basic Monitors

Standard II

The following are all specifically mandated.

Temperature

- The temperature may be measured from many locations including:
  - skin, nasopharynx, esophageal, bladder, rectal, or a pulmonary arterial catheter.

- **Core temperatures** obtained preferably from
  - a **pulmonary catheter**,
  - **esophageal** probe,
  - or **rectal probe**

Anesthetic Monitoring

OBJECTIVES

At the end of the lecture you will be able to know the basics of anesthetic monitoring as follows:

- Definition
- What , When, How to monitor
- The policies that govern modern monitoring
  (Standards I and Standards II)

- The **basic monitors** and the **advanced monitors**
  - **Arterial Oxygen Saturation- SpO2**
  - Expired CO2 - ETCO2
  - Awareness under anesthesia
    - Means to monitor the wakeful state of the brain
  - Other somatosensory and motor monitoring
  - Brief introduction about invasive hemodynamic monitoring and oxygenation of the brain
  - The neuromuscular junction relaxation monitoring

Anesthetic Monitoring

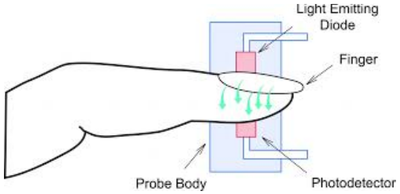
Modalities for Anesthetic Monitoring

Pulse Oximetry (SpO_2)

Is one of the **most commonly employed monitoring modalities in anesthesia**.

It is a **non-invasive** way to monitor the oxygenation of a patient's hemoglobin.

A sensor with both red and infrared wavelengths is placed on the patient.



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Absorption of these wavelengths by the blood is measured and **oxygen saturation (SpO_2)** can be calculated.

Anesthetic Monitoring

Modalities for Anesthetic Monitoring

Oximetry

Basic Concepts

There are two main types of oximetry:

Fractional oximetry

SaO_2

Can only be measured by an **arterial blood sample**

and Functional oximetry

SpO_2

Can be measured noninvasively by a **standard pulse oximeter**

Anesthetic Monitoring

Modalities for Anesthetic Monitoring

Oximetry

Basic Concepts

Fractional oximetry

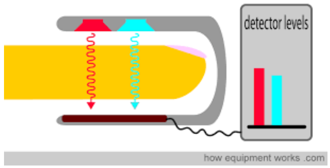
$$SaO_2 = \frac{\text{Oxyhemoglobin}}{(\text{oxyhemoglobin} + \text{deoxyhemoglobin} + \text{methemoglobin} + \text{carboxyhemoglobin})}$$

Functional oximetry

$$SpO_2 = \frac{\text{Oxyhemoglobin}}{(\text{oxyhemoglobin} + \text{deoxyhemoglobin})}$$

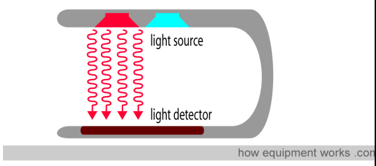
Anesthetic Monitoring

Modalities for Anesthetic Monitoring

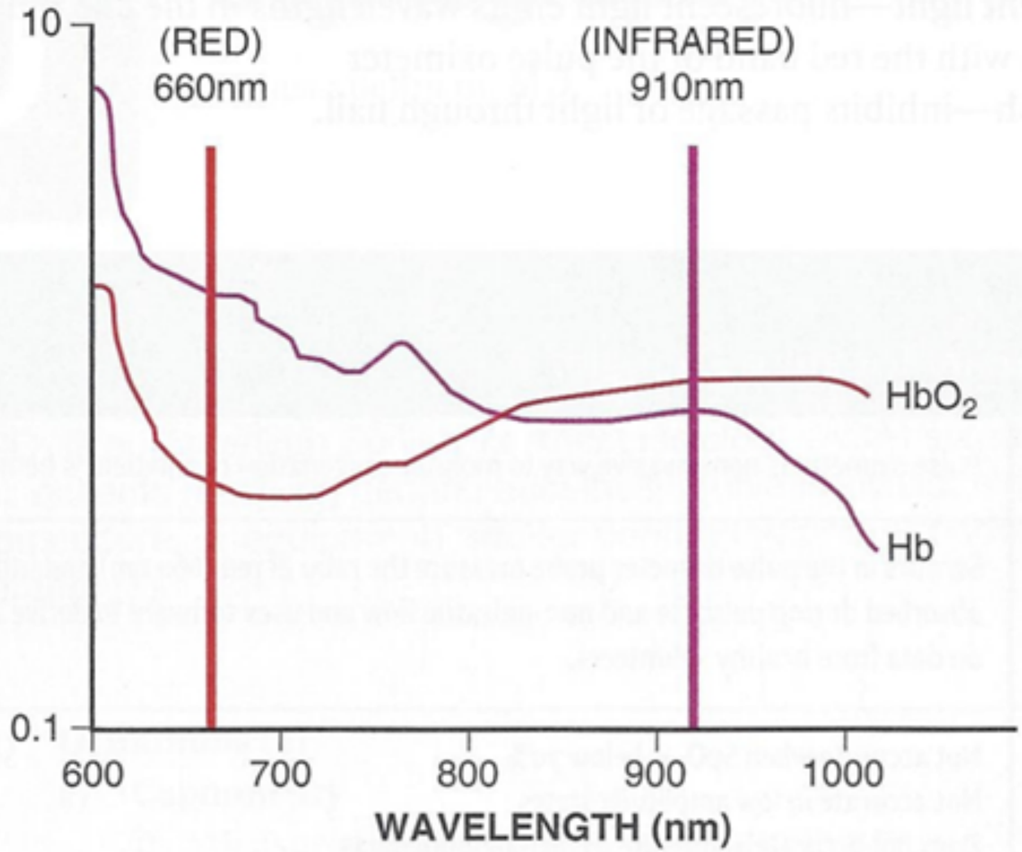


How pulse oximetry works

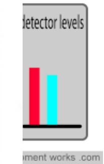
a) A pulse oximeter emits two wavelengths of light:



Anesthetic Monitoring



Oxygenated hemoglobin (*red line*) absorbs more infrared light and allows more red light (*vertical red line*) to pass through. Deoxygenated hemoglobin (*purple line*) absorbs more red light and allows more infrared light (*vertical purple line*) to pass through. Adapted from red and infrared light absorption. http://www.oximeter.org/pulseox/principles.htm accessed March 8, 2010



Anesthetic Monitoring

Modalities for Anesthetic Monitoring

Accuracy of the pulse oximeter

The calibration to derive SpO2 from the $(AC/DC)_{66}0/(AC/DC)_{940}$ ratio **was made from studies of healthy volunteers**

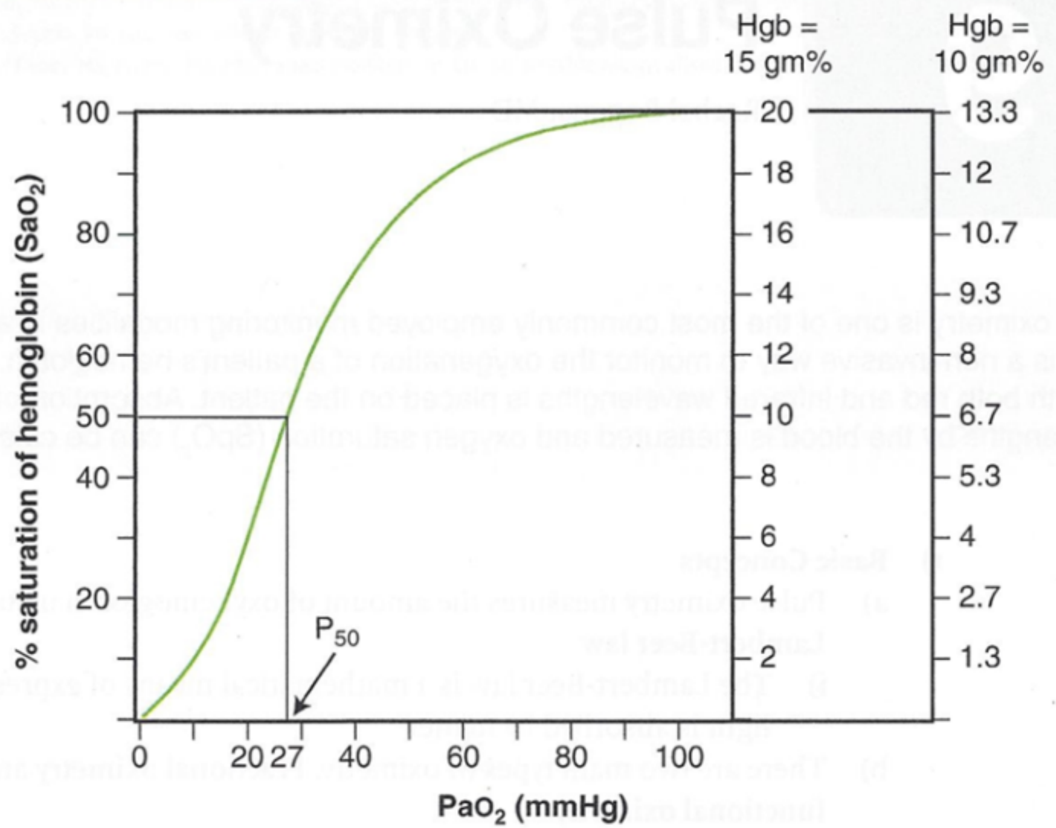
a) If the **SpO2 i**s between **70% and 100%, the pulse oximeter is accurate to within 5%**

b) It is **not accurate below 70%**

- because calibration of the pulse oximeter involved healthy volunteers whose SpO2 did not routinely reach levels <70%

Anesthetic Monitoring

Relationship between SaO2 and PaO2



The oxygen dissociation curve showing the relationship between SpO_2 and PaO_2. P_{50} is the PaO_2 at which hemoglobin is 50% saturated with oxygen. The normal value is 27 mmHg. Adapted from Martin L. *All you really need to know to interpret arterial blood gases*. 2nd ed. Philadelphia: Lippincott Williams & Wilkins; 1999.

SaO2 %	PaO2 mmHg
99	175
95	80
94	70
90	60
85	50
80	45
75	40
70	37
65	34
60	31
55	29
50	27
45	25
40	23

TABLE 1. Values for standard human blood O_2 dissociation curve at 37˚C, pH = 74, extrapolated between data in [7].

PO_2	%Sat	PO_2	%Sat	PO_2	%Sat
1	0.60	34	65.16	80	95.84
2	1.19	36	68.63	85	96.42
4	2.56	38	71.94	90	96.88
6	4.37	40	74.69	95	97.25
8	6.68	42	77.29	100	97.49
10	9.58	44	79.55	110	97.91
12	12.96	46	81.71	120	98.21
14	16.89	48	83.52	130	98.44
16	21.40	50	85.08	140	98.62
18	26.50	52	86.59	150	98.77
20	32.12	54	87.70	175	99.03
22	37.60	56	88.93	200	99.20
24	43.14	58	89.95	225	99.32
26	48.27	60	90.85	250	99.41
28	53.16	65	92.73	300	99.53
30	57.54	70	94.06	400	99.65
32	61.69	75	95.10	500	99.72

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Anesthetic Monitoring

Modalities for Anesthetic Monitoring

What is the relationship between SaO2 and PaO2

Additional Information only

- The absorption spectrum of deoxygenated hemoglobin is very steep at 600 nm in the red range so small changes in the amount of deoxyhemoglobin can cause very wide variances in SpO_2

Anesthetic Monitoring

Modalities for Anesthetic Monitoring

Pulse oximetry is affected by

- Low amplitude states
- Dyshemoglobinemias

- Patients with sickle cell anemia presenting in a vasoocclusive crisis can have an inaccurate SpO2 reading

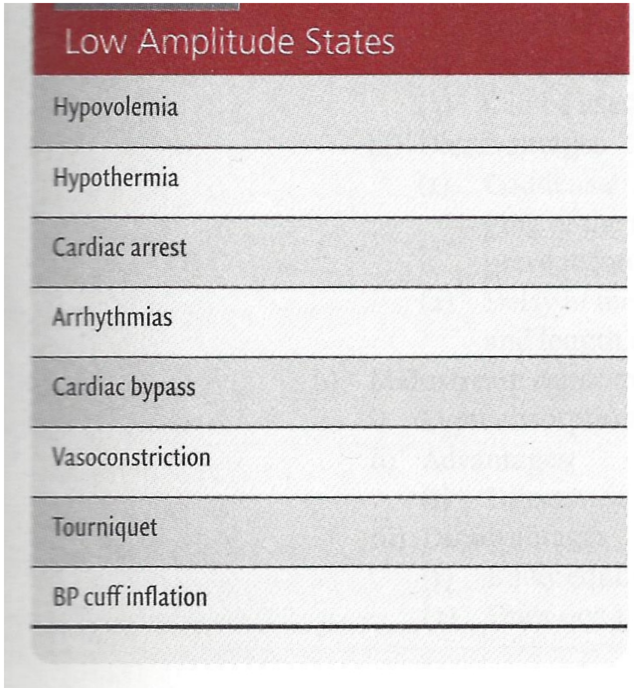
Anesthetic Monitoring

Modalities for Anesthetic Monitoring

Pulse oximetry is not as accurate in low amplitude states

Low perfusion makes it difficult for the pulse oximeter to distinguish a true signal from background noise

- Hypovolemia
- Hypothermia
- Cardiac arrest
- Arrhythmias
- Vasoconstriction
- BP cuff inflation
- Tourniquet
- Cardiac Bypass



Low Amplitude States
Hypovolemia
Hypothermia
Cardiac arrest
Arrhythmias
Cardiac bypass
Vasoconstriction
Tourniquet
BP cuff inflation

Anesthetic Monitoring

Modalities for Anesthetic Monitoring

Dyshemoglobinemias

Pulse oximetry only accurately measures oxyhemoglobin and deoxyhemoglobin—all other forms of hemoglobin are not accurately measured

- Carboxyhemoglobin is measured as 90% oxyhemoglobin (and 10% deoxyhemoglobin)
  - Thus, when there are high amounts of carboxyhemoglobin it will overestimate the SpO2
  - This is an important consideration in patients exposed to smoke or fires
- Methemoglobin absorbs equal amounts of red and infrared light so the SpO2 will read 85%
  - Methemoglobin is formed when iron goes from it's +2 ferrous form to the +3 ferric state
  - The ferric state of iron displays a left shift on the oxygen dissociation curve and releases oxygen less easily

Anesthetic Monitoring

Modalities for Anesthetic Monitoring

Dyshemoglobinemias

Methemoglobinemia can be caused by many drugs.

