Hemodynamic Monitoring in the Intensive Care Unit

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Cover Illustration by Christine Schaar

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Preface

Over the past three volumes, the Critical Care Medicine Board Review Manual has covered a variety of essential topics in critical care medicine, including endocrine emergencies, acute poisonings, electrolyte disturbances, and nosocomial infections in the intensive care unit. In Volume 4 we continue to use a case-based format to focus on the most common issues relating to critical care. Brief introductory remarks are followed by a case report. Broad-based questions following the case presentation are answered in the subsequent discussion. Most articles conclude with several board review questions. This format presents the information in a relevant, concise manner, serving as a review tool for board examinations as well as for in-service examinations.

Volume 4 addresses the following topics:

Part 1—Hemodynamic Monitoring in the Intensive Care Unit
Part 2—Antibiotic Usage in the Intensive Care Unit
Part 3—Ethical Considerations in the Intensive Care Unit
Part 4—Update on Mechanical Ventilation in the Intensive Care Unit

This part deals with hemodynamic monitoring, a particularly controversial issue in critical care medicine. Pulmonary artery catheterization, an invasive monitoring technique that is widely used in intensive care units, has endured a tremendous amount of criticism over the past several years. There is substantial risk involved in placing the catheter, as well as risk associated with its continued presence in the pulmonary artery. Furthermore, there are no credible scientific data demonstrating significant benefit in patient outcomes resulting from the use of the information obtained. Finally, misinterpretation of the data gathered from the catheter has the potential to do harm. Recently, several prominent physicians have called for a moratorium on pulmonary artery catheterization.

Despite the controversy, many physicians claim that the information obtained from pulmonary artery catheterization is indispensable when caring for critically ill patients with cardiovascular or pulmonary decompensation. In this issue we provide useful information to guide clinicians in the proper use of this controversial device. The potential pitfalls that can accompany placement of the catheter and interpretation of the data obtained will be discussed so that these pitfalls may be avoided at bedside.

The adequacy of cardiac output and oxygen transport can also be assessed via peripheral arterial cannulation, pulse oximetry, and capnography. Although peripheral arterial cannulation is the gold standard for evaluating gas exchange, pulse oximetry and capnography are noninvasive alternatives with few potential complications. The discussion of these techniques includes information that can be obtained, as well as pitfalls in gathering and interpreting such information. In this manner we hope to guide the reader to a more appropriate and judicious use of the equipment discussed.

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I. INTRODUCTION

The ability to accurately evaluate oxygen transport and intravascular volume is essential to the management of patients in the intensive care unit (ICU). Bedside clinical evaluation is vague or nondiagnostic. Even when the clinician has the correct diagnosis or management plan, it can be difficult to assess how conservatively or aggressively to apply the appropriate intervention. Hemodynamic monitoring allows the clinician to obtain data for a quantitative analysis of physiologic parameters that can affect cardiac output, cardiovascular performance, gas exchange, and ultimately, tissue oxygenation.

The well-equipped ICU uses many different technologies that yield important information about adequacy of perfusion. Some techniques evaluate cardiac output directly; others evaluate the effects that adequate or inadequate perfusion have on end-organ function. This review concentrates on four of the more commonly used modalities.

It is important to emphasize that these measurements must be made accurately, interpreted appropriately, and then acted upon in the context of the patient’s illness if they are to have a positive effect on the patient’s outcome. Therefore it is insufficient to understand only how to make the measurements; the clinician must understand how to interpret the data, understand the limitations of the technology, and apply the information obtained to a sound treatment regimen that makes sense for the individual patient.

Normal values for commonly used hemodynamic parameters are provided in Table 1. Formulae necessary to calculate derived hemodynamic parameters are provided in Table 2.

