CARDIOLOGY Rounds®

As presented in the rounds of the Division of Cardiology, St. Michael's Hospital, University of Toronto

Bedside right heart catheterization and invasive monitoring

By AFSANEH POURDOWAT, MD, and GORDON MOE, MD

In 1929, Werner Forssmann first demonstrated that a catheter could be advanced safely into the human heart from a peripheral vessel; he did this by advancing a urethral catheter into his own heart. During the late 60s and early 70s, H.J.C. Swan and William Ganz developed a balloon-tipped floatation catheter that could be inserted into the pulmonary artery (PA). The function of the catheter was to provide continuous intracardiac pressure measurements at the bedside. Since these initial designs, there have been many modifications to the PA catheter. We are now able to take frequent measurements of cardiac output with the thermodilution method and, with blood samples drawn from the catheter, venous oxygen saturation measurements are also possible. Although the PA catheter – also called the Swan-Ganz catheter – was initially used in the management of acute myocardial infarction (AMI), it is now widely used to manage patients with a variety of critical illnesses and to guide therapeutic decisions in the intensive care setting. In many instances, however, the indications for its use vary significantly among institutions and its utilization, safety, and efficacy continue to be shadowed by controversy. This issue of *Cardiology Rounds* reviews the intracardiac measurements possible with the PA catheter and presents the benefits and complications associated with its use.

Measurements possible with the PA catheter (Figure 1)

It is possible to directly measure intracardiac pressures through the PA catheter; these include right atrial (RA), right ventricular (RV), and PA pressures. In addition, by inflating the balloon, measurement of pulmonary artery occlusion pressure (PAOP) is possible, which can be used to estimate pulmonary capillary wedge pressure (PCWP). These measurements, in turn, can be used to estimate left atrial (LA) and left ventricular (LV) end-diastolic pressure (LVEDP). The PA catheter can also be used for measuring cardiac output by the thermodilution method, mixed venous oxygen saturation, and via oximetry to detect an intracardiac shunt. These actual and derived measurements are based on the following assumptions:

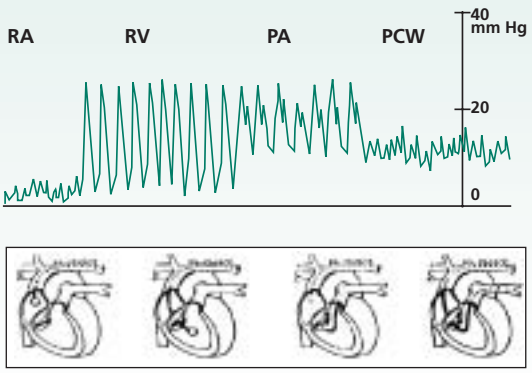
- Central venous pressure (CVP) is equal to RA pressure, which in turn is equal to RV diastolic pressure in the absence of heart or lung disease.
- PA pressure tracing contains the first positive upstroke produced by RV systole, followed by a dicrotic notch on the downstroke when the pulmonary valve closes. Systolic PA pressure ranges from 20 mm Hg to 30 mm Hg and, in the absence of pulmonic stenosis, is equivalent to RV systolic pressure
- When the PA catheter is correctly placed in the "wedged" position with the balloon inflated, the PA pressure tracing changes to PAOP or PCWP. PCWP is used to estimate LA pressure

Editor's note: This May issue, as well as the upcoming June/July issue of *Cardiology Rounds,* are late in reaching you. This delay was caused by the SARS emergency measures imposed in most of the hospitals in Toronto during March and April. During that time, almost all academic rounds were cancelled. We apologize for the delay in the series.

Gordon Moe, MD
Editor, *Cardiology Rounds*

St. Michael's Hospital
30 Bond St.,
Suite 7049, Queen Wing
Toronto, Ont. M5B 1W8
Fax: (416) 864-5941

Figure 1: Intracardiac pressure wave forms during passage through the heart



providing the tip of the catheter is placed in the proper lung zone and there is no vascular obstruction (eg, a pulmonary vein stenosis) downstream. For left-sided filling pressures to be correctly reflected by PCWP, there should theoretically be a noninterrupted column of blood from the tip of the catheter to the left-sided heart chambers.