- •Nitrates
- •Nitrites
- •Local anesthetics (eg Benzocaine)
- •Chlorates
- •Antimalarials
- •Antineoplastics
- •Sulfonamide
- •Dapsone (antibiotic)
- •Metoclopramide (antiemetic)

Causes of Methemoglobinemia
Nitrates/Nitrites
Local anesthetics (e.g., Benzocaine or Hurricaine Spray)
Chlorates
Antimalarials
Antineoplastics
Sulfonamides
Dapsone
Metoclopramide

Anesthetic Monitoring

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Anesthetic Monitoring

Standards for Anesthetic Monitoring

Normal capnogram

a) Phase I

Initiation of expiration

CO_2 free gas from anatomic dead space

b) Phase II

Expiration of mixture of dead space and alveolar gas

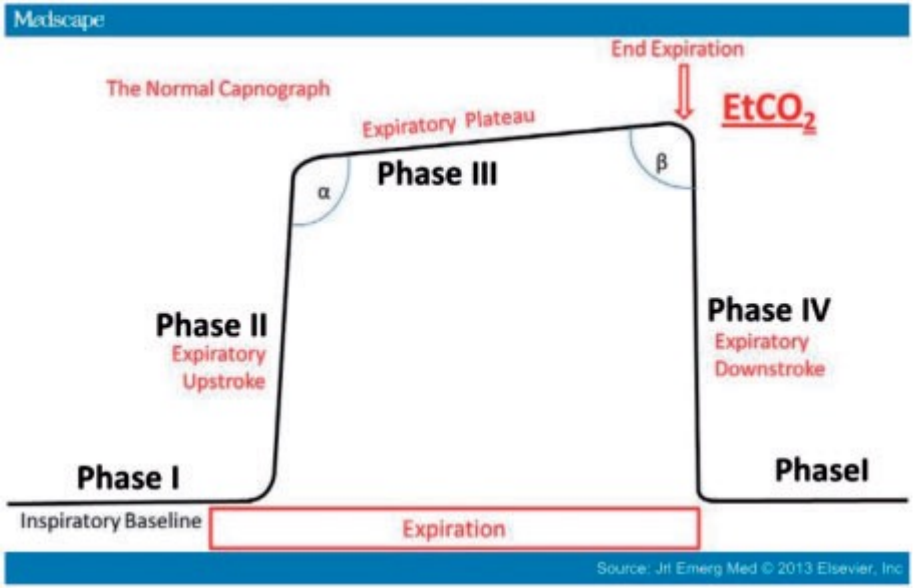
c) Phase **III**

Alveolar **plateau**

CO2-rich gas from alveoli

d) Phase IV or 0

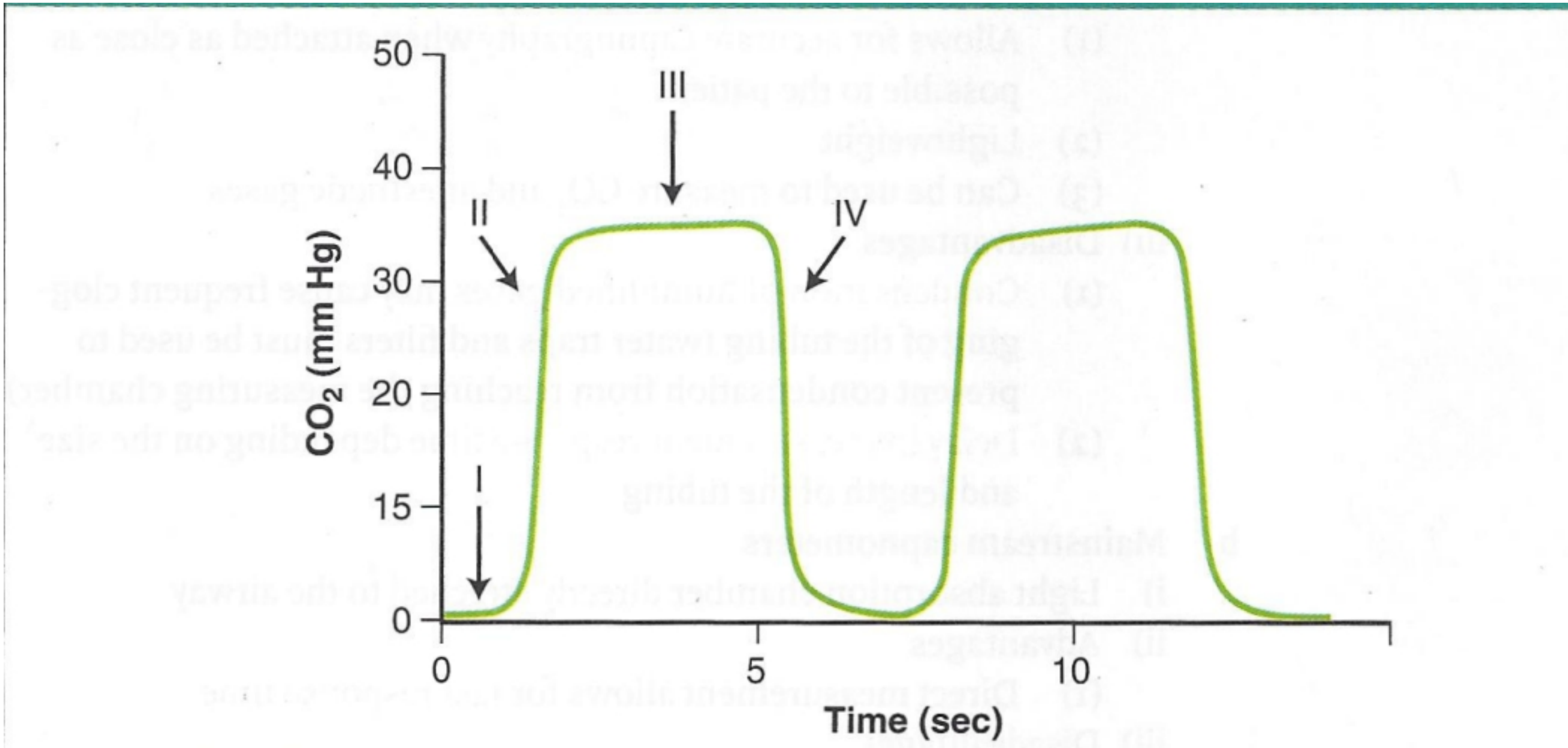
Inspiration



Ian Kerslake et al, BJA Education, 17 (5): 178–183 (2017)

Anesthetic Monitoring

Standards for Anesthetic Monitoring



Reproduced from Eisenkraft JB, Leibowitz AB. Hypoxia and equipment failure. In: Yao FS, ed. *Yao & Artusio's Anesthesiology: Problem-Oriented Patient Management*. 6th ed. Philadelphia, PA: Lippincott Williams & Wilkins; 2008:1185, with permission.

Anesthetic Monitoring

Standards for Anesthetic Monitoring

Clinical uses of capnography

- Regarding the expired CO_2, it provides

Qualitative information

- Ensures the endotracheal tube is within the respiratory tract
- Indicates adequacy of breathing in spontaneously ventilating non-intubated patients

Quantitative information

- Ensure adequate cardiac output
- Approximation of $PaCO_2$ (see in next slides)
- Indicates adequacy of ventilation in controlled ventilating intubated patients.

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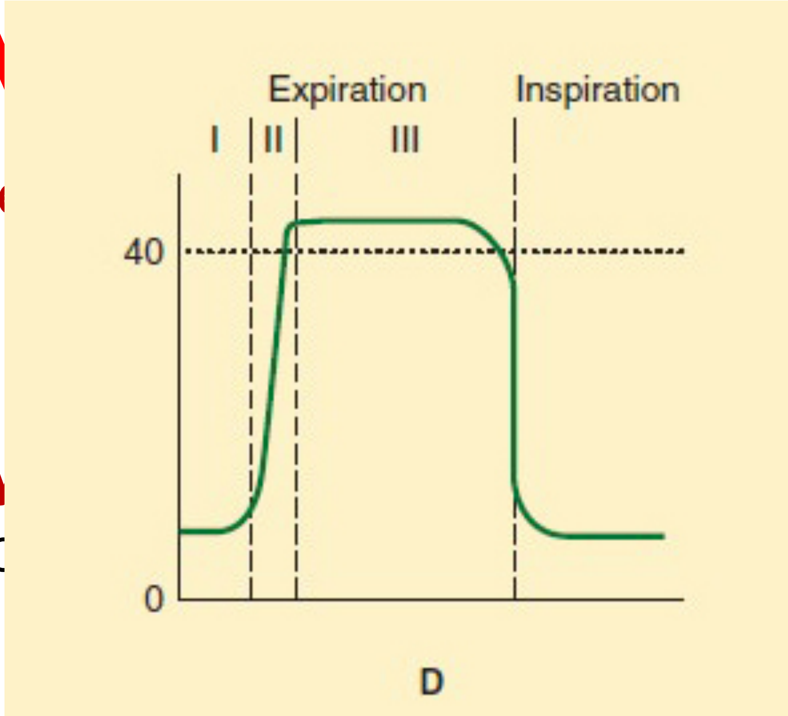
Standards for Anesthe

Clinical uses of capnography

- Regarding the inspired C



Quantitative information

- ensure that the patient is not breathing back any CO2 from the anesthesia ventilator, that would be a cause of respiratory acidosis
- Otherwise CO2 absorber of the anesthesia machine should be exchanged.

Anesthetic Monitoring

Standards for Anesthetic Monitoring

Clinical uses of capnography

- Regarding the expired CO2, it provides

Quantitative information

- Noninvasive **estimate of PaCO2**
  - Assumes the normal 2 to **5 mm Hg difference between expired ($PETCO_2$) and arterial ($PaCO_2$)**

- The gradient between **$PETCO_2$** and **$PaCO_2$** may be **increased with**
  - age
  - pulmonary disease
  - pulmonary embolus
  - low cardiac output
  - hypovolemia

Anesthetic Monitoring

Standards for Anesthetic Monitoring

Typical $ETCO_2$ trace in hypoventilation or rarely malignant hyperpyrexia

- Fever
- Sepsis
- **Malignant hyperthermia**
- **Hypoventilation (CO_2 accumulation)**
- Hyperthyroidism
- Shivering

Anesthetic Monitoring

Standards for Anesthetic Monitoring

Sudden drop in $ETCO_2$- represents reduction in pulmonary blood flow i.e. drop in cardiac output, pulmonary embolus

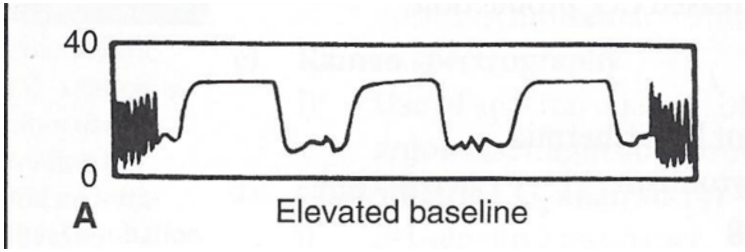
- Causes of decreased $ETCO_2$
  - Decreased cardiac output
  - Hypovolemia
  - **Pulmonary embolism**
  - Hypothermia
  - Hyperventilation

