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The Swan-Ganz Catheters: Past, Present, and Future A Viewpoint

Kanu Chatterjee, MB, FRCP(Lond), FRCP(Edin)

Abstract—The Swan-Ganz balloon flotation catheter was introduced in 1970. It can be placed at the bedside within a few minutes even in critically ill patients. Although placement of these catheters is not difficult, some training and experience are required to avoid complications and for proper interpretation of the hemodynamic data that can be obtained by pulmonary artery catheterization. Because of the many advantages of balloon flotation catheters compared with conventional catheters, they have been used without a proper indication and frequently overused in critical care units, resulting in many complications, including mortality. The prospective randomized trials have reported that in the majority of clinical circumstances, the routine use of balloon flotation catheters is not indicated. These results are not surprising because balloon flotation catheters are diagnostic and not therapeutic tools. That we have learned a great deal about hemodynamics in critically ill patients with the use of balloon flotation catheters should not be ignored or forgotten. Furthermore, our clinical knowledge of hemodynamics has been made possible because of extensive experience gained from directly determined hemodynamics with the use of balloon flotation catheters. It should also be realized that despite the introduction and refinement of newer noninvasive imaging modalities, a number of clinical circumstances exist in which determination of hemodynamics with the use of a balloon flotation catheter is necessary and should be considered, but only by experienced physicians. With the proper use of Swan-Ganz catheters, our knowledge of hemodynamics has been enhanced considerably. Its abuse, particularly by relatively inexperienced operators, has resulted in serious complications, including death. Prospective randomized clinical trials have demonstrated that the routine use of Swan-Ganz catheters does not provide any benefit. However, use of the Swan-Ganz catheter is still indicated in many situations. (*Circulation*. 2009;119:147-152.)

Key Words: catheters ■ devices ■ hemodynamics ■ history ■ Swan-Ganz catheterization

The idea that pulmonary artery catheterization is feasible and may be useful in the understanding of cardiac physiology and pathology was conceived >80 years ago. Its clinical application outside the catheterization laboratory, particularly in the management of unstable and critically ill patients, however, was delayed until balloon flotation catheters were introduced in clinical practice. As expected after introduction of any new and exciting technique, device, or surgical and pharmacological therapeutic modality, catheterization with the use of balloon flotation catheters did not escape the phenomenon of overuse and abuse, which resulted in undesirable and unnecessary complications. However, the knowledge gained in cardiac hemodynamic pathophysiology through the use of balloon flotation catheters should not be ignored. Furthermore, bedside hemodynamic studies have provided understanding of the hemodynamic correlates of abnormal clinical and echocardiographic findings in critically ill patients. A fairly extensive personal experience with the use of balloon flotation catheters, almost from the time of their introduction, and many observations about their use and abuse form the basis of this viewpoint.

Evolution of Pulmonary Artery Catheters

In 1929, Dr Warner Forssmann introduced a catheter into his own heart and established that right heart catheterization is feasible in humans. However, the catheter was advanced only into the right atrium.¹ Drs Andre Cournand and Dickinson Richards developed catheters that could be advanced into the pulmonary arteries and can be used to study the pathophysiology of congenital and acquired heart diseases.^{1,2} In 1956, Drs Forssmann, Cournand, and Richards received the Nobel Prize in medicine for their discoveries.¹⁻³ In 1964, Dr Bradley introduced the miniature diagnostic catheters that can be used in severely ill patients.⁴ In 1965, Dr Fife constructed self-guiding pulmonary artery catheters.⁵ In 1969, Drs Scheinman, Abbot, and Rapaport used a flow-directed right heart catheter for measurement of right heart pressures.⁶ However, balloon flotation flow-directed catheters that can be used at the bedside, without fluoroscopy, were introduced by Drs Swan and Ganz in 1970 (Figure).⁷ The balloon flotation catheters, popularly known as “Swan-Ganz” catheters, were further developed for measuring cardiac output (by the thermodilution technique), for right atrial and right ventricular pacing,