II. CASE 1 PRESENTATION

Case patient 1 is a 55-year-old man who presents to the emergency department complaining of dizziness. His past medical history is significant for long-standing insulin-dependent diabetes mellitus, alcohol abuse, hypertension, and a myocardial infarction he sustained 2 years previously. On examination, he is lethargic and diaphoretic. His pulse rate is 130 bpm and regular, his respiratory rate is 26 breaths/min and hypopneic. His blood pressure is 90/60 mm Hg supine and 70/50 mm Hg sitting upright. The remainder of his
physical examination is pertinent only for a 1-cm ulcerative lesion over his left lateral malleolus. The area around the lesion is tender to palpation and to passive range of motion of the ankle. The joint itself is erythematous and swollen, and there is a fluctuance to the joint space.

Blood is drawn for culture and laboratory analysis. Leukocyte count is 21,100 cells/mm³ with 80% polymorphonuclear neutrophils and 16% band cells. Blood chemistries are as follows: sodium, 144 mEq/L; potassium, 3.8 mEq/L; chloride, 105 mEq/L; bicarbonate, 15 mEq/L; glucose, 600 mg/dL; urea nitrogen, 50 mg/dL; creatinine, 1.3 mg/dL; uric acid, 5.3 mg/dL. Arterial blood gas values are pH, 7.33; PaO₂, 93 mm Hg; PaCO₂, 29 mm Hg; Hb, 9.9 g/dL.

A toxicology screen is negative for drugs. Urinalysis is negative for ketones, proteins, and glucose. A bedside chest radiograph is essentially unremarkable. Electrocardiography exhibits sinus bradycardia, poor R-wave progression in the anterior leads, and borderline left ventricular hypertrophy.

Arthrocentesis of the affected ankle is performed and yields 3 mL of frank serosanguinous purulent material. Patient 1 is given insulin and intravenous fluids, is started on empiric antibiotics, and is admitted to the medical ICU.

The blood and synovial fluid contain gram-positive cocci in clusters. Aggressive fluid therapy is continued without improvement in blood pressure. The patient’s oxygen saturation has dropped mildly, to 93%, and urine output is approximately 20 mL/hr. Low-dose dopamine is initiated and a Swan-Ganz catheter is placed to gather more specific hemodynamic data, as well as to determine how aggressive fluid administration should be.

The pulmonary artery catheter is inserted without complications and the following data are collected: right atrial pressure, 3 mm Hg; right ventricular pressure, 20/5 mm Hg; pulmonary artery pressure,
20/10 mm Hg; pulmonary capillary wedge pressure (PCWP), 7 mm Hg; cardiac output, 8.5 L/min.

- Is pulmonary artery catheterization warranted in patient 1?
- How can accuracy of the wedge pressure measurement be assessed?
- What technical and pathophysiologic aspects are important in the interpretation of cardiac output?

**PULMONARY ARTERY CATHETERIZATION**

The pulmonary artery catheter is a flexible, multiple-lumen, balloon-tipped tube that is inserted into a central vein (ie, internal jugular, subclavian, or femoral). After balloon inflation, blood flow causes the migration of the catheter through the right side of the heart into the pulmonary outflow tract. The location of the inflated balloon during insertion can be tracked by monitoring waveform morphology (Figure 1). Eventually, the balloon tip migrates into either the right or left pulmonary artery until it “wedges” itself, resulting in a state of “no flow” distal to the balloon tip. This results in an equalization of pressures downstream, allowing an estimation of left atrial pressure, and thus left ventricular end-diastolic pressure.

Since its introduction in the early 1970s, the Swan-Ganz pulmonary artery catheter has been fraught with controversy regarding its use and its ability to affect patient outcome. Despite the controversy, the pulmonary artery catheter has become commonplace in ICUs, although there appears to be a trend toward a decline in its use in the past few years. A moratorium on its use has been proposed based on a study suggesting that its placement was associated with poorer outcomes. Many organizations, including the Society of Critical Care Medicine and the American College of Chest Physicians, are taking steps to examine the clinical literature and offer recommendations.