Anesthetic Monitoring

Standards for Anesthetic Monitoring

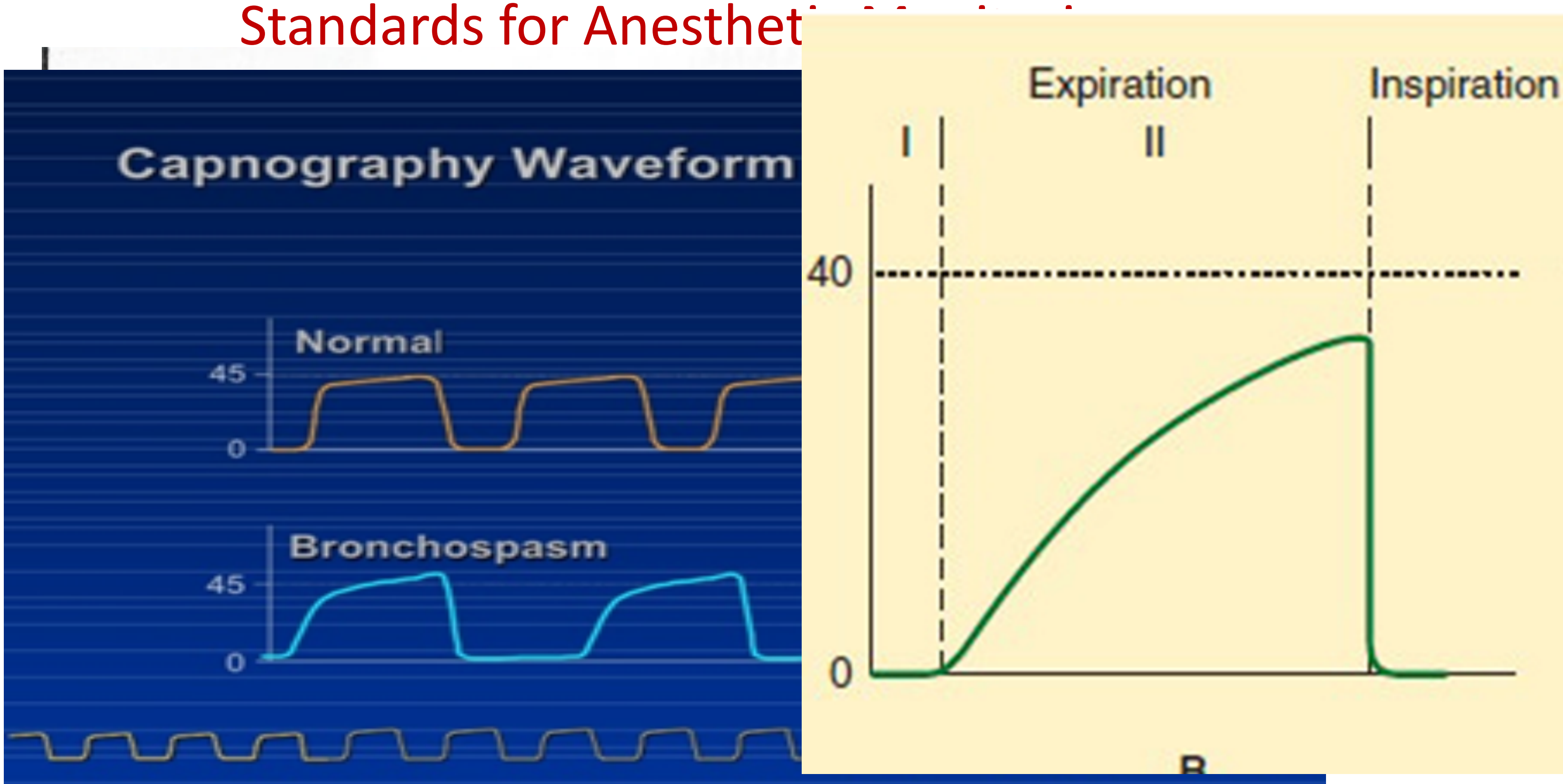
Clinical uses of capnography

- **Detection of problems with the anesthetic breathing system**
  - Rebreathing of CO_2
  - Incompetent valves
  - Circuit disconnect
  - Circuit leak



Anesthetic Monitoring

Standards for Anesthet

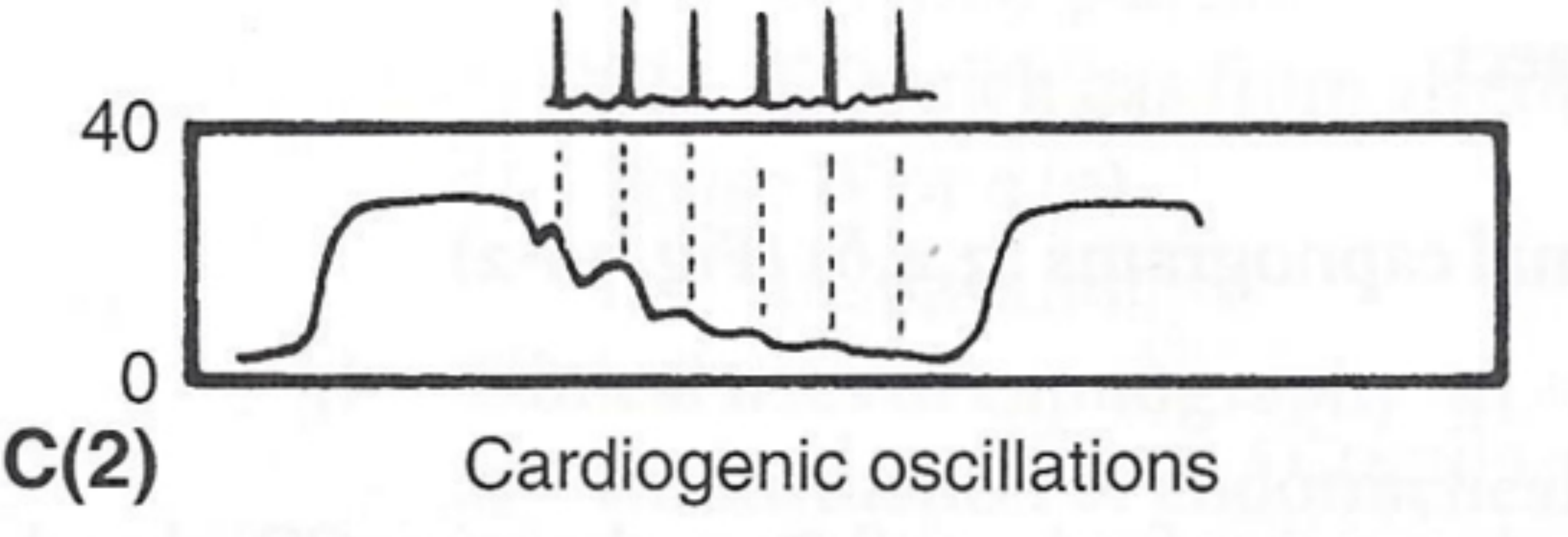


b) Obstruction to expiratory gas flow

- Prolonged Phase II and steeper Phase III slope
- Occurs with bronchospasm, COPD, kinked endotracheal tube

Anesthetic Monitoring

Standards for Anesthetic Monitoring



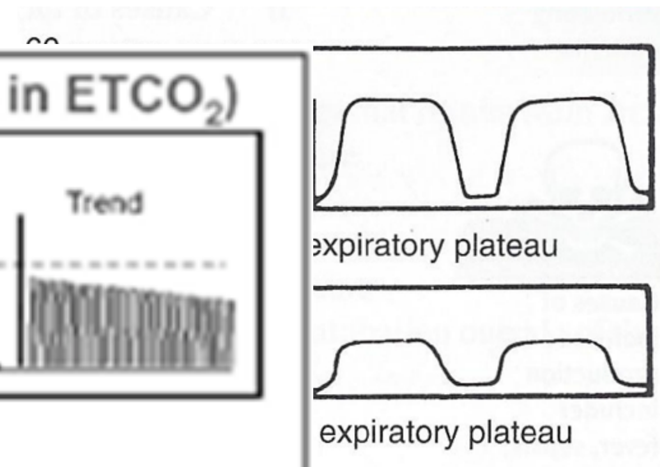
- Indicates return of spontaneous respiratory efforts

d) Cardiogenic oscillations

- Oscillations of small gas movements during phase III and IV (or 0)
- Produced by aortic and cardiac pulsations

Anesthetic Monitoring

Standards for Anesthetic Monitoring



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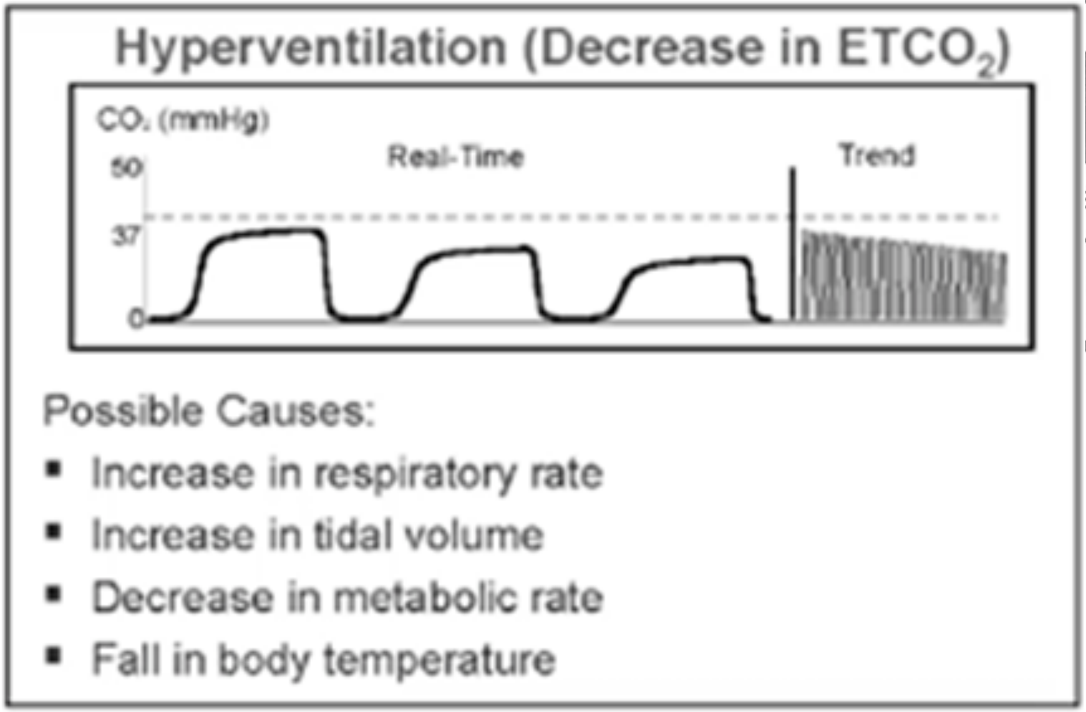

e) In

-
-
  - ➢ inadequate minute ventilation

f) Decreased measured CO2

- Displayed as Decreased plateau height
- Indicate
  - ➢ decreased CO2 production state or
  - ➢ increased minute ventilation

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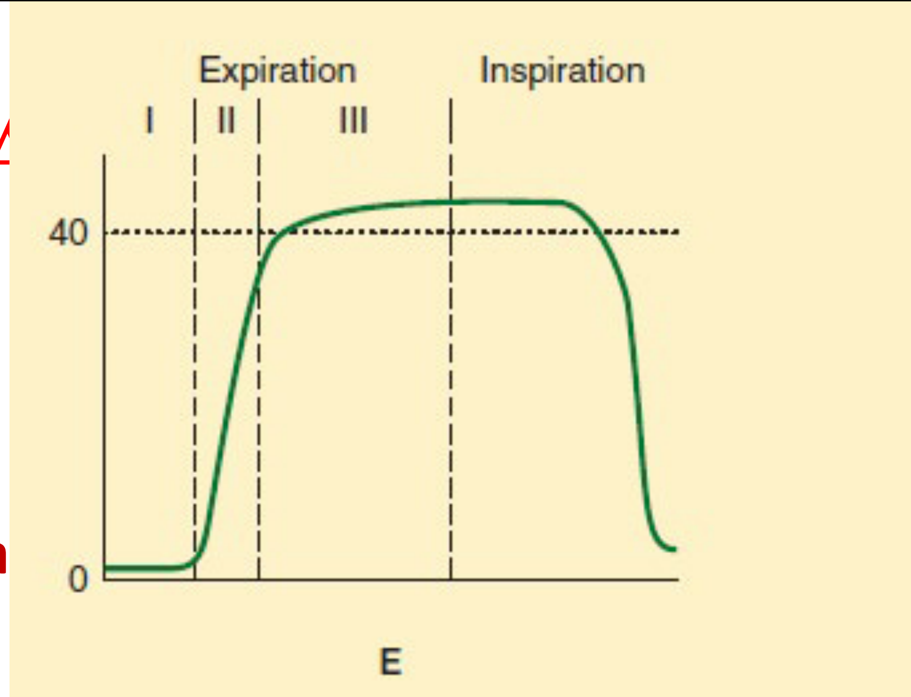


Oesophageal intubation- gradually decreasing $ETCO_2$ value

waveforms

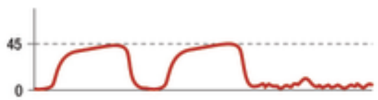
h) Esophageal intubation
- Initial presence of CO2 followed by no CO2

Anesthetic Monitoring

Standards for Anesthetic Monitoring

Sudden loss of waveform

- ET tube disconnected, dislodged, kinked or obstructed
- Loss of circulatory function

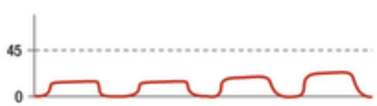


Decreasing $EtCO_2$

- ET tube cuff leak
- ET tube in hypopharynx
- Partial obstruction

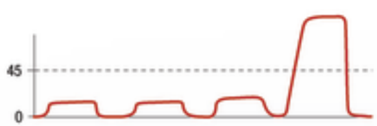
CPR Assessment

- Attempt to maintain minimum of 10mmHg



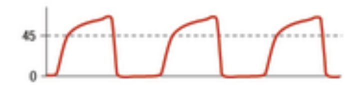
Sudden increase in $EtCO_2$

- Return of spontaneous circulation (ROSC)



Bronchospasm (“Shark-fin” appearance)