Gravity dependence of pulmonary flow: ventilation-perfusion relationships

The lung can be divided into 3 vertical zones with respect to the gravity-dependent distribution of blood flow (Figure 2).

In *zone 1* (apical portion of the lungs), the alveolar pressure (Palv) is greater than both the mean pulmonary artery pressure (Ppa) and the pulmonary venous pressure (Ppv). In this case, the flow of blood depends on Palv, so the measurements reflect Palv.

In *zone 2* (central portion), Ppa is greater than Palv, and Palv is greater than Ppv; therefore, the flow depends on the net balance between Ppa and Palv.

A catheter tip that is placed in zones 1 and 2 does not have a direct connection via an uninterrupted blood column with the LV.

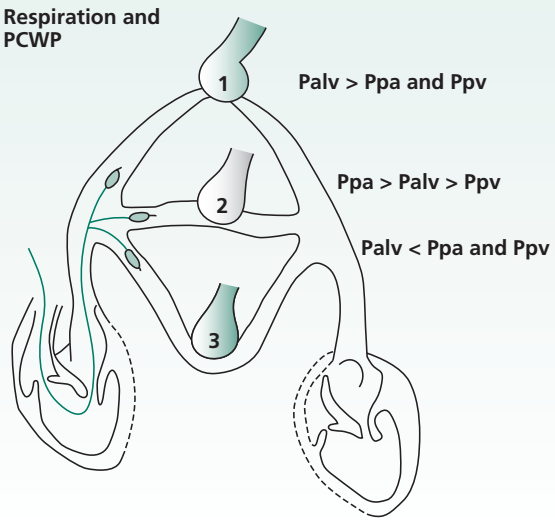
In *zone 3* (lung bases), Palv is less than Ppa and Ppv, so the flow is not interrupted and PCWP should correctly reflect LA pressure and LV end-diastolic pressure, provided there is no mitral valve disease.

When a patient is in a supine position, most of the lung consists of zone 3. However, in critically ill patients, many conditions including mechanical ventilation and positive end expiratory pressure may invalidate the above assumptions.

Controversies concerning the use of the PA catheter

Placement of a PA catheter is an invasive procedure that may be associated with a variety of complications, some of which can be fatal. The mortality rate due to complications arising from placement of a PA catheter is estimated to be 0.02% to 1.5%. It is estimated that more than

Figure 2: Relationship between ventilation, lung zones, and PCWP measurements



PCWP = pulmonary capillary wedge pressure
Palv = alveolar pressure, Ppa = pulmonary artery pressure
Ppv = pulmonary venous pressure

1.2 million PA catheters are sold each year in the United States and that the annual personnel and non-personnel costs related to PA catheter use exceeds 2 billion dollars.[1]

Despite more than 30 years of experience with the PA catheter and the hemodynamic data they provide to make therapeutic decisions, one critical question remains: Do therapeutic decisions based on hemodynamic data obtained from PA catheters improve outcomes?

In 1987, Gore et al[2] first reported outcomes of patients subjected to bedside PA cannulation and hemodynamic monitoring. In an observational study of 3263 patients with AMI, hospitalized from 1975 to 1984, 13.9% underwent hemodynamic monitoring using a PA catheter. Almost all had severe heart failure, hypotension, or cardiogenic shock. The unadjusted case-fatality rate for patients with heart failure or hypotension who had invasive hemodynamic monitoring was reported to be higher than the rate for patients without monitoring. The case-fatality rate for patients with cardiogenic shock was 74% for those who had hemodynamic monitoring, compared to 79% for those who did not. The use of a PA catheter was associated with a longer hospital stay, but there was no difference in survival between the 2 groups during the 5-year follow up.

