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CRITICAL CARE MEDICINE BOARD REVIEW MANUAL

Monitoring in the Intensive Care Unit

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Cover Illustration by Kathryn K. Johnson

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INTRODUCTION

Current management of critically ill patients in the intensive care unit (ICU) requires ample knowledge of monitoring devices employed in this setting. Physicians must understand the technical aspects of monitoring devices (eg, insertion and maintenance) and clinical issues around their use (indications, complications) and be able to interpret and apply the data they provide. Although monitoring systems have become increasingly more complex, the basic principles and components of good monitoring in the ICU remain unchanged. This manual discusses the most commonly used devices in the ICU, including pulmonary artery catheters (PAC), arterial catheters, intracranial pressure (ICP) monitors, and capnography.

PULMONARY ARTERY CATHETERIZATION

The PAC was first described by Swan et al in 1970. Since its introduction, the PAC has made a significant impact on bedside monitoring of patients' hemodynamic status by providing direct measurements of vascular pressures, including central venous, right-sided intracardiac, pulmonary artery, and pulmonary artery wedge pressures.

The PAC is 110 cm long and has an outside diameter of 2.3 mm (7 Fr) (Figure 1). The catheter has a balloon at its tip with a maximum capacity of 1.5 mL that is used for “flow directing” the catheter through the heart into a branch of the pulmonary artery. The catheter has 2 ports: a distal port at the tip of the catheter that opens to pulmonary artery lumen and a proximal port located 30 cm from the tip that opens to the right atrium. A thermistor located 4 cm from the tip is used to calculate cardiac output. An extra channel located 14 cm from the tip is used for infusions and for inserting temporary pacemaker leads into the right ventricle. A fiberoptic system allows the oxygen content of mixed venous blood to be continuously determined via the distal port, and a thermal filament can be used for continuous determination of cardiac output. A large-bore introducer catheter is used to insert the PAC.

INDICATIONS AND COMPLICATIONS

There are diagnostic and therapeutic indications for pulmonary artery catheterization. Monitoring with a PAC can be used to diagnose different types of shock, pulmonary edema, cardiac tamponade, acute mitral regurgitation, and constrictive pericarditis and to evaluate for such conditions as pulmonary hypertension and left-to-right intracardiac shunts. Therapeutic indications include guiding therapy for patients with shock, fluid management, management of high-risk patients perioperatively, and management of patients with heart failure and following cardiac surgery. Because no study has demonstrated improved outcome with use of PAC monitoring, all indications are based on expert opinion.

Absolute contraindications to pulmonary artery catheterization include tricuspid or pulmonary valve mechanical prosthesis/stenosis, right heart mass (thrombus and/or tumor), cyanotic congenital heart disease (specifically, tetralogy of Fallot), latex allergy (latex-free catheters are available), and previous pneumonectomy. In patients with pneumonectomy, pulmonary artery rupture is lethal, and balloon inflation may cause a severe rise in pulmonary vascular resistance. Relative contraindications include risk for arrhythmias, anticoagulation, proposed pneumonectomy, and cardiopulmonary bypass surgery.

Complications associated with pulmonary artery catheterization are divided into 3 types: those related to vascular access, insertion of the PAC, and maintenance of the catheter. Vascular access complications include arterial puncture (2%–16%), pneumothorax (2%–4%), and tension pneumothorax. Insertion of the catheter is complicated mainly by arrhythmias, most of which are premature ventricular beats or nonsustained ventricular tachycardia. Patients with cardiac disease are at risk of serious ventricular tachycardia or ventricular fibrillation (< 1%). Right bundle branch block can develop in approximately 5% of patients who undergo catheter insertion. This complication can be significant in patients with preexisting left bundle branch block by placing the patient at risk for complete heart block. In patients with...
preexisting heart block, pacing equipment should be available prior to inserting the catheter. Knotting of the catheter occurs in less than 1% of insertions and is seen mainly in patients with dilated cardiac chambers.

Maintenance of the PAC is associated with the catastrophic complication of pulmonary artery rupture in less than 1% of patients. This complication has a mortality of 50%; risk factors are age over 60 years, pulmonary hypertension, and anticoagulation therapy. Pulmonary artery rupture should be considered if the patient develops hemoptysis after inflation of the balloon. Treatment consists of immediate positioning of the patient with the bleeding side down, intubation with a double lumen endotracheal tube, increasing positive end-expiratory pressure (PEEP), and attempting embolization. Surgical intervention is likely necessary. The risk of catheter infection and sepsis is less than 0.5% per day. Finally, pulmonary infarction has been associated with pulmonary artery catheterization in less than 7% of patients. The risk for infarction is increased with distal migration of the tip of the PAC.

