

Bedside Flow-Directed Balloon Catheterization in the Critically Ill Patient

J. EUGENE MILLEN

Pulmonary Physiologist and Technical Director, Respiratory Intensive Care Unit, Medical College of Virginia, Health Sciences Division of Virginia Commonwealth University, Richmond, Virginia

FREDERICK L. GLAUSER, M.D.

Chief, Pulmonary Division, Medical College of Virginia, Health Sciences Division of Virginia Commonwealth University, Richmond, Virginia

Prior to 1970, catheterization of the right heart and pulmonary artery required the use of fluoroscopic guidance and was only performed in specialized research units and/or the cardiac catheterization laboratory. The need to assess the hemodynamic status of the left atrium and ventricle on a continuing basis brought about the development of the flow-directed balloon-tipped catheter.¹ With the availability of this tool, routine bedside right heart catheterization has become a reality in the critical care units of many community hospitals. This technique provides the physician with the means for indirectly appraising left heart hemodynamics and to gauge the effects of various modes of therapy on tissue perfusion by monitoring the pulmonary artery and pulmonary capillary wedge pressures (PCWP), cardiac outputs, and mixed venous P_{O_2} ($P\bar{v}O_2$).

Relationship Between Pulmonary Capillary Wedge Pressure (PCWP) and Left Ventricular End Diastolic Pressure

The term pulmonary capillary wedge pressure originated many years before the discovery of the flow-directed catheter. During routine diagnostic right heart catheterizations, it was customary to ad-

vance the rigid catheter, under fluoroscopic guidance, from a large pulmonary artery to a more peripheral position. Here resistance was met within a small pulmonary artery branch whose inside diameter approximated that of the catheter. The catheter was then forcibly advanced a short distance until it became physically wedged. This "wedging" occluded the pulmonary artery pressure tracing and monitored the distal or downstream pressure, that is, left heart pressures were reflected retrograde through the pulmonary capillaries to the catheter tip. These same pressures can now be monitored at the bedside, employing the flow-directed catheter by inflating the balloon and temporarily obstructing pulmonary artery pressures and flow.

Since the PCWP is an indirect reflection of the left atrial pressure, it is used as an assessment of the left ventricular filling pressure during diastole. The value of this measurement is important in the diagnosis and management of the critically ill patient.

Indications for Bedside Pulmonary Artery Catheterization

Although there are no universally agreed upon, absolute indications for the use of the flow-directed catheter, the following list includes many of the clinical conditions in which hemodynamic monitoring may be useful.

Correspondence and reprint requests to Mr. Eugene Millen, Box 93, Medical College of Virginia, Richmond, VA 23298.

1. As a guide to fluid management
 - a. acute renal failure
 - b. acute pancreatitis
 - c. burn patients
2. Evaluation and management of shock states
 - a. septic
 - b. hypovolemic
 - c. cardiogenic
3. Diagnosis and management of respiratory failure
 - a. adult respiratory distress syndrome
 - b. primary pulmonary hypertension
 - c. pulmonary embolism
4. Diagnosis of cardiac dysfunction
 - a. cardiac tamponade
 - b. constrictive pericarditis
 - c. mitral insufficiency
 - d. intracardiac shunts (left to right)
5. Assessment of left ventricular function
 - a. acute myocardial infarction
 - b. congestive heart failure
 - c. post-open heart surgery
 - d. ventricular afterload reduction

Catheter Insertion

Our choice of insertion routes are the median basilic, internal jugular, femoral, and subclavian veins, in that order. (We are particularly hesitant to employ the subclavian approach because of the chance of pneumothorax which may be poorly tolerated in the critically ill patient). Percutaneous guide wire insertion (Fig. 1) is normally used, although on rare occasions a surgical cutdown of a median basilic vein may be necessary.



Fig. 1—Percutaneous catheter introducer consisting of wire guide (small arrow), dilator (double arrow) and sheath (large arrow). This assembly is used in conjunction with a 16 gauge teflon needle.