- Asthma
- COPD

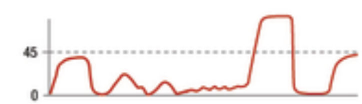


Hypoventilation

Hyperventilation

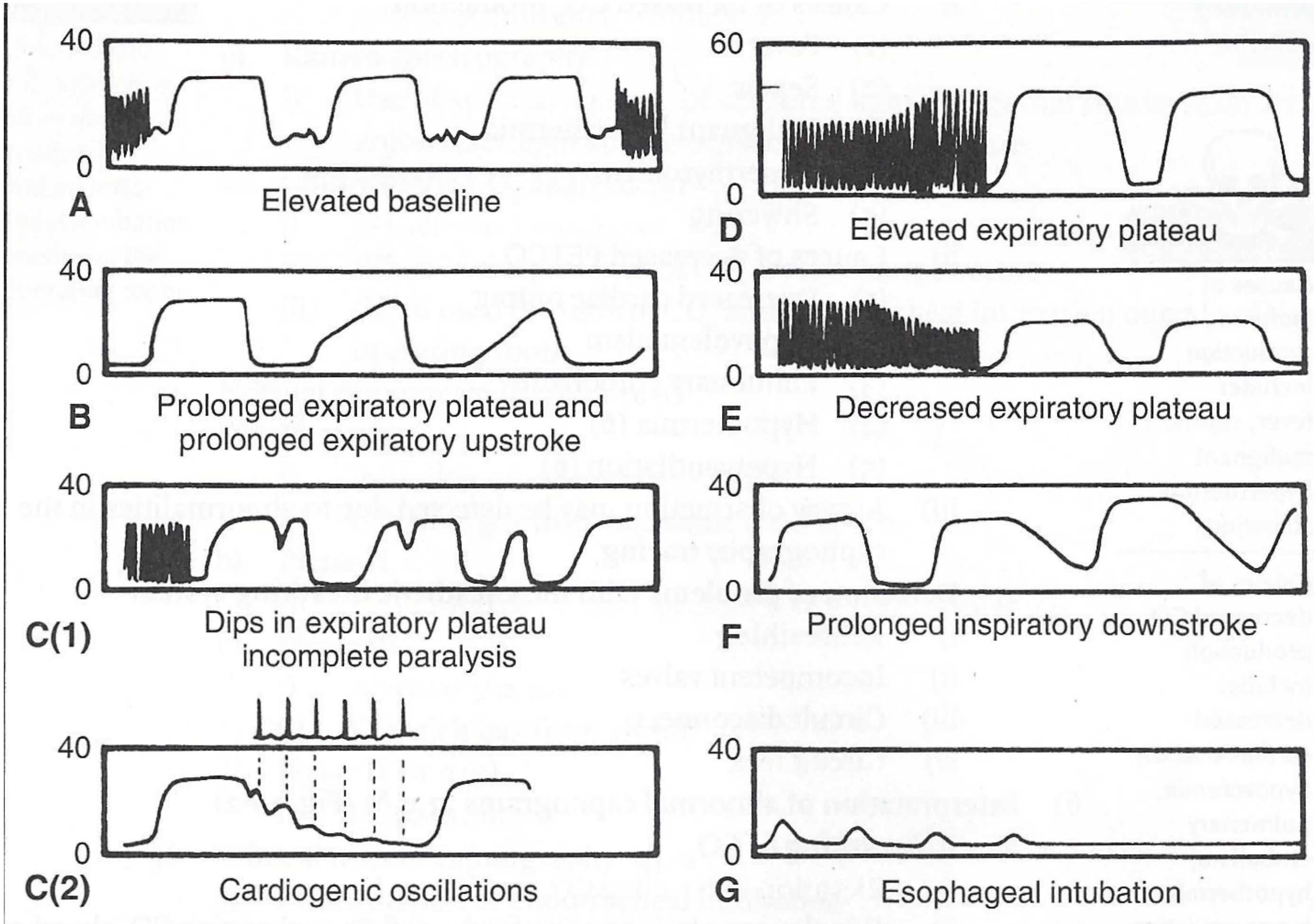
Decreased $EtCO_2$

- Apnea
- Sedation



Anesthetic Monitoring

Standards for Anesthetic Monitoring



Reproduced from Eisenkraft JB, Leibowitz AB. Hypoxia and equipment failure. In: Yao FS, ed. *Yao & Artusios Anesthesiology*. 6th ed. Philadelphia, PA: Lippincott Williams & Wilkins, 2008:1186, with permission.

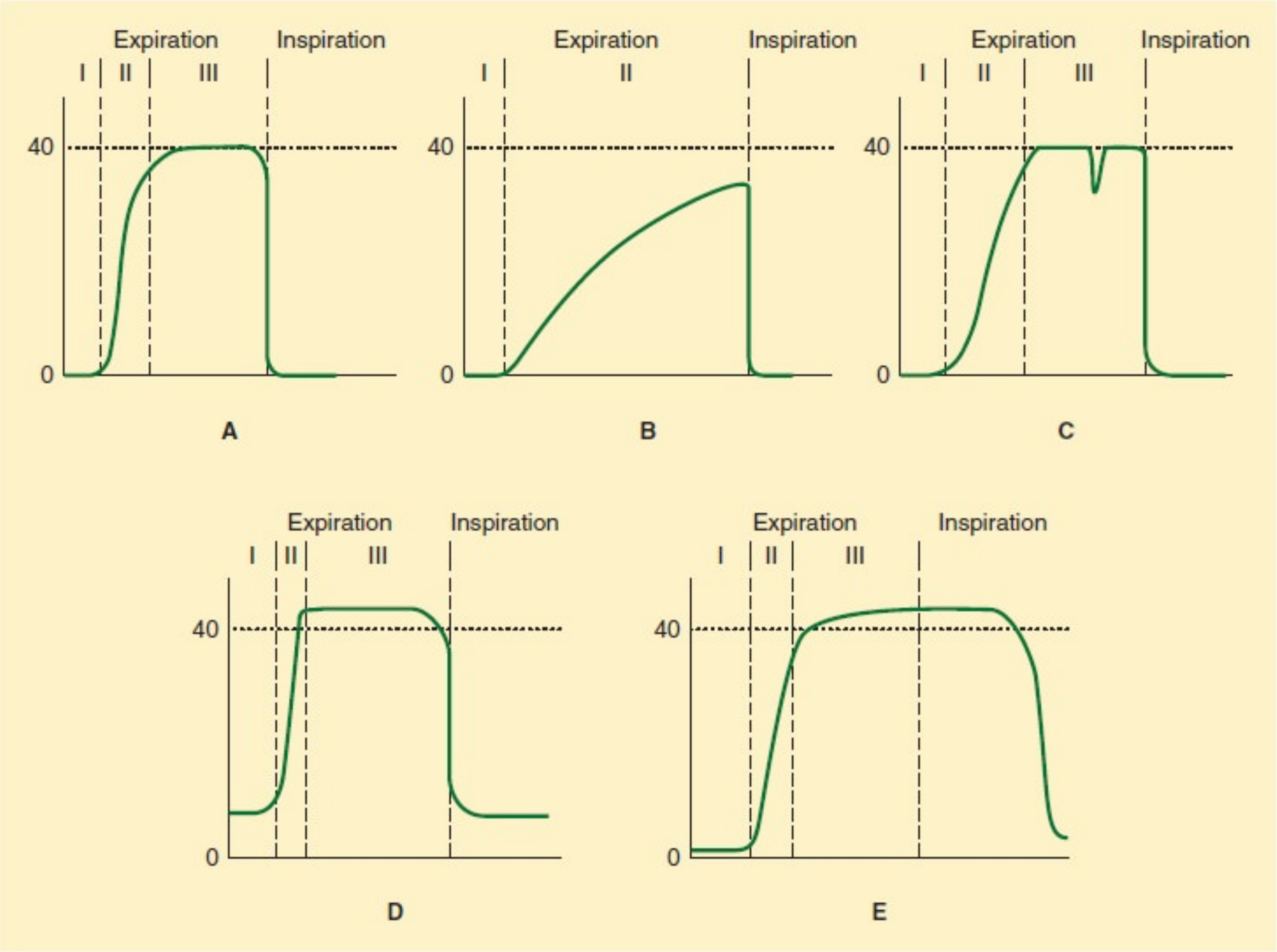


FIGURE 6–5 **A**: A normal capnograph demonstrating the three phases of expiration: phase I—dead space; phase II—mixture of dead space and alveolar gas; phase III—alveolar gas plateau. **B**: Capnograph of a patient with severe chronic obstructive pulmonary disease. No plateau is reached before the next inspiration. The gradient between end-tidal CO_2 and arterial CO_2 is increased. **C**: Depression during phase III indicates spontaneous respiratory effort. **D**: Failure of the inspired CO_2 to return to zero may represent an incompetent expiratory valve or exhausted CO_2 absorbent. **E**: The persistence of exhaled gas during part of the inspiratory cycle signals the presence of an incompetent inspiratory valve.

Anesthetic Monitoring

OBJECTIVES

At the end of the lecture you will be able to know the basics of anesthetic monitoring as follows:

- Definition
- What , When, How to monitor
- The policies that govern modern monitoring
  (Standards I and Standards II)
- The **basic monitors** and the **advanced monitors**
  - Arterial Oxygen Saturation- SpO_2
  - Expired CO_2 - $ETCO_2$
  - **Awareness under anesthesia**
    - **Means to monitor the wakeful state of the brain**
  - Other somatosensory and motor monitoring
  - Brief introduction about invasive hemodynamic monitoring and oxygenation of the brain
  - The neuromuscular junction relaxation monitoring

Anesthetic Monitoring

Modalities for Anesthetic Monitoring

Processed EEG and Awareness Monitoring

Intra-operative awareness with recall involves

- explicit recall of sensory perceptions during general anesthesia including aspects of their surgical environment, procedure, and even pain related to the intervention.

- is defined as a patient having an unexpected and undesirable recall of wakefulness

Processed EEG analysis has been developed as a method to monitor depth of anesthesia intraoperatively

- and can be used as an effect-site monitor to aid in titration of anesthetic drugs and may be useful in reducing the incidence of intra-operative awareness with recall.

Anesthetic Monitoring

Modalities for Anesthetic Monitoring

Processed EEG and Awareness Monitoring

Intra-operative awareness with recall

Symptoms

The most common symptoms reported by patients

- **Auditory perceptions such as voices or noises,**
- **followed by loss of motor function**
  - (inability to move, *sensation of weakness, or paralysis), pain, and feelings of helplessness, anxiety, panic, impending death, or catastrophe.*

Awareness with recall can lead **to anxiety, sleep difficulties, insomnia, irritability, nightmares, and posttraumatic stress disorder.**

Anesthetic Monitoring

Modalities for Anesthetic Monitoring

Processed EEG and Awareness Monitoring

Intra-operative awareness with recall

Incidence

- varies among studies, countries, anesthetic techniques, patient characteristics, and types of surgery.

- **The most commonly cited rate of intra-operative awareness is 0.2%** .

  This figure is thought to reflect the incidence in routine cases but **not including cardiac or obstetric surgeries**.

When further stratified, awareness occurs in approximately

1.14% to 1.5% of cardiac surgery cases,

0.4% of obstetric cases, and

11% to 43% of trauma surgeries.

Awareness with recall associated with pain is estimated to occur in 0.01% to 0.03% of cases.

Anesthetic Monitoring

Modalities for Anesthetic Monitoring

Processed EEG and Awareness Monitoring

Intra-operative awareness with recall

Risk Factors

Factors associated with increased risk of awareness with recall include

- "light" anesthesia (e.g., delivering a low level of inhaled anesthetic minimum alveolar concentration),
- history of intra-operative awareness
- chronic use of central nervous system depressants
- younger age
- obesity
- inadequate or misused anesthesia delivery systems

Anesthetic Monitoring

Modalities for Anesthetic Monitoring

Processed EEG and Awareness Monitoring

Intra-operative awareness with recall

Assessment and Diagnosis

- Often it is **difficult to know for sure** that intra-operative awareness with recall occurred.
- If the patient is not asked specifically about it, they **may not report it voluntarily.**
- Or, the patient may **recollect hearing sounds** during surgery, when in fact they are remembering something **that occurred in the recovery room.**

Anesthetic Monitoring

Modalities for Anesthetic Monitoring

Processed EEG and Awareness Monitoring

Intra-operative awareness with recall

Assessment and Diagnosis

One accepted method to assess intra-operative awareness with recall is to conduct three structured interviews with **open ended questions at intervals of 24 hours, between 24 and 72 hours, and at 30 days after surgery** (awareness may not arise until days to weeks postoperatively).

Anesthetic Monitoring

Modalities for Anesthetic Monitoring

Processed EEG and Awareness Monitoring

Intra-operative awareness with recall

Prevention and Vigilance

- **Monitor delivered volatile anesthetic levels**

  The unintended inadequate delivery of volatile anesthetic agents ("light anesthesia") during maintenance of anesthesia may be avoided by the **addition of a low alarm limit to end-tidal gas monitoring settings,** as well as use of a **"near empty" alarm** in anesthetic vaporizers.

Anesthetic Monitoring

Modalities for Anesthetic Monitoring

Processed EEG and Awareness Monitoring

Intra-operative awareness with recall

Prevention and Vigilance

- **Monitor processed EEG signals**

  Depth of anesthesia monitoring, via the processed EEG,

  - has proved useful in reducing the amount of anesthetic drugs
  - optimizing extubation times
  - and in some studies **reducing awareness with recall.**

Although most anesthesiologists in the UK, USA, and Australia accept that clinical signs are unreliable indicators of awareness, **few believe that** monitors of anesthetic depths should be used for all routine cases

Anesthetic Monitoring

Modalities for Anesthetic Monitoring

Processed EEG and Awareness Monitoring

- **Monitor processed EEG signals**
- Several brain-function monitors based on the processed electroencephalogram (EEG) or evoked potentials have been developed to assess anesthetic depth.

