Clinical Measurements

A Quick Guide to Capnography

Recording and analysis of the CO_2 waveform and its use in differential diagnosis

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PHILIPS

This guide provides convenient views of a selection of CO_2 waveforms, along with interpretation to explain their relationship to other routine physiological monitoring waveforms.

These illustrated waveforms are semi-schematic diagrams presented in their ideal shape.

Contents

Analyzing the CO_2 waveform

The CO_2 waveform can be analyzed for five characteristics:
–Height
–Frequency
–Rhythm
–Baseline
–Shape

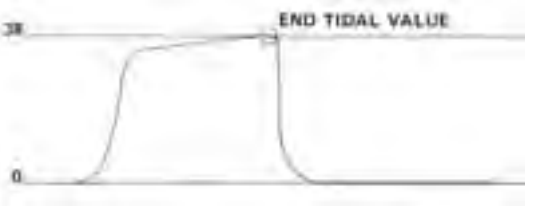
The normal end-tidal value is approximately: 38 mmHg or 5% $etPCO_2$

- Height depends on the end-tidal CO_2 value $etPCO_2$
- Frequency depends on the respiratory rate
- Rhythm depends on the state of the respiratory center or on the function of the ventilator
- Baseline should be zero
- There is only one normal shape (see page 12)

The CO_2 waveform

The waveforms are typically recorded or displayed at two different speeds:

Real-time (high) speed at 12.5 mm/sec



Trend (slow) speed at 25 mm/min

Important basic rules

1. A **sudden drop** in CO_2 to zero or to a low level always indicates a technical disturbance or defect:
   - Spontaneous breathing or ventilated patients
     - Kinked ET-tube
     - CO_2 analyzer defective
   - Ventilated patients
     - Total disconnection
     - Ventilator defective

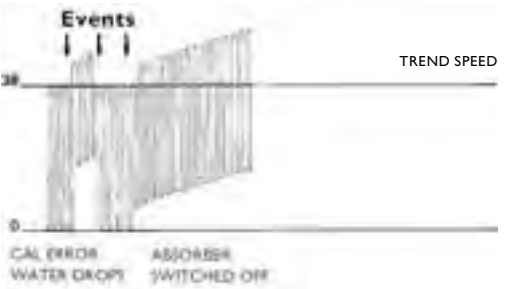
2. A **sudden change** in baseline, sometimes combined with changes in plateau level, indicates:
   - Calibration error
   - CO_2 absorber saturated (check capnograph with room air)
   - Water drops in analyzer or condensation in airway adapter

CHECK CAPNOGRAPH !

Important basic rules

1.

2.



3. A **sudden decrease** in CO_2 value (but not to zero) with spontaneous or ventilated breathing indicates:
   - Leakage in the respiratory system (low airway pressure)
   - Obstruction (high airway pressure)

4. An **exponential decrease** in CO_2 (washout curve) within one or two minutes always indicates a sudden disturbance in lung circulation or ventilation:
   - Circulatory arrest
   - Embolism
   - Sudden decrease in blood pressure
   - Sudden severe hyperventilation

Important basic rules

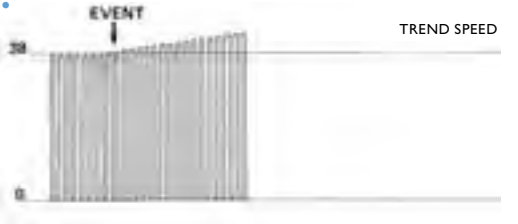
3.

4.

5. **Gradual increase** in CO_2 for spontaneous or controlled breathing indicates:
   - Developing hypoventilation
   - Absorption of CO_2 from peritoneal cavity (laparoscopy)
   - Rapidly rising body temperature

6. **Sudden increase** in CO_2 (spontaneous or controlled ventilation):
   - Injection of sodium bicarbonate
   - Sudden release of tourniquet (legs, arms, etc.)
   - Sudden increase in blood pressure (e.g., intravenous adrenaline)

5.