Following introduction, the catheter tip is advanced to the intrathoracic vena cava (a distance of 35 to 40 cm from the femoral or basilic vein and 15 to 20 cm from the internal jugular insertion site) where the balloon is then inflated with from 0.5 to 1 cc of air. With the balloon acting as a sail, the catheter is pushed through the right atrium and ventricle and into the pulmonary artery (Fig. 2). The position of the catheter tip is determined by the pressure contour tracing monitored throughout the procedure (Fig. 3). As the catheter tip reaches smaller caliber pulmonary arteries, the balloon occludes the vessel, producing a wedge pressure tracing. During catheter advancement, the electrocardiogram is carefully monitored by the nurse assisting with the procedure. The nurse reports the number of successive PVCs as a warning to the physician to change the position of the catheter tip.

Hemodynamic and Physiological Indices Derived from Flow-directed Catheters

Pulmonary capillary wedge pressure (PCWP). The PCWP reflects left ventricular end diastolic filling pressures in the absence of left atrial or mitral valve dysfunction (mitral stenosis, mitral insufficiency, left atrial myxoma, and other conditions). The normal pulmonary wedge pressure ranges from 6 to 12 mm Hg with a value greater than 12 mm Hg, implying either left ventricular dysfunction or fluid overload. To differentiate these two clinical conditions, a cardiac output and/or $P\bar{v}O_2$ needs to be obtained. (See below) A low pulmonary wedge pressure, that is, below 6 mm Hg, implies "pure" intravascular fluid depletion such as occurs with hemorrhage, or

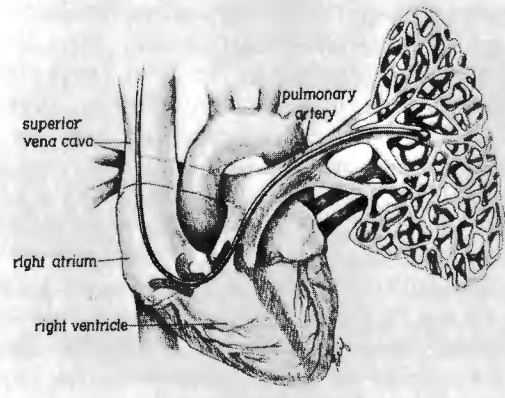


Fig. 2—Flow-directed catheter advanced from superior vena cava through the heart into a branch of left pulmonary artery.

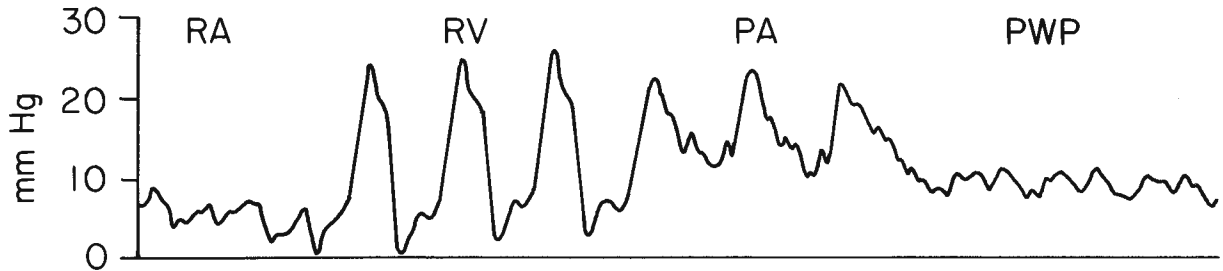


Fig. 3—Idealized recording of pressures seen as catheter is passed from right atrium (RA), right ventricle (RV), and pulmonary artery (PA); with the balloon inflated, the pulmonary wedge pressure (PWP) is obtained.