Anesthetic Monitoring

Modalities for Anesthetic Monitoring

Processed EEG and Awareness Monitoring

Intra-operative awareness with recall

- **BIS (Aspect Medical Systems).**
  - **The most widely used monitor is the BIS monitor.**
  - **This device integrates several parameters of an EEG into a calculated, dimensionless variable (0 to 100).**
    - It is important to note that bispectral index (BIS)is a probability distribution where a measure of **40 does not provide a 100% guarantee of no awareness.**

Anesthetic Monitoring

Modalities for Anesthetic Monitoring

Processed EEG and Awareness Monitoring

- i) **BIS values between 40 and 60 purportedly indicate adequate general anesthesia for surgery,**
- ii) and values below 40 indicate a deep hypnotic state.
- iii) **Targeting a range of BIS values between 40 and 60 is marketed to help prevent anesthesia awareness while allowing for minimization the anesthetic dose.**

Anesthetic Monitoring

Modalities for Anesthetic Monitoring

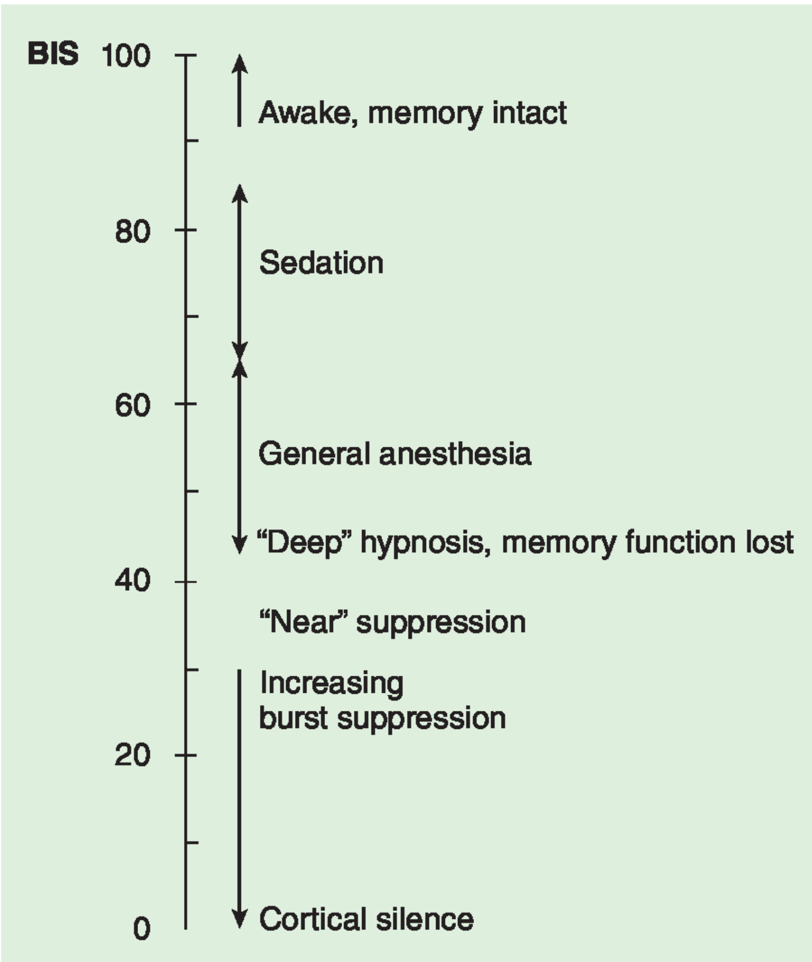


FIGURE 6–10 The Bispectral Index Scale (BIS versions 3.0 and higher) is a dimensionless scale from 0 (complete cortical electroencephalographic suppression) to 100

The term bispectral applies because it incorporates both power and phase spectrums of an EEG into the calculated 0 to 100 value

TABLE 6–1 Characteristics of the commercially available monitors of anesthetic depth.

Parameters	Machine/ Manufacturer	Consumable	Physiologic Signals	Recommended Range of Values for Anesthesia	Principles of Measurement
Bispectral index (BIS)	A-2000/Aspect Medical Systems, Newton, MA	BIS sensor	Single channel EEG	40–60	BIS is derived from the weighted sum of three EEG parameters: relative α/β ratio; bio-coherence of the EEG waves; and burst suppression. The relative contribution of these parameters has been tuned to correlate with the degree of sedation produced by various sedative agents. BIS ranges from 0 (asleep)–100 (awake).
Patient state index (PSI)	Patient state analyzer (PSA 400)/ Physiometrix, Inc., N. Billerica, MA	PSArray[2]	4-channel EEG	25–50	PSI is derived from progressive discriminant analysis of several quantitative EEG variables that are sensitive to changes in the level of anesthesia, but insensitive to the specific agents producing such changes. It includes changes in power spectrum in various EEG frequency bands; hemispheric symmetry; and synchronization between brain regions and the inhibition of regions of the frontal cortex. PSI ranges from 0 (asleep)-100 (awake).
Narcotrend stage Narcotrend index	Nacrotrend monitor/ Monitor-Technik, Bad Bramstedt, Germany	Ordinary ECG electrode	1–2 channel EEG	Narcotrend stage D_{0-2} to C_1, which corresponds to an index of 40–60	The Narcotrend monitor classifies EEG signals into different stages of anesthesia (A = awake; B_{0-2} = sedated; C_{0-2} = light anesthesia; D_{0-2} = general anesthesia; $E_{0,1}$ = general anesthesia with deep hypnosis; $F_{0,1}$ = burst suppression). The classification algorithm is based on a discriminant analysis of entropy measures and EEG spectral variables. More recently the monitor converts the Narcotrend stages into a dimensionless number from 0 (asleep) to 100 (awake) by nonlinear regression.
Entropy	S/5 Entropy Module, M-ENTROPY/ Datex-Ohmeda, Instrumentarium Corp., Helsinki, Finland	Special entropy sensor	Single-channel EEG	40–60	Entropy described the 'irregularity' of the EEG signal. As the dose of anesthetic is increased, EEG becomes more regular and the entropy value approaches zero. M-ENTROPY calculates the entropy of the EEG spectrum (spectral entropy). In order to shorten the response time, it uses different time windows according to the corresponding EEG frequencies. Two spectral parameters are calculated: state entropy (frequency band 0–32 Hz) and response entropy (0–47 Hz), which also includes muscle activity. Both entropy variables have been re-scaled, so that 0 is asleep and 100 is awake.
Aline autore-gressive index (AAI)	AEP/2 monitor/ Danmeter A/S, Odense, Demark	Ordinary ECG electrode	AEP	10–25	AAI is derived from the middle latency AEP (20–80 ms). AAI is extracted from an autoregressive model with exogenous input (ARX model) so that only 18 sweeps are required to reproduce the AEP waveform in 2–6 s. The resultant waveform is then transformed into a numeric index (0–100) that describes the shape of the AEP. AAI > 60 is awake, AAI of 0 indicates deep anesthesia.
Cerebral state index (CSI)	Cerebral state monitor (CSM), Danmeter A/S, Odense, Demark	Ordinary ECG electrode	Single-channel EEG	40–60	CSI is a weighted sum of (1) α ratio, (2) β ratio, (3) difference between the two and (4) burst suppression. It correlates with the degree of sedation by an 'adaptive neuro-fuzzy inference system'. CSI ranges from 0 (asleep) to 100 (awake).

EEG, electroencephalogram; ECG, electrocardiogram; AEP, auditory evoked potential.

Reproduced, with permission, from Chan MTV, Gin T, Goh KYC: Interventional neurophysiologic monitoring. Curr Opin Anaesthesiol 2004;17:389.

Anesthetic Monitoring

Modalities for Anesthetic Monitoring

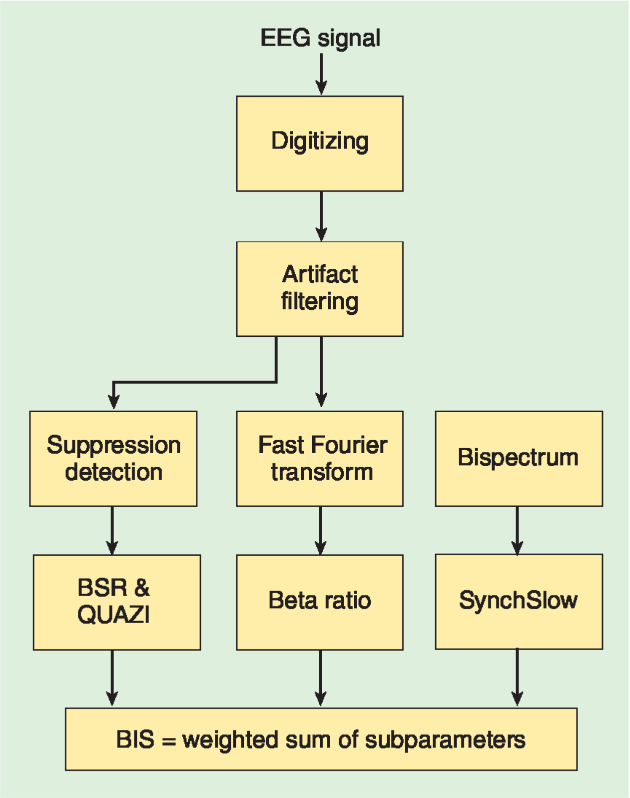


FIGURE 6–9 Calculation of the Bispectral Index. EEG, electroencephalogram; BSR, burst suppression ratio; BIS, Bispectral Index Scale. (Reproduced, with permission, from Rampil IJ: A primer for EEG signal processing in anesthesia. Anesthesiology 1998;89:980.)

Anesthetic Monitoring

TABLE 6–2 Checklist for preventing awareness.

- ✓ Check all equipment, drugs, and dosages; ensure that drugs are clearly labeled and that infusions are running into veins.
- ✓ Consider administering an amnesic premedication.
- ✓ Avoid or minimize the administration of muscle relaxants. Use a peripheral nerve stimulator to guide minimal required dose.
- ✓ Consider using the isolated forearm technique if intense paralysis is indicated.
- ✓ Choose potent inhalation agents rather than total intravenous anesthesia, if possible.
- ✓ Administer at least 0.5 to 0.7 minimum alveolar concentration (MAC) of the inhalation agent.
- ✓ Set an alarm for a low anesthetic gas concentration.
- ✓ Monitor anesthetic gas concentration during cardiopulmonary bypass from the bypass machine.
- ✓ Consider alternative treatments for hypotension other than decreasing anesthetic concentration.
- ✓ If it is thought that sufficient anesthesia cannot be administered because of concern about hemodynamic compromise, consider the administration of benzodiazepines or scopolamine for amnesia.
- ✓ Supplement hypnotic agents with analgesic agents such as opioids or local anesthetics, which may help decrease the experience of pain in the event of awareness.
- ✓ Consider using a brain monitor, such as a raw or processed electroencephalogram but do not try to minimize the anesthetic dose based on the brain monitor because there currently is insufficient evidence to support this practice.
- ✓ Monitor the brain routinely if using total intravenous anesthesia.
- ✓ Evaluate known risk factors for awareness, and if specific risk factors are identified consider increasing administered anesthetic concentration.
- ✓ Redose intravenous anesthesia when delivery of inhalation anesthesia is difficult, such as during a long intubation attempt or during rigid bronchoscopy.

Reproduced, with permission, from Mashour GA, Orser BA, Avidan

Pro

Patient State	Device	Features	Reading
Wakeful	EEG	↑f, ↓Amp, blinks	↑γ, β, α, ↓θ, δ
	SEF_{95}	Twenties	26 Hz.
	BIS	High β ratio	96
	Entropy	High entropy	97
	AAI	↓lat, ↑ΔAmp	81
	NI	EEG f band analysis	A
	ETAG	Age-adjusted MAC	0 MAC
Sedated	EEG	α oscillations	↓γ, β, ↑α, θ, δ
	SEF_{95}	High teens	19 Hz.
	BIS	Low β ratio	78
	Entropy	High entropy	85
	AAI	↑ing lat, ↓ing ΔAmp	45
	NI	EEG f band analysis	B/C
	ETAG	Age-adjusted MAC	0.4 MAC
Unresponsive	EEG	Spindles, K, ↓f	↑α, θ, δ
	SEF_{95}	Low teens	14 Hz.
	BIS	Bispectral coherence	52
	Entropy	Entropy drop	43
	AAI	↑ing lat, ↓ing ΔAmp	30
	NI	EEG f band analysis	D
	ETAG	Age-adjusted MAC	0.8 MAC
Surgically Anesthetized	EEG	Slow δ waves, ↓f	δ dominance
	SEF_{95}	< 12 Hz.	10 Hz.
	BIS	Bispectral coherence	42
	Entropy	Low entropy	38
	AAI	↑ing lat, ↓ing ΔAmp	22
	NI	EEG f band analysis	E
	ETAG	Age-adjusted MAC	1.3 MAC
Deeply Anesthetized	EEG	BS, isoelectricity	Bursts & flat
	SEF_{95}	< 2 Hz. (BS corrected)	2 Hz.
	BIS	High BSR	9
	Entropy	Burst suppression	8
	AAI	↑ latency, ↓ ΔAmp	11
	NI	EEG f band analysis	F
	ETAG	Age-adjusted MAC	2 MAC

Frontal Electroencephalography (EEG) Trace

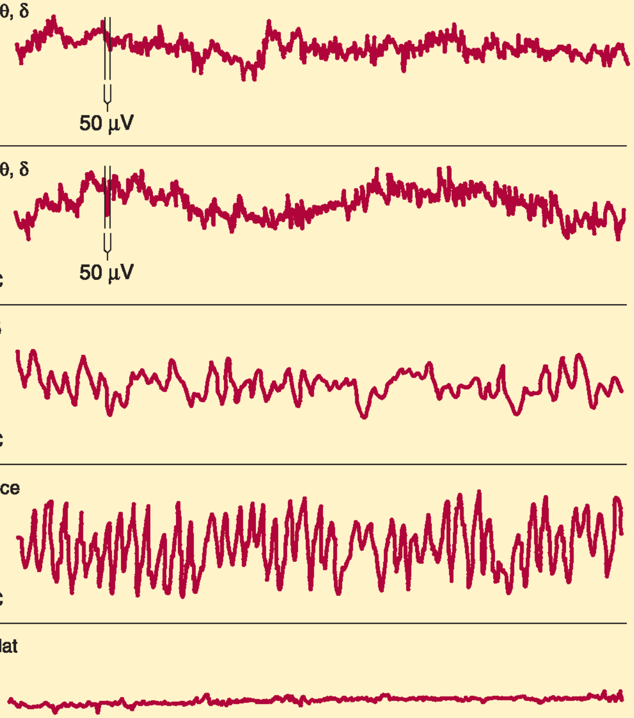


FIGURE 6–8 Patient states, candidate depth of anesthesia devices or approaches, key features of different monitoring approaches, and possible readings at different depths of anesthesia. The readings shown represent examples of possible readings that may be seen in conjunction with each frontal electroencephalography trace. The electroencephalography traces show 3-s epochs (x-axis), and the scale (y-axis) is 50 μV. AAI, A-Line Autoregressive Index (a proprietary method of extracting the mid-latency auditory evoked potential from the electroencephalogram); Amp, amplitude of an EEG wave; BIS bispectral index; blinks, eye blink artifacts; BS, burst suppression; BSR, burst suppression ratio; EEG, electroencephalography; ETAG, end-tidal anesthetic gas concentration; *f*, frequency; *γ, β, α, θ, δ*, EEG waves in decreasing frequencies (*γ*, more than 30 hertz [Hz]; *β*,12–30 Hz; *α*, 8–12 Hz; *θ*, 4–8 Hz; *δ*, 0–4 Hz); K, K complexes; Lat, latency between an auditory stimulus and an evoked EEG waveform response; MAC, minimum alveolar concentration; NI, Narcotrend index; SEF_{95}, spectral edge frequency below which 95% of the EEG frequencies reside; Spindles, sleep spindles. (Reproduced, with permission, from Mashour GA, Orser BA, Avidan MS: Intraoperative awareness: from neurobiology to clinical practice. Anesthesiology 2011;114:1218.)

