CAPNOGRAPHY WAVEFORMS
Normal Waveforms

Respiratory rate is generally between 12–20 breaths per minute for adults.

- Breathing pattern occurs approximately once every 3–5 seconds
- Inspired air contains little to no carbon dioxide and expired air contains about 4–6% CO₂
- Baseline normally at zero

The normal respiratory rates referenced in this document are for adults. Young children (< 12 years old) will have higher normal RR depending on age.2

In neonates and those with very high RR, the waveform may not demonstrate a clear alveolar plateau (Phase III).3

### VALUES

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>SpO₂</td>
<td>Normal</td>
</tr>
<tr>
<td>etCO₂</td>
<td>Normal</td>
</tr>
<tr>
<td>RR</td>
<td>Normal</td>
</tr>
<tr>
<td>Waveform</td>
<td>Normal</td>
</tr>
</tbody>
</table>

### INTERVENTION

None required, continue sedation

### NORMAL RESPIRATORY RATE BY AGE (BREATHS/MINUTE)

<table>
<thead>
<tr>
<th>Age</th>
<th>Normal Respiration Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Infants (&lt;1 y)</td>
<td>30–53</td>
</tr>
<tr>
<td>Toddler (1–2 y)</td>
<td>22–37</td>
</tr>
<tr>
<td>Preschool (3–5 y)</td>
<td>20–28</td>
</tr>
<tr>
<td>School-age (6–11 y)</td>
<td>18–25</td>
</tr>
<tr>
<td>Adolescent (12–15 y)</td>
<td>12–20</td>
</tr>
</tbody>
</table>

**NORMAL WAVEFORM PHASES**

**Overview**

- **Phases**

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**Phase I:**
- Gas is exhaled from the large conducting airways which contain little to no CO₂.
- Begins with air leaving the trachea, posterior pharynx, mouth, and nose.
- Dead space is identified as the first upward deviation from baseline.

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**Phase II:**
- A mixture of gas from the conducting airways and alveoli.

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**Phase III:**
- The alveolar plateau.

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**Phase 0:**
- Inspired air.

The waveform should return to baseline, the frequency should match the patient’s respiratory rate and the height of the waveform should be between 35-45 mmHg, which is the normal etCO₂ reading.

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Phases Overview

Normal

Abnormal

Apnea

Hypoventilation

Bradypneic hypoventilation

Hypopneic hypoventilation

Hyperventilation

Tachypnea with hypocarbia

Rebreathing of CO₂

Partial airway obstruction

Lower airway obstruction / COPD

Cardiac arrest with manual CPR

Return of spontaneous circulation (ROSC)

Curare cleft

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Four Phases:
- **Phase I**: exhaled gas from conducting airways
- **Phase II**: a mixture of gas from the conducting airways and alveoli
- **Phase III**: the alveolar plateau
- **Phase 0**: inspired air

The waveform should return to baseline, the frequency should match the patient’s respiratory rate and the height of the waveform should be between 35-45 mmHg, which is the normal etCO₂ reading.

**PHASE II:**
- The ascending phase, CO₂ from the alveoli begins to reach the upper airway and mix with the dead space air
- CO₂ is detected in exhaled air and is identified as the gradual upslope of the horizontal line between the end of phase I and the beginning of phase III

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**Normal Waveform Phases**

**Four Phases:**
- **Phase I:** exhaled gas from conducting airways
- **Phase II:** a mixture of gas from the conducting airways and alveoli
- **Phase III:** the alveolar plateau
- **Phase 0:** inspired air

The waveform should return to baseline, the frequency should match the patient’s respiratory rate and the height of the waveform should be between 35-45 mmHg, which is the normal etCO₂ reading.

**Phase III:**
- The carbon dioxide concentration curve remains relatively constant, as primarily alveolar gas is exhaled, known as alveolar plateau
- The alveolar plateau is flat with a slight upward tilt toward the end

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Four Phases:
- **Phase I**: exhaled gas from conducting airways
- **Phase II**: a mixture of gas from the conducting airways and alveoli
- **Phase III**: the alveolar plateau
- **Phase 0**: inspired air

The waveform should return to baseline, the frequency should match the patient’s respiratory rate and the height of the waveform should be between 35-45 mmHg, which is the normal etCO₂ reading.

**END OF PHASE III:**
- The end of exhalation
- Contains the highest concentration of CO₂, labeled etCO₂.

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Normal Waveform Phases

**PHASE 0:**
- Inhalation will begin
- Oxygen fills the airway and CO₂ levels drop back to zero
- Amount of measured CO₂ quickly drops to zero
- Return to baseline is called phase 0⁴

The waveform should return to baseline, the frequency should match the patient’s respiratory rate and the height of the waveform should be between 35-45 mmHg, which is the normal etCO₂ reading⁴

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Abnormal Waveforms

Capnography provides a continuous, real-time indication of adequacy of ventilation.

