16. Routine Monitoring in the ICU

Daniel R. Brown, M.D., Ph.D.

A 65-year-old male has just undergone a carotid endarterectomy under general anesthesia. His arterial line was inadvertently pulled while he was transferred to the ICU bed. He is somnolent but easily arousable. Past medical history is significant only for peripheral vascular disease.

Monitoring in the ICU may exist for diverse reasons: observation for detection of changes in physiologic status, intensive titration of therapy, and/or detection of breaches of safety (e.g., ventilator disconnection), among others. By definition, patients are admitted into the ICU because they require a higher level of care. Monitoring is a significant part of that care, whether it involves monitoring by human caregivers and/or medical machines. The patient's condition and the likelihood that his condition will rapidly change should determine the level of monitoring. One task of the ICU physician is to continually evaluate the need of a patient for a particular level of monitoring. Ideally, monitors should be used to confirm or further define problems that have been discovered by careful physical examination and clinical assessment.

I. Noninvasive monitoring in the ICU
  A. Blood pressure
    1. Use of noninvasive BP vs. invasive BP determined as in O.R.
    2. Similar concerns as to cuff size and site of measurement
  B. ECG
    1. 5-lead and ST-segment analysis in patients at risk for ischemia
    2. Arrhythmias may be first sign of electrolyte imbalance
    3. Rhythm and rate are monitored as part of vital signs
  C. Pulse oximetry (SpO_2)
    1. A monitor of oxygenation
      a) Use of supplemental oxygen negates ability to use SpO_2 as monitor of ventilation
      b) Not a monitor of perfusion unless plethysmographic waveform is utilized; only a crude measure if used
      c) More artifacts in ICU (vs. O.R.) with patient movement
  D. Temperature
    1. Site of measurement important, must be noted with each measurement
    2. Fever is associated with significant increase in mortality
  E. Peripheral nerve stimulator
    1. Mandatory use when patient under neuromuscular blockade
    2. Response to train of four (TOF) to be recorded with regular vital signs
  F. Capnography
    1. Can be used in non-intubated patients as a monitor of ventilation
    2. Difficulty in long-term use with humidification of ventilator circuit
    3. End-tidal CO_2: arterial CO_2 gradient changes can be due to ventilation or perfusion changes; end-tidal CO_2 should be noted with each blood gas
  G. Non-invasive cardiac output (CO)/cardiac function
    1. Echocardiography: transthoracic (TTE) or transesophageal (TEE)
      - Accurate TTE may not be possible in edematous patients; can be used for detection of ischemia, assessment of preload, and ejection fraction. TEE better for assessment of right ventricle, pulmonary circulation and aortic dissection.
    2. Doppler noninvasive/thoracic impedance
      - Newer monitors; can correlate well with invasive CO monitor. Can be used for trending and rapid evaluation of changes in therapy.
    3. Respiratory CO_2-derived cardiac output measurements in mechanically ventilated patients via proprietary technology
  H. Radiology/Ultrasound
    1. Consult with radiologist to make sure the test is the right one for the presumed diagnosis
    2. Many tests may need proper preparation of the patient (NPO, bowel prep, contrast, etc.).
    3. Prepare patients with poor renal function (avoid hypovolemia, consider bicarbonate and/or N-

acetylcysteine) or allergy to contrast (consider histamine blockers and/or steroids).
4. Bedside ultrasound can be used for serial evaluation and follow-up exams

I. Gastric tonometry
1. Measures changes in gastric mucosal CO_2 by allowing equilibration of CO_2 partial pressures between a fluid-filled balloon and the mucosal layers
2. Used as a monitor of tissue hypoxia because the increase in CO_2 is a reflection of decreased perfusion or anaerobic metabolism

II. Invasive monitoring

A. Arterial lines
1. Used with unstable patients or those receiving vasoactive infusions
2. Insertion either percutaneous or by cut-down
   a) Cut-down associated with more morbidity
3. Sites: radial, femoral, dorsalis pedis, axillary, posterior tibial, temporalis
   a) Check for collateral circulation (controversial)
   b) Axillary site with higher risk of infection

B. Central lines (see section 17: Rational Use of the PA Catheter)
1. Sites: Internal/external jugular, subclavian, femoral
2. Cardiac output measurements via non-pulmonary artery catheter devices; may include additional measurements such as lung water
3. Associated morbidity and mortality (including infection, bleeding, arrhythmias, emboli, arterial puncture/catheterization, pneumothorax (subclavian and internal jugular), thrombosis, catheter misdirection, or perforation of insertion vessel, more central vein or even the heart).

C. ICP monitoring
1. Useful in closed head injury patients at risk for intracranial hypertension and herniation
2. Ventriculostomy vs. bolt: differences in infection rates, ease of placement, therapeutic possibilities.

