

CO₂ Monitoring and Capnometry

Clinical examples



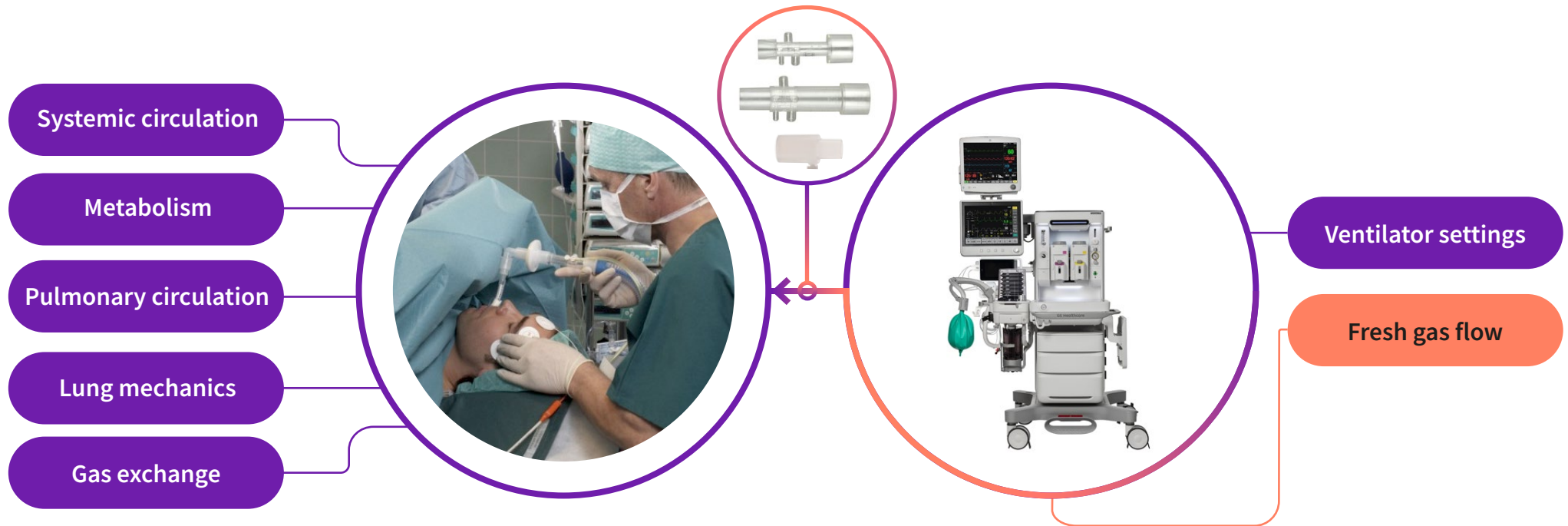
Note: The clinical examples shown are not actual case studies but were created to illustrate how the measurements might behave given the stated conditions.

Table of contents

1 Capnometry	2 Response time of various parameters to respiration-related mishaps	3 CO ₂ Production, Transport and Elimination
4 Using ET _{CO} ₂ to Control Ventilation	5 Differences in ventilation	6 Normal Ventilation-/ Perfusion Ratio
7 Ventilation-Perfusion Mismatch	8 Normal capnogram	9 Capnography
10 Benefits of normoventilation	11 Hypocapnia/Hyperventilation	12 Hypercapnia/Hypoventilation
13 Rebreathing	14 Esophageal intubation	15 Cardiac arrest and resuscitation, sudden fall to zero
16 Vasopressors, bicarbonate, tourniquet	17 Efforts of spontaneous breaths	18 Partially obstructed airway
19 Sudden disappearance of CO ₂ waveform	20 Sudden decrease of ET _{CO} ₂	21 Cardiogenic Oscillations
22 Sample flow rate effect	23 Clinical benefits	24 Suggested reading

Capnometry

Easy way to follow ventilation, circulation and metabolism

































Some specific benefits of CO₂ monitoring:

- Continuous
- Non-invasive
- Easy
- May help prevent ventilator related mishaps
- Follow-up of optimized ventilation
- Rapid verification of endotracheal intubation
- Quick detection of problems in the airway or malfunction of the ventilator or gas supply
- Objective, continuous and non-invasive indicator of adequacy of ventilation
- Disturbances in gas exchange, circulation and metabolism may be easily recognized
- May help reduce the need for frequent blood gas analyses, since EtCO₂ trends approximate the changes in PaCO₂

Response time of various parameters to respiration-related mishaps

That table¹ shows how fast detector both EtCO₂ and Fi-EtO₂ are in several critical situations. Even SpO₂ is widely used, its response time is much slower than airway gases. SpO₂ is measured on the peripheral site and EtCO₂ represents the alveolar values.

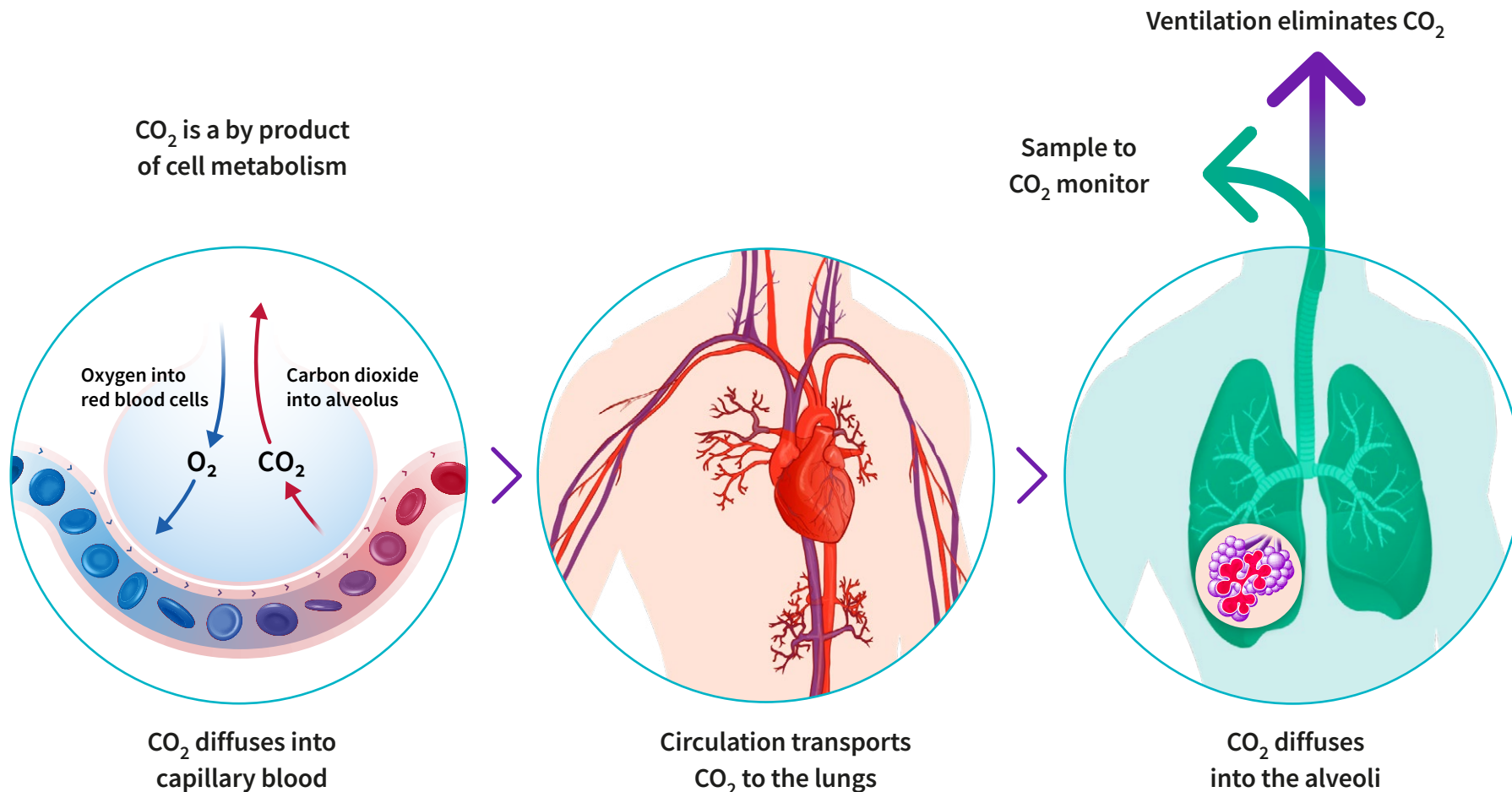
	Esophageal intubation	Disconnection	Sudden hyperventilation	Sudden circuit hypoxia	Embolism	Malignant hyperthermia
FiO ₂						
EtO ₂						
Fi-EtO ₂						
EtCO ₂						
SpO ₂						