The main point of contention is that despite the highly specific information gleaned from the pulmonary artery catheter, studies have yet to reveal an improvement in patient outcome associated with its use. Studies have revealed that pulmonary artery catheter measurements are more sensitive than clinical signs in diagnosing myocardial injury, ischemia, and the severity of heart failure. The pulmonary artery catheter has been valuable in determining physiologic aberrations in elderly patients and preoperative patients that were not evident from clinical examination alone. Hemodynamic derangements representative of several conditions are listed in Table 3.

**Indications**

Pulmonary artery catheterization is most commonly
indicated to determine fluid status or assess response to fluid administration in the face of significant cardiopulmonary dysfunction. As in case patient 1, fluid status uncertainty often accompanies shock, multiorgan failure, severe cardiopulmonary disease, complicated surgical procedures, and complicated myocardial infarction.

Cardiac output, PCWP, and pulmonary systolic and diastolic pressures can be measured directly, and mixed venous blood can be sampled. With these data and blood samples, the cardiac index, systemic vascular resistance, pulmonary vascular resistance, stroke volume, and both oxygen delivery and consumption can be derived.

Cardiac output and PCWP are the parameters most often measured at bedside in the ICU and are the focus of this discussion.

Pulmonary Capillary Wedge Pressure

Certain conditions must be met in order to verify the accuracy of the PCWP measurement: wedge pressure must be equal to or less than the diastolic pulmonary artery pressure, and the catheter tip must be in West zone 3 (Figure 2) of the lung, where arterial pressures are greater than venous pressures, which, in turn, are greater than alveolar pressures. Alveolar pressures can usually be confirmed with a lateral chest radiograph. The tip of the catheter should be located below the level of the left atrium and posteriorly.

PCWP measurements should be performed and interpreted by the same personnel to avoid confusion in interpretation, because relative changes in values are more important than absolute values. PCWP measurements are made at end-expiration when pleural pressures are nearly zero. A left atrial pressure curve with a characteristic wedge tracing should be present and disappear with deflation, yielding the pulmonary artery tracing.

Mechanical ventilation can have a significant effect on the wedge pressure measurement. The addition of positive end-expiratory pressure (PEEP) to mechanical ventilation increases pleural pressure. The increase in pleural pressure is transmitted to the wedge pressure, elevating it. This effect generally becomes clinically important when PEEP exceeds 10 cm H₂O. In a patient with normal lung compliance, subtracting half of the PEEP value from the PCWP reading will yield a more accurate estimation of the true left ventricular end diastolic pressure. In a patient with stiff or noncompliant lungs, approximately 25% of the PEEP value should be subtracted from the PCWP results.

The clinician should also be cognizant of the hemodynamic changes that occur with higher levels of PEEP. Resulting increased intrathoracic pressures prevent venous return, thus diminishing cardiac output. Reduced cardiac output, in turn, results in lowered blood pressure.

Cardiac Output

The cardiac output is measured by thermodilution methodology. A precise quantity of saline is injected, either iced or at room temperature (either of which is significantly cooler than the patient’s blood). The injectate is infused into the proximal port of the catheter,
which is typically in the right atrium. After the blood and the injectate mix, the blood temperature will fall as a function of the relative amounts of injectate volume and blood flow. A thermistor located in the catheter wall about 4 cm from the tip of the catheter (which is in the central pulmonary artery) continuously measures the temperature of the blood after the injection of the cool fluid. Higher blood flow (ie, higher cardiac output) results in a smaller fall in blood temperature. A lower cardiac output allows a greater cooling effect of the injectate, resulting in a larger decrease in the blood temperature. The application of these data to a fairly sophisticated equation allows the calculation of cardiac output.