This chapter is a revision of the original chapter authored by Clayton C. Cowan, M.D. and Thomas H. Fuhrman, M.D.

READING LIST:

1. Marino P. The ICU Book. Philadelphia: Lea & Febiger; 1991, pp. 89-90. An excellent overview of critical care concepts. Very readable and concise.
2. Zimmerman ZL, editor. Critical Care Refresher Course. Society of Critical Care Medicine; 1997, p. 171. Useful as a review text for exam study. Less detailed than the usual textbook.
3. Mark JB. Getting the most from a CVP catheter. ASA Refresher Course Lectures, 1997. A great review of CVP waveform interpretation.
4. Howell MD, Curley FJ, and Smyrnios NA: Routine monitoring in critically ill patients. In: Irwin RS and Rippe JM (eds) Irwin and Rippe's Intensive Care Medicine 6th Edition. Wolters Kluwer/Lippincot Williams & Williams (Philadelphia) 2008.
5. Zimmerman ZL, editor. Critical Care Refresher Course. Society of Critical Care Medicine; 1997, pp. 112-113.

QUESTIONS:

16.1. All of the following statements concerning noninvasive BP monitoring are true EXCEPT:

A. In elderly, hypertensive subjects, the diastolic pressure may exceed the actual pressure by 10 mmHg.
B. Noninvasive BP measurements are significantly more inaccurate than arterial line pressures in low-flow states.
C. Noninvasive BP measurements overestimate the actual systolic pressure of patients with cardiac failure.
D. An indication for the use of invasive arterial pressure monitoring is the need to begin vasoactive drug therapy.
E. In obese patients, if the noninvasive BP cuff is too small, the BP will read higher than the actual pressure.

16.2. Indications for inserting or maintaining a PA catheter include all of the following EXCEPT:

A. High-risk surgery planned in a patient with poor left ventricular function
B. Shock which is refractory to multiple therapeutic modalities
C. Pulmonary edema of uncertain etiology
D. Oliguria in a patient with normal left ventricular function
E. Titration of pressors and/or inotropes

16.3. All of the following statements concerning the CVP tracing are true EXCEPT:

A. "A" waves result from atrial contraction.
B. "C" waves are a result of tricuspid valve closure and ventricular contraction.
C. When a patient has a junctional rhythm, prominent "A" waves (cannon "A" waves) may result.
D. The waves of a CVP tracing tend to be sharper and more distinct with fast heart rates than with normal heart rates.
E. Cardiac tamponade changes the normal, biphasic CVP tracing into a monophasic tracing, obliterating the "Y" descent.

16.4. True statements concerning the internal jugular approach of central venous cannulation include all of the following EXCEPT:

A. In patients with tracheostomies, the internal jugular approach has a higher risk of infection than the subclavian approach.
B. With an internal jugular approach, there is no risk of pneumothorax.
C. It is safe to attempt an internal jugular approach on the same side as a failed subclavian approach without first obtaining a chest X-ray.
D. Accidental puncture of the carotid artery occurs in 2-10% of internal jugular vein cannulation attempts.
E. The presence of an internal jugular catheter usually results in greater patient discomfort than a subclavian catheter.

16.5. All of the following are true concerning intracranial pressure monitoring EXCEPT:

A. The ventriculostomy is a more accurate and reliable method for measuring ICP than the subarachnoid hollow screw (bolt).
B. An advantage of the ventriculostomy over the bolt is that it allows for the drainage of CSF with increases in ICP.
C. Ventriculostomies carry an 8%-11% risk of infection within 5 days of placement.
D. Since a ventriculostomy is directly attached to a water column manometer, it requires no electrical equipment.
E. The subarachnoid hollow screw or bolt carries a higher risk of infection and bleeding complications than ventriculostomy.

17. Rational Use of the Pulmonary Artery Catheter (PAC)

Fanni Nhuch, M.D., Ricardo Martinez-Ruiz, M.D., Miguel A. Cobas, M.D.

A 73-year-old man presents to the hospital emergency medicine department with a chief complaint of progressive shortness of breath. The patient has a history of a dilated cardiomyopathy thought to be ischemic in nature with an ejection fraction of less than 20%. Additionally, he has a history of life-threatening cardiac arrhythmias and has an automatic implantable cardiodefibrillator. Over the week prior to admission, the patient has complained of a cough and other cold symptoms with progressive respiratory failure. Chest x-ray on admission shows a prominent left lung infiltrate involving the entire lung and some infiltrate on the right. The patient is admitted to the medical/surgical intensive care unit.