Response time:  Fast <20s  Slow <60s  Late >60s

¹ Stenqvist O, Paloheimo M, Meriläinen P, Paloviita P. Patient Oxygen Appliguide - your margin of safety. Datex Division Instrumentarium Corp, 1992.

CO₂ production, transport and elimination

Oxidation of Glucose is an essential part of the energy metabolism and CO₂ is a waste product which must be continually removed. From the cells carbon dioxide diffuses into the capillary blood and subsequently to the venous circulation returning blood from the periphery to the right side of the heart. When the heart contracts, the mixed venous blood is pumped through the pulmonary circulation to the lungs for gas exchange. The exhalation phase of breathing eliminates CO₂ from the body. Although the lungs are by no means emptied, the final part of the exhaled gas is almost pure alveolar gas.



Using EtCO₂ to Control Ventilation

During spontaneous breathing, our respiratory center located in the brain, automatically regulates PaCO₂ being close to 40 mmHg by increasing or decreasing the minute ventilation according to the metabolism.

During mechanical ventilation, the use of sedatives can negatively affect respiratory drive. In that case, normoventilation cannot be adequately maintained without monitoring. In the presence of neuromuscular blocking agents, spontaneous respiration ceases further illustrating the need for continuous monitoring of ventilation.

Spontaneous breathing



Respiratory drive maintains normocarbica

PaCO₂

ETCO₂

Mechanical ventilation



Continuous ETCO₂ monitoring reflects the adequacy of minute ventilation proportional to CO₂ production

Differences in ventilation

Perioperative care



- Mostly planned operations
- Patient generally has healthy lungs
- Patients are anesthetized and often paralyzed
- No work of breathing concerns
- Short-term monitoring

Intensive care

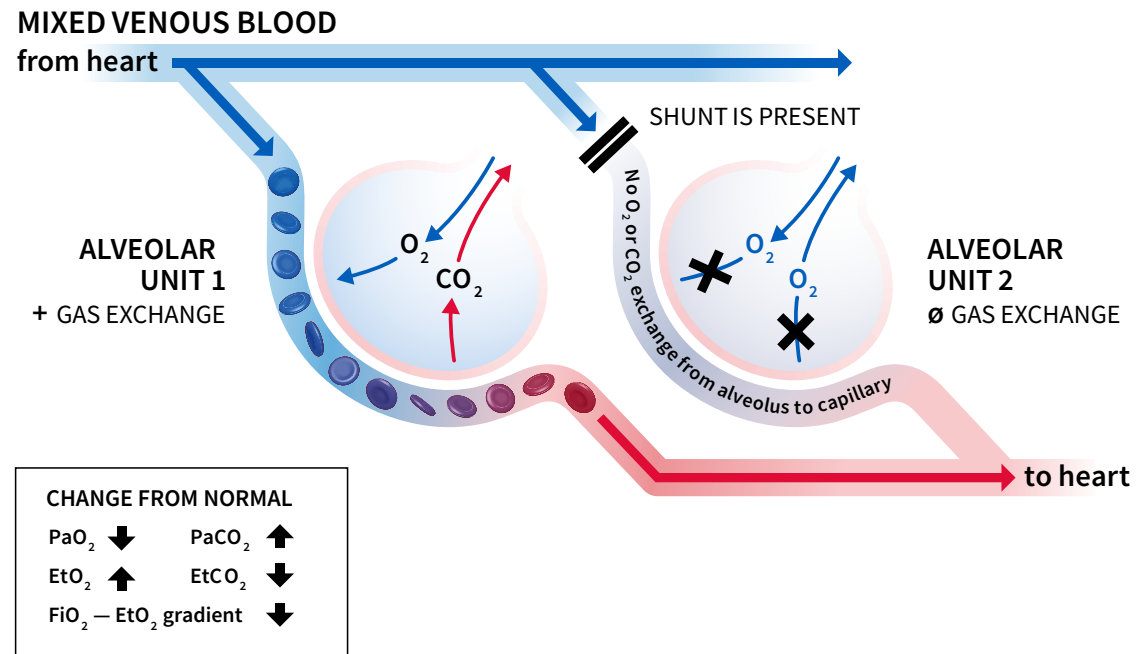
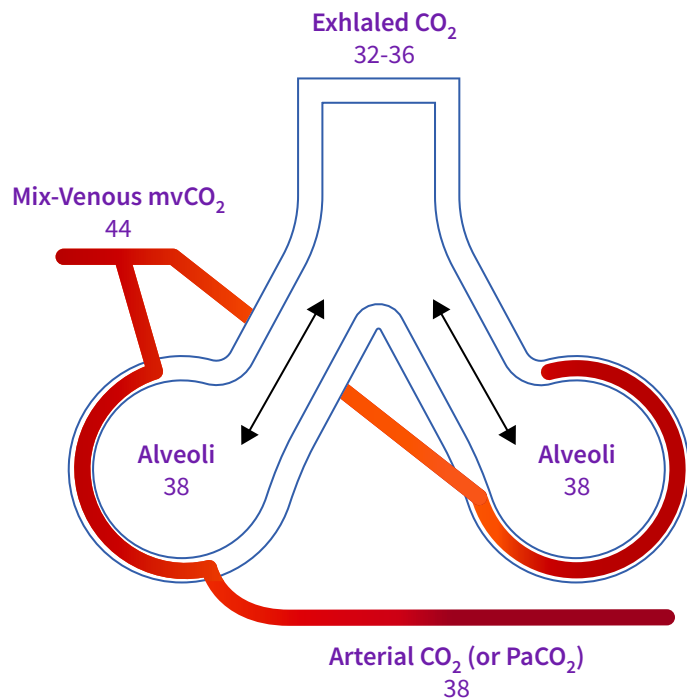


- Very complex & started at sub-optimal times
- Many different pathologies & traumas
- Try to maintain spontaneous ventilation
- Try to keep the work of breathing to a minimum

Normal ventilation/perfusion ratio

No significant aACO₂ difference

In a healthy person with optimal ventilation-perfusion ratio aACO₂ difference is 1-4 mmHg. The arterial-to-alveolar difference is due to a mismatch of ventilation and perfusion of the alveoli in the lungs. Even in healthy patients, there are some parts of the lungs which are not perfused as well as they are ventilated or vice versa.