Capnography provides the earliest indication of evolving respiratory compromise.

Any deviations in the carbon dioxide waveform must be investigated.

Five characteristics of a capnogram should be evaluated:
- Frequency
- Rhythm
- Height
- Baseline
- Shape

Addressing Abnormal Waveforms:

If abnormal waveforms are indicated:
- Check the patient’s status
- Check the patient’s sampling line to rule out any technical (or device related) issues
- Compare the capnogram with other physiological parameters e.g. ECG/HR, SpO₂, blood pressure, temperature, and acid-base balance
### What It Is:
- No breath for 10 seconds or longer
- Central in nature with no respiratory effort, or obstructive, respiratory effort without air movement
- Capnography alone does not provide apnea differentiation

### Causes of Apnea:
- Cardiac arrest
- Respiratory arrest (e.g., opioids, sedatives, etc.)
- Equipment failure
- Displaced airway adjunct
- Sleep apnea

### Values
<table>
<thead>
<tr>
<th>SpO₂</th>
<th>Normal or ↓ depending on duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>etCO₂</td>
<td>Zero</td>
</tr>
<tr>
<td>RR</td>
<td>Zero</td>
</tr>
</tbody>
</table>

**Waveform**
This waveform trend is condensed. The patient has a normal waveform, then for the period when shallow breathing has a series of short non-plateauing waveforms during which CO₂ accumulation occurs in the bloodstream. When the patient takes a normal plateauing waveform breath, the CO₂ will be elevated as they blow off retained CO₂.

**Other**
No chest wall movement or breath sounds

### Intervention
- Reassess patient
- Use
  - Stimulation
  - Bag mask ventilation
  - Reversal agents (as appropriate)
- Cease drug administration

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Hypoventilation

**WHAT IT IS:**
- Build-up of carbon dioxide as a result of insufficient elimination of the byproduct
- May result during normal respiratory rate, slow respiratory rate (bradypnea), or insufficient tidal volume (hypopnea)
- Shape or “morphology” of the capnogram is normal with rapid increase in phase II, gradual, smooth, possibly prolonged upslope during phase III, abrupt descent to baseline during inhalation
- The hallmark sign for hypoventilation is an elevated CO₂ level above 45 mmHg in the presence of normal perfusion/circulation and metabolism

**CAUSES OF HYPOVENTILATION:**
- Decrease in respiratory rate
- Decrease in tidal volume
- Chest compressions during CPR
- Obesity Hypoventilation Syndrome (OHS)
- Use of Central Nervous System (CNS) depressant drugs
- Opioids
- Increase in metabolic rate
- Rapid rise in body temperature (malignant hyperthermia)

**INTERVENTION**
Any sign of apnea, altered ventilation, or oxygen desaturation prompted an intervention that consisted of (i) patient stimulation, (ii) withholding medication, (iii) a chin lift or jaw thrust maneuver, and (iv) increasing oxygen supplementation.

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## WHAT IT IS:
- Form of hypoventilation
- Hypercarbia: presence of an abnormally high level of carbon dioxide in the circulating blood
- Respiratory rate may vary but generally slow and below a rate of 12 breaths per minute, representing bradypnea
- Enlarged waveform with a rapid increase in phase II, gradual and smooth upslope during phase III, abrupt descent during phase 0 back to inhalation
- End-tidal carbon dioxide levels generally above normal
- Breathing pattern usually regular, occurs less often than once every 5 seconds

## CAUSES OF BRADYPNEIC HYPOVENTILATION:
- Narcotic overdose
- Central Nervous System (CNS) depression or heavy sedation

## VALUES

<table>
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<tr>
<th>Parameter</th>
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<tbody>
<tr>
<td>SpO₂</td>
<td>Normal</td>
</tr>
<tr>
<td>etCO₂</td>
<td>↑</td>
</tr>
<tr>
<td>RR</td>
<td>↓</td>
</tr>
<tr>
<td>Waveform</td>
<td>Increased amplitude and width</td>
</tr>
</tbody>
</table>

## INTERVENTION

- Reassess patient and continue sedation
- Cease drug administration or reduce dosing
- Assess for airway obstruction
- Consider supplemental oxygen

WHAT IT IS:
- Hypopnea, shallow breathing less than 0.5 liters in adult patient
- Bradypnea, low respiratory rate, less than 12 breaths per minute
- Shape or morphology of the capnogram abnormal with short, non-plateauing waveform and slow respiratory rate, followed by a higher concentration of CO₂ when a deep breath is taken
- Seen during procedural sedation or with use of opioids