“relative” intravascular depletion as is seen in the early stages of septic shock. Once again cardiac output or $P\bar{v}O_2$ determinations will help differentiate these entities. (See below)

Cardiac output. Balloon-tipped flow-directed catheters are available with thermodilution cardiac output capabilities. These triple lumen catheters have an orifice located 30 cm proximal from the tip through which room temperature or iced saline, or 5% dextrose solutions, can be injected for the purpose of obtaining a cardiac output.² A thermistor bead located near the tip of the catheter detects changes in temperature from which cardiac outputs can be computed.

Mixed venous P_{O_2} ($P\bar{v}O_2$). The flow-directed catheter also permits sampling of true mixed venous blood (obtained from the pulmonary artery) for P_{O_2} and oxygen content determinations. The $P\bar{v}O_2$ (normal range in a nonanemic patient, 35 to 40 torr) reflects changes in cardiac output and tissue perfusion. As tissue perfusion and/or cardiac output decreases, the $P\bar{v}O_2$ decreases as peripheral tissues extract more oxygen from the blood. For example, a patient with a high PCWP and a normal or elevated $P\bar{v}O_2$ has a normal or elevated cardiac output thus implicating fluid overload as the cause for the elevated PCWP. In a patient whose PCWP is elevated and $P\bar{v}O_2$ (and thus cardiac output) is low, tissue perfusion has been compromised due to left ventricular dysfunction. In contrast, a patient with a low PCWP and a low mixed $P\bar{v}O_2$ (usually below 30 torr) probably has “pure” intravascular fluid depletion and will need intravenous fluids to correct the deficiency. A low PCWP and an inappropriately elevated $P\bar{v}O_2$ (usually above 30 torr) is usually a sign of sepsis. In this condition peripheral arteriovenous shunting occurs with failure to extract oxygen at the cellular level.

Shunt equation (Q_s/Q_t). The degree of physio-

logical and/or anatomic shunting which occurs in patients with both cardiac and pulmonary disease(s) can be calculated by employing the standard shunt formula and obtaining true mixed venous oxygen contents from the flow-directed catheter when in the pulmonary artery position. The shunt calculation, although somewhat cumbersome and complicated, can be used as an index for weaning patients from ventilators, for determining the most appropriate level of positive end expiratory pressure (PEEP), and for following the improvement or deterioration in the patient’s cardiopulmonary status on a day-to-day basis.

Complications

As with any other invasion procedure, flow-directed catheterization can be associated with complications but probably in less than 1% to 2% of all insertions.³

1. Ventricular and atrial arrhythmias, including ventricular tachycardia and fibrillation.
2. Pulmonary infarction
3. Ruptured cordae tendeneae of the tricuspid valve.
4. Rupture of a pulmonary artery and/or capillary with subsequent hemorrhage
5. Infections
6. Knotting of catheters.

The Nurse’s Role

The critical care nurse plays an important and essential role during and following the catheterization. It is his or her responsibility not only to set up and calibrate the transducers but also to assist during the actual catheterization. The nurse must be proficient in monitoring the electrocardiogram during catheter placement and inform the physician of any potentially serious arrhythmias. Additionally, he or she must be an expert in monitoring and reporting

the pulmonary artery and pulmonary wedge pressures. Finally, the nurse must be acquainted with the problems associated with obtaining accurate pressure measurements and be alert to possible complications that can occur with the flow-directed catheter.

In summary, with the aid of the balloon-tipped flow-directed catheter, we are now able to measure pulmonary artery and pulmonary capillary wedge pressures at the bedside. The results obtained from pulmonary artery catheterization have added greatly to the management of the critical ill patient.

REFERENCES

1. SWAN HJC, GANZ W, FORRESTER J, ET AL: Catheterization of the heart in man with use of a flow-directed balloon-tipped catheter. *N Engl J Med* 283:447-451, 1970.
2. FORRESTER J, GANZ W, DIAMOND G, ET AL: Thermodilution cardiac output determination with a single flow-directed catheter. *Am Heart J* 83:306-311, 1972.
3. FOOTE GA, SCHABEL SI, HODGES M: Pulmonary complications of the flow-directed balloon-tipped catheter. *N Engl J Med* 290:927-931, 1974.