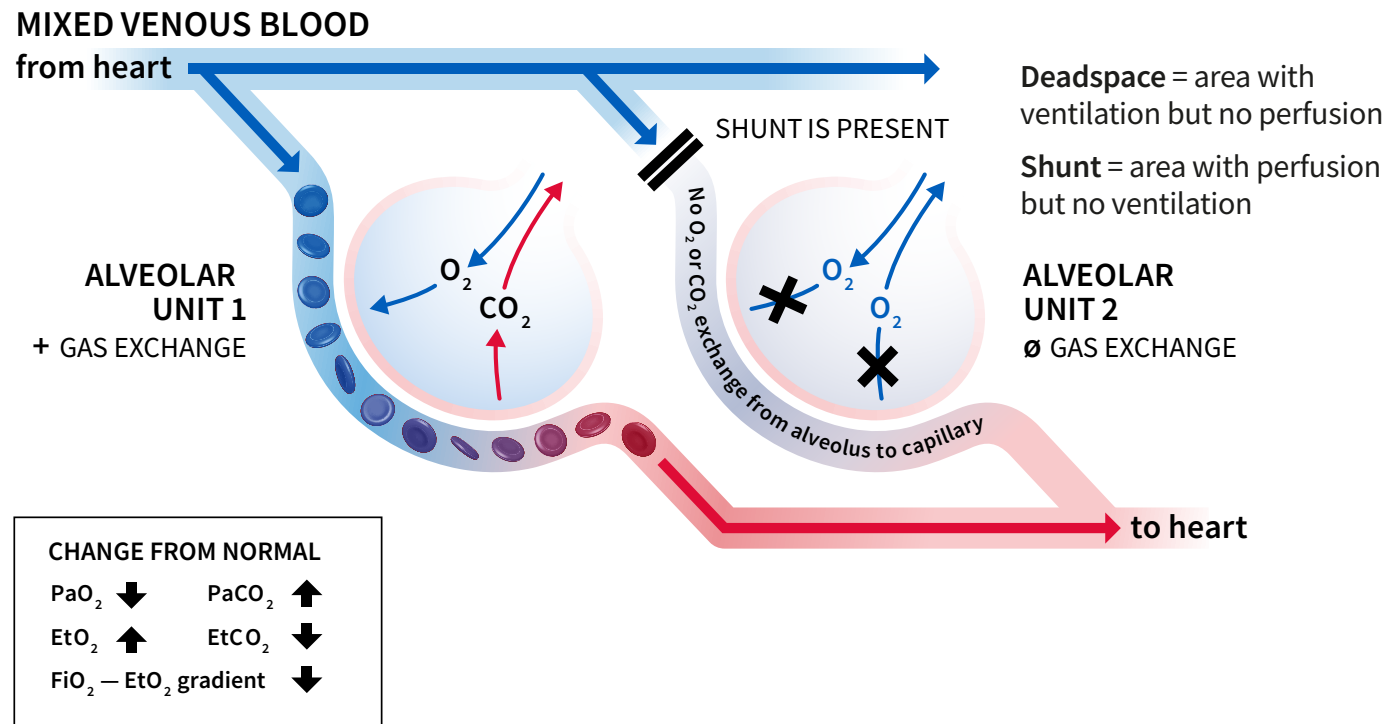


a=arterial
A=Alveolar

Ventilation-perfusion mismatch

Increased aACO₂ difference

Capnography provides continuous information on EtCO₂, and when you compare the changes to PaCO₂ (ABG) you will follow the degree of ventilation-perfusion mismatch and possibly reduce frequency of blood gas analyses.



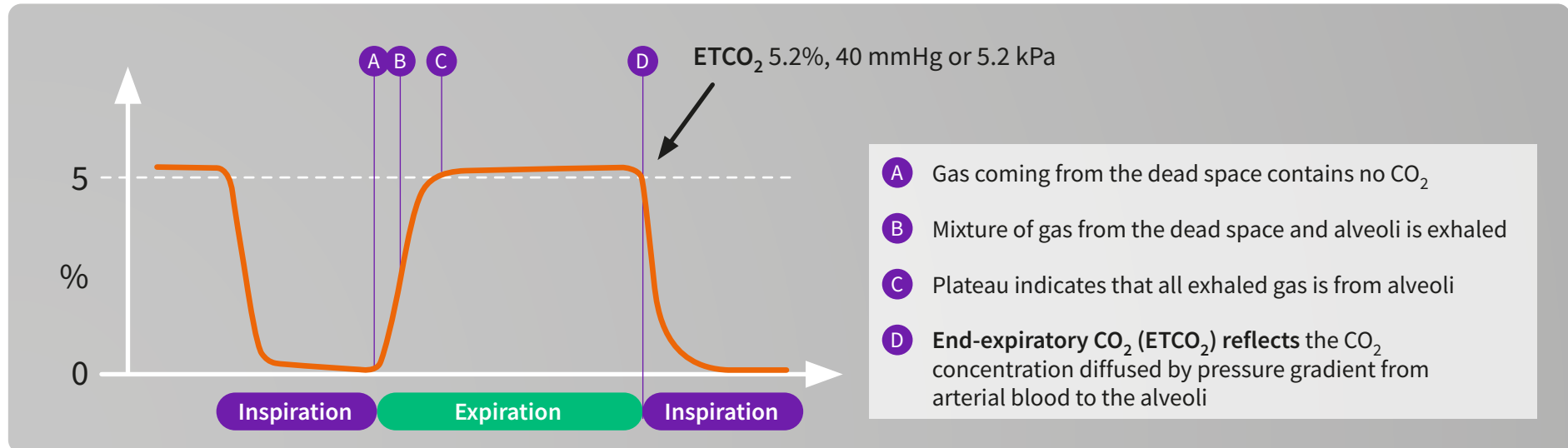
Parts of the lungs may also be well-perfused but poorly ventilated. Main reasons for shunt perfusion:

- Obstructed bronchi (mucus, foreign bodies, infection)
- Unilateral endobronchial intubation
- Increased closing volume (diaphragm pushing against the lungs)

Main reasons for dead space ventilation are:

- Pulmonary thromboembolism
- Patient position (side lying)
- Pulmonary hypoperfusion