**PREPARING THE CATHETER SYSTEM**

Prior to insertion of the catheter, a series of steps must be taken to ensure that the pressure measurements obtained by the PAC are accurate.

**Zeroing and Leveling**

First, the tubing and catheter system must be flushed and checked for air bubbles, and all open caps must be closed. Once this is accomplished, the system must be referenced to atmospheric pressure at a specific level, a process known as zeroing and leveling (also known as referencing). This is done by placing the reference stopcock at the level of the phlebostatic axis, which is located in the mid-axillary line at the level of the fourth intercostal space, and opening the transducer to the atmosphere (air). Then, the stopcock between the transducer and the port to the atmosphere is opened; the monitor should read zero when the zero button on the pressure amplifier system is pressed. Next, the reference stopcock is closed to air and opened between the catheter and transducer, which makes the system read pressure from the patient. If the position of the patient changes, the system has to be releveled.

**Calibration**

In most cases, calibration does not need to be done because transducers are precalibrated by the manufacturer. If the transducer is suspected to be malfunctioning, a new transducer must be used.

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**Figure 1. Pulmonary artery catheter.**

Damping and Resonant Frequency

Damping is the extent to which waves diminish as they oscillate back and forth within a system. Fluid-filled systems are usually underdamped, which means that oscillations do not quickly diminish. Some degree of damping is required, but both underdamping and overdamping decrease the accuracy of the waveform measurements, the former by augmenting the waves and the latter by diminishing the waves. Factors that diminish waveforms (overdamping) include air or blood/fibrin in the tubing, kinks in the tubing, and soft, compliant tubing. Factors that augment waveforms (underdamping) include long tubing and numerous stopcocks.

The square wave test (also known as the fast-flush test) is used to help adjust the system for ideal damping. It is performed by exposing the system to high pressures (up to 300 mm Hg) with a fast liquid flush and evaluating the system’s response. To conduct this test, the recording instrument is activated and a fast flush is released, producing a square wave that in a properly damped system quickly returns to baseline. The response is assessed by
observing the number of bounces at the end of the square wave. In a properly damped system, there should be 1 or 2 bounces at the end of the wave (Figure 2A). In an underdamped system, more than 2 bounces will be present (Figure 2B). In an overdamped system, bounces are absent, and the wave gradually descends to baseline (Figure 2C). If there are 2 bounces following the square wave, damping is assessed by comparing the height of the second bounce to the height of the first bounce: it should be less than one third the height of the first bounce (Figure 2D). If there are more than 2 boxes of the recording paper between the bounces, then the system is underdamped, regardless of the height of the bounces.

**PAC Insertion and Interpretation of Pressure Tracings**

The most common sites of insertion are the right internal jugular vein and the subclavian vein; however, the external jugular, femoral, and antecubital veins can be used. Fluoroscopic guidance may be needed when inserting via the femoral or antecubital veins. A sterile technique must be used to reduce risk for infectious complications. The balloon should be inflated only when the tip is in the right atrium. Once the tip is in the atrium, the catheter should never be advanced without inflating the balloon and never withdrawn without deflating the balloon. The balloon should be deflated at all times except when taking measurements. The operator must follow the pressure tracings on the monitor throughout the procedure.

The pressure waveforms change as the catheter is advanced through the right atrium and ventricle and into the pulmonary artery (Figure 3).\(^\text{11}\) It is important that the physician be able to recognize the different waveform tracings to follow the progress of the catheter.

**Right Atrial Waveform**

Normal right atrial pressure is 0 to 7 mm Hg. A competent tricuspid valve is required to obtain accurate readings. The components of right atrial waveforms are as follows (Figure 4):

- a wave reflects atrial systole and occurs after the P wave.
- c wave reflects tricuspid valve closure and occurs at the end of QRS.
- x descent represents the decrease in atrial pressure due to atrial diastole.
- v wave represents atrial filling that occurs during ventricular systole, and hence it occurs after the T wave.