Anesthetic Monitoring

OBJECTIVES

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- The **basic monitors** and the **advanced monitors**
  - Arterial Oxygen Saturation- SpO_2
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  - Awareness under anesthesia
    - Means to monitor the wakeful state of the brain
  - **Other somatosensory and motor monitoring**
  - Brief introduction about invasive hemodynamic monitoring and oxygenation of the brain
  - The neuromuscular junction relaxation monitoring

Anesthetic Monitoring

Modalities for Anesthetic Monitoring

Neurophysiologic Monitoring And Anesthetic Management

- Neurophysiologic monitoring or neuromonitoring allows **early detection of events that may increase postoperative neurological morbidity.**
- The aim of monitoring is to **identify changes in brain, spinal cord, and peripheral nerve function prior to irreversible damage.**
- Neuromonitoring is also useful in identifying anatomical structures.

Anesthetic Monitoring

Modalities for Anesthetic Monitoring

Neurophysiologic Monitoring And Anesthetic Management

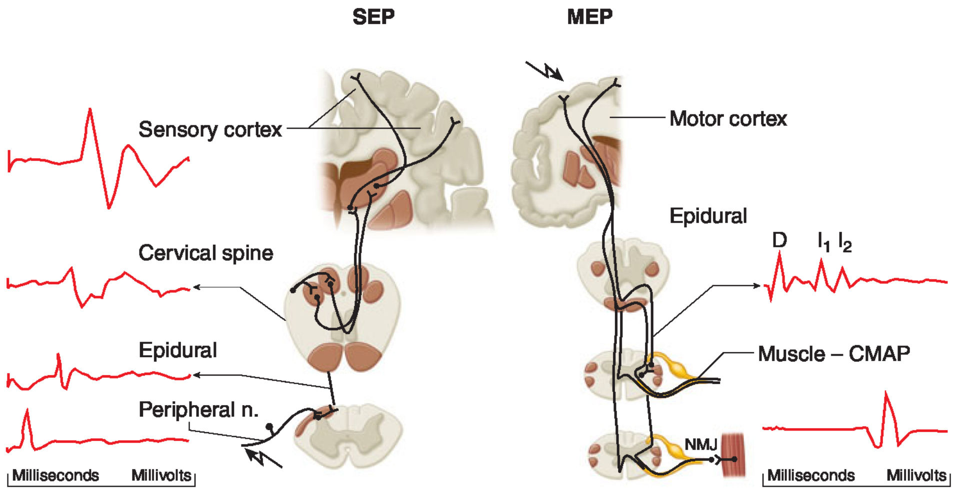

FIGURE 6–11 Neuroanatomic pathways of somatosensory-evoked potential and motor-evoked potential. The somatosensory-evoked potential (SEP) is produced by stimulation of a peripheral nerve wherein a response can be measured. The electrical volley ascends the spinal cord by the posterior columns and can be recorded in the epidural space and over the posterior cervical spine. It crosses the mid-line after synapsing at the cervicomedullary junction and ascends the lemniscal pathways having a second synapse in the thalamus. From there, it travels to the primary sensory cortex where the cortical response is measured. The motor-evoked potential (MEP) is produced by stimulation of the motor cortex leading to an electrical volley that descends to the anterior horn cells of the spinal cord via the corticospinal tract. After synapsing there it travels via a peripheral nerve and crosses the neuromuscular junction (NMJ) to produce a muscle response. The MEP can be measured in the epidural space as D and I waves produced by direct and indirect (via internuncial neurons) stimulation of the motor cortex, respectively. It can also be measured as a compound muscle action potential (CMAP) in the muscle. (Reproduced, with permission, from Sloan TB, Janik D, Jameson L: Multimodality monitoring of the central nervous system using motor-evoked potentials. Curr Opin Anaesthesiol. 2008;21:560.)

Anesthetic Monitoring

Modalities for Anesthetic Monitoring

Neurophysiologic Monitoring and Anesthetic Management

- Somatosensory evoked potentials (SSEP)
- Brainstem auditory evoked potentials (BAEP)
- Motor evoked potentials (MEP)
- Electroencephalography (EEG)

Anesthetic Monitoring

Modalities for Anesthetic Monitoring

Neurophysiologic Monitoring and Anesthetic Management

- **Somatosensory evoked potentials (SSEP)**

SSEP are the recording, usually at the cerebral cortex, of responses from electrically stimulated peripheral afferent nerves.

The most commonly used peripheral nerves are median, ulnar, posterior tibial, and common peroneal nerves.

Anesthetic Monitoring

Modalities for Anesthetic Monitoring

Neurophysiologic Monitoring and Anesthetic Management

Brainstem auditory evoked potentials (BAEP)

BAEP are the recording of brainstem responses to auditory stimuli.

BAEP monitors the function of the entire auditory pathway along the acoustic nerve, through the brain stem to the cerebral cortex.

Anesthetic Monitoring

Modalities for Anesthetic Monitoring

Neurophysiologic Monitoring and Anesthetic Management

- Motor evoked potentials (MEP)

MEP is the recording obtained from electrical stimulation of the motor cortex, which elicits potentials in the spinal cord or (myogenic) potentials from the innervated muscle.

Monitors motor pathway function

Anesthetic Monitoring

Modalities for Anesthetic Monitoring

Neurophysiologic Monitoring and
Anesthetic Management

Electromyography (EMG)

EMG is the recording of electrical activity of muscle and therefore an indirect indicator of function of the innervating peripheral nerve.

This technique is also used to identify and verify the integrity of a peripheral nerve, including cranial nerves as well as pedicle screw testing during spine surgery.

EMG is only sensitive to neuromuscular blocking agents.

Anesthetic Monitoring

Modalities for Anesthetic Monitoring

Neurophysiologic Monitoring and Anesthetic Management

Electroencephalography (EEG)

- EEG monitoring can be a useful supplement to surgery when
  - Seizure foci need to be identified
  - The general state of cerebral metabolism needs monitoring
  - Cerebral ischemia can occur
- EEG is a standard of care in many institutions for carotid endarterectomy.

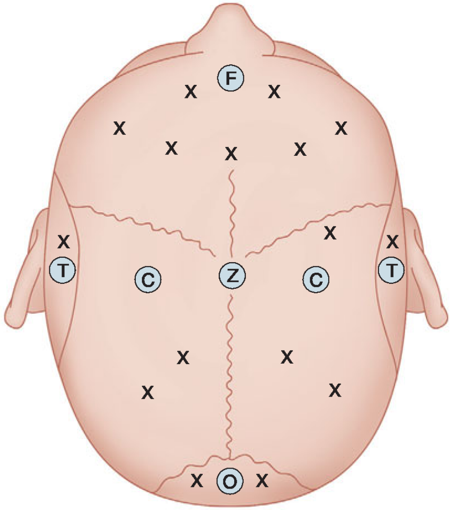

FIGURE 6–7 International 10–20 system. Montage letters refer to cranial location. F, frontal; C, coronal; T, temporal; O, occipital; Z, middle.

Anesthetic Monitoring

Modalities for Anesthetic Monitoring

Neurophysiologic Monitoring and
Anesthetic Management

Electroencephalography (EEG)

iii) EEG is the recording of brain electrical activity and is highly dependent on anesthetic depth.

(I) Alpha waves are rhythmically regular waves of 8 to 12 Hz seen in a lightly anesthesized patient.

A faster, disorganized beta (>12 Hz) rhythm is seen upon awakening.

Slower theta waves (4 to 8 Hz) are seen with deep inhalation or moderate dose narcotic anesthesia.

Slow delta waves (<4 Hz) indicate deep anesthesia, or ischemia if the amplitude is low.

Patient State	Device	Features	Reading
Wakeful	EEG	↑f, ↓ Amp, blinks	↑ γ, β, α, ↓ θ, δ
	SEF_{95}	Twenties	26 Hz.
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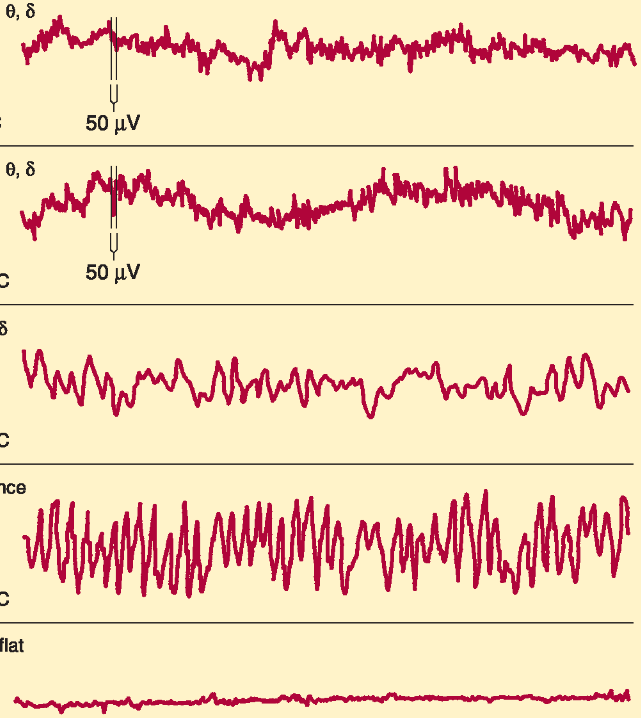

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Anesthetic Monitoring

Modalities for Anesthetic Monitoring

CEREBRAL OXIMETRY

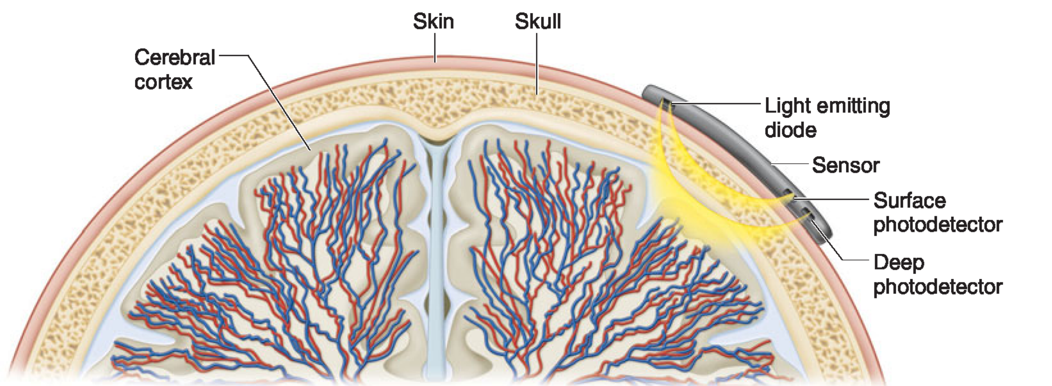
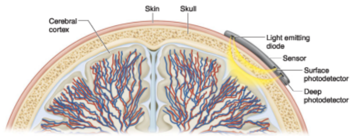


FIGURE 6–12 Principle of the INVOS® near-infrared spectroscopy technique. (Reproduced, with permission, from Rubio A, Hakami L, Münch F, Tandler R, Harig F, Weyand M: Noninvasive control of adequate cerebral oxygenation during low-flow antegrade selective cerebral perfusion on adults and infants in the aortic arch surgery. J Card Surg 2008;23:474.)

Regional saturations of less than 40% on NIRS measures, or changes of greater than 25% of baseline measures, may be a sign of neurological events secondary to decreased cerebral oxygenation.

Anesthetic Monitoring

Modalities for Anesthetic Monitoring



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CEREBRAL OXIMETRY

Cerebral oximetry uses near infrared spectroscopy (NIRS).

Using reflectance spectroscopy near infrared light is emitted by a probe on the scalp

Receptors are likewise positioned to detect the reflected light from both deep and superficial structures.

As with pulse oximetry, oxygenated and deoxygenated hemoglobin absorb light at different frequencies.

Likewise, cytochrome absorbs infrared light in the mitochondria.

The NIRS saturation largely reflects the absorption of venous hemoglobin, as it does not have the ability to identify the pulsatile arterial component.

Regional saturations of less than 40% on NIRS measures, or changes of greater than 25% of baseline measures, may herald neurological events secondary to decreased cerebral oxygenation.