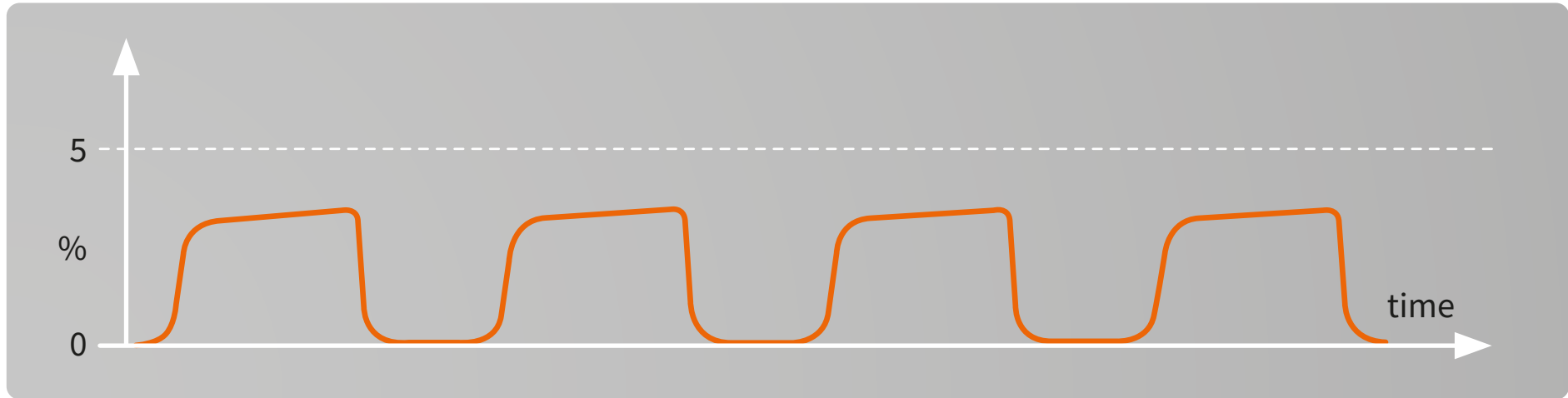
Normal capnogram



The CO₂ waveform is referred to as the capnogram and it reflects the different stages in breathing. The capnogram is an important diagnostic tool because its shape is virtually identical in all basically healthy patients. Any change in shape should be investigated.

EtCO₂ represents the CO₂ value at the end of expiration and this is typically displayed on the monitor screen.

Capnography



Normocapnia	EtCO ₂	4.6 - 5.9 vol %	35-45 mmHg ¹
Hypocapnia	EtCO ₂	less than 4.6 vol %	35 mmHg
Hypercapnia	EtCO ₂	more than 5.9 vol %	45 mmHg

Common terms in CO₂ monitoring:

- "capno" means CO₂ level in breath
- "hyper" means too much
- "hypo" means too little
- "carbia" refers to CO₂ level in the blood

Units for measurement

The following transformation formula can be used with sufficient accuracy at normal atmospheric pressure of 760 mmHg (at sea level and at normal body temperature):

vol %	volume percentage
mmHg	partial pressure in millimeters of mercury
kPa	partial pressure in kilopascals
	1 vol % = 1 kPa, 1 kPa = 7.6 mmHg, 1 mmHg = 0.13 vol%

Alveolar minute ventilation is typically adjusted to achieve normocapnia, where EtCO₂ is in the range 4.6 - 5.9 vol % (35 - 45 mmHg) (at atmospheric pressure corresponding to sea level and at normal body temperature).

¹ PetCO₂ normal values: Variables Associated with EtCO₂ Values. Prehospital Emergency Care, 16(2): 250-256.

Tobin, M. J., & Grenvik, A. (1984). Monitoring of the Patient in the Intensive Care Unit. New England Journal of Medicine, 310(18): 1170-1179.

Benefits of normoventilation

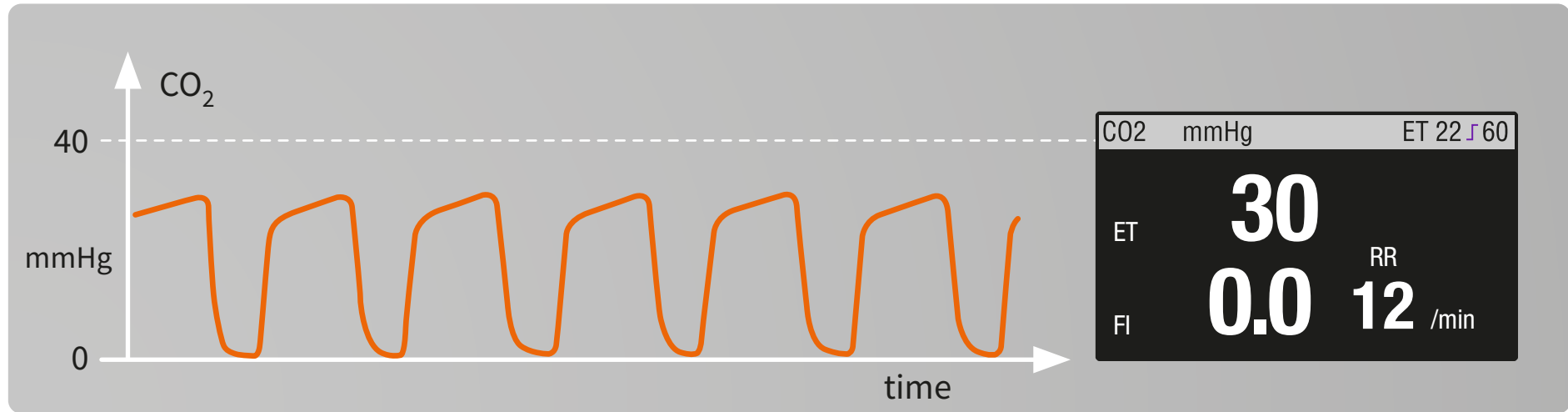
- Maintains normal physiology
- Maintains normal cerebral perfusion¹
- Spontaneous breathing reappears easily
 - short uneventful recovery

With normoventilation, disturbances in ventilation, circulation and metabolism can be more easily recognized and monitoring enables to maintain the physiologically optimal minute ventilation. Spontaneous breathing can be instituted more easily by allowing the EtCO₂ rise at the end of the anesthesia and patient usually experiences a more rapid recovery.

During lengthy anesthesia, there is typically a very gradual decrease in EtCO₂ due to the depressant effect of anesthetic agents and the effect of hypothermia slowing the patient's metabolism.

¹ Z. Kalenda, Mastering Infrared Capnography, p48, 1989

Hypocapnia/Hyperventilation²



An ETCO_2 level lower than normal, less than 4.6 vol % (35 mmHg), is called hypocapnia.

Possible reasons:

- Hyperventilation
- Decreased cardiac output
- Decreased metabolism
- Hypothermia

In anesthesia the common cause of hypocapnia is too high alveolar ventilation (hyperventilation)

In recovery or ICU hypocapnia in the spontaneously breathing patient may be result of hyperventilation due to fear, pain, failed weaning attempt or shock (circulatory failure)

Disadvantages of prolonged hyperventilation:

- Vasoconstriction leading to decreased coronary and cerebral blood flow
- Unnecessary respiratory alkalosis
- Depression of respiratory center

In specific cases there may be an advantage in hyperventilating the patient. For example, in neuroanesthesia hypocarbia may be used to deliberately reduce cerebral perfusion and intracranial pressure.