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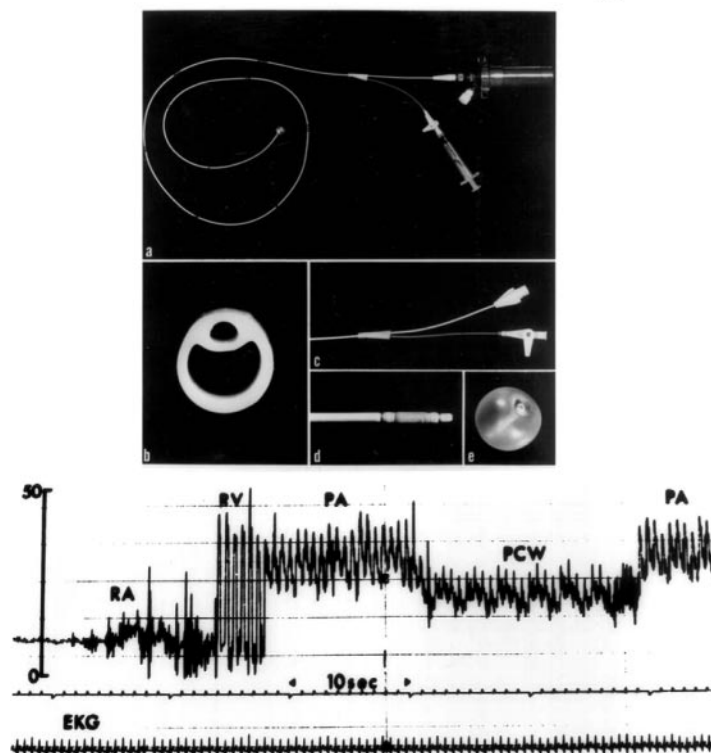
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The Pulmonary Artery Catheter



William Ganz and H.J.C. Swan

Figure. The double lumen balloon flotation catheter and its placement at the bedside without fluoroscopy and by monitoring intracardiac pressures. Photograph of Drs Swan and Ganz is also shown. RA indicates right atrium; RV, right ventricle; PCW, pulmonary capillary wedge; and PA, pulmonary artery. Figure courtesy of Dr Peter Ganz, Chief of Cardiology at San Francisco General Hospital, University of California, San Francisco.

and for measuring right-sided pressures, including pulmonary capillary wedge pressure.^{8,9} Furthermore, infusion pores have been incorporated to facilitate administration of drugs with the use of the same catheter.

Clinical Use and Abuse of Balloon Flotation Catheters

The balloon flotation catheter has achieved widespread use in critical care units because of its several advantages over conventional catheters. It can be used without fluoroscopy at the bedside even in critically ill patients. The placement of the catheter does not require much experience, and the catheter can be inserted quickly. With the use of some catheters, it is possible to measure right atrial, pulmonary artery, and pulmonary capillary wedge pressures and to determine cardiac output and oxygen saturations in the right heart chambers. Because of these advantages, its use increased rapidly in the management of acute myocardial infarction and high-risk cardiac and noncardiac surgical patients. The Swan-Ganz catheter was used so frequently by residents and fellows in coronary care, medical, surgical, and other critical care units and during cardiac and noncardiac surgery that "Swan" soon became a verb. (A common expression in the critical care units during clinical rounds was, "We swanned the patient.")

Acute Myocardial Infarction

After investigating hemodynamic changes in a large number of patients with acute myocardial infarction admitted to the Myocardial Infarction Research Unit of the Cedars Sinai Medical Center of Los Angeles, the concept of hemodynamic subsets ("Forrester classification") and therapies based on these subsets were introduced.^{10,11} These conceptual frameworks of management of patients with acute myocardial infarction based on hemodynamic changes were immediately accepted by the physicians caring for patients with acute myocardial infarction. Furthermore, it soon became obvious that the accurate diagnosis of the major complications of myocardial infarction such as cardiogenic shock, acute mitral regurgitation due to papillary muscle infarction, and ventricular septal rupture is possible at the bedside with the use of balloon flotation catheters and that hemodynamic monitoring may facilitate the management of these complications.

The bedside hemodynamic studies in the Myocardial Infarction Research Unit reported a number of new and clinically relevant observations. The optimal level of left heart filling pressures by determining pulmonary capillary wedge pressure (14 to 18 mm Hg) in acute myocardial infarction was defined.¹² The response to various therapeutic interventions was also reported. It was reported that furosemide, a commonly used loop diuretic for treatment of pulmonary conges-

tion, may decrease pulmonary capillary wedge and right atrial pressures even before the onset of diuresis.¹³ It was also observed that “digitalis,” another commonly used pharmacological agent for treatment of heart failure, can produce deleterious effects in patients with acute myocardial infarction.¹⁴ The observation that the vasodilator sodium nitropruside produces marked beneficial hemodynamic effects in severe mitral regurgitation also resulted from studies with the use of balloon flotation catheters.¹⁵

Hemodynamic indices were developed to assess the prognosis of patients with acute myocardial infarction. A markedly decreased cardiac output, left ventricular stroke work, and elevated pulmonary capillary wedge pressure indicating impaired left ventricular systolic function were shown to be adverse hemodynamic predictors.^{10,16} However, it had already been reported that clinical and radiological findings are as effective as hemodynamics to assess the prognosis of acute myocardial infarction.¹⁷

It should be appreciated that bedside hemodynamic studies were performed before reliable echocardiography and Doppler echocardiography were available. Furthermore, transthoracic and transesophageal echocardiography, including Doppler echocardiography, can be performed presently at the bedside in critically ill patients. Therefore, the diagnosis of complications of acute myocardial infarction, including the pathogenesis of cardiogenic shock, can be made by echocardiography, and bedside catheterization is not necessary. However, although the complications of acute coronary syndromes can be diagnosed by echocardiography, determination of hemodynamics by balloon flotation catheters is still necessary to assess the severity of the hemodynamic abnormalities and to formulate appropriate therapy, particularly in patients with cardiogenic shock.