CAUSES OF HYPOPNEIC HYPOVENTILATION:
- Narcotic overdose
- Central Nervous System (CNS) depression
- Heavy sedation or stroke

VALUES¹
- SpO₂: Normal
- etCO₂: ↓
- RR: ↓
- Waveform: Decreased amplitude

INTERVENTION¹
- Reassess patient and continue sedation
- Reassess patient
- Cease drug administration or reduce dosing
- Assess for airway obstruction
- Consider supplemental oxygen

HYPERVENTILATION

WHAT IT IS:

▪ Low carbon dioxide level resulting from excessive elimination through rapid or deep breathing or from metabolic acidosis
▪ Breathing pattern or rhythm is usually regular
▪ Shape or morphology of the capnogram is normal with a rapid increase in phase II, gradual, smooth and possibly shortened or peaked upslope during phase III, and an abrupt descent to baseline during inhalation
▪ The hallmark sign of hyperventilation is a decreased CO₂ level below 35 mmHg in the presence of normal perfusion/circulation and metabolism

CAUSES OF HYPERVENTILATION:

▪ Anxiety/panic disorder
▪ Excessive exercise beyond VO₂ max
▪ Increase in respiratory rate
▪ Increase in tidal volume
▪ Metabolic acidosis
▪ Fall in body temperature

VALUES

SpO₂ Normal
etCO₂ ↓
RR ↑
Waveform Decreased amplitude and width

INTERVENTION

None required, continue sedation
Hyperventilation can be a sign of anxiety or metabolic issues

<table>
<thead>
<tr>
<th>Normal</th>
<th>Abnormal</th>
<th>Apnea</th>
<th>Hypoventilation</th>
<th>Bradypneic hypoventilation</th>
<th>Hypopneic hypoventilation</th>
<th>Hyperventilation</th>
</tr>
</thead>
</table>

**TACHYPNEA WITH HYPOCARBIA**

**WHAT IT IS:**
- Respiratory rate may vary but generally is rapid and above a rate of 20 breaths per minute
- Breathing pattern is usually regular and occurs at least once every 3 seconds
- Shape of capnogram is normal with rapid increase in phase II, gradual upslope during phase III, and abrupt descent during phase 0 back to baseline during inhalation

**CAUSES OF TACHYPNEA WITH HYPOCARBIA:**
- Pulmonary embolism
- Diabetic ketoacidosis
- Hyperosmolar hyperglycemic nonketotic coma (HHNC)
- Pain
- Hypoxemic Respiratory Failure

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### WHAT IT IS:

- Respiratory rate generally between 12-20 breaths per minute in an adult patient.
- Breathing pattern or rhythm usually normal, occurs approximately once every 3-5 seconds.
- Shape or morphology of the capnogram is normal with a rapid increase in phase II, gradual and smooth upslope during phase III.
- Characteristic pattern for rebreathing CO₂ value may also rise with each successive breath or remain the same due to hyperventilation.

### CAUSES OF REBREATHEING OF CO₂

- Air trapping in patients with a history of asthma or Chronic Obstructive Pulmonary Disease (COPD).
- Rebreathing exhaled gas (tent effect).
- Malfunction in the exhalation valve of the Bag Valve Mask (BVM) or ventilator.

### CAUSES

- Faulty expiratory valve
- Inadequate inspiratory flow
- Partial rebreathing
- Insufficient expiratory time
- Exhausted CO₂ absorber

### INTERVENTION

- Replace / correct faulty valve
- Increase inspiratory flow to mask / breathing circuit
- Remove draping or reposition patient to prevent trapped exhaled air
- Increase inspiratory time
- Replace soda lime in breathing circuit
PARTIAL AIRWAY OBSTRUCTION

WHAT IT IS:

▪ Spasmodic closure of the larynx
▪ Respiratory rate between 12 and 20 breaths per minute in adult patient
▪ Breathing pattern usually regular, occurs approximately once every 3-5 seconds
▪ Shape or morphology of the capnogram normal with a rapid increase in phase II, gradual and smooth upslope during phase III, and an abrupt descent during phase 0 back to baseline during inhalation
▪ Presence of noisy respirations or inspiratory stridor unusual in some cases of partial airway
▪ Waveform becomes erratic, progressively more dampened, returns to increase in height as the retained CO₂ is eliminated

CAUSES OF PARTIAL AIRWAY OBSTRUCTION

▪ Relaxation > Partial blockage / collapse of upper airway, secretions in the airway, head position
▪ Laryngospasm
▪ Misplaced ETT / airway