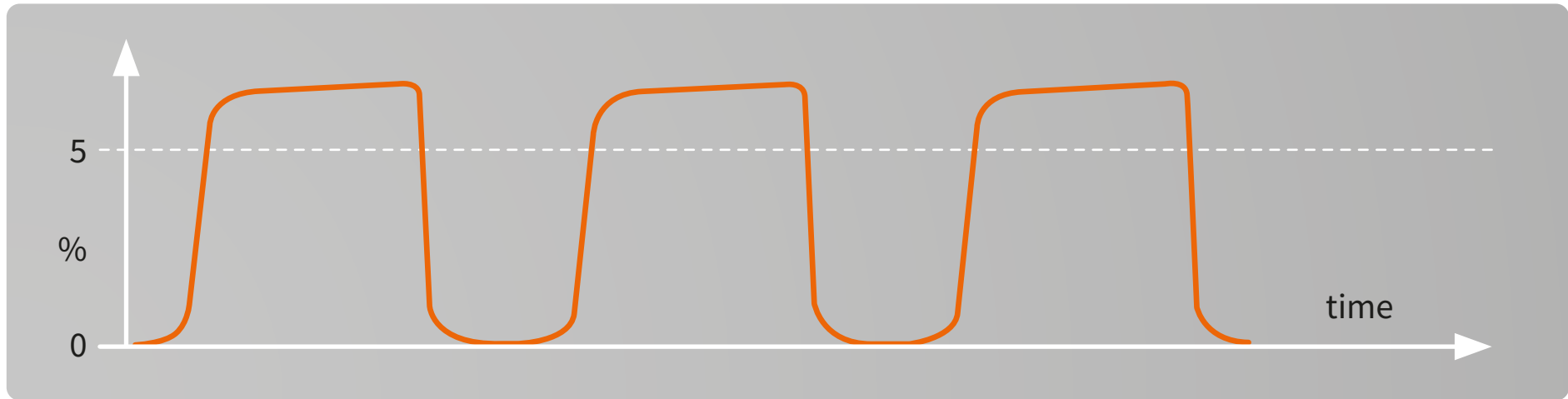
² PetCO_2 normal values: Variables Associated with EtCO_2 Values. Prehospital Emergency Care, 16(2): 250-256.

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Hypercapnia/Hypoventilation²



An ETCO₂ level higher than normal, more than 5.9 % (45 mmHg), is called hypercapnia.

Possible reasons:

Hypoventilation

A. Spontaneous respiration

- Depression of respiratory center
- Mechanical disturbances (muscle paresis, hemo/pneumothorax, airway obstruction)

B. Artificial ventilation

- Airway obstruction
- Pneumothorax
- Leak
- Disconnection
- Over-feeding (excess calorie intake)

- Ventilator dysfunction
- Mismanagement of artificial ventilation
- Rebreathing
- Permissive hypercapnia
- Circulatory insufficiency
- Altered V/Q ratio
- Increased metabolism (e.g. burn patients)
- Bicarbonate infusion
- Compensated metabolic alkalosis depression of respiratory center

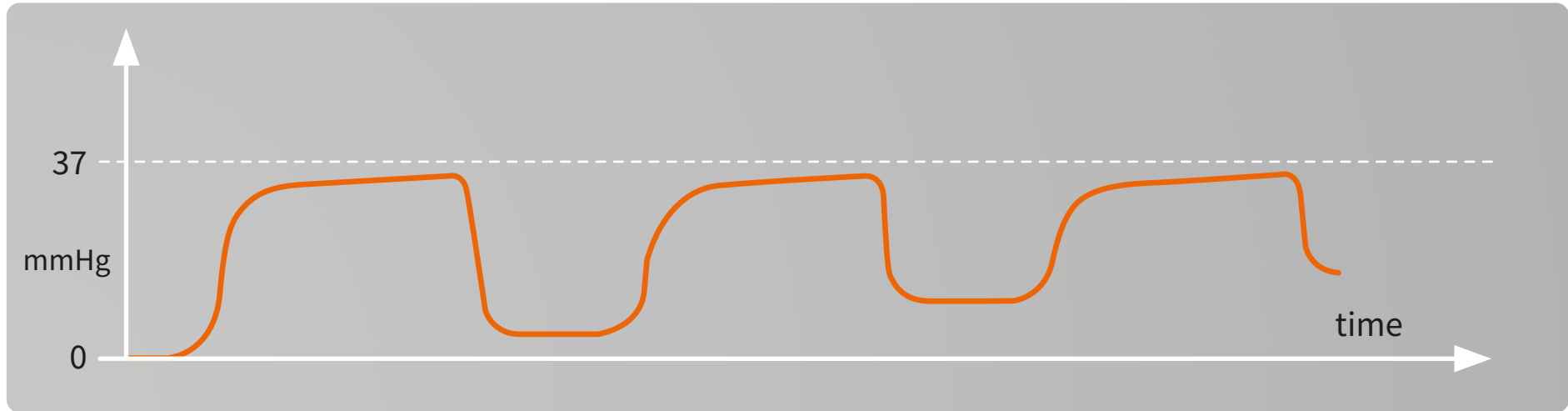
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Rebreathing²



Failure of the capnogram to return to the baseline may indicate rebreathing of the exhaled CO₂. This can be an inherent feature of the anesthesia delivery system (for example with Mapleson type of breathing systems) or it may be due to an exhausted CO₂ absorber in a circle system. Finally, it may also be due to inadequate fresh gas flow given to the patient as set in the ventilator.

Monitoring FiO₂ is the best method to determine the optimal fresh gas flow. **Ref.** Text book: *Understanding Anesthesia equipment. 5th edition. 2008 by Lippincott Williams & Wilkins*

If expiratory time is too short for CO₂ curve to represent the EtCO₂ value, the next inspiration will contain CO₂ which can be seen as a rise in the baseline.

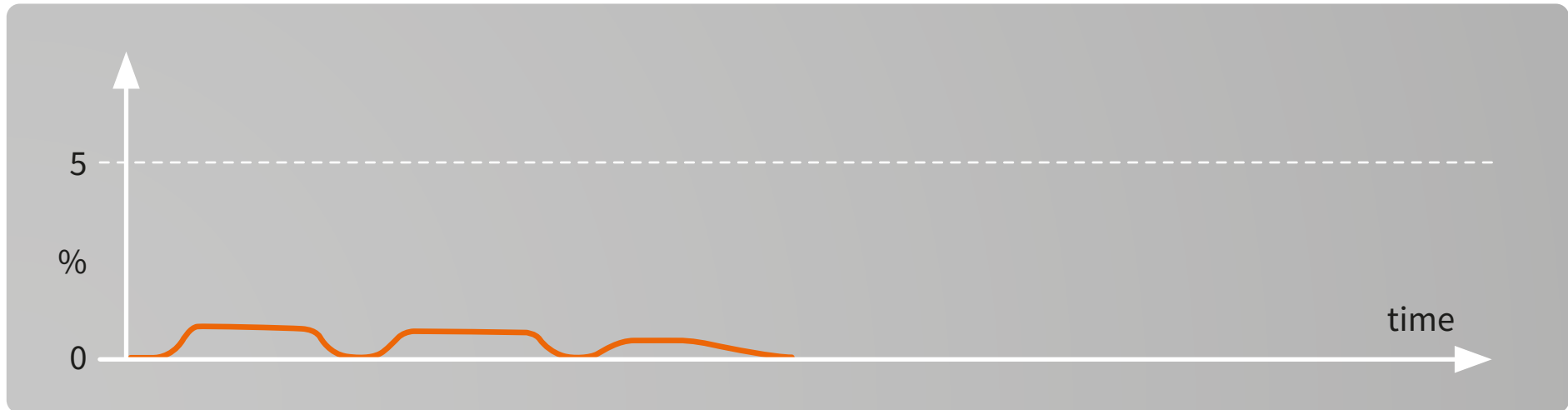
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Esophageal intubation²



If intubation is difficult i.e. vocal cords are not visible, it may happen that the ET-tube is inserted accidentally into the esophagus. If this is not detected immediately the patient will die. The best indicator for early detection is capnometry.