The following day the patient develops progressive respiratory failure with tachypnea and is intubated and started on mechanical ventilation. Because the etiology of his respiratory failure is unclear (CHF vs. pneumonia), a pulmonary artery catheter (PAC) is inserted. His hemodynamic profile revealed a low blood pressure (BP), low filling pressures with a low cardiac output (CO). Modest amounts of fluids were given which resulted in an increase in CO with just a slight increase in filling pressures. The calculated systemic vascular resistance (SVR) was low after volume expansion, suggesting a picture of low tone state from sepsis. After the patient responded to appropriate antibiotics he was able to be weaned from the ventilator. The patient spent some extra days at the facility and was discharged home in his previous state of health.

Although condemned in some recent literature, the PAC has enjoyed a long and robust history of use for clarification of cardiovascular status and manipulation of hemodynamic parameters. With the preceding case, the data clarified the diagnosis of pneumonia, as the patient had adequate cardiac function without evidence of congestive heart failure and fluid overload. Management of this patient based only on clinical skills could certainly have missed the proper diagnosis and delayed the appropriate treatment. Proper use of the PAC, however, requires a sophisticated understanding of proper data collection and interpretation. When used for the proper indications and interpreted appropriately, data derived from a PAC is indispensable in augmenting information about a critically ill patient's clinical situation.

I. Indications for use of the PAC: The PAC is used to obtain a hemodynamic picture of the cardiovascular system. This means we are trying to establish the relationship between the filling pressures of the cavities and their function i.e. generate a Starling curve for the ventricle. This is done by obtaining a pulmonary capillary wedge pressure (PCWP) and CO, two of the distinctive parameters that this catheter can provide. It is also used to assess oxygen delivery by measuring mixed venous oxygen saturation (SvO_2).
   A. Monitoring filling pressures: PCWP
      1. When the balloon is inflated the catheter tip moves from a central position to wedge in a more peripheral vessel. Flow then stops and a static fluid column is created.
      2. The pulmonary venous system is a low-resistance circuit; the pressure at this junction normally closely approximates mean left atrial pressure. Mean left atrial pressure approximates left ventricular end-diastolic pressure unless an atrial myxoma, mitral disease or severe left ventricular failure exists.
      3. By itself PCWP is an inadequate measure of the distending force exerted upon the ventricular myocardium and an unreliable estimator of preload or fiber stretch actually achieved. Two other important variables must be taken into account: the distensibility of the ventricular myocardium (myocardial compliance) and the pressure surrounding the heart and great vessels (transmural pressure).
      4. Ventricular Compliance: the failure of PCWP to correlate with the left ventricular diastolic volume is at least partially accounted for by the variations in left ventricular compliance, secondary to events such as myocardial ischemia, ventricular hypertrophy, etc.
      5. Transmural Pressure= PCWP - juxtacardiac pressure (stretching force exerted upon the left ventricle). Under most circumstances juxtacardiac pressure closely parallels mean

intrapleural pressure, and, at the end-expiration is when pressure inside the chest cavity is closest to atmospheric (that's why we should always measure PCWP at the end of expiration).
Thus to accurately interpret the PCWP, one must always consider the extramural pressure: pleural pressure, PEEP, auto-PEEP, increased intra-abdominal pressure (abdominal compartment syndrome), cardiac tamponade, etc.

B. Monitoring cardiac output
   1. After injection of a known quantity of cold solution (usually 10 ml or normal saline), blood temperature is measured continuously by a rapidly responding thermistor positioned downstream in the lumen of central pulmonary artery.
   2. The change in temperature over time (area under the curve) is inversely proportional to the blood flow acting to restore the thermal baseline. A normal curve peaks early and exhibits a smooth contour. For variations to be minimized, each recorded value should be the average of three or more determinations.
   3. Except during significant hypothermia or very high cardiac output states, there will be no difference if the solution injected is at 0 degree Celsius or ambient temperature, if the computer is adjusted to accept relevant input.
   4. The port at which the cold solution will be injected does not affect the recorded value as long as it is upstream from the tricuspid valve. Also a slow and interrupted injection of the solution may give rise to erroneous values.
   5. Errors can also result from operator negligence: Cardiac output will not be accurate if the injectate temperature constant is entered incorrectly, if the injected volume differs from the expected amount, or if the injectate probe is not immersed in the environment of its reference temperature. An intracardiac shunt or significant disease of the tricuspid or pulmonic valve may also interfere with accurate output determination.

C. Monitoring oxygen transport:
   1. The PAC catheter allows sampling of pulmonary artery blood for determination of SvO_2.
   2. The tip of the catheter should be located proximally in the pulmonary artery, and blood should be withdrawn slowly so that admixture with oxygenated post capillary blood does not occur.
   3. SvO_2 is a good parameter of the relationship between oxygen delivery and consumption.
   4. Changes in SvO_2 vary directly from changes in cardiac output, hemoglobin concentration, and SaO_2 and inversely with oxygen consumption.
   5. SvO_2 normal value is 75%.