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**Figure 2.** (A) Optimal damping. (B) Underdamping. Note there are more than 2 boxes between bounces, and the second bounce is nearly the same height as the first bounce. Pressures measured by this system will be overestimated. (C) Overdamping. Bounces are absent, and there is a gradual descent to baseline. Pressures measured by this system will be underestimated. (D) Normal square wave test. Ideal system has ≤ 1 block between bounces. If there are 1.5 to 2 blocks, the second bounce should be \(1/3\) the height of the first. If there are more than 2 bounces, the system is inaccurate. (Adapted with permission from AACN and the PACEP Collaborative 2005.)
Abnormalities in the right atrial waveform correspond to important clinical scenarios as follows:

- Tall v waves occur in tricuspid regurgitation due to regurgitation of blood during ventricular systole.
- Atrial fibrillation results in loss of the normal a wave.
- Atrial flutter produces a sawtooth-shaped flutter wave.
- Cannon a waves (tall a waves) occur in atrioventricular dissociation.
- Equalization of right atrial pressure with the right ventricular end-diastolic pressure and the pulmonary artery wedge pressure (PAWP) can be seen with cardiac tamponade, constrictive pericarditis, and restrictive cardiomyopathies.

Right Ventricular Waveforms

When the PAC enters the right ventricle, the waveform shows a sharp, rapid upstroke, a rounded peak, and a rapid downstroke (Figure 5). The PAC can measure the peak right ventricular systolic pressure (normal, 15–25 mm Hg) and the right ventricular end-diastolic pressure (normal, 3–12 mm Hg). Frequent premature ventricular contractions may occur while the PAC is in the right ventricle.

Pulmonary Artery Waveform

The pulmonary artery waveform is similar in appearance to the systemic pressure waveform (see Arterial Catheters) (Figure 6). As the PAC moves into the pulmonary artery, diastolic pressure increases (normal, 8–15 mm Hg) and the systolic pressure (normal, 15–25 mm Hg) remains almost the same as right ventricular systolic pressure. Also, the dicrotic notch, reflecting closure of the pulmonic valve, will be seen. The peak systolic pressure occurs within the T wave, and end-diastolic pressure occurs at the end of QRS complex.

Pulmonary Artery Wedge Pressure

PAWP (also known as pulmonary capillary wedge pressure and pulmonary artery occlusion pressure) can be obtained when the balloon becomes “wedged” in a branch of the pulmonary artery. It is assumed to reflect left ventricular end-diastolic pressure as long as there is no obstruction to blood flow between the left atrium and left ventricle. PAWP should be the same or lower than pulmonary artery end-diastolic pressure.

The PAWP waveform is similar to the right atrial waveform (Figure 3 and Figure 7). It has 3 main components:

- a wave reflects left atrial contraction and occurs at the end or after QRS.
- c wave occurs with closure of the mitral valve (often not seen).
- v wave is due to filling of the left atrium when the mitral valve is closed; it is found after the T wave.

Two changes in the PAWP waveform signify important clinical scenarios: (1) elevated a waves, which occur with anything that increases resistance to left ventricular filling, and (2) elevations in v waves, which occur when there is acute volume overload in the left atrium (mitral regurgitation, ventricular septal defect, post-myocardial infarction). The mean PAWP is calculated by averaging the pressure values at the top and bottom of the a wave.

There are 4 factors that affect the accuracy of PAWP measurements: the position of the PAC in relation to the lung zones, PEEP, respiration, and “wedging” of the PAC.
Lung zones. The lung is divided into 3 “zones” based on the interrelationship between pulmonary artery pressure, pulmonary capillary pressure, and alveolar pressure. The accuracy of wedge pressure measurements is affected by the lung zone in which the distal end of the catheter is positioned. When the catheter is positioned in a zone where alveolar pressure (zone 1) or arterial pressure (zone 2) is greater than capillary pressure, the pressure at the end of the catheter will not reflect PAWP. In lung zone 3, pulmonary capillary pressure is higher than alveolar pressure and allows a more accurate determination of left atrial pressure or PCWP.

PEEP. There are 2 forms of PEEP, the therapeutic form applied by a mechanical ventilator and air-trapping caused by incomplete expiration of alveolar gas (auto-PEEP). The effects of PEEP on PAWP depend on the compliance of the lung. The true PAWP can be estimated by subtracting one half of the PEEP from the PAWP if lung compliance is normal, and one fourth of PEEP if lung compliance is decreased. Usually, the effects of PEEP on PAWP readings become clinically significant with PEEP levels above 15 mm Hg.