Some CO₂ may be detected due to gas entering the stomach during manual ventilation. After removal of the endotracheal tube and successful re-intubation, high EtCO₂ values are recorded because of CO₂ accumulation during apnea.

American Heart Association (AHA) recommends to use capnography to confirm the correct positioning of the ET-tube as well as in confirmation of the effectiveness of chest compressions during CPR.

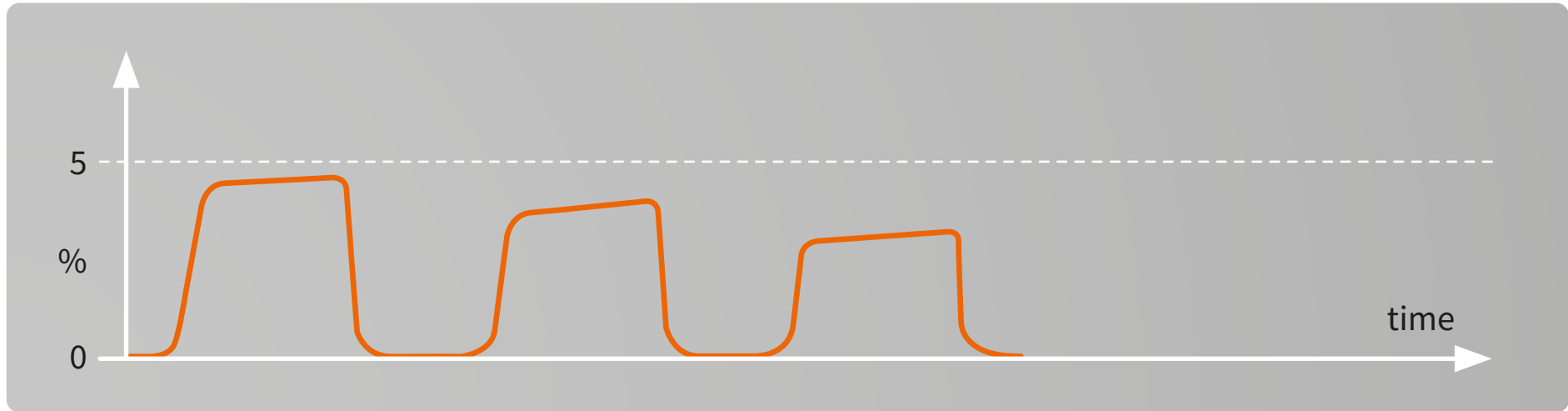
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Cardiac arrest and resuscitation, sudden fall to zero²



EtCO₂ monitoring provides a continuous information in detecting return of spontaneous circulation during cardiac resuscitation.

American Heart Association (AHA) recommends to use capnography to confirm the correct positioning of the ET-tube as well as in confirmation of the effectiveness of chest compressions during CPR.

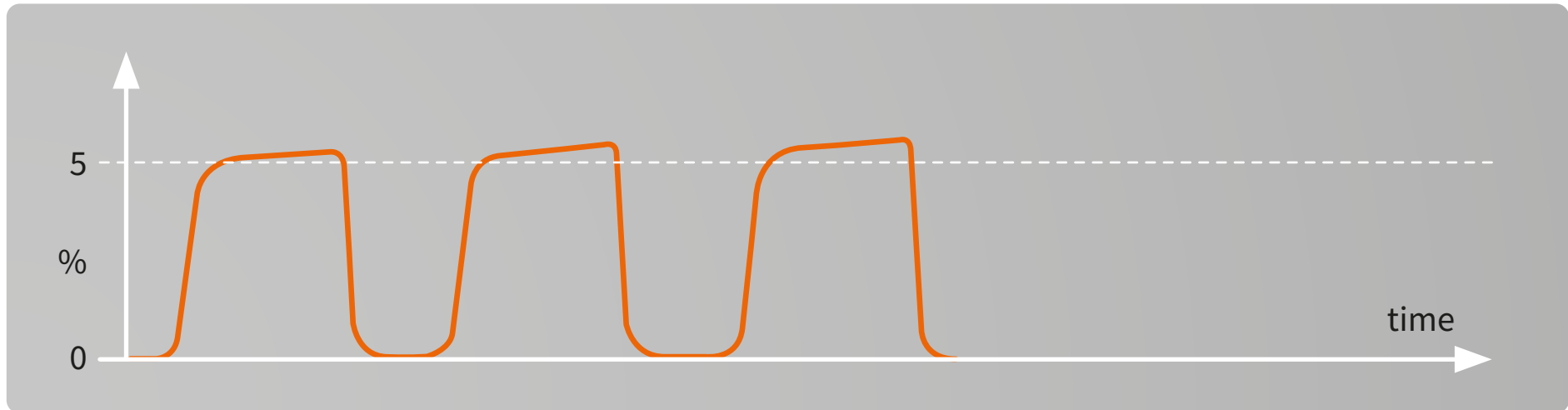
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Vasopressors, bicarbonate, tourniquet²



Sudden but transient rise in ETCO_2 while inspired CO_2 remains zero may be due to the release of a tourniquet or infusion of bicarbonate.

Some orthopedic operations are performed using tourniquet in order to get the surgical field bloodless. The use of tourniquet will lead to ischemic reaction in the limb and after the release of tourniquet the acidotic substance will be released into the circulation. This effect can be seen as transient rise in ETCO_2 .

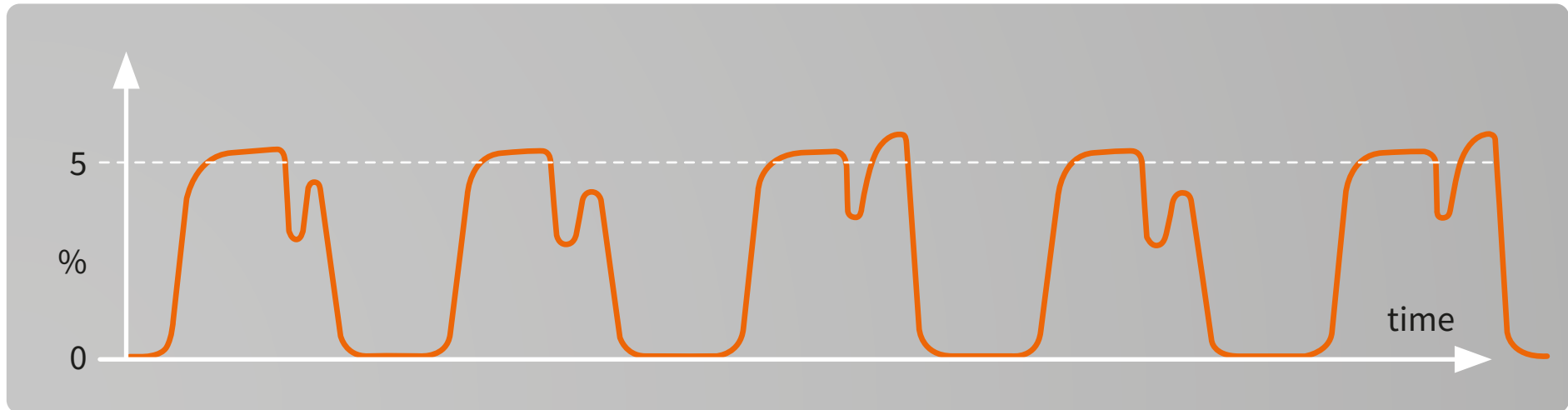
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Efforts of spontaneous breaths²