Anesthetic Monitoring

Modalities for Anesthetic Monitoring

Invasive hemodynamic monitoring

Central Venous Pressure

- involves placement of a sterile catheter into one of the large central veins
- allows for multiple modalities of intervention along with the option of monitoring central venous pressure (CVP).
-

CVP monitoring can be a useful tool for **evaluating intravascular volume and preload** in the absence of

- left ventricular (LV) dysfunction (ejection fraction <40%),
- severe mitral valve disease, pulmonary hypertension,
- or significant reduction in LV compliance (ischemia/diastolic dysfunction).

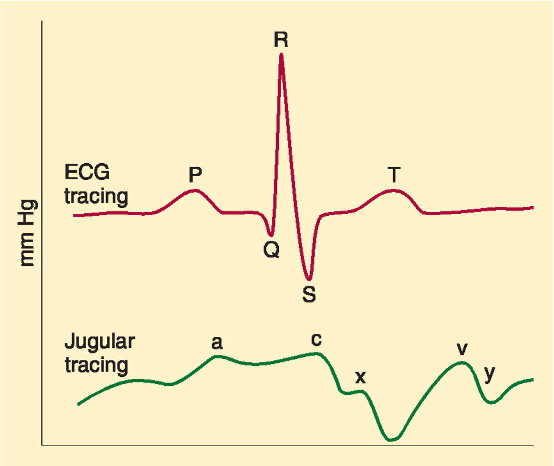


FIGURE 5–19 The upward waves (*a, c, v*) and the downward descents (*x, y*) of a central venous tracing in relation to the electrocardiogram (ECG).

Anesthetic Monitoring

Modalities for Anesthetic Monitoring

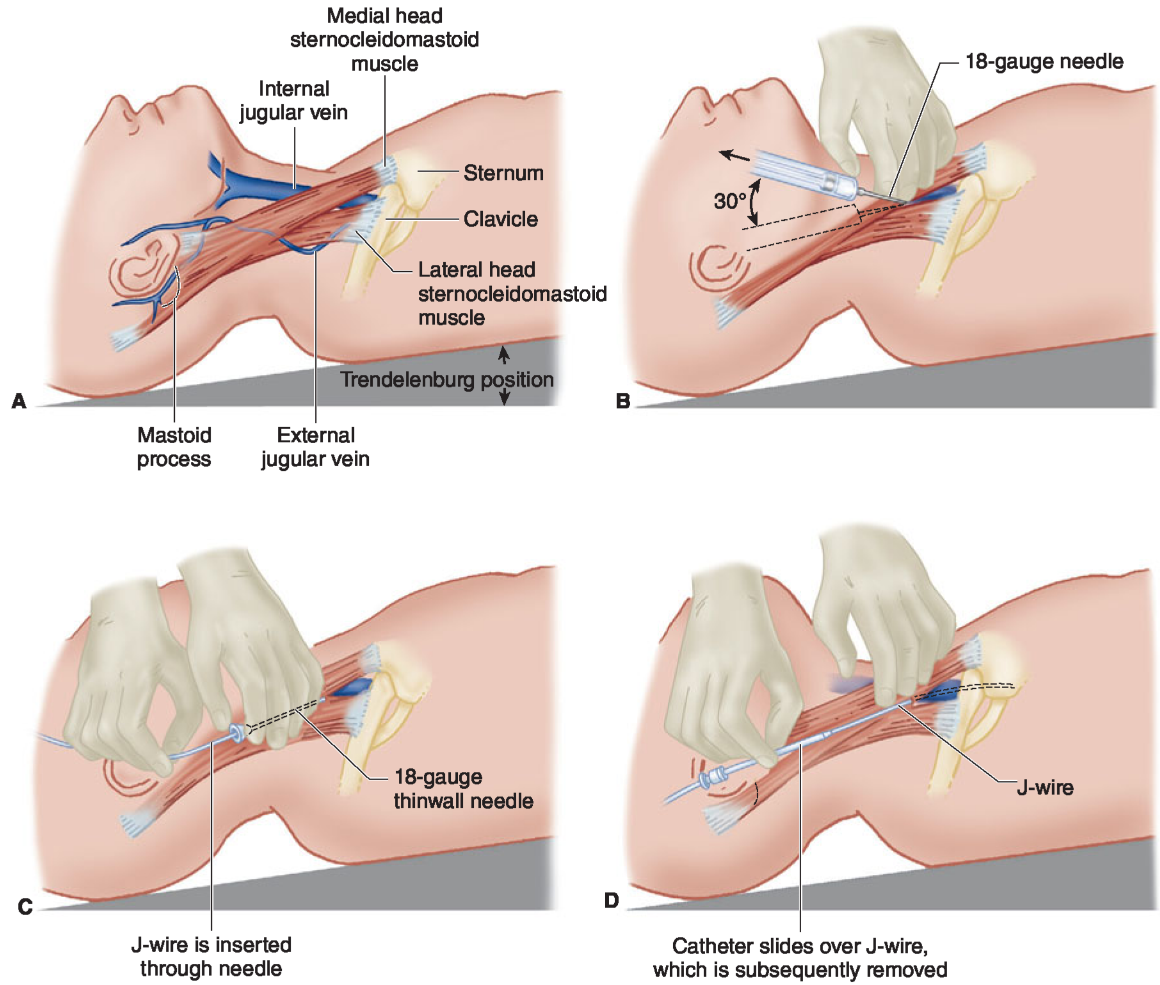


FIGURE 5–16 Right internal jugular cannulation with Seldinger's technique (see text).

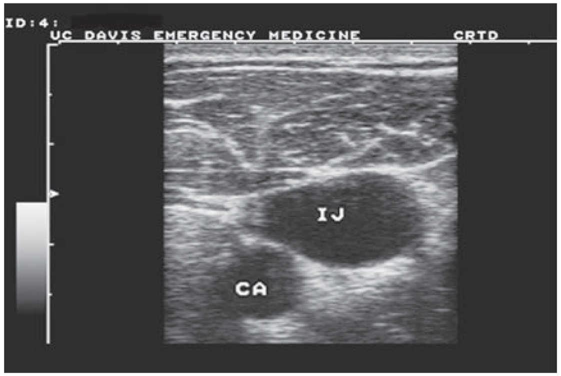
Anesthetic Monitoring

Modalities for Anesthetic Monitoring

Invasive hemodynamic monitoring

Central Venous Pressure

A



B

FIGURE 5–17 **A**: Probe position for ultrasound of the large internal jugular vein with deeper carotid artery and **B**: corresponding ultrasound image. CA, carotid artery; IJ, internal jugular vein. (Reproduced, with permission, from Tintinalli JE, et al: *Tintinalli's Emergency Medicine: A Comprehensive Study Guide*, 7th edition, McGraw-Hill, 2011.)

Anesthetic Monitoring

Modalities for Anesthetic Monitoring

Invasive hemodynamic monitoring

Pulmonary Artery Pressure

The pulmonary artery (PA) catheter is a controversial but potentially powerful tool, offering information about

- **cardiac filling pressures**,
- **cardiac output (CO),**
- derived parameters of cardiac performance,
- and **mixed venous oxygen saturation ($Sv0_2$).**

ASA consensus opinion is that

"PA catheter monitoring may reduce perioperative complications if critical hemodynamic data obtained are accurately interpreted and appropriate treatment is instituted.

Anesthetic Monitoring

Modalities for Anesthetic Monitoring

Invasive hemodynamic monitoring

Pulmonary Artery Pressure

$$CO = SV \times HR$$

$$SV = CO/HR$$

$$\text{Blood pressure} = CO \times \text{systemic vascular resistance (SVR)}$$

Anesthetic Monitoring

Modalities for Anesthetic Monitoring

Invasive hemodynamic monitoring

Pulmonary Artery Pressure

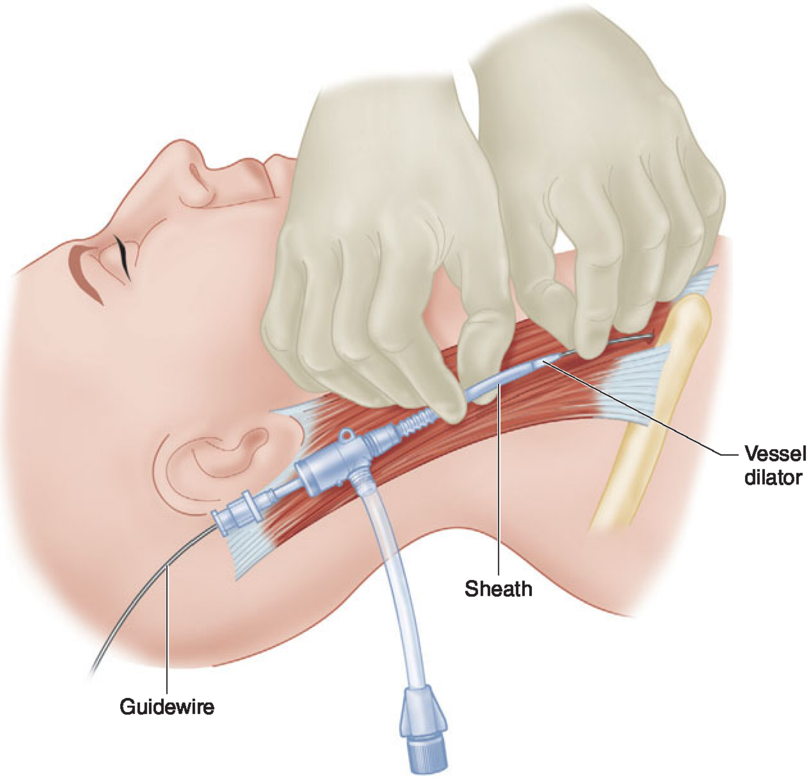


FIGURE 5–21 A percutaneous introducer consisting of a vessel dilator and sheath is passed over the guidewire.

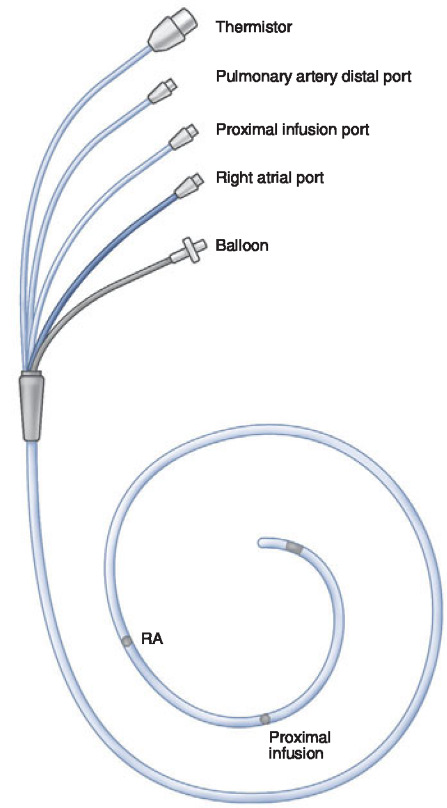


FIGURE 5–20 Balloon-tipped pulmonary artery flotation catheter (Swan–Ganz catheter). RA, right atrium.

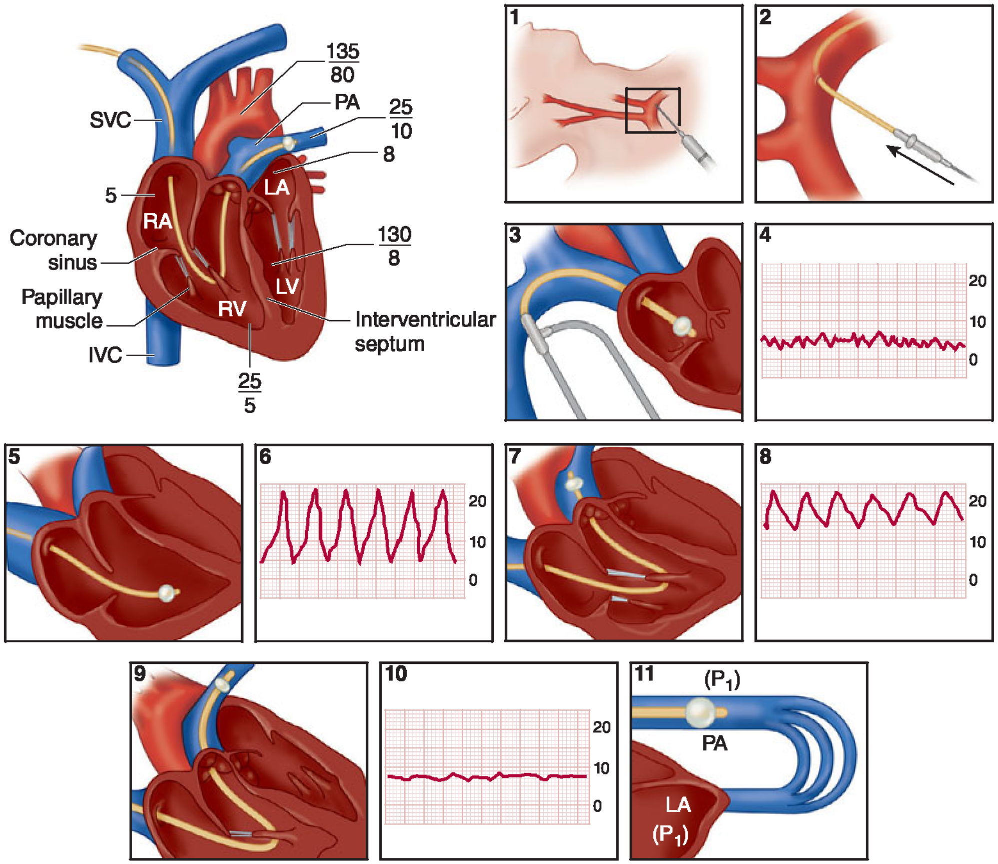


FIGURE 5–22 Although its utility is increasingly questioned, pulmonary artery catheters continue to be a part of perioperative management of the cardiac surgery patient. Following placement of a sheath introducer in the central circulation (panels 1 and 2), the pulmonary artery catheter is floated. Central line placement should always be completed using rigorous sterile technique, full body draping, and only after multiple, redundant confirmations of the correct localization of the venous circulation. Pressure guidance is used to ascertain the localization of the PA catheter in the venous circulation and the heart. Upon entry into the right atrium (panels 3 and 4), the central venous pressure tracing is noted. Passing through the tricuspid valve (panels 5 and 6) right ventricular pressures are detected. At 35 to 50 cm depending upon patient size, the catheter will pass from the right ventricle through the pulmonic valve into the pulmonary artery (panels 7 and 8). This is noted by the measurement of diastolic pressure once the pulmonic valve is passed. Lastly, when indicated the balloon-tipped catheter will wedge or occlude a pulmonary artery branch (panels 9, 10, and 11). When this occurs, the pulmonary artery pressure equilibrates with that of the left atrium which, barring any mitral valve pathology, should be a reflection of left ventricular end-diastolic pressure. (Redrawn and reproduced, with permission, from Soni N. *Practical Procedures in Anaesthesia and Intensive Care.* Butterworth Heinemann, 1994.)