VALUES¹

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</tr>
<tr>
<td>etCO₂</td>
<td>Normal</td>
</tr>
<tr>
<td>RR</td>
<td>Variable</td>
</tr>
<tr>
<td>Waveform</td>
<td>Normal</td>
</tr>
<tr>
<td>Other</td>
<td>Noisy breathing and / or inspiratory stridor</td>
</tr>
</tbody>
</table>

INTERVENTION¹

- Full airway patency restored with airway alignment (head tilt / chin lift, suction or clear the airway, encourage deep breath)
- Noisy breathing and stridor resolve
- Reassess patient
- Establish IV access
- Consider supplemental O₂
- Cease drug administration

LOWER AIRWAY OBSTRUCTION / COPD

WHAT IT IS:

▪ Respiratory rate may vary but is generally >20 breaths per minute (tachypnea) in the adult patient

▪ Often accompanied by a reduced tidal volume, wheezes or rhonchi may be present

▪ Breathing pattern is usually regular and occurs once every 3 seconds or less in the compromised patient

▪ Typical shape or morphology of the capnogram is abnormal with a marked phase II to phase III curve with a shark fin appearance, abrupt descent during phase 0 back to baseline during inhalation

▪ Shark fin is seen in more severe bronchospasm

CAUSES OF LOWER AIRWAY OBSTRUCTION / COPD:

▪ Asthma

▪ Allergy

▪ Chronic Obstructive Pulmonary Disease (COPD) i.e. emphysema/bronchitis or pulmonary edema

▪ Uneven emptying of alveoli

▪ Prolonged expiratory phase (Phase II/III)

▪ Obstruction in the expiratory limb of the breathing circuit

▪ Presence of a foreign body in the upper airway

▪ Partially kinked or occluded artificial airway

VALUES

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<tr>
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<tbody>
<tr>
<td>etCO₂</td>
<td>Normal, ↓ or ↑ depending on duration and severity of bronchospasms</td>
</tr>
<tr>
<td>RR</td>
<td>Normal, ↓ or ↑ depending on duration and severity of bronchospasms</td>
</tr>
<tr>
<td>Waveform</td>
<td>Curved</td>
</tr>
<tr>
<td>Other</td>
<td>Wheezing</td>
</tr>
</tbody>
</table>

INTERVENTION

Reassess patient

Bronchodilator therapy

Cease drug administration

WHAT IT IS:

▪ Used when a patient’s heart has stopped

▪ Provide blood flow to the brain and vital organs, such as the heart and lungs

▪ Rate and depth determines the blood flow to the lungs, also known as pulmonary perfusion:
  ▪ Determines amount of CO₂ that is delivered to the lungs for removal when the ventilation is provided\(^{11,12}\)
  ▪ Monitoring capnography during CPR can alert the clinician that compressions are ineffective due to rescuer fatigue or technique. A decrease in the etCO₂ parameter and waveform trends can provide objective data indicating a need to reevaluate clinician technique
  ▪ Prolonged low etCO₂ (<10 mmHg) after 20 minutes may be indicative of failed resuscitation

OTHER POSSIBLE CAUSES:

▪ Decreased or absent cardiac output
▪ Decreased or absent pulmonary blood flow
▪ Sudden decrease in CO₂ values

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RETURN OF SPONTANEOUS CIRCULATION (ROSC)

WHAT IT IS:
▪ During CPR:
  ▪ Measurable amount of carbon dioxide is produced
  ▪ Manual compressions deliver 20-30% of normal systemic blood flow
  ▪ CO₂ values varied and production is markedly lower than normal
  ▪ Levels should remain consistent with effective compressions
▪ During cardiorespiratory arrest, there is a massive systemic buildup of carbon dioxide
▪ Return of spontaneous circulation (ROSC) results in a rapid and abrupt influx of CO₂

OTHER POSSIBLE CAUSES:
▪ Increase in cardiac output
▪ Increase in pulmonary blood flow
▪ Gradual increase in CO₂ production
## Curare Cleft

### WHAT IT IS:
This capnogram is rarely seen. It occurs in mechanically ventilated patients who make an effort to breathe. With their feeble inspiratory effort, some fresh gas sucked from the ventilator tubing and past the capnometer, generating this pattern.

### Causes of Curare Cleft:
- Patient is mechanically ventilated
- Depth of cleft is proportional to degree of muscle relaxants
- Spontaneous ventilatory efforts during a ventilator-delivered breath during mechanical ventilation

<table>
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- Hypopneic hypoventilation
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| Tachypnea with hypocarbia |
| Rebreathing of CO₂ |
| Partial airway obstruction |
| Lower airway obstruction / COPD |
| Cardiac arrest with manual CPR |
| Return of spontaneous circulation (ROSC) |
| Curare cleft |