Efforts of spontaneous breaths can be seen as a “camel” capnogram

Insufficient muscular relaxation and/or inadequate depth of anesthesia are allowing the patient “fight” against the mechanical ventilation. These shallow, efforts of spontaneous breaths can be seen as clefts on the capnogram plateau.

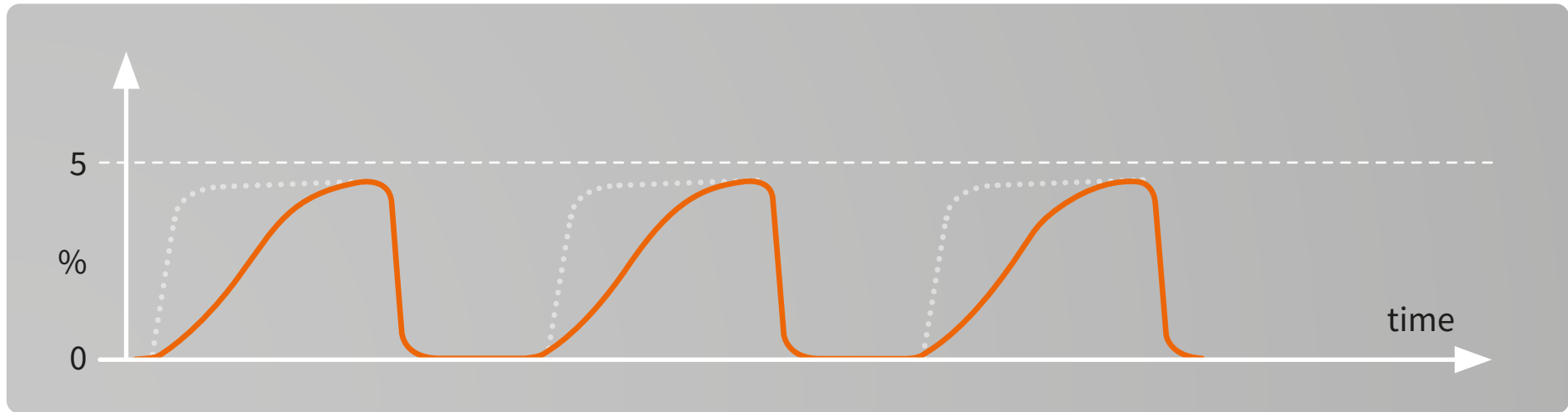
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Partially obstructed airway²



A deformed capnogram, with a slowly rising leading edge, may indicate a partial obstruction of the airway.

Possible causes:

- Secretions
- Bronchospasm
- Kink of ET-tube

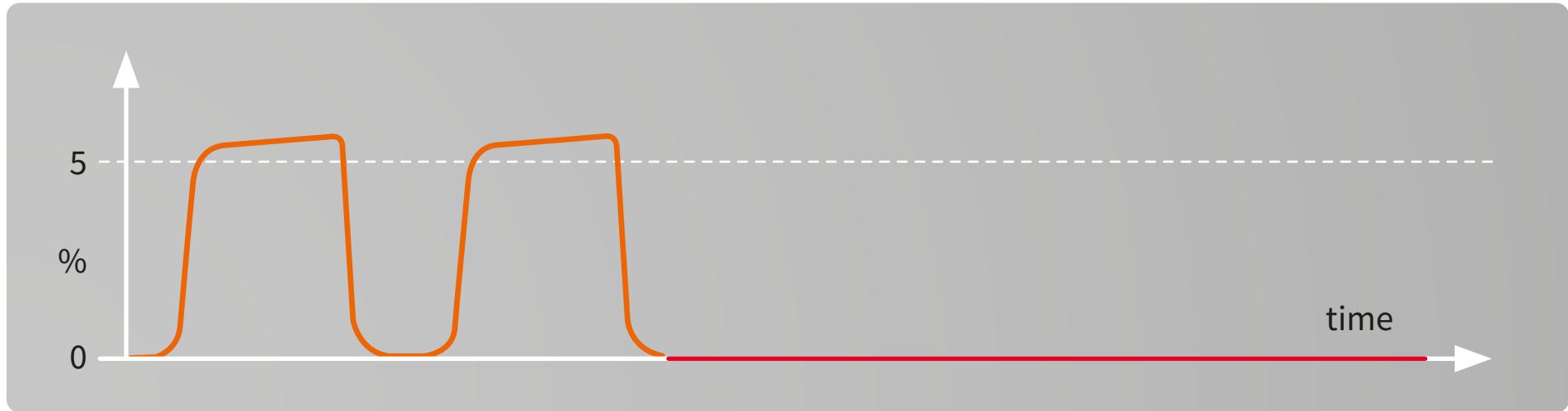
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Sudden disappearance of CO₂ waveform²



If the CO₂ waveform is normal but then drops to zero from one breath to the next.

Possible reasons:

- Ventilator disconnection
- Totally obstructed ET-tube
- Gas sampling line disconnected
- Cardiac arrest