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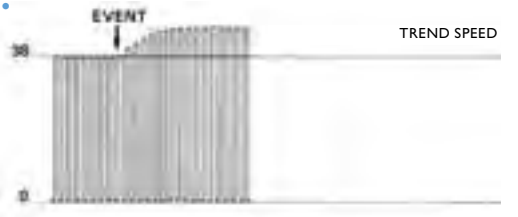
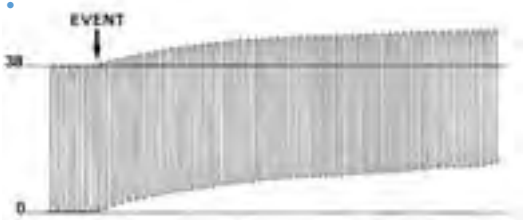


7. **Gradual upshift** in the CO_2 baseline and topline can result from:
   - Saturation of CO_2 absorber
   - Calibration error
   - Technical error in CO_2 analyzer
   - Increasing dead-space, resulting in re-breathing
   - CO_2 absorber switched off

8. **Gradual lowering** of the end-tidal CO_2. The curve retains its normal shape but the height of the plateau falls gradually. In an artificially ventilated patient, this can be caused by:
   - Gradual hyperventilation
   - Lowering body temperature
   - Decreasing body or lung perfusion

7.

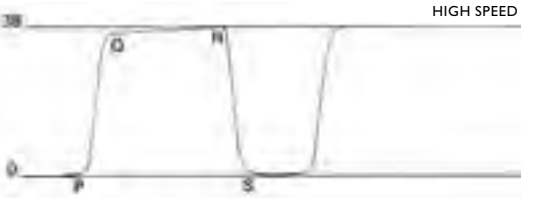


TREND SPEED

8.

TREND SPEED

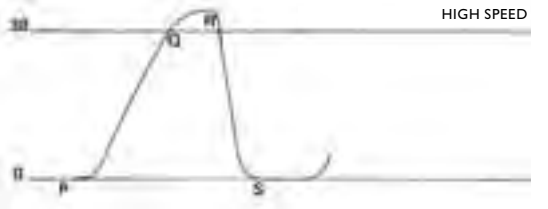
The normal capnogram



There is only one normal shape.
Characteristics:

- Rapid increase from P to Q
- Nearly horizontal plateau between Q and R (slightly sloping up to R)
- From R rapid decrease to zero
- Points P, Q, R, and S appear as rounded corners. (P, Q, R is the expiratory phase. R, S, P is the inspiratory phase.)
- Slope of the plateau depends on the condition of the airways and lung tissue
- End-tidal value is **only** equivalent to the alveolar CO_2 when a nearly horizontal plateau is seen

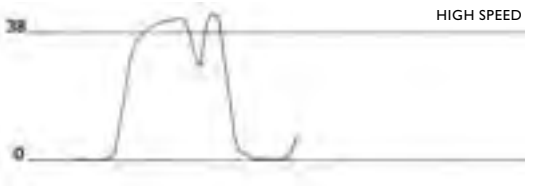
Expiratory problems



In general, any airway obstruction limiting expiration.

Possible explanations:
- Kinked tube (developing out of a previously normal shape)
- Foreign body
- Herniated cuff (developing out of a previously normal curve)
- Bronchospasm
- Emphysema
- Bronchial asthma

"Curare" capnogram*



- Caused by lack of coordination between intercostal muscles and diaphragm
- Note the cleft in right third of the plateau. CO_2 mostly too high. The depth of the cleft is proportional to the degree of muscle paralysis. Seen only in spontaneous respiration, or when the patient starts to fight the ventilator
- Also seen in patients with cervical transverse lesions

* The expression "curare capnogram" was given at the time that curare was a generally accepted muscle relaxant (about 1960). Nowadays, other muscle relaxants are in use, but the shape of the capnographic curve in patients who are partially paralyzed is still the same.

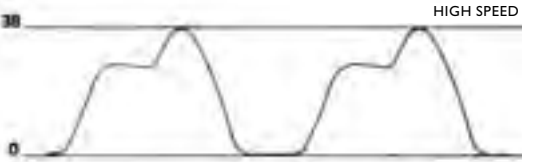
Cardiogenic oscillations

Caused by the beating of the heart against the lungs:

- Small tidal volume in combination with low respiratory rate
- At the end of a very long expiration

Can be caused by a central depression of the respiratory system or by the ventilator running too slowly.