In 1990, Zion et al[3] also reported a similar lack of benefit in an observational cohort of 5841 patients with AMI. As in the report by Gore et al,[2] mortality was higher in patients who received therapy based on PA catheter-derived hemodynamic data. As these observational studies are subject to therapeutic decision biases, there have been several calls for randomized clinical trials to assess the efficacy and safety of invasive hemodynamic monitoring. Accordingly, the Ontario Intensive Care Study Group

Table 1: Relationship of right heart catheterization (RHC) to survival for matched pairs of patients managed with and without RHC.[5]

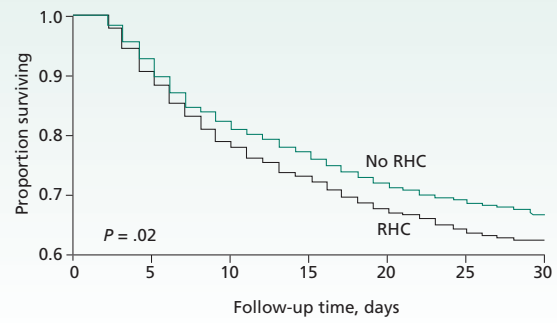
Survival interval	Survival, No. (%)		OR (95% CI)	P
	No RHC (n=1008)	RHC (n=1008)		
30 d	677 (67.2)	630 (62.5)	1.24 (1.03-1.49)	.03
60 d	604 (59.9)	550 (54.6)	1.26 (1.05-1.52)	.01
180 d	522 (51.2)	464 (46.0)	1.27 (1.06-1.52)	.009
Hospital	629 (63.4)	565 (56.1)	1.39 (1.15-1.67)	.001

attempted to perform a randomized trial of the use of PA catheters in critically ill patients with hypoxemia, hypotension, or oliguria.[4] Of the first 148 potentially eligible patients, 52 were excluded from the trial because the attending physicians believed it would be unethical not to insert a PA catheter. The results, which appeared to favour no right heart catheterization, were difficult to interpret.

In 1996, Connors et al[5] published a study that attempted to minimize the therapeutic selection bias by prospectively comparing patients who received invasive hemodynamic monitoring and matched patients. The authors matched the patients who were selected according to the propensity score for condition severity using multivariable logistic regression. This study was conducted on 5735 critically ill adult patients receiving care in intensive care units affiliated with 5 teaching hospitals in the US from 1989 to 1994. The patients had one of the following conditions:

- acute respiratory failure
- chronic obstructive pulmonary disease
- heart failure
- cirrhosis
- nontraumatic coma
- colonic cancer with metastasis to the liver
- nonsmall cell carcinoma of the lung
- multi-organ system failure (MOSF) with malignancy
- sepsis.

Figure 3: Survival of 2016 patients with and without RHC matched for disease category and propensity score



The key outcome measures were survival time, cost of care, intensity of care, and length of stay in the ICU.

The follow-up time was 6 months and to minimize treatment selection bias, patients were stratified into quintiles using the propensity score. Within each quintile, patients managed with PA catheters and invasive hemodynamic monitoring were compared to matched patients managed without hemodynamic monitoring for each variable. The results are summarized in Table 1 and Figure 3. Survival was significantly greater in the population managed without right heart catheterization (RHC) using PA catheters. The patients who were managed with RHC using PA catheters had a higher rate of mortality. Furthermore, the cost of care was higher in these patients. The results sparked a call for a moratorium on the use of RHC. Subsequently, multiple expert consensus documents were published to regulate the indications for bedside RHC.

The ACC Expert Consensus Document

In 1998, following a number of requests, an Expert Consensus Document was published by the American College of Cardiology (ACC) to clarify its position on RHC and invasive hemodynamic monitoring.[6] In this document, the ACC acknowledged that RHC was a diagnostic tool that was not harmful by itself. The ACC suggested that if there was any harm associated with the tool, it should be attributed to the misuse of the catheter or to improper data acquisition and interpretation. Insertion of the PA catheter, in addition to complications associated with central line insertion (arterial puncture, nerve injury, pneumothorax, air embolism etc.), is associated with various complications (Table 2). To prevent these complications, the ACC made the following recommendations: strict sterile technique should be implemented; catheters should not be advanced after 24 hours of insertion; and catheters should be removed in 3 days (replacement over guidewires or through repeat venipuncture does not reduce the risk of infection). If concordance between PAOP and PA diastolic pressure is established, frequent PAOP measurements should be avoided. Fluoroscopy guidance is recommended in the presence of temporary pacemakers, new permanent pacemakers, automatic implantable defibrillators,