Because cardiac output varies as a function of the respiratory cycle, it is important when taking sequential readings to inject the saline at the same time in the respiratory cycle, if possible, to improve accuracy and reproducibility. To minimize errors, measurements of cardiac output should be made during expiration. Alterations in intrathoracic pressures and venous return can disrupt venous inflow during inspiration. Timing of the injection to a precise part of the respiratory cycle can be somewhat difficult in the tachypneic or mechanically ventilated patient because it takes about 10 seconds from the time of injection for the cooled blood to flow past the thermistor. To improve accuracy, it is advised to average several measurements (typically 3 to 5) at regularly spaced intervals.

Arrhythmias and dysrhythmias may cause variability in the cardiac output measurement. The injection of iced saline has been associated with the development of atrial fibrillation and bradycardia. If these arrhythmias occur, the use of room temperature injectate is suggested.

Cardiac output measurements may be inaccurate in patients with either pulmonary or tricuspid valve regurgitation. This is because part of the flow during systole will be retrograde flow and will interfere with the thermodilution calculation of the true cardiac output.

Several technical errors can also result in inaccurate measurements. Unknown changes in the injectate temperature will cause overestimation or underestimation of the cardiac output. Once removed from the ice bath, a 10 mL syringe of iced saline can warm as much as 1°C in 30 to 60 seconds. In a clenched hand it can warm as quickly as 1°C every 15 seconds. These seemingly mild elevations in injectate temperature will result in falsely elevated cardiac output calculations.

Errors in injectate volume can also result in inaccuracies. The standard volume of injectate used is 10 mL. Any deviation from this standard will result in a false estimation of cardiac output. Care should be taken to check the circuit for leaks because this is a common cause of injectate loss.

Finally, the clinician should be aware of catheter position. If the catheter has migrated too far distally and wedged itself without balloon inflation, the thermistor may not be fully exposed to the blood cooled by the injectate, yielding a falsely elevated cardiac output measurement. If the proximal port is located in the superior vena cava instead of in the right atrium, injectate may be lost before coming in contact with the thermistor, resulting in an inaccurate measurement.

**Complications**

Pulmonary artery catheterization is an invasive procedure with potential complications. These complications must be weighed against the potential benefits of the procedure. Fortunately, most of the common complications are preventable and infrequent.

Complications are most frequently related to insertion of the catheter. Pneumothorax is a common complication, especially if the subclavian approach is used or if cannulation is difficult. Pneumothorax is less frequent when the internal jugular or femoral approach is used.

Every possible measure should be taken to ensure complete sterility during placement (ie, sterile preparation, drape, and gown). If these measures are adhered to, line sepsis and infection at the site can be kept to a minimum.
It is not uncommon during cannulation for many types of arrhythmias to occur, such as premature ventricular contractions and even unsustained runs of ventricular tachycardia. If an arrhythmia occurs, simply retracting the catheter and starting over may suffice to correct it. If arrhythmia occurs repeatedly, administration of lidocaine may be warranted.

A less frequent complication is pulmonary infarction, caused by the occlusion of a smaller branch of the pulmonary vascular tree by the catheter tip. Monitoring the catheter tip position on chest films and noting a change in the pulmonary artery waveform to a continuous wedge tracing waveform should help prevent this from happening.

The most serious complication is pulmonary artery rupture. Rupture can result from withdrawal of the catheter with the balloon inflated or from overinflation of the balloon relative to pulmonary artery size. Rupture may also occur in patients with pulmonary hypertension. Immediate surgical consultation is warranted because exsanguination and death are frequent sequela of this complication.

III. CASE 2 PRESENTATION

Case patient 2 is a 55-year-old man who is brought to the emergency department by his family the morning after he had gone out binge drinking with friends from work. His wife was awakened earlier that morning when she heard him retching in his sleep. Upon waking him, she found him to be grossly lethargic and short of breath. The patient has a smoking history of more than 50 pack-years.