D. Provide cardiac pacing capability as well as patient monitoring:
   1. Pacing PAC
   2. Paceport catheter with special lumen for pacing wire

E. Provide special right ventricular function monitor:
   1. Right ventricular ejection fraction
   2. Right ventricular end diastolic volume

II. Insertion procedure

A. Intravascular route
   1. Right or left internal jugular
   2. Right or left subclavian
   3. Right or left femoral

- "If the blood can float to the heart, then you can float the Swan to the heart"

B. Technique of insertion
   1. Access vein with side arm introducer inserted by Seldinger technique
   2. 8-French catheter will pass through 9-French introducer
   3. Balloon-tipped catheter floated into position with flow of blood through right ventricle into pulmonary artery (Remember: advance with the balloon inflated, pull back with the balloon deflated!)
   4. Position of catheter during insertion determined by identifying right atrial(20 cm), right ventricle(35 cm), pulmonary artery(45 cm) and pulmonary capillary wedge(50 cm) traces on bedside monitor.
   5. Alternatively, fluoroscopy can guide the passage of the catheter

III. Choice of catheters determined by monitoring and/or treatment needs of the patient

A. Standard thermodilution catheter provides cardiac output, pulmonary artery pressures, and pulmonary capillary wedge pressure
B. Continuous cardiac output catheter provides the same information but a heated wire in the catheter determines flow or cardiac output data regularly and automatically
C. Fiberoptic catheter measures mixed venous oxygen saturation by reflectance spectrophotometry and can be combined with standard or continuous cardiac output catheter
D. Pacing catheters permit cardiac pacing by insertion of a wire through a pace port or by the use of pacing electrodes on the surface of the catheter
E. Right ventricular ejection fraction catheter also determines end diastolic volume and right ventricular ejection fraction

IV. Complications of a PAC
A. Insertion complications:
1. Vascular injury
2. Bleeding
3. Cardiac arrhythmias
4. Pneumothorax
5. Air embolism
B. Monitoring complications:
1. Infection
2. Pulmonary infarction
3. Pulmonary artery rupture
4. Right bundle-branch block (or complete heart block if existing left bundle-branch block)
5. Venous thrombosis
6. Mural thrombus
7. Valvular or endocardial vegetations

V. Value of the PAC:
A. The right diagnosis leads to the right treatment.
B. It is only a diagnostic tool; its benefits depend on what you do with the numbers you get. Recent criticism of the catheter claims increased mortality rate with its use. Possible causes for these findings are:
1. Poorly matched patient populations
C. Poor understanding and improper utilization of data obtained by the catheter may explain the lack of benefit.
D. Careful interpretation of data helps clarify important questions in complicated patients.
E. It is important to make a hemodynamic diagnosis and then treat appropriately i.e. if the patient has a low tone state with good or high CO and low BP, the therapy should be to increase tone by giving a vasopressor. If the numbers give you a low CO with low filling pressures, the presumptive diagnosis is hypovolemia and fluids should be administered.
F. Always interpret the data taking into account the transmural pressure gradient and compliance of the ventricle.
G. A filling pressure in isolation tells you very little about the cardiovascular system status. Always associate a filling pressure with a function parameter (CO, CI, SV). You are generating the Starling curve for that ventricle!

This chapter is a revision of the original chapter authored by John W. Hoyt, M.D.

READING LIST:

1. Connors AF Jr, Dawson NV, Shaw PK. Hemodynamic status in critically ill patients with and without acute heart disease. Chest 1990;98:1200-1206.
This paper might be characterized as a second generation justification for use of the PA catheter. Now the issue was not demonstrating the adequacy or inadequacy of clinical skills when compared to the PA catheter but instead

the impact of hemodynamic information on clinical decisions. Dr. Connors found that physicians changed treatment 50% of the time when they had hemodynamic information obtained from a PA catheter.