Table 2: Complications associated with insertion of a PA catheter

- **Arrhythmias**
  - Premature atrial and ventricular contractions
  - Sustained ventricular arrhythmia in patients with coronary artery disease or previously known ventricular arrhythmias
  - RBBB (with pre-existing LBBB causing complete heart block)
- **Knotting of the catheter**
- **Pulmonary artery rupture**
- **Thrombophlebitis**
- **Venous or intracardiac thrombus**
- **Pulmonary infarction**
- **Endocarditis and other line infections** (much more frequent than with central lines)

RBBB = right bundle branch block; LBBB = left bundle branch block

RA or RV dilatation, and severe tricuspid regurgitation. Fluoroscopy is also recommended in the presence of LBBB (higher risk of complete heart block) to minimize manipulation and to facilitate the rapid insertion of a transvenous pacemaker wire if needed.

To minimize data acquisition errors, the ACC recommends that the zero pressure point be defined at the mid-axillary line and meticulous flushing of the catheter, the transducer, and the tubing system be done. In addition, the ACC recognizes that current ICU practice is to record the pressures at end-exhalation; this practice differs from that in the cardiac catheterization laboratory where mean pressures are measured throughout the respiratory cycle, creating discrepancies between measurements. The ACC also recognizes that the PAOP is an imperfect estimation of PCWP. Although PCWP exceeds PAOP only by a few mm Hg in normal lung, it may exceed PAOP by 10 to 15 mm Hg in sepsis and other inflammatory disorders, thus pulmonary edema can occur despite seemingly "acceptable" PAOP. The PAOP reflects LA pressure and LVEDP only in the absence of mitral stenosis, significant mitral regurgitation, and ventricular compliance abnormality. Thermodilution cardiac output estimation could be inaccurate in the presence of arrhythmias, tricuspid regurgitation, or intracardiac shunting. The ACC has provided guidelines on indications for use of RHC in various cardiac conditions (Table 3).

A randomized trial into RHC-guided treatment

In response to calls from different expert committees, a randomized clinical trial was performed and published earlier this year.[7] In this trial, 1994 high-risk surgical patients >60 years-of age, with American Society of Anesthesiologists (ASA) class III or IV risk

Table 3: ACC guidelines for RHC use in cardiac conditions

Heart Failure

- Differential diagnosis between hemodynamic and permeability pulmonary edema
- Dyspnea and contribution of left heart failure to respiratory failure
- Differential diagnosis between cardiogenic shock and noncardiogenic shock
- Guiding therapy in patients with concomitant manifestations of forward and backward heart failure
- Differential diagnosis of tamponade when physical examination is inconclusive and 2D-echo is unavailable
- Guidance of perioperative management in patients with decompensated heart failure, undergoing high- or intermediate-risk noncardiac surgery
- Diagnosis of pulmonary vasoconstriction and reversibility prior to heart transplantation

In all the above conditions, the ACC recommends first that noninvasive diagnostic methods (eg, physical examination or 2-dimensional echocardiography) or trial of fluid challenge and diuretics be tried.

Acute myocardial infarction

- Differential diagnosis between cardiogenic and hypovolemic shock when initial fluid challenge and low-dose inotropic medications have failed
- Guidance of management of cardiogenic shock
- Short-term guidance for management of AMI mechanical complications
- Guidance of management in RV infarction with hypotension and signs of low cardiac output not responding to volume expansion and low dose inotropic medications
- Acute pulmonary edema not responsive to treatment

Perioperative cardiac surgery patients

- Differential diagnosis of low cardiac output
- Differential diagnosis between RV and LV dysfunction and tamponade
- Guidance for management of severe low cardiac output syndromes
- Diagnosis and guidance for management of pulmonary hypertension

In all the above conditions, noninvasive diagnostic methods, including 2D-echocardiography and physical examination, are first recommended.