On examination patient 2 is mildly obese, agitated, diaphoretic, and in moderate respiratory distress. His pulse rate is 120 bpm, respiration rate is greater than 40 breaths/min and breathing is labored, and blood pressure is 150/90 mm Hg. Bilateral decreased breath sounds are evident throughout all lung fields but are particularly worse in the right upper lung zones. Wheezing is heard throughout. Oxygen saturation by pulse oximeter (SpO2) on room air is 83%. A room air blood gas measurement is obtained and reveals: pH, 7.36; PCO2, 44 mm Hg; PO2, 50 mm Hg. He is started on continuous β-agonist nebulization and administered oxygen via 100% nonrebreathing mask.

Thirty minutes later, pulse oximetry reveals an SpO2 of 98%. The patient looks a bit more somnolent with no major change in his lung examination. A blood gas measurement is repeated and reveals: pH, 7.28; PCO2, 55 mm Hg; PO2, 180 mm Hg. It is decided to intubate the patient and institute mechanical ventilation. There is some difficulty in fully visualizing the cords on intubation, but the patient is intubated without incident, good breath sounds are heard bilaterally, and capnography reveals a good waveform. The endotracheal tube is secured and the patient is transported to the ICU.

- What is the gold standard technique for monitoring gas exchange?
- What noninvasive techniques are available for monitoring gas exchange? What are their benefits and drawbacks?

DISCUSSION

The most commonly used monitors of gas exchange in the ICU are (1) continuous blood pressure monitoring via arterial cannulation, (2) pulse oximetry, and (3) capnography. Parameters used to evaluate gas exchange include pH, Pco2, and Paco2.

PERIPHERAL ARTERIAL CANNULATION

Arterial cannulation is a favored technique because it allows continuous monitoring of blood pressure and mean arterial pressure and also because it provides improved accessibility for arterial blood gases and other blood draws. Arterial blood gases are the gold standard for evaluating gas exchange.

The major drawbacks of arterial cannulation are its invasiveness, the large degree of skill required for placement, and its potential for complications. Complications include thrombosis, infection, and median nerve damage. Arterial sticks also cause substantial discomfort to the patient. The noninvasive techniques of pulse oximetry and capnography allow indirect approximation of oxygen tension and carbon dioxide tension, respectively.

PULSE OXIMETRY

Indications

Pulse oximetry may be indicated for assessing oxygenation during weaning from mechanical ventilation, for monitoring oxygenation during invasive procedures, for monitoring patients with potential for hypoxemia, or for titrating oxygen administration.

Detection Methods

Pulse oximetry values are based on direct measurement of the absorption spectra of oxyhemoglobin (HbO2) and deoxygenated hemoglobin (Hb). Pulse oximetry allows continuous noninvasive monitoring of arterial oxygen saturation (SaO2) but provides only an indirect measurement of arterial oxygen tension (Pao2).
Human adult blood contains four types of hemoglobin: HbO₂, Hb, methemoglobin (metHb), and carboxyhemoglobin (COHb). Under normal circumstances, amounts of both metHb and COHb are negligible. The characteristics of light absorption in the red and infrared regions of the spectrum are different for each of these hemoglobins (Figure 3). The amount of oxygenated hemoglobin can be determined by the passage of light of a known wavelength through a particular substance.

Commercial pulse oximeters currently available separate light transmission into a baseline (DC) component and a measurable (AC) component. The DC component corresponds to soft tissue and nonpulsatile blood, and the AC component corresponds to the arterial pulse.

Pulse oximeters utilize two wavelengths, red (660 nm) and infrared (940 nm), allowing the separation of HbO₂ and Hb levels. A significant drawback of this technique is that because only two wavelengths are used, levels of COHb and metHb cannot be separated from the HbO₂ level. Consequently, if either COHb or metHb is increased, oximeter probes will overestimate the true SaO₂.