2. Connors AF Jr, McCaffree DR, Gray BA. Evaluation of right heart catheterization in the critically ill patient without acute myocardial infarction. N Engl J Med 1983;308:263-267.
   Appearing in the New England Journal, this paper had a substantial effect on the use of PA catheters. The authors demonstrated that clinical skills were not adequate to predict cardiac output and pulmonary capillary wedge pressure. They demonstrated that only by invasive monitoring could one obtain accurate information for better medical decision making.
3. Connors AF, Speroff T, Dawson NV, et al. The effectiveness of right heart catheterization in the initial care of critically ill patients. JAMA 1996;276(11):889-897.
   This paper is the latest in attacks on the value of a PAC. The authors compare a population of patients monitored with a PA catheter to a matched population of unmonitored patients. The results of the paper show a higher mortality rate in the monitored population. Accompanying editorial suggested the moratorium on the use of a PA catheter if clear evidence cannot be obtained to demonstrate the value of the PA catheter.
4. Eisenburg PR, Jaffe AS, Schuster DP. Clinical evaluation compared to PACization in the hemodynamic assessment of critically ill patients. Crit Care Med 1984;12(7):549-553.
   This manuscript is a repeat of the Connors paper in the New England Journal from a year before. The authors substantiated Connors' findings that clinical skills are inadequate for accurate information about cardiac function and good medical decision-making.
5. Fein AM. Is PACization necessary for the diagnosis of pulmonary edema? Am Rev Respir Dis 1984;129:1006-1009.
   Pulmonary edema may have a cardiac or noncardiac diagnosis. This paper demonstrates the difficulty of accurately categorizing pulmonary edema by clinical skills alone. Once again, this manuscript has been commonly quoted as a justification for invasive hemodynamic monitoring with a PA catheter.
6. Forrester JS, Diamond G, McHugh TJ, et al. Filling pressures in right and left sides of the heart in acute myocardial infarction: A reappraisal of central venous pressure monitoring. N Engl J Med 1971;285:190.
   This historical paper was a significant clinical force in increasing the use of PA catheters in the ICU. The paper demonstrated that patients with cardiac disease and a normal CVP might have low or normal or high pulmonary capillary wedge pressures. Thus the clinical value of the PA catheter was substantiated and the need was demonstrated for more invasive monitoring of intravascular volume for better clinical decision-making about fluid administration.
7. Gore JM, Goldberg RJ, Spodick DH, et al. A community-wide assessment of the use of Pulmonary Artery Catheters in patients with acute myocardial infarction. Chest 1987;92;721-727.
   This was the original clinical attack on the value of the PA catheter. A retrospective study of cardiac patients in community hospital CCUs demonstrated a higher mortality rate when a PA catheter was used. There was no attempt to match monitored and unmonitored patients except for diagnosis. An accompanying editorial suggested that many lives might be saved if clinicians stopped using the PAC.
8. Iberti TJ, Fischer EP, Leibowitz AB, et al. A multicenter study of physician's knowledge of the Pulmonary Artery Catheter. JAMA 1990;264:2928-2932.
   One of the key issues in the most recent Connors paper demonstrating an increased mortality rate with the use of a PA catheter is user education. In this paper Iberti demonstrated a surprisingly poor knowledge level among clinicians commonly using the PA catheter. This paper has been recently repeated by Trotter once again demonstrating a knowledge defect. It is now being speculated that increased mortality rate with the use of the PA catheter might be due to user error and poor knowledge.
9. Swan HJC, Ganz W, Forrester J, et al. Catheterization of the heart in man with the use of flow directed balloon-tipped catheter. N Engl J Med 1970;283-447.
   This is a historical paper of great significance to critical care. It was in this manuscript that the use of the balloon-tipped and flow-directed PAC was first introduced.
10. Tuman KJ, McCarthy RJ, Speiss BD, et al. Effect of PACization on outcome in patients undergoing coronary artery surgery. Anesthesiology 1989;70:199-206.
   This paper is a more recent and better designed prospective study of the value of the PA catheter. Unfortunately, Tuman was unable to demonstrate a difference in cardiac surgery patients. His population size may be small, and in the sickest patients who were unmonitored there could be some information that eventual monitoring made a difference in reversing their cardiac problems. The paper is certainly not convincing in its support of hemodynamic monitoring.
11. Wheeler AP, Bernard GR, Thompson BT, Shoenfeld D, et al. Pulmonary-Artery versus Central Venous Catheter to Guide Treatment of Acute Lung Injury. The New England Journal of Medicine. Boston: May 2006. Vol. 354, Iss 21; pg 2213-2225.
   This study is a randomized trial comparing hemodynamic management guided by PAC with hemodynamic

management guided by central venous catheter. The primary outcome was mortality during the first 60 days before discharge home. The conclusion shows that PAC-guided therapy did not improve survival or organ function, but was associated with more complications than CVC guided therapy.

12.The ESCAPE Investigators and ESCAPE Study Coordinators: Evaluation Study of Congestive Heart Failure and PACization Effectiveness (The ESCAPE Trial). JAMA, October 5,2005. Vol 294, No 13: 1625-1633.
Randomized Controlled Trial to determine wheter PAC use is safe and improves clinical outcomes in patients hospitalized with severe symptomatic and recurrent heart failure. No affect in overall mortality and hospitalization.

13.Marini JJ. Obtaining Meaningful Data From the Swan-Ganz Catheter. Respiratory Care. July 1985, Vol 30, No 7: 572-584.
Classic review article about hemodynamics and PA catheter. It discusses the issue of the transmural pressure gradients, the effect of compliance in the PCWP and its relation to volume assessment.