Primary pulmonary hypertension

- Exclusion of post-capillary causes of pulmonary hypertension (elevated PAOP)
- Establishment of diagnosis of pre-capillary pulmonary hypertension (normal PAOP)
- Selection of patients for long-term treatment with vasodilator therapy based on acute response
- Assessment of hemodynamic variables before lung transplant

Table 4: Randomized trial of the use of RHC in patients undergoing major surgeries[7]			
Variable	Standard-care group	Catheter group	P value
Length of hospital stay – days			
Median	10	10	0.41
Interquartile range	7-15	7-15	
In-hospital mortality – no. (%)	77 (7.7)	78 (7.8)	0.93
Myocardial infarction – no. (%)	33 (3.4)	40 (4.3)	0.41
Congestive heart failure – no. (%)	108 (11.2)	119 (12.6)	0.36
Supraventricular tachycardia – no. (%)	88 (9.1)	84 (8.9)	0.95
Ventricular tachycardia – no. (%)	2 (0.2)	2 (0.2)	1.00
Pulmonary embolism – no. (%)	0	8 (0.9)	0.004
Renal insufficiency – no. (%)	95 (9.8)	70 (7.4)	0.07
Hepatic insufficiency – no. (%)	26 92.7)	23 (2.4)	0.84
Sepsis from central venous catheter or pulmonary-artery catheter – no. (%)	13 (1.3)	12 (1.3)	0.95
Wound infection – no. (%)	83 (8.6)	66 (7.0)	0.23
Pneumonia – no. (%)	70 (7.3)	63 (6.7)	0.70
Adverse events due to pulmonary-artery catheters or central venous catheters – no. (%)			
Pulmonary infarction	0	1 (0.1)	1.00
Hemothorax	0	2 (0.2)	0.24
Pulmonary hemorrhage	0	3 (0.3)	0.12
Pneumothorax	4 (0.4)	8 (0.9)	0.36
Arterial puncture	1 (0.1)	3 (0.3)	0.37

scores undergoing urgent or major elective surgeries, were randomized to RHC-guided treatment versus treatment according to clinical assessment. Treatment was directed toward the following physiological goals:

- Oxygen-delivery index of 550 to 600 ml/min/m^2 of body surface area
- Cardiac index of 3.5 to 4.5
- Mean arterial pressure of 70 mm Hg
- PCWP of 18 mm Hg
- Heart rate <120 beats/min
- Hematocrit >27

The primary outcome was in-hospital mortality from any cause and secondary outcomes were 6- and 12-month mortality and in-hospital morbidity (AMI, LV failure, arrhythmia, pneumonia, pulmonary emboli, renal insufficiency, liver insufficiency, and sepsis). The results are summarized in Table 4. There was no significant difference in mortality and morbidity between the 2 groups except for pulmonary embolism, which was significantly higher in the catheter group. The investigators therefore concluded that there was no benefit to therapy directed by PA catheter over standard care in elderly, high-risk, surgical patients requiring intensive care.

The ESCAPE trial

A randomized trial is currently underway to evaluate PA catheter-guided treatment in patients with heart failure.[8] The Evaluation Study of Congestive Heart Failure and Pulmonary Artery Catheterization Effectiveness (ESCAPE) trial is a multicentre, randomized trial designed to test the long-term safety and efficacy of treatment guided by hemodynamic monitoring and clinical assessment versus that guided by clinical assessment alone, in patients hospitalized with New York Heart Association class IV CHF. Five hundred patients will be randomly assigned to receive either medical therapy with hemodynamic monitoring or medical therapy with only clinical assessment. The primary endpoint is the number of days that patients are hospitalized or die during the 6-month period after randomization. Secondary endpoints include changes in mitral regurgitation, peak oxygen consumption, and natriuretic peptide levels. Other secondary endpoints will be pulmonary artery catheter- associated complications, resource utilization, quality of life measures, and patient preferences regarding survival. To date, recruitment of patients has remained relatively slow.