Respiratory effects. During spontaneous ventilation, a negative pressure drives inspiration while expiration occurs passively. During positive pressure ventilation, inspiration is driven by positive pressure, which will result in a falsely elevated PAWP. At end expiration, the intrathoracic pressure as well as pleural pressure will be equal to atmospheric pressure regardless of the mode of ventilation. Therefore, PAWP must always be measured at end expiration.

Final positioning of the catheter. The PAC must be positioned such that a wedge can be obtained using 75% to 100% of the 1.5 mL volume of the balloon. If a wedge is obtained at less than 1 mL, the PAC has to be withdrawn to avoid vessel rupture. If a wedge cannot be obtained after maximum balloon inflation, the catheter tip has to be further advanced to prevent it from slipping back into the right ventricle, which increases the risk of arrhythmias. Once the desired position is reached, the catheter should be secured in place and the length of the catheter that was inserted should be documented. Obtain a chest radiograph to confirm the position of the catheter. The correct position is 3 to 5 cm from the midline. Daily chest radiographs are recommended to monitor the position of the PAC.

Troubleshooting

If the catheter does not advance to the right ventricle, fill the balloon with sterile water instead of air, and place the patient in the left lateral decubitus position. When the right ventricle is entered, deflate the balloon and reinflate with air. If the catheter will not advance into the pulmonary artery, it is usually due to coiling in the right ventricle. Withdraw the catheter into the superior vena cava and reinsert using firm and smooth movement. When arrhythmias occur, withdraw the catheter into the superior vena cava and the arrhythmia should disappear. Complete heart block and sustained ventricular tachycardia (rare) warrant treatment. Finally, if it is
not possible to obtain a PAWP, consider whether there is nonuniform balloon inflation. If pulmonary hypertension is not present, consider diastolic pulmonary artery pressure as PAWP.

ARTERIAL CATHETERS

Arterial catheters are used to directly record intravascular pressures and are used almost universally in ICU settings, mainly for monitoring systemic pressure accurately and easily for accessible arterial blood sampling. The radial, femoral, axillary, and brachial arteries are commonly used access sites. Although it has been suggested that radial artery catheters are associated with fewer complications than femoral arteries, it has been shown that they have similar complication rates. It is important to differentiate between pressure and flow. When the heart contracts and ejects the stroke volume, it generates a pressure wave and a flow wave. The pressure wave travels approximately 20 times faster than the flow wave. When the vascular impedance of the vessels is abnormal, the arterial pressure is not a reliable measurement of arterial flow. Measurement of mean arterial pressure (MAP) is superior to systolic pressure for 2 reasons: MAP is the driving force for blood flow and does not change between the aorta and peripheral arteries. Systolic pressure increases distally, but this is associated with narrowing of the pressure wave so that a normal isolated systolic pressure does not necessarily indicate normal blood flow. Most monitors measure the MAP by calculating the area under the pressure waveform and dividing it by the duration of the cardiac cycle. Although MAP can be estimated using a formula (MAP = diastolic pressure + 1/3 pulse pressure), electronic measurement is preferred.

The system for monitoring arterial pressure is a fluid-filled system and is thus a resonant system. Each system has its own resonant frequency and if it is subjected to a waveform with a frequency that approaches its resonant frequency, then the 2 frequencies will be added, resulting in an augmented response from the system. A system that amplifies the waveform is called an underdamped system. However, if the system has a high damping factor, the waveform will diminish too rapidly. The fast-flush test is used to assess the resonant frequency and damping of the monitoring system. A fast flush is released, causing the pressure to rise abruptly and plateau. Depending on the way the system recovers at the end of the flush, one can observe whether the system is underdamped or overdamped. The major frequency in the arterial pulse is approximately 5 Hz; if the frequency of the system is close to 5 Hz, there will be distortion (amplification). The frequency of the system is calculated by dividing the paper speed by the distance between the oscillations at the end of the flush (Figure 8). When the system is overdamped, the system should be flushed again or the line should be replaced. When the system is underdamped, shorter tubing and/or fewer stopcocks should be used.

The most common complications of arterial lines are bleeding, infection, pseudoaneurysm, limb ischemia, arteriovenous fistula, and thrombosis. Clinically significant thrombosis occurs in less than 1% of patients, and it is more common in smaller arteries (eg, radial and dorsalis pedis). In adults, arterial lines should not be changed on a regular basis unless there are signs of infection. Catheter-related infections occurred in less than 10% of radial and femoral artery lines used for more than 96 hours.