QUESTIONS:

17.1. Appropriate indications for the PAC include all of the following EXCEPT:
- A. Monitor intravascular volume in the hypovolemic patient
- B. Monitor cardiac output in the patient with an acute myocardial infarction
- C. Measure left ventricular ejection fraction in a patient with cardiomyopathy
- D. Determine oxygen transport and extraction in the septic patient

17.2. Which of the following answers best justifies the use of a fiber-optic PAC:
- A. There is a reliable correlation between SvO2 and cardiac output
- B. There is a reliable correlation between SvO2 and the global balance of oxygen supply and demand
- C. There is reliable correlation between SvO2 and oxygen consumption
- D. There is reliable correlation between SvO2 and arterial oxygenation

17.3. Which of the following patient populations are most likely to have a rupture of the pulmonary artery during hemodynamic monitoring with a PAC?
- A. Patients with pulmonary artery hypertension
- B. Patients with cardiogenic shock
- C. Patients with septic shock
- D. Patients with a low left ventricular end diastolic volume

17.4. In an average size adult male of approximately 70 kg one might expect to reach the right ventricle during insertion of the PAC through the right internal jugular vein at which of the following distances:
- A. 20-25 cm
- B. 30-35 cm
- C. 40-45 cm
- D. 50-55 cm

17.5. On which condition the mixed venous oxygen saturation correlates with the level of perturbation in systemic oxygen delivery?
- A. Septic shock
- B. Anaphylactic shock
- C. Spinal shock
- D. Cardiogenic shock

18. Echocardiography in the Intensive Care Unit

Frank Rosemeier, M.D., Miguel A. Cobas, M.D.

A known hypertensive, 68-year-old obese, female accident victim with a femur fracture and blunt chest and abdominal trauma becomes acutely hypoxemic and hemodynamically unstable within the first hour of admission to the intensive care unit. She was endotracheally intubated and sedated for respiratory distress in the ER with otherwise stable vital signs and transferred to the intensive care unit after initial management according to ATLS protocol. On examination, she is agitated, HR 110, BP 75/55, SpO_2 92% on FiO_2 1.0. Breath sounds are heard bilaterally, JVP is not visualized, heart sound appear distant, abdominal examination is negative for acute peritoneal signs and distention, but limited due to body habitus. Despite manual bag ventilation with 100% oxygen and a fluid challenge via a large bore intravenous catheter her cardiopulmonary status continues to deteriorate.

Unexplained hemodynamic instability is an archetypical indication for the use of ultrasonography as a diagnostic tool in the critically ill patient. Both, transthoracic (TTE) and transesophageal (TEE) echocardiography are useful as rapid, noninvasive bedside techniques to diagnose and manage refractory hypotension in a time sensitive manner. Especially after standard management including volume resuscitation and administration of inotrope and vasopressor infusions fail to stabilize the patient, additional information obtained via real-time images or Doppler flow patterns may lead to an elusive diagnosis. Frequently, resuscitation efforts are redirected based on the information obtained from echocardiography. Some observational studies indicate that in about half of critically ill patients, TEE changes management strategies despite the presence of a pulmonary artery catheter. Like most other monitors and diagnostic procedures however, echocardiography should be regarded as an adjunct, which requires expertise to integrate the images with other data relevant to the overall assessment of the patient.

The preceding case presentation demonstrates the diagnostic dilemma of unexplained and delayed shock in a multitrauma patient. The scenario is compatible with hypovolemia secondary to concealed hemorrhagic shock from a delayed ruptured spleen, but is also consistent with a variety of other scenario such as ventricular failure from acute myocardial infarction, acute valvular dysfunction, cardiac tamponade, fat embolism, and traumatic aortic dissection. Echocardiography may circumvent the time-consuming process of placing invasive catheters, which require additional monitoring equipment, accurate interpretation of hemodynamic parameters and have been to be shown to be of variable benefit.

The following outline aims to provide a basic understanding of the use of echocardiography in the critically ill patient. However, the content will not substitute for formal echocardiographic education and training.

I. Indications:

National guidelines base their recommendations according to the level of scientific evidence.
Class I: conditions for which there is evidence and/or general agreement that a given procedure or treatment is useful or effective.
Class IIa: the evidence is in favor of the treatment or procedure, but opinion may diverge.
Class IIb: evidence is less convincing
Class III: evidence may potentially be harmful.

The list of Class I indications below can be extended to include preexisting cardiovascular and pulmonary conditions in the critical ill patient such as acute coronary syndromes, valvular dysfunction, and pulmonary disease.