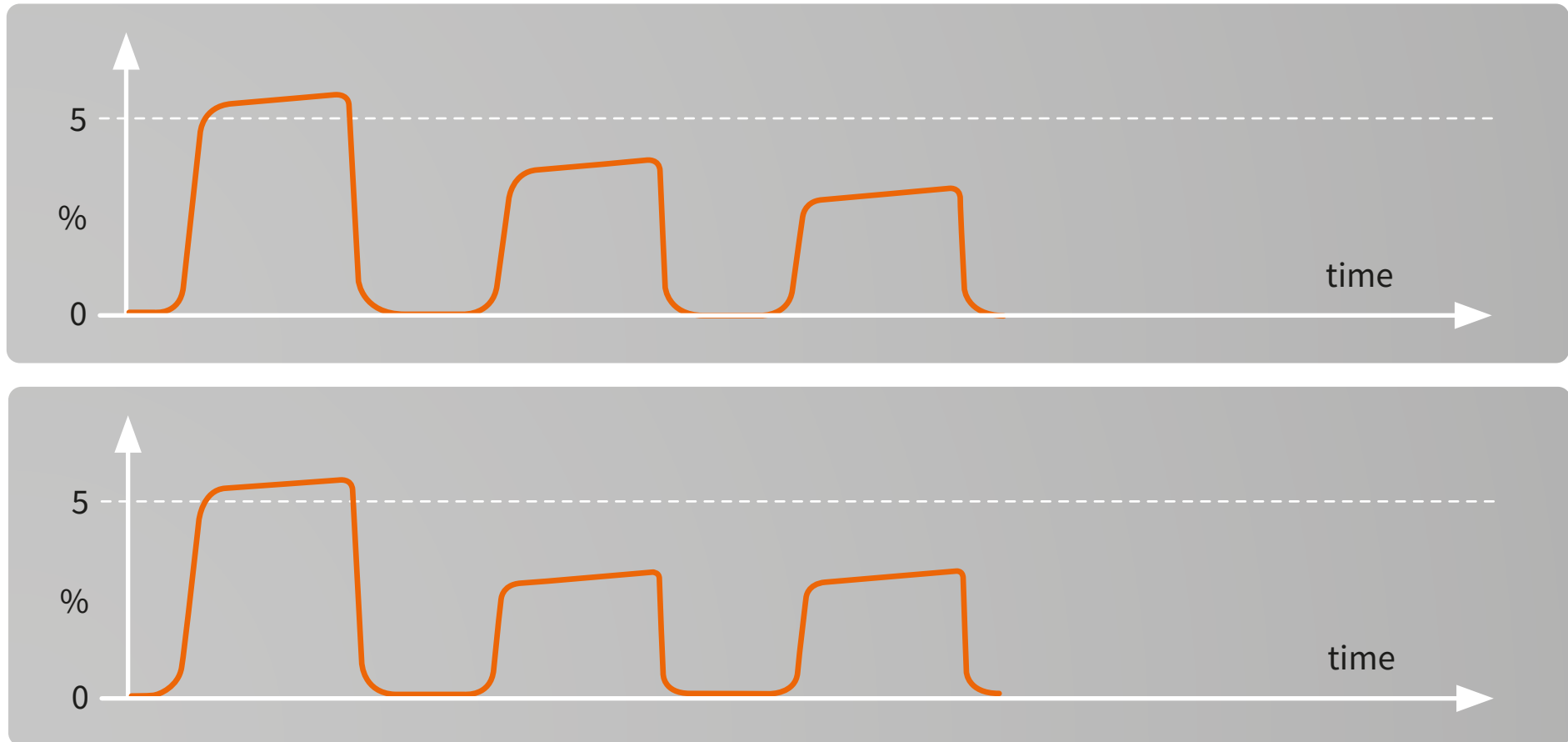
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Sudden decrease of ETCO_2 ²



A rapid fall in ETCO_2 over a period of several breaths may indicate:

- Pulmonary embolism
- Cardiac arrest
- Severe hypotension (massive bleeding)
- Leak in sampling system

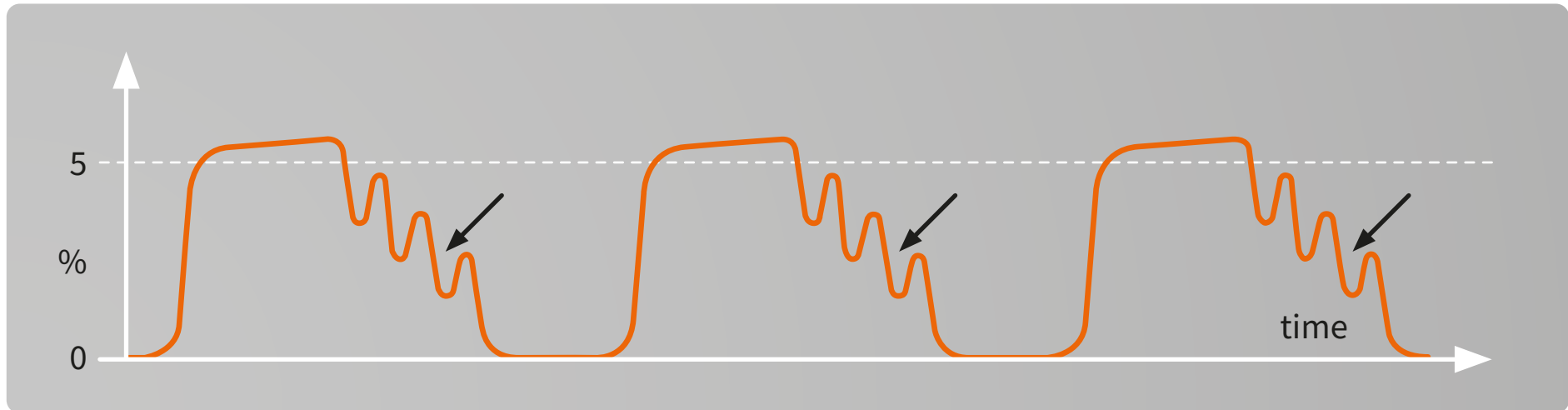
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Cardiogenic oscillations²



Cardiogenic oscillations in the expiratory CO₂ wave are caused by thoracic gas movements resulting from cardiac contractions during side stream gas sampling.

Possible reasons:

- Continuous gas flow fed directly into the inspiratory limb
- Side stream gas sampling taken at the Y-piece
- Slow respiration rate
- Long expiration time

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Sample flow rate effect

- Table presents different sampling volumes depending on respiration rate
- The I:E ratio is assumed to be 1:2

Note: You can change the sample flow/min and I:E ratio values to see how the sampled gas is distributed per breathing cycle.

Gas volumes sampled during inspiration and expiration phases of a single breath depends on respiratory rate and I:E ratio. Input the values of sample flow (V mL/min), inspiratory and expiratory ratio (I:E) to see sample flow rate effect.

Sample flow		V (ml/min) =		
I:E Ratio		I =	E =	
Respiration Rate [breath/min]	Duration of inspiration [second]	Duration of expiration [second]	Gas sampled during inspiration [ml]	Gas sampled during expiration [ml]
10				
20				
30				
40				
50				
60				
70				
80				
90				
100				
110				
120				

The effect of the sample flow rate by the side stream analyzer is seen in the table. The amount of gas drawn by the monitor is dependent on the respiratory rate. When the respiratory rate increases the sample gas will decrease by breath. Also the total volume sampled is divided between the inspiration and expiration.

Example: with a respiration of 30, which may be common for small babies, the total volume sampled is 4 ml only, where 1,3 ml is drawn during the inspiration. This makes the 120 ml flow rate feasible for small babies as well.

Clinical benefits

Patient safety

- Confirms the correct place of ET-tube
- Continuous measurement to detect hyperventilation or hypoventilation quickly
- Estimation of increased/decreased shunt
- ETCO_2 trend vs PaCO_2

Optimal minute ventilation=normoventilation

Suggested reading

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Rationales and Applications for Capnography, Monitoring During Sedation, Devin Carr, MSN, MS, RN, RRT, ACNS-BC, NEA-BC, CPPS and Anna Cartwright, BSN; RNclinicalfoundations.org

End-Tidal Capnography

Updated: Jan 17, 2020.

Author: Robert Thomas Arrigo, MD, MS; Chief Editor: Zab Mosenifar, MD, FACP, FCCP

How to Read and Interpret End-Tidal Capnography Waveforms

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