Rapid flush of the arterial line can result in retrograde flow that can embolize air or clots to the cerebral circulation. Therefore, flushing must be done with extreme caution and with very small volumes.

INTRACRANIAL PRESSURE MONITORING

ICP can be measured in the subarachnoid, intraventricular, epidural, or the intraparenchymal tissues. Normal ICP is 0 to 15 mm Hg. Cerebral perfusion pressure is the difference between MAP and ICP. Cerebral autoregulation ensures adequate cerebral blood flow over a wide range of cerebral perfusion pressure (50–150 mm Hg), but autoregulation may be affected by ischemia, hypercapnia, hypoxia, stroke, or trauma (Figure 9). In patients with chronic hypertension, the autoregulation set point is shifted to the left and thus higher blood pressure is needed to maintain adequate perfusion to the brain.

INDICATIONS

ICP monitoring and an arterial line are used to calculate the cerebral perfusion pressure accurately to direct therapy; therefore, any cause of an increased ICP is a potential indication for an ICP monitor. Closed head trauma is the most common indication. Others include intracerebral hemorrhage, stroke, hydrocephalus, Subarachnoid hemorrhage, and sagittal sinus thrombosis.

The main contraindications are infection at the site of insertion and coagulopathy.
TYPES OF MONITORS

There are 4 types of monitors used, and these differ based on anatomic site of insertion. The intraventricular monitor is the most commonly used. It allows therapy to be administered rapidly through draining of cerebrospinal fluid to decrease ICP. The most important complication associated with intraventricular monitors is infection, which can occur in up to 20% of patients. The risk of infection increases with duration of use.20,21 Changing the catheter does not seem to lower the risk of infection.21

The intraparenchymal monitor is inserted directly into the brain parenchyma. These monitors are characterized by ease of insertion and lower risk of infection and bleeding compared with intraventricular devices.18,22 However, they cannot be used to drain cerebrospinal fluid and tend to lose accuracy with days of use.23 Subarachnoid bolts often clog and are unreliable; these monitors are rarely used. Epidural monitors use optical devices that rest on the dura mater. These too are often inaccurate and are used mainly in coagulopathic patients with liver failure because of their significantly lower risk of intracerebral hemorrhage.24

WAVEFORM ANALYSIS

The components of an ICP waveform are as follows (Figure 10):

• P1 (percussion wave), which reflects arterial pulsation reflected in the cerebral ventricles
• P2 (tidal wave), which represents the intracranial compliance
• P3 (dicrotic wave), which represents aortic valve closure or venous pulsations

When abnormal compliance or increased ICP occurs, the normal components of ICP waveforms disappear and they are described as A and B waveforms. In abnormal conditions, all the normal waveforms increase in amplitude; specifically, the P2 waveform increases and does not demonstrate a plateau morphology, resulting in the B and A waveform appearance (Figure 11):

• A waves (plateau waves), which represent cerebral ischemia and brain damage and precede severe increases in ICP. A sudden drop in the A wave amplitude signifies exhaustion of ICP. These waves may reach up to 100 mm Hg in amplitude.
• B waves, which represent decreased intracranial compliance. They usually precede A waves in chronology, are rhythmic, have a saw-tooth appearance, and may reach up to 50 mm Hg in amplitude.

CAPNOGRAPHY

Capnography is used primarily in anesthesiology to monitor ventilation. Its main use in the ICU is to confirm
correct endotracheal tube placement. Capnometry is the measurement and display of exhaled CO\textsubscript{2} on a digital monitor. Capnograms record CO\textsubscript{2} waveforms and are of 2 types: time capnogram, which plots instantaneous CO\textsubscript{2} concentration against time in a respiratory cycle, and volume capnogram, which plots CO\textsubscript{2} concentration against expiratory volume in a respiratory cycle.\textsuperscript{25,26} The time capnogram is the simpler and more popular form.