A. Class I indications for echocardiography in the ICU
  1. Critically ill patient
    a) Hemodynamic instability
      (1) Hypovolemia
      (2) Vasodilatation
      (3) Ventricular failure
        (a) Left ventricular failure

(b) Right ventricular failure
(c) Biventricular failure
(d) Sepsis related cardiomyopathy
(e) Left ventricular diastolic failure
(4) Pulmonary embolus
(5) Acute valvular dysfunction
(6) Cardiac tamponade

b) Suspected aortic dissection (TEE)
c) Unexplained hypoxemia
d) Sources of emboli (TEE if considering left atrium)

2. Critically injured patient
   a) Serious blunt or penetrating chest trauma for suspected pericardial effusion or tamponade or aortic dissection
   b) Mechanically ventilated multiple-trauma or chest trauma patients
   c) Suspected preexisting valvular or myocardial disease in the trauma patient
   d) Hemodynamic instability in the multitrauma patient without chest trauma, but with crush or deceleration injury mechanism with potential cardiac or aortic injury
   e) Radiographic widening of the mediastinum with suspected thoracic aortic injury
   f) Needle injury from central venous catheter or pericardiocentesis with or without signs of tamponade.

II. Indications for primary transesophageal echocardiography

TTE devices facilitate an urgent, focused, qualitative assessment in many patients. Frequently in critically ill patients an adequate TTE assessment cannot be achieved and progression to a TEE examination is indicated. Although TEE is more invasive and requires considerable expertise, it may provide superior imaging and overcomes some of the limitation of TTE.

A. Inferior image quality of TTE in:
   1. Mechanical ventilation with high PEEP
   2. Severe obesity, emphysema
   3. Pneumothorax, pneumopericardium or subcutaneous emphysema
   4. Presence of chest and mediastinal tubes
   5. Surgical incisions and dressings
B. Superior image quality of TEE in:
   1. Thoracic aortic dissection
   2. Assessment of endocarditis
   3. Intracardiac thrombus
   4. Visualization of thoracic aorta, left atrial appendage, prosthetic valves
   5. Postcardiotomy patients to rule out mediastinal tamponade

III. Contraindications to insertion of a TEE probe

A. Absolute contraindications
   1. Esophageal pathologies
      a) Stricture
      b) Mass or tumor
      c) Diverticulum
      d) Mallory Weiss tear
      e) Dysphagia or odynophagia not evaluated previously
   2. Cervical spine instability
B. Relative contraindications
   1. Esophageal varices
   2. Recent esophageal or gastric surgery
   3. Oropharyngeal carcinoma
   4. Upper gastrointestinal bleeding
   5. Severe cervical arthritis
   6. Atlantoaxial disease

IV. Preparation of the patient

Informed consent should be obtained from the patient, if conscious, or the medical power of attorney. The risk and benefit and conduct of the procedure should be explained in simple, understandable language.

A. Incidence of complication for intraoperative TEE
   1. Mortality (0.01 to 0.0.3%)
   2. Morbidity (0.2%)
      a) Odynophagia (0.1%)
      b) Dental injury (0.03%)
      c) Endotracheal tube malposition (0.03%)
      d) Upper gastrointestinal hemorrhage (0.03%)
      e) Esophageal perforation (0.01%)

The patient is ideally positioned in the left lateral decubitus position for either TTE or TEE. TTE is well tolerated, but requires a cooperative patient. For a TEE examination the patient should be NPO for six hours, and tube feeds should be held with the exception of emergencies. Adequate sedation and appropriate hemodynamic and cardiovascular monitoring according to American Society of Anesthesiologists monitoring standards is essential for the TEE examination for both the non-intubated and intubated patient. Administration of sedatives may cause hemodynamic instability and the presence of a qualified care provider and availability of vasopressor agents are recommended.

V. Image acquisition

A comprehensive TEE evaluation encompasses the acquisition and interpretation of 2D images and Doppler data of 20 cross sectional views, in contrast to 8 image plans in a focused, basic assessment. One of the most useful cross sections is the transgastric short axis view at the level of the midpapillary muscles (see Figure 18.1). This TEE image is obtained by forwarding the TEE probe into the stomach and directing the ultrasound beam across the heart. The image obtained of the left ventricle resembles a donut with the right ventricle hugging the left in a crescent shape. This image plane allows for the evaluation of the left and right ventricular myocardium, papillary muscles, and pericardium. Pathological processes such as ventricular dysfunction and the presence of pericardial fluid can be identified. However, an examination, which is limited and focused needs to be accurate as erroneous interpretation of limited data may lead to a wrong diagnosis and possibly harmful management strategies.

VI. The hemodynamically unstable patient

Unexplained hypotension or hypotension refractory to appropriate fluid resuscitation and or vasopressor therapy is a common problem in the emergency room and intensive care unit alike. Table 1 presents some chief echocardiographic features of common etiologies for hypotension. For an initial, rapid examination the transgastric midpapillary view should be developed. Simple visualization in real-time by an experienced echocardiographer, who can rapidly estimate systolic and diastolic areas, myocardial wall thickening and endocardial wall excursion, allows for fast assessment of volume status and global ventricular function,. Wall motion can be described in terms of normokinesia, hypokinesia, akinesia, and dyskinesia, the latter being characterized by the ventricular wall moving outwards instead of contracting towards the middle in systole.