Anesthetic Monitoring

Modalities for Anesthetic Monitoring

TransEsophageal Echocardiography

Transesophageal echocardiograpy (TEE) is a monitoring modality gaining popularity in the field of anesthesiology due to its versatility, reliability, and safety.

It was initially used as a diagnostic tool primarily by cardiologists but has become a mainstay in intraoperative cardiac anesthesia and its utility is extending into other areas as well.

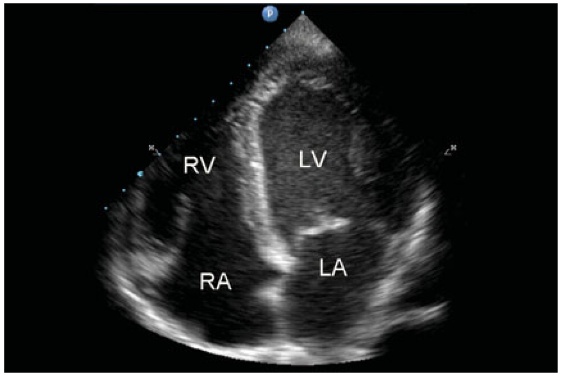


FIGURE 5–27 Normal apical four-chamber view. RV, right ventrical; LV, left ventricle; RA, right atrium; LA, left atrium. (Reproduced, with permission, from Carmody KA, et al: *Handbook of Critical Care and Emergency Ultrasound*. McGraw-Hill, 2011.)

Anesthetic Monitoring

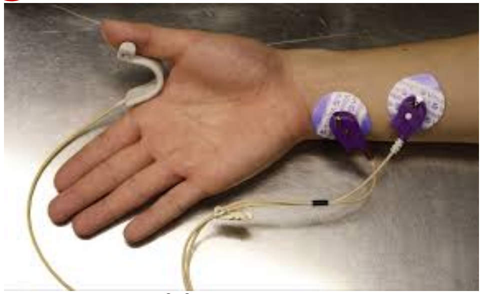
OBJECTIVES

At the end of the lecture you will be able to know the basics of anesthetic monitoring as follows:

- Definition
- What , When, How to monitor
- The policies that govern modern monitoring
  (Standards I and Standards II)
- The **basic monitors** and the **advanced monitors**
  - Arterial Oxygen Saturation- SpO2
  - Expired CO2 - ETCO2
  - Awareness under anesthesia
    - Means to monitor the wakeful state of the brain
  - Other somatosensory and motor monitoring
  - Brief introduction about invasive hemodynamic monitoring and oxygenation of the brain
  - **The neuromuscular junction relaxation monitoring**

Anesthetic Monitoring

Modalities for Anesthetic Monitoring


https://fa.wikipedia.org

PERIPHERAL NERVE STIMULATION

Neuromuscular transmission (NMT) monitoring

Indications

- The neuromuscular function of all patients **receiving intermediate- or long-acting neuromuscular blocking agents should be monitored**.
- Assessing paralysis during **rapid-sequence inductions** or during **continuous infusions of short-acting agents**.

Furthermore, peripheral nerve stimulators can help locate nerves to be blocked by regional anesthesia.

Anesthetic Monitoring

Modalities for Anesthetic Monitoring

Neuromuscular transmission (NMT) monitoring

Contraindications

There are no contraindications to neuromuscular monitoring,.

Atrophied muscles in areas of hemiplegia or nerve damage may appear refractory to neuromuscular blockade secondary to the proliferation of receptors.

Determining the degree of neuromuscular blockade using such an extremity could lead **to potential overdosing of competitive neuromuscular blocking agents.**

Anesthetic Monitoring

Modalities for Anesthetic Monitoring

Neuromuscular transmission (NMT) monitoring

Techniques & Complications

https://en.wikipedia.org/wiki/Neuromuscular_monitoring

A peripheral nerve stimulator delivers current (60- 80 mA) to a pair of either ECG silver chloride pads or subcutaneous needles placed over a peripheral motor nerve.

https://topslide.net/embed/tof-watch-objective-neuromuscular-transmission-monitors-because-patients-should-not-be-extubated-until-tof-never-miss-a-twitch

The evoked mechanical or electrical response of the innervated muscle is observed.

Although electromyography provides a fast, accurate, and quantitative measure of neuromuscular transmission, visual or tactile observation of muscle contraction is usually relied upon in clinical practice.

Anesthetic Monitoring

Modalities for Anesthetic Monitoring

Neuromuscular transmission (NMT) monitoring

Techniques & Complications

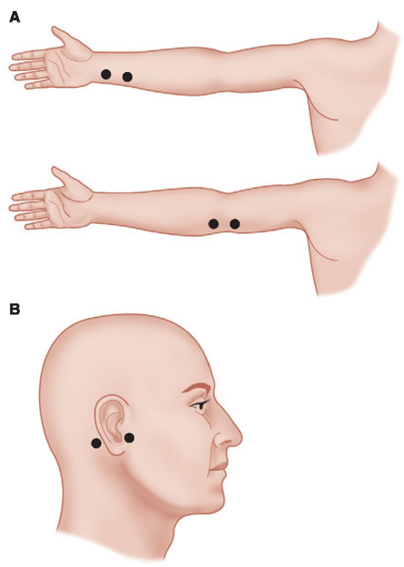


FIGURE 6–13 **A:** Stimulation of the ulnar nerve causes contraction of the adductor pollicis muscle. **B:** Stimulation of the facial nerve leads to orbicularis oculi contraction. The orbicularis oculi recovers from neuromuscular blockade before the adductor pollicis. (Reproduced, with permission, from Dorsch JA, Dorsch SE: *Understanding Anesthesia Equipment*, 4th ed. Williams & Wilkins, 1999.)

1. **Ulnar nerve stimulation of the adductor pollicis muscle**
2. **facial nerve stimulation of the orbicularis oculi**

are most commonly monitored.

- **Direct stimulation of muscle should be avoided**

- Complications of nerve stimulation are limited to **skin irritation and abrasion** at the site of electrode attachment

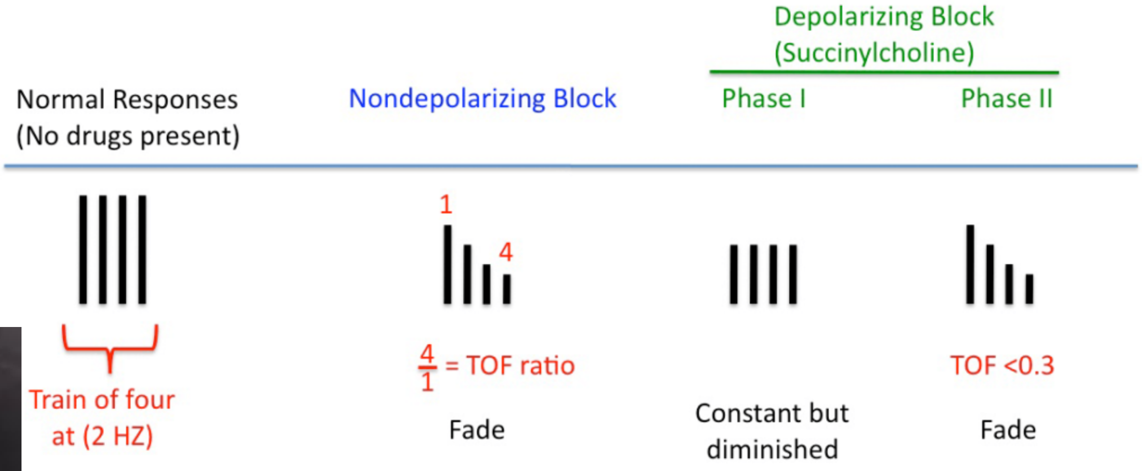
Anesthetic Monitoring

Modalities for Anesthetic Monitoring

Neuromuscular transmission (NMT) monitoring

Modes of stimulation

- Single Twitch
- **Train of four**
- Double Burst Stimulation
- Post Tetanic Count



<u>Common TOF Guidelines</u>:

TOF 0.15-0.25: indicates adequate surgical relaxation

TOF >0.9: needed for safe extubation & recovery after surgery

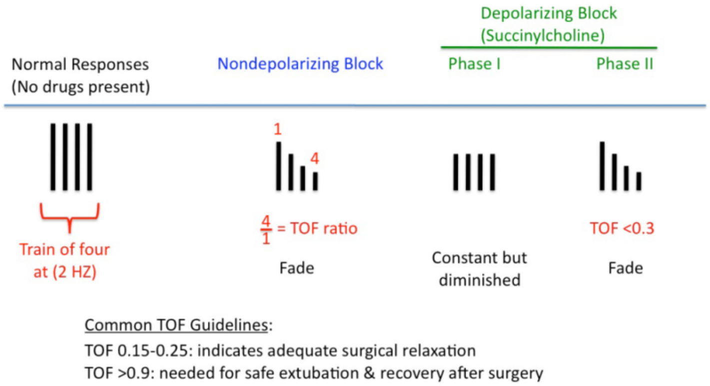
Anesthetic Monitoring

Modalities for Anesthetic Monitoring

Neuromuscular transmission (NMT) monitoring

Modes of stimulation

- **Train-of-four stimulation** denotes four successive 200-µs stimuli in 2 sec (2 Hz).
- The twitches in a train-of-four pattern progressively fade as nondepolarizing muscle relaxant block increases.
- The ratio of the responses to the first and fourth twitches is a sensitive indicator of nondepolarizing muscle paralysis.
- Ratio of fourth twitch over the first twitch should be greater than or equal to 90% to give the reversal (neostigmine and glycopyrrolate)



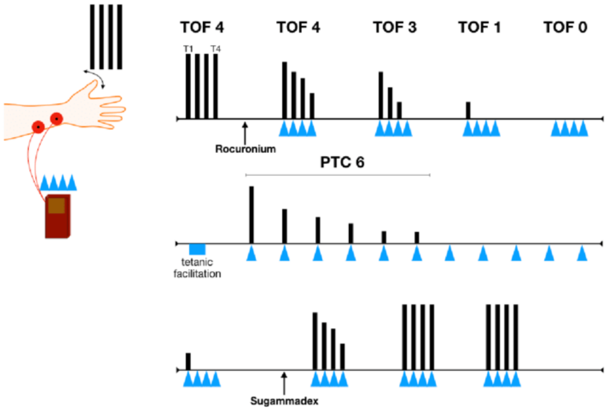
Anesthetic Monitoring

Modalities for Anesthetic Monitoring

Neuromuscular transmission (NMT) monitoring

Modes of stimulation

- Because it is difficult to estimate the train-of-four ratio, it is more convenient to visually observe the **sequential disappearance of the twitches,** as this also correlates with the extent of blockade:



- Disappearance of the
  - fourth twitch represents a 75% block
  - Third twitch : an 80% block,
  - Second twitch a 90% block.
- Clinical relaxation usually requires 75% to 95% neuromuscular blockade.

Anesthetic Monitoring

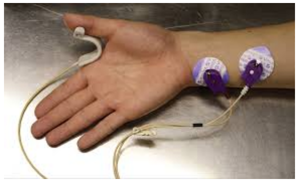
Modalities for Anesthetic Monitoring

Neuromuscular transmission (NMT) monitoring

Clinical Considerations and Extubation Criteria

•The diaphragm, rectus abdominis, laryngeal adductors, and orbicularis oculi muscles recover from neuromuscular blockade **sooner than** do the adductor pollicis.

•Other indicators of adequate recovery include sustained (≥5 s) head lift, the ability to generate an inspiratory pressure of at least –25 cm H_2O, and a forceful hand grip.



•Twitch tension is reduced by hypothermia of the monitored muscle group (6%/°C).

•Decisions regarding adequacy of reversal of neuromuscular blockade, as well as timing of extubation, should be made only by considering both the patient's clinical presentation and assessments determined by peripheral nerve stimulation.

Anesthetic Monitoring

Modalities for Anesthetic Monitoring

Neuromuscular transmission (NMT) monitoring

Clinical Considerations

Postoperative residual curarization remains a problem in post-anesthesia care, producing potentially injurious airway and respiratory function compromise.

Reversal of neuromuscular blocking agents is warranted, as is the use of intermediate acting neuromuscular blocking agents instead of longer acting drugs.

Monitoring Neuromuscular Function (2018)
https://www.youtube.com/watch?v=rm0yjMNj3n0

Train of four technique with a peripheral neuromuscular stimulator
https://www.youtube.com/watch?v=CNWRDP-bv2E

Anesthetic Monitoring

Modalities for Anesthetic Monitoring

Electrolytes/Acid Base

Coagulation

Urine output

References:

- **Morgan and Mikhail, Clinical Anesthesiology 6th Ed**
- **Miller's Anesthesia 8th Ed**
- www.asahq.org
- Other