Camel capnogram



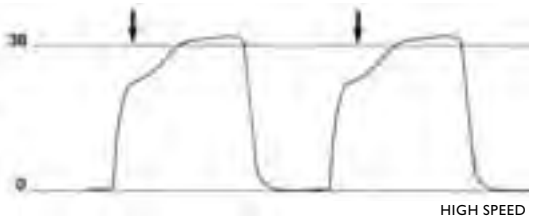
- Can be seen in patients in the lateral position on the operating table
- During either spontaneous or controlled respiration

Iceberg capnogram

Caused by a combination of a muscle relaxant and a central acting analgesic drug (e.g., morphine, fentanyl, etc.):

- Mixture of cardiogenic oscillations and "curare" cleft (see page 14)
- No plateau. Low respiratory rate
- CO_2 higher than normal
- Seen only in spontaneous respiration

Leakage in the respiratory system



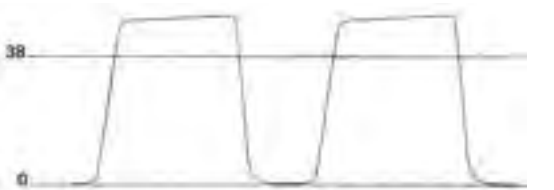
HIGH SPEED

Irregularity mostly in expiratory limb (see arrows):

- Shape and site of this irregularity depend on the localization and severity of the leak in the anesthetic system (cuff, valves, tubing, etc.). CO_2 could be too high due to hypoventilation or too low due to the addition of leaking air
- Other possible leakage shapes have to be differentiated from other disturbances (e.g., camel curve (see page 16), etc.)

High end-tidal CO_2

A. With normal respiratory rate

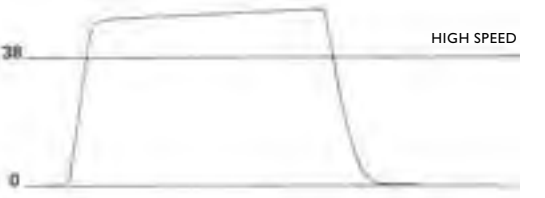


HIGH SPEED

Normal plateau but higher than normal end-tidal CO_2. Can be seen in artificially ventilated patients:

- When the ventilator is running at normal respiratory rate but the minute volume is too low
- With primary normal respiratory rate and minute volume but with a rapidly rising body temperature (e.g., in malignant hyperthermia)

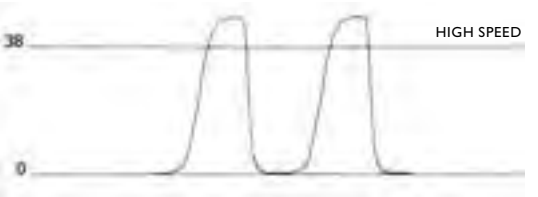
B. With bradypnea



Long plateau but higher than normal CO_2. Respiratory depression without an attempt to compensate can be seen:

- In cases of high ICP or respiratory depression due to morphinic-based drugs (e.g., pethidine, fentanyl, etc.)
- In artificially ventilated patients, when the ventilator is running with both respiratory rate and minute volume too low

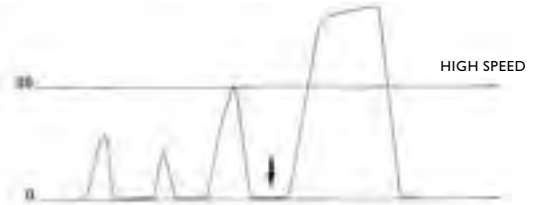
C. Hypoventilation with tachypnea



Short plateau but higher than normal end-tidal CO_2. Respiratory depression with an attempt to compensate by higher respiratory rate can be caused by:

- Volatile anesthetics during spontaneous respiration (e.g., halothane, etc.)
- Ventilator running at high rate but with low tidal volume

D. Very severe hypoventilation

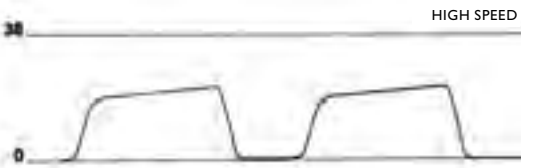


Very severe hypoventilation (very low tidal volume) with a high respiratory rate as an attempt to compensate. A misleading low level of CO_2 is recorded on the capnogram. Mostly no proper plateau. After thorax compression or forced exhalation (see arrow), true CO_2 value becomes visible:

- Can be seen under spontaneous or controlled breathing
- In patients with spontaneous respiration but with severe respiratory paralysis caused by paralyzed respiratory muscles
- Malfunction of ventilator or leakage in respiratory system

Low end-tidal CO_2

A. With normal respiratory rate



With normal respiratory rate and plateau but a lower than normal end-tidal CO_2. Can be observed in artificially ventilated patients:

- When the ventilator runs with a normal rate but the minute volume is too high
- Who are in shock
- With normal respiratory rate and tidal volume but with a low body temperature

Can also be seen in patients with spontaneous respiration when they are compensating a metabolic acidosis.

B. With bradypnea

With bradypnea but a lower than normal end-tidal CO_2 and a long plateau in:

- Artificially ventilated patient when the ventilator is running at a low rate and a high minute volume
- In patients with spontaneous respiration with:
  - Damage to the central nervous system (e.g., the so-called central neurogenic hyperventilation)
  - A low body temperature and respiratory depression caused by analgesics

C. With tachypnea

With tachypnea but a lower than normal end-tidal CO_2 and short plateau:

- In patients on artificial ventilation when the ventilator is running at high rate and with a high minute volume
- In patients with spontaneous respiration who are:
  - In pain
  - Trying to compensate a metabolic acidosis
  - Hypoxic
- In some cases of central neurogenic hyperventilation
- In severe shock conditions

Cheyne-Stokes respiration

Only seen with spontaneous respiration. Cardiac oscillations (indicated by the arrows) after every respiratory group.

- Can be seen in cases of severe cerebral arteriosclerosis, brain damage, intoxication, etc.

Heaving respiration

Can be seen in some patients as a transition condition between Cheyne-Stokes and normal breathing.

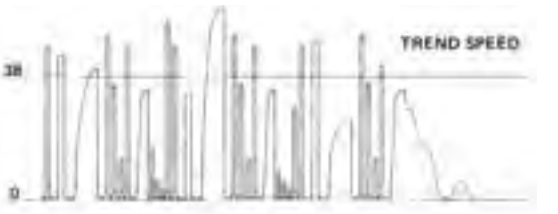
- Only seen with spontaneous respiration. The tidal volume changes regularly, hence the waving characteristic of the upper limit on the capnographic trend recording.

Gasping respiration

- Very low respiration rate (2-6/min)
- CO_2 mostly higher than normal
- Often cardiogenic oscillations after every capnographic curve (see arrows)

Seen in very severe respiratory depression or in dying patients

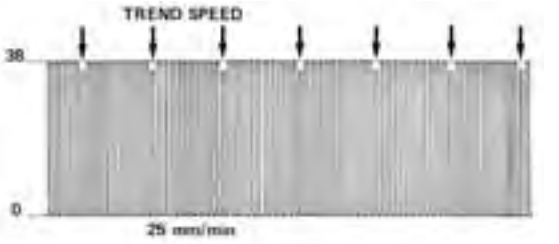
Very irregular or chaotic respiration



- No regularity
- All curves differ in size, shape, and height. Average CO_2 level above normal

Seen in severe cerebral damage

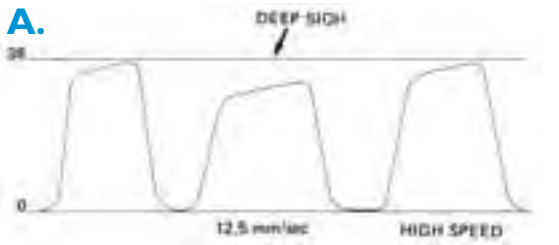
Sighing respiration

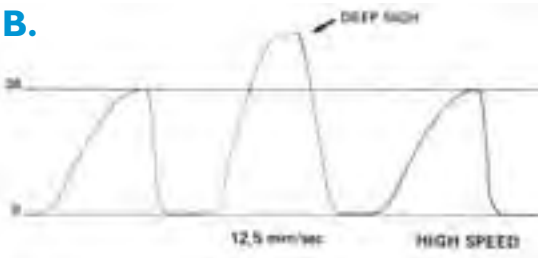


- A regular pattern with regular intervals interrupted by a deep sigh (indicated by arrows)
- Physiological in babies, small children , and very old people during sleep or when under an anesthetic
- Pathological in young people and adults when deep sighs are more frequent than once in 5 minutes. An indication of brain damage
- Average CO_2 level can be normal, high, or lower than normal

Some disturbances of the respiratory rhythm

Can also be seen in ventilated patients when the ventilator has an intermittent deep sigh mechanism. In normal lungs, the deep sigh CO_2 level is lower than average (A). In cases of obstructive lung disease, the deep sigh level will be higher than average (B).