Table 18.1. TEE findings for common etiologies of refractory hypotension in the ICU population

Etiology	TEE findings
Hypovolemia	Decreased end-diastolic area Normal or decreased end-systolic area Increased fractional area change Normal myocardial thickening Normal to increased endocardial excursion "Kissing" papillary muscles
Left ventricular outflow tract obstruction	Small, hyperdynamic left ventricle Mosaic pattern of flow in left ventricular cavity on Doppler Systolic anterior motion of the mitral valve
Failing left ventricle	Increased end-diastolic area Increased end-systolic area Decreased fractional area change

Failing right ventricle	"D" shape left ventricle in transgastric view Intraventricular septum bulges towards the left ventricle Increased right ventricular size > 1/3 of left
Vasodilatation	Normal to low end-diastolic area Decreased end-systolic area Increased fractional area change Increased myocardial thickening Increased endocardial excursion
Cardiac tamponade	Pericardial effusion Diastolic collapse of right-sided chambers or left atrium Dilated, on-collapsible inferior vena cava
Aortic dissection	Intimal flap Aorta with two lumen Aortic regurgitation Pericardial effusion
Pulmonary embolus	Right ventricular dysfunction Dilated right-sided chambers Flow through a patent foramen ovale Echogenic density

VII. Other use of ultrasound in the ICU setting

A. Central line placement
B. Assessment of pleural effusions
C. Assessment of intra-abdominal fluid collections
D. Urinary bladder scan
E. Focused assessment of the trauma patient
F. Assistance in placement of intra-aortic balloon counter pulsation
G. Evaluation of flow in ventricular assist devices
H. Weaning from ventricular assist devices or extracorporeal membranous oxygenator

VIII. Conclusion

The use of echocardiography is growing in the ICU setting and may rapidly assist the clinician in obtaining additional information in the unstable critically ill patients. Often, management strategies are redirected or optimized based on the echo information, even in the presence of invasive monitoring. Prospective, randomized trials on the impact of echocardiography may be difficult to conduct. As guidelines for the conduct of ICU echocardiography are developed, the importance of operator expertise, as with any technology, need be emphasized as inappropriate use and inaccurate interpretation may result in inappropriate interventions.

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QUESTIONS:

18.1. Class I indication for echocardiography in the critical care setting include:
- A. Monitoring function of assist devices
- B. Hemodynamic instability in an intubated patient with invasive monitoring lines
- C. Facilitation of pulmonary artery catheter positioning
- D. Spontaneously ventilating, hemodynamically stable chest trauma patient
- E. Monitoring placement of intra-aortic balloon counterpulsation devices

18.2. Absolute contraindication to transesophageal echocardiography includes:
- A. Rheumatic arthritis
- B. Know esophageal varices
- C. Bleeding diathesis
- D. Esophageal stricture
- E. Recent gastric surgery

18.3. A known hypertensive, 68-year-old obese, female accident victim with a femur fracture, blunt chest, and abdominal trauma becomes acutely hypoxemic and hemodynamically unstable. Initial management step(s) in order of importance include primarily.
- A. Establishment of an airway, breathing, circulation, and possible drug administration
- B. Intravenous fluid challenge
- C. Emergent sedation, intubation, and ventilation
- D. Administration of a vasopressor
- E. Urgent bedside echocardiography

18.4. The above patient was stabilized and intubated in the emergency room and transferred to the ICU where refractory hypoxemia developed. Echocardiographic features of traumatic dissection of the aorta consist of all of the following, EXCEPT:

A. Intimal flap in the lumen of the aorta
B. Pericardial effusion
C. Aortic insufficiency
D. D-shape left ventricle
E. Two lumens in the ascending aorta

18.5. The above patient underwent emergent repair of a thoracic dissection with aortic valve replacement complicated by postoperative hemorrhage. Within 4 hours postop she gets progressively hypotensive requiring frequent adjustment of vasopressor therapy and repeated fluid challenges. Echocardiographic features consistent with pericardial tamponade include all of the following, EXCEPT:

A. Loculated fluid in the posterior portion of the mediastinum
B. Diastolic collapse of the right ventricle
C. Decreased left ventricular end-diastolic area
D. Small, collapsible inferior vena cava
E. Right ventricular dysfunction

18.6. On postoperative day 3 the above patient develops atrial fibrillation with ST segment changes. Echocardiographic features of ventricular dysfunction may include:

A. Increased myocardial thickening
B. Decreased end-diastolic area
C. Increased right ventricular size
D. Increased endocardial excursions
E. Kissing papillary muscles