The partial pressure of CO\textsubscript{2} at end of expiration (end-tidal CO\textsubscript{2}) (PETCO\textsubscript{2}) is an approximation of alveolar CO\textsubscript{2} (PACO\textsubscript{2}), and PACO\textsubscript{2} is an approximation of arterial CO\textsubscript{2} (Paco\textsubscript{2}). Under normal conditions, Paco\textsubscript{2} = PETCO\textsubscript{2} = PA CO\textsubscript{2}. The difference between Paco\textsubscript{2} and PETCO\textsubscript{2}, known as the P(a-ET)CO\textsubscript{2} gradient, is a function of underperfused alveoli (ie, physiologic dead space). Thus, the P(a-ET)CO\textsubscript{2} gradient can be used as an index of alveolar dead space.\textsuperscript{27} The normal gradient is usually less than 6 mm Hg. The most common method used to measure CO\textsubscript{2} in respiratory gases is infrared light absorbance, although other methods are available (eg, Raman spectrometry and mass spectrometry).

**PHASES OF A TIME CAPNOGRAM**

A time capnogram can be viewed as having 2 phases: an inspiratory phase (phase 0 or IV) and an expiratory phase (phases I, II, and III) (Figure 12).\textsuperscript{25,26} At the end of inspiration, the lungs and airways are filled with CO\textsubscript{2}-free air; with time CO\textsubscript{2} diffuses from the blood to the alveoli. The concentration of CO\textsubscript{2} in the alveoli is determined by the ratio of ventilation to perfusion (V/Q); thus, alveoli with a higher V/Q ratio will have a lower CO\textsubscript{2} concentration compared with those with a lower V/Q ratio. In areas of dead space in the lung, there is no exchange of gases and CO\textsubscript{2} is absent. At the beginning of exhalation, the CO\textsubscript{2} detector at the mouth will detect no CO\textsubscript{2}, which is phase I of the capnogram. This phase represents the physiologic dead space. As exhalation continues, the level of exhaled CO\textsubscript{2} increases slowly as gas from the alveoli is exhaled, until it reaches a peak. This represents phase II of the capnogram, which reflects a mixture of the physiologic dead space and the alveoli gas. When only alveolar gas is being exhaled, the CO\textsubscript{2} concentration plateaus, which is phase III of the capnogram. Phase III represents the alveoli, and it always has a slight positive slope due to continuous diffusion of CO\textsubscript{2} into the alveoli. PETCO\textsubscript{2} is measured at the peak of phase III. At the end of phase III, inspiration starts and the CO\textsubscript{2} concentration drops gradually to zero, which is phase 0 or IV of the capnogram.

**CLINICAL APPLICATIONS**

An increased PETCO\textsubscript{2} level may be the result of fever, malignant hyperpyrexia, increased cardiac output, hyperventilation, an exhausted CO\textsubscript{2} absorber, limb tourniquet release, and partial airway obstruction.\textsuperscript{25} A decreased PETCO\textsubscript{2} level may be the result of hypothermia, decreased cardiac output, cardiac arrest, pulmonary embolism, hyperventilation, apnea, endotracheal tube dislodgment, and circuit malfunction.

Capnography wave shapes and changes in PETCO\textsubscript{2} are suggestive of certain clinical scenarios:

- Increased slope of phase III: chronic obstructive pulmonary disease (Figure 13)
Horizontal phase III with large P(a-ET)CO₂ gradient: pulmonary embolism, decreased cardiac output (both will increase alveolar dead space), hypovolemia

- PETCO₂ drop to 0: dislodged tube, endotracheal obstruction
- Sudden drop in PETCO₂: air leak, partial obstruction
- Exponential decrease in PETCO₂: severe hyperventilation, cardiopulmonary event
- Gradual decrease in PETCO₂: hyperventilation, decreasing temperature, gradual hypovolemia
- Sudden increase in PETCO₂: NaHCO₃ administration, release of limb tourniquet
- Gradual increase in PETCO₂: fever, hypoventilation

Capnography has 2 clinically relevant pulmonary applications. It is used to evaluate the effectiveness of therapy in bronchospasm. An increasing slope of phase III indicates worsening of the obstruction. Also, it is used to determine optimal PEEP, with the lowest P(a-ET)CO₂ gradient representing optimal PEEP.

LIMITATIONS

There are several limitations to capnography. Patients with low cardiac output will have decreased readings. Use is limited in critically ill patients due to rapidly changing clinical situations and variables (dead space volume, V/Q ratio). PEEP and high airway pressures will decrease alveolar ventilation and hence decrease the readings. In acute respiratory distress syndrome due to high respiratory rates and low tidal volume used during mechanical ventilation, the dead space will increase, affecting the accuracy of capnography.

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