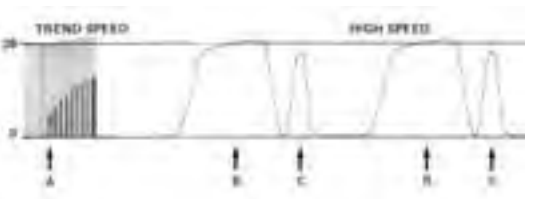
Patient fights the ventilator

When a patient starts to breathe against the ventilator (A), the regular pattern of the capnogram is interrupted. The respiratory activity of the patient increases quickly. The end-tidal CO_2 rises slightly due to the increasing metabolism of the contracting respiratory muscles.

Capnogram created by the ventilator (B).

Capnogram created through the attempted spontaneous respiration of the patient (C).

- During an anesthetic this capnogram indicates that another dose of muscle relaxant should be given to the patient



Note:
Combinations of the waveforms discussed up to this point are always possible. Results depend on the clinical condition of the patient and the technical status of the instrumentation used.

The iceberg capnogram is an example of a combination waveform. (see page 17)

Differential diagnosis

Correct interpretation of the many possible capnographic curves can only be achieved by comparison with other parameters recorded simultaneously. This makes a differential diagnosis possible. Useful parameters for this purpose are:

– ECG/heart rate
– Blood pressure (direct or indirect)
– Body temperature
– Plethysmogram (taken from the earlobe or finger)
– $PaCO_2$
– PaO_2
– Airway pressure
– Central venous pressure
– Acid-base status

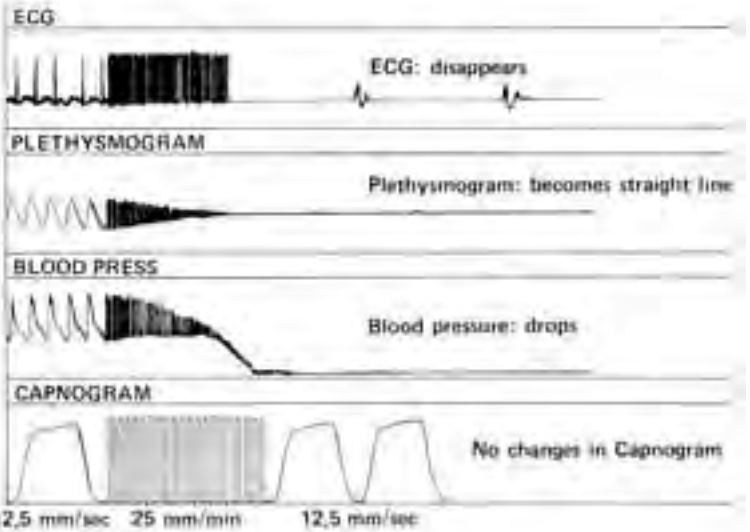
Example 1

– ECG: disappears, no heart rate
– Pleth: becomes a straight line
– Blood pressure: drops
– Capnogram: no change

Interpretation:

Technical defect when the vital signs monitor (ECG, pleth, blood pressure) and the capnograph are separate instruments.

Patient is not in danger. Without proper circulation a normal capnogram is not possible.


ECG
ECG: disappears
PLETHYSMOGRAM
Plethysmogram: becomes straight line
BLOOD PRESS
Blood pressure: drops
CAPNOGRAM
No changes in Capnogram
12,5 mm/sec
25 mm/min
12,5 mm/sec