Accuracy

Pulse oximeters yield a confidence interval of 95% ± 4% at saturations greater than 70%. At saturations that are less than 70%, they are much less accurate. Significant levels of metHb and COHb can alter the accuracy of pulse oximetry, overestimating the true oxygen saturation. Some commonly used medications oxidize ferrous (Fe²⁺) hemoglobin to ferric (Fe³⁺) hemoglobin, resulting in methemoglobinemia (Table 4). This will cause an overestimation of HbO₂ level in the blood. The clinician should be aware that when methemoglobinemia is treated with intravenous methylene blue, the methylene blue will cause an underestimation of the true oxygen saturation. Other settings in which gross inaccuracies will occur include shock states, hypothermia, and vasospasm—conditions in which the pulse may be weak. Arterial saturation may be underestimated in African-American patients and other dark-skinned patients.

CAPNOGRAPHY

Capnography is a noninvasive means of monitoring carbon dioxide levels on a breath-to-breath basis. The basic precept of capnography is that end-tidal carbon dioxide tension (PETCO₂)—the tension of carbon dioxide in the expired air at the end of exhalation—is equal to (or nearly equal to) PaCO₂. Carbon dioxide readily diffuses across the capillary-alveolar membrane and equilibrates to an alveolar carbon dioxide tension (PACO₂) of approximately 40 mm Hg. In healthy individuals, the arterial-alveolar carbon dioxide difference should not be more than 2 to 3 mm Hg, and the PACO₂ and the PETCO₂ should be identical. Under these circumstances PETCO₂ and PaCO₂ are virtually identical.

Capnography is not a reliable indicator of arterial carbon dioxide tension in patients who are critically ill and intubated. These patients usually have significant lung disease with distorted ventilation-perfusion relationships. The PETCO₂ in these patients therefore does not necessarily approximate the PaCO₂.
Phases of the Capnogram

The normal exhalation during capnography is quadriphasic (Figure 4). The four phases include dead space gas from the apparatus itself, anatomic dead space gas (from the conducting airways), alveolar gas, and alveolar dead space gas. Alveolar gas and alveolar dead space gas are assumed to be expelled simultaneously.

In identifying the phases on the capnogram, the dead space from the endotracheal tube itself is not visible and can be ignored. Phase 1 of the capnogram thus is designated as the beginning of expiration, when carbon dioxide is first being detected. Phase 2 is characterized by a sharply rising carbon dioxide tension that denotes anatomic dead space mixed with alveolar gas. Phase 3, the alveolar plateau, represents the remaining alveolar gas being expelled. The last point of this plateau is the PETCO₂. This is the value that, under normal pulmonary physiologic conditions, closely approximates PaCO₂.

Detection Methods

Expired carbon dioxide can be measured colorimetrically or by infrared detection. Colorimetric carbon dioxide detection is the simplest method used, but it is only semiquantitative. A colorimetric capnometer is a small device that contains a filter impregnated with metacresol purple, a pH-sensitive dye that changes color to yellow on exposure to carbon dioxide. The device is disposable and inexpensive and fits over the top of the endotracheal tube. The most common clinical application of these capnometers is for verifying endotracheal tube placement. Endotracheal intubation exposes the dye to expired carbon dioxide, causing it to change color. Esophageal intubation will not result in color change.

An infrared capnometer consists of an infrared analyzer connected to the endotracheal tube. The analyzer is located either in the mainstream of the endotracheal tube or within a sidestream sampling device. Because carbon dioxide has a very characteristic absorption in the infrared spectrum, the amount present can be quantitatively assessed in this manner.

Indications

There are only two accepted definitive indications for which capnography has been established: to assess cardiopulmonary resuscitation and to verify endotracheal tube placement.

Capnography has been shown experimentally to be a reliable indicator of both adequate and inadequate chest compression during cardiopulmonary resuscitation. If chest wall compressions are inadequate or are stopped, the PETCO₂ falls because of the reduction in cardiopulmonary circulation. A rapid increase in PETCO₂ at the outset of cardiopulmonary resuscitation has been associated with successful outcomes; conversely, a failure of PETCO₂ to increase with apparently adequate compressions is associated with poor outcome.