Conclusion

Despite years of experience with PA catheters and RHC in the management of patients with a variety of disorders, there continues to be a lack of evidence supporting their benefit. RHC and invasive monitoring may potentially be associated with serious complications and significant cost. Although it is very appealing to have numeric values and to treat according to these values, patients may not necessarily accrue additional benefit beyond that obtained from good clinical judgment. To prevent causing harm to patients, expert recommendations regarding indications and practice patterns should be considered. Furthermore, all alternative noninvasive diagnostic tests and trials of different therapeutic options should be considered first. For patients to benefit from RHC, it is crucial to improve our knowledge of the proper indications for use of PA catheters, data interpretation, potential shortfalls, and to realize that RHC does not replace good clinical assessment.

References

1. Dalen JE. The pulmonary artery catheter-friend, foe, or accomplice? *JAMA* 2001;286:348-50.
2. Gore JM, Goldberg RJ, Spodick DH, Alpert JS, Dalen JE. A community-wide assessment of the use of pulmonary artery catheters in patients with acute myocardial infarction. *Chest* 1987;92: 721-27.
3. Zion MM, Balkin J, Rosenmann D, *et al.* Use of pulmonary artery catheters in patients with acute myocardial infarction. Analysis of experience in 5,841 patients in the SPRINT Registry. SPRINT Study Group. *Chest* 1990;98:1331-35.
4. Guyatt G. A randomized control trial of right-heart catheterization in critically ill patients. Ontario Intensive Care Study Group. *J Intensive Care Med* 1991;6:91-95.
5. Connors AF Jr, Speroff T, Dawson NV, *et al.* The effectiveness of right heart catheterization in the initial care of critically ill patients. SUPPORT Investigators. *JAMA* 1996;276:889-97.
6. Mueller HS, Chatterjee K, Davis KB, *et al.* ACC expert consensus document. Present use of bedside right heart catheterization in patients with cardiac disease. American College of Cardiology. *J Am Coll Cardiol* 1998;32:840-64.
7. Sandham JD, Hull RD, Brant RF, *et al.* A randomized, controlled trial of the use of pulmonary-artery catheters in high-risk surgical patients. *N Engl J Med* 2003;348:5-14.
8. Shah MR, O'Connor CM, Sopko G, Hasselblad V, Califf RM, Stevenson LW. Evaluation Study of Congestive Heart Failure and Pulmonary Artery Catheterization Effectiveness (ESCAPE): design and rationale. *Am Heart J* 2001;141:528-35.

Upcoming meetings

30 August - 2 September 2003
25th Annual Congress of the European Society of Cardiology
Vienna, Austria
CONTACT: Registration Office
Tel: 33-0-492-947-612
Fax: 33-0-492-947-610
Email: registration@escardio.org

21-24 September 2003
7th Annual Scientific Meeting of the Heart Failure Society of America
Las Vegas, Nevada
CONTACT: Gail Brophy, Project Manager – HFSA
Tel: 973-248-3332 or 651-642-1633
Fax: 973-248-3334 or 651-642-1502
Web Site: www.hfsa.org

24- 27 October 2003
19th InterAmerican Congress of Cardiology (Jointly with the CCS)
Toronto, ON
CONTACT: Canadian Cardiovascular Society Secretariat
Tel: 1-613-238-2870
Fax: 973-248-3334 or 651-642-1502
E-Mail: iacc2003@intertaskconferences.com

25-29 October 2003
Canadian Cardiovascular Congress
Toronto, ON
CONTACT: Ms. Stephanie Mutschler, CMP, (Manager of Meetings)
Tel: 613-238-2304; Toll free: 866-317-8461
Fax: 613 326-2727
E-Mail: meetings@ccs.ca or cardiocongress@intertaskconferences.com
Web Site: www.cardiocongress.org

9-12 November 2003
American Heart Association Scientific Sessions 2003
Orlando, Florida
CONTACT: Tel: 214-706-1543 Fax: 214-706-5262
E-Mail: sessions@heart.org
Web Site: www.scientificsessions.org

Change of address notices and requests for subscriptions to *Cardiology Rounds* are to be sent by mail to P.O. Box 310, Station H, Montreal, Quebec H3G 2K8 or by fax to (514) 932-5114 or by e-mail to info@snellmedical.com. Please reference *Cardiology Rounds* in your correspondence. Undeliverable copies are to be sent to the address above.

This publication is made possible by an educational grant from

Novartis Pharmaceuticals Canada Inc.