Example 2

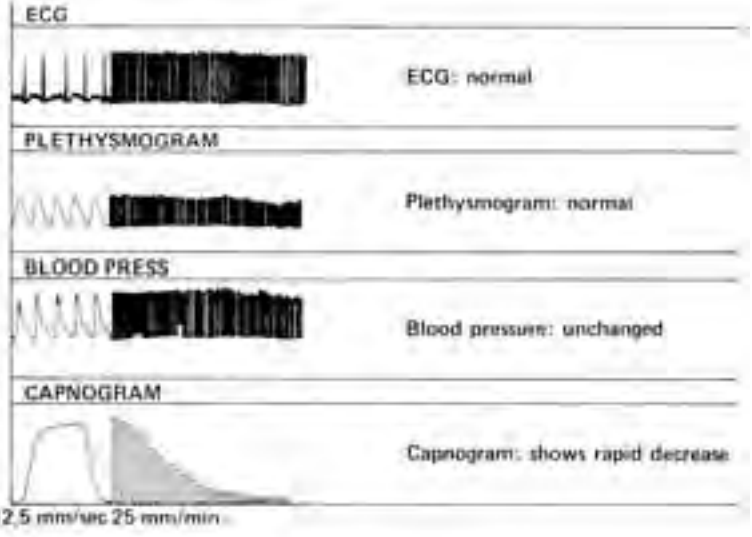
– Controlled respiration, temperature 37°C
– ECG: normal
– Pleth: normal
– Blood pressure: constant
– Capnogram: rapid decrease in CO_2

Possible interpretations:

– Considerable leakage in the respiration system. **PATIENT IN DANGER**
– Technical disturbance in capnograph. Patient not in danger

Differential diagnosis:

– Check airway pressure
– Check capnograph with own expiratory air (always around 38 mmHg or 5%)

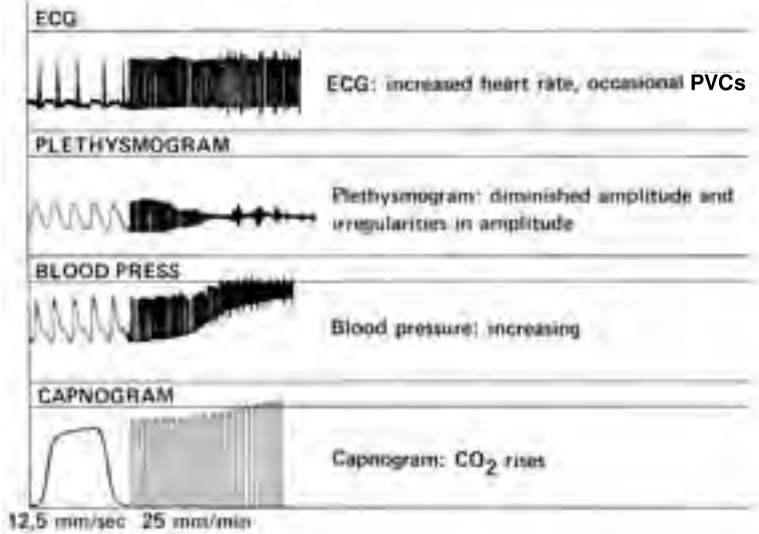

ECG
ECG: normal
PLETHYSMOGRAM
Plethysmogram: normal
BLOOD PRESS
Blood pressure: unchanged
CAPNOGRAM
Capnogram: shows rapid decrease
12,5 mm/sec 25 mm/min

Example 3

– ECG: increased heart rate, occasional PVCs
– Pleth: diminishing amplitude and irregularities in amplitude
– Blood pressure: increasing
– Capnogram: CO_2 level rises

Possible interpretations:

– Adrenaline intoxication (e.g., local anesthesia)
– Effect from manipulating a pheochromocytoma
– Effect from painful stimulus
– Patient awakes
– **PATIENT POSSIBLY IN DANGER**


ECG
ECG: increased heart rate, occasional PVCs
PLETHYSMOGRAM
Plethysmogram: diminished amplitude and irregularities in amplitude
BLOOD PRESS
Blood pressure: increasing
CAPNOGRAM
Capnogram: CO_2 rises
12,5 mm/sec 25 mm/min