Capnography is of benefit in verifying endotracheal tube or percutaneous tracheostomy placement, especially in patients in whom anatomic landmarks or anatomy may not be easily visualized (eg, obese patients, patients with previous surgeries of the larynx or hypopharynx). Esophageal intubation can be easily recognized by an abnormal waveform with a low PETCO₂.

Accuracy

There are several caveats regarding use of capnometry to verify endotracheal tube placement. In rare situations, such as when the stomach has been inflated with air, a false-positive capnogram may occur. A false-negative capnogram may occur even with correct endotracheal tube placement if the patient’s cardiac output is very low. Although useful, capnography should therefore not be considered a substitute for other means of verifying tube placement. The clinician should still listen for bilateral breath sounds, look for symmetrical expansion, and obtain a chest radiograph.

Capnography has been proposed as a noninvasive means of monitoring patients on mechanical ventilation during the weaning process. Unfortunately, because intubation and mechanical ventilation are associated with distorted ventilation-perfusion relationships, PETCO₂ frequently underestimates the true arterial CO₂. Therefore, arterial blood gas measurements must still be used to confirm substantial changes in PETCO₂.

Table 4. Medications and Other Agents That Can Cause Methemoglobinemia

<table>
<thead>
<tr>
<th>Nitrates/nitrites</th>
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<tr>
<td>Amyl nitrite</td>
<td>Primaxine</td>
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<td>Nitroglycerin</td>
<td>Phenazopyridine</td>
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<td>Nitroprusside</td>
<td>Chemical agents</td>
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<td>Local anesthetics</td>
<td>Aniline dyes</td>
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<td>Lidocaine</td>
<td>Toluidine</td>
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<td>Benzocaine</td>
<td>Nitrobenzene</td>
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<td>Procaine</td>
<td>Nitrophenol</td>
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<tr>
<td>Sulfa drugs</td>
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BOARD REVIEW QUESTIONS

Choose the single best answer for each question.

1. All of the following statements regarding pulmonary capillary wedge pressure (PCWP) and cardiac output (CO) measurements are true EXCEPT:
   A) Both parameters should be measured at end expiration
   B) High levels of positive end-expiratory pressure (PEEP) lead to overestimation of the PCWP
   C) The choice of iced versus room temperature injectate does not affect accuracy of CO measurements
   D) The proximal port should be in the superior vena cava

2. Which one of the following conditions is associated with a prominent v wave in the PCWP waveform?
   A) Aortic regurgitation
   B) Mitral regurgitation
   C) Tricuspid regurgitation
   D) Pulmonary regurgitation

3. All of the following conditions are associated with a normal PCWP waveform EXCEPT:
   A) Pulmonary embolism
   B) Adult respiratory distress syndrome
   C) Pulmonary hypertension
   D) Mitral stenosis

4. Which of the following conditions is the most serious potential complication of pulmonary artery catheters?
   A) Pulmonary infarction
   B) Line sepsis
   C) Pulmonary artery rupture
   D) Thrombosis

5. Pulse oximetry is a useful adjunct in each of the following situations EXCEPT:
   A) Weaning from mechanical ventilation
   B) Monitoring a patient with a bilobar pneumonia
   C) Monitoring during endoscopy
   D) Monitoring during severe shock

6. A pulse oximetry level may be overestimated in all of the following patients EXCEPT:
   A) A patient with carbon monoxide poisoning
   B) A patient who has been on nitroprusside for 3 days
   C) A patient being treated with methylene blue
   D) A patient complaining of dyspnea after receiving topical lidocaine for endoscopy

7. The only established uses for capnography are:
   A) Assessing the adequacy of cardiopulmonary resuscitation
   B) Verifying endotracheal tube placement
   C) Monitoring while weaning from mechanical ventilation
   D) Assessing the titration of PEEP
   E) A and B
   F) B and C
   G) A, B, C, and D
**ANSWERS**

1. D
2. C
3. D
4. C
5. D
6. C
7. E
8. D
9. B
10. C

**REFERENCES**


**SUGGESTED READINGS**


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