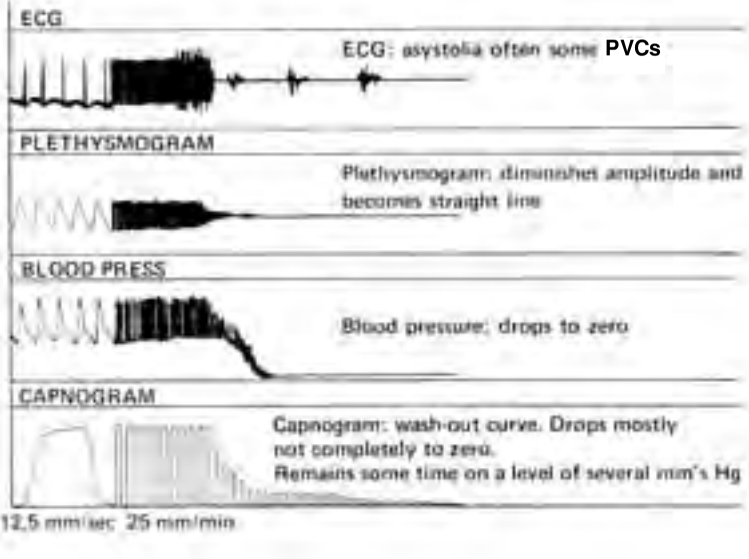
Example 4

– ECG: asystole, after some PVCs
– Pleth: diminishing amplitude developing into a straight line
– Blood pressure: drops to zero
– Capnogram: washout curve. Value drops towards zero but holds at a level of several mmHg

Interpretation:

This combination is typical for cardiac arrest even though there can still be some electrical activity in the ECG.

PATIENT IN MORTAL DANGER

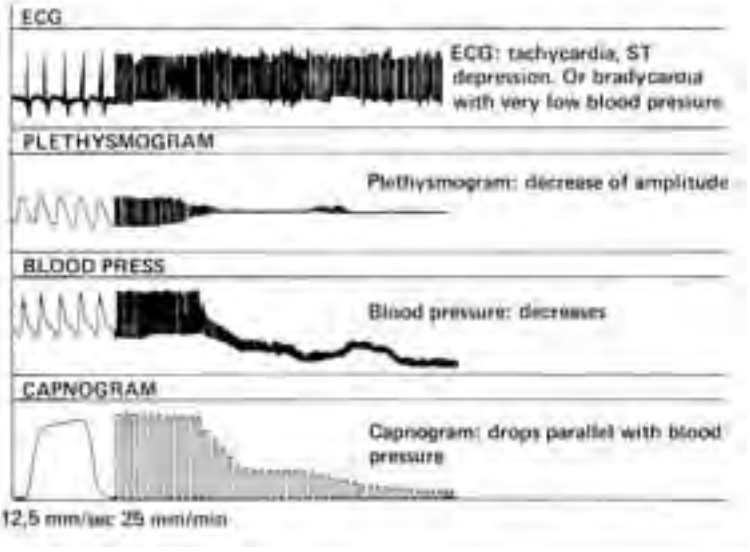

ECG
ECG: asystolia often some PVCs
PLETHYSMOGRAM
Plethysmogram: diminishes amplitude and becomes straight line
BLOOD PRESS
Blood pressure: drops to zero
CAPNOGRAM
Capnogram: wash-out curve. Drops mostly not completely to zero.
Remains some time on a level of several mm's Hg
12,5 mm/sec 25 mm/min

Example 5

– ECG: tachycardia, ST depression. Or bradycardia with very low blood pressure
– Pleth: decrease in amplitude
– Blood pressure: decreases
– Capnogram: drops in parallel with blood pressure

Possible interpretations:

– Severe blood loss
– Severe circulatory collapse through other causes:
  – Anaphylactic shock
  – Cardiac malfunction
  – Overdose of certain cardio-depressing drugs (e.g., halothane or barbiturates)
– **PATIENT IN DANGER**


ECG
ECG: tachycardia, ST depression. Or bradycardia with very low blood pressure
PLETHYSMOGRAM
Plethysmogram: decrease of amplitude
BLOOD PRESS
Blood pressure: decreases
CAPNOGRAM
Capnogram: drops parallel with blood pressure
12,5 mm/sec 25 mm/min

Example 6

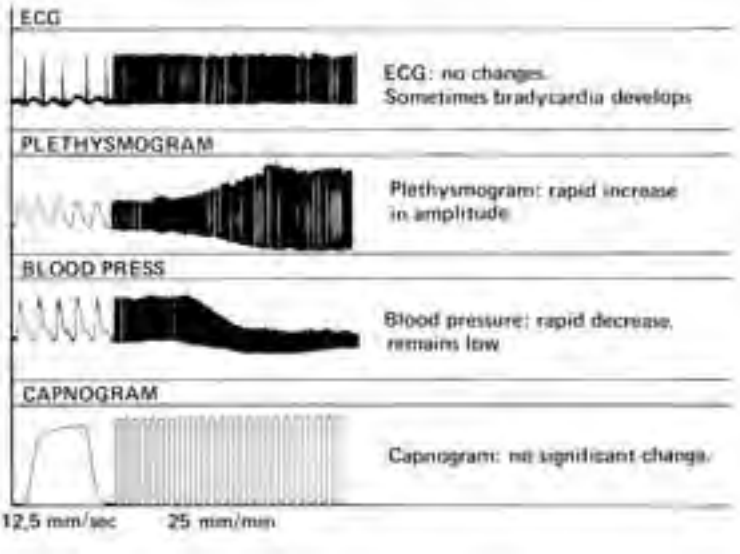
– ECG: no changes. Sometimes bradycardia develops
– Pleth: rapid increase in amplitude
– Blood pressure: rapid decrease, remains low
– Capnogram: no significant change

Possible interpretations:

– Effect of neuroleptic drugs (e.g., Droperidol), alpha-blocker or ganglion blockers or anesthetic drugs
– Induction of anesthesia

Blood pressure decreases due to vasodilatation. Perfusion improved.

Patient is not in danger as long as the capnogram remains unchanged.


ECG
ECG: no changes.
Sometimes bradycardia develops
PLETHYSMOGRAM
Plethysmogram: rapid increase
in amplitude
BLOOD PRESS
Blood pressure: rapid decrease,
remains low
CAPNOGRAM
Capnogram: no significant change
12,5 mm/sec
25 mm/min

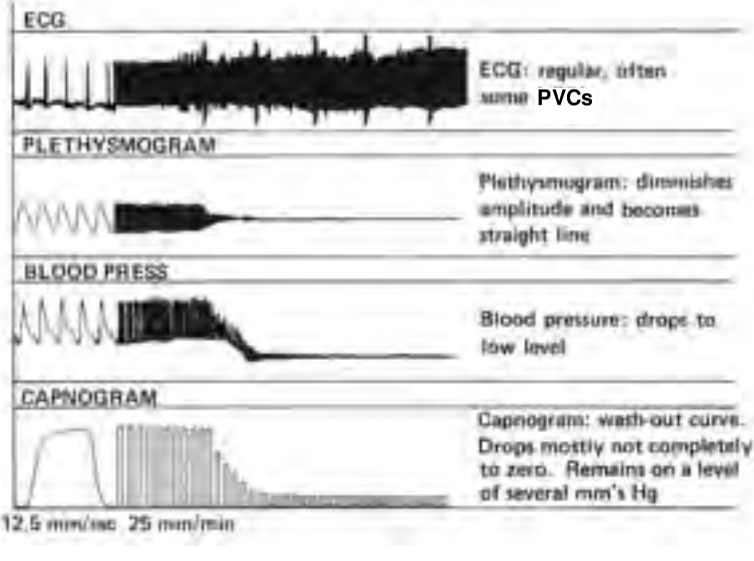
Example 7

– ECG: remains unchanged at first although hypoxic changes may occur after a few minutes with PVCs
– Pleth: develops into an almost straight line (often within ten seconds) This may be preceded by a broadening of the record for a few seconds
– Blood pressure: falls within thirty seconds (often to a very low level)
– Capnogram: falls within one minute (often to a very low level of etCO_2)

Interpretation:

Large pulmonary embolism (often air embolism). Recovery is usually gradual. Even after a small air embolism, which is not life-threatening, the capnogram does not return to its original level for at least five to ten minutes.

PATIENT IN SEVERE DANGER


ECG
ECG: regular, often some PVCs
PLETHYSMOGRAM
Plethysmogram: diminishes amplitude and becomes straight line
BLOOD PRESS
Blood pressure: drops to low level
CAPNOGRAM
Capnogram: wash-out curve. Drops mostly not completely to zero. Remains on a level of several mm's Hg
12,5 mm/sec 25 mm/min

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Other Publications

- Atlas of Capnography
  Smalhout/Kalenda
  Kerckebosch - Zeist
  The Netherlands
- The Suffocating Child
  Smalhout/Vaughan
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