The treatments of acute myocardial infarction have dramatically changed in recent years, and presently the essential therapy is reperfusion of ischemic myocardium. Thus, treatments based on hemodynamic subsets are not usually necessary, and the routine use of balloon flotation catheters may be associated with the increased risk of morbidity and mortality reported in several recent studies. In 1987, Gore et al¹⁸ reported that the use of pulmonary artery catheters was associated with a significantly higher in-hospital mortality in patients with congestive heart failure, hypotension, or both in combination complicating acute myocardial infarction. However, this study used “propensity analysis” and was not a prospective randomized trial. Even in the era of reperfusion therapy, it appears that the use of pulmonary artery catheterization is associated with an increased risk of mortality. The post hoc analysis of the data from the Global Utilization of Streptokinase and Tissue Plasminogen Activator for Occluded Coronary Arteries (GUSTO) IIb and GUSTO III trials reported that the hazard ratio for the risk of 30-day mortality with pulmonary artery catheterization in patients without cardiogenic shock was increased almost 5-fold.¹⁹ Although proper randomized trials are lacking in acute coronary syndromes, routine pulmonary artery catheterization is not indicated in patients with acute myocardial infarction. It should be emphasized, however, that in patients with cardiogenic shock due to left ventricular or right ventricular myocardial

infarction after reperfusion therapy, the use of balloon flotation catheters to determine the hemodynamic response to supportive therapy is still necessary and strongly recommended.

Non-Acute Coronary Syndrome High-Risk Patients

Bedside balloon flotation catheterization has been used in medical and surgical intensive care units for determining the causes of hypotension and shock and for distinguishing between hemodynamic and permeability pulmonary edema. It has been used for optimization of oxygen delivery by increasing cardiac output by pharmacological interventions and by maintaining optimal volume status. It has also been used for regulation of diuretic, vasoactive, and inotropic drug therapy.

Because of the ease of catheter placement at the bedside and of the potential benefits, pulmonary artery catheterization with the use of balloon flotation catheters became almost a routine monitoring technique during cardiac and noncardiac surgery and for the treatment of adult respiratory distress syndrome (ARDS), sepsis, and even severe chronic heart failure.

However, the routine use of balloon flotation catheters, sometimes even without appropriate indications, resulted in inevitable adverse complications, including death. It is not surprising that various derogatory remarks appeared in the literature such as the following article titles: “Death by Pulmonary Artery Flow-Directed Catheter: Time for a Moratorium?”²⁰; “Is It Time to Pull the Pulmonary Artery Catheter?”²¹; “The Pulmonary Artery Catheter: Friend, Foe or Accomplice?”²²; and “Recently Published Papers: Dying Swans and Other Stories.”²³

Although it was initially thought that randomized clinical trials are not appropriate and may not be feasible, some investigators recommended that “prospective studies to define the clinical value of pulmonary artery catheterization are needed, but must be designed very carefully in order to identify unequivocally the effect of pulmonary artery catheterization on outcome in critically ill patients.”²⁴

After several years, however, randomized clinical trials were performed in non-acute coronary syndromes, which uniformly documented that routine bedside pulmonary artery catheterization is not only not beneficial but may be associated with increased morbidity and mortality.

A randomized clinical trial in the high-risk patients in intensive care reported no clear evidence of benefit or harm by managing critically ill patients with pulmonary artery catheterization.²⁵ Another randomized trial with high-risk surgical patients showed no mortality benefit but an increase in complications such as incidence of pulmonary embolism.²⁶ Many other studies have reported similar results.^{27,28}

One of the common indications for bedside hemodynamic monitoring with the use of balloon flotation catheters in the high-risk noncardiac surgical patients has been to optimize oxygen delivery and consumption with adequate volume and inotropic support.²⁹ However, aggressive inotropic therapy may be associated with inappropriate increase in myocardial oxygen consumption, increased arrhythmias, and adverse outcome that is not due to use of Swan-Ganz catheters but due

to inappropriate therapy. Prospective clinical trials, however, failed to demonstrate any better outcome with maximizing oxygen consumption by hemodynamic monitoring.³⁰ Another frequent indication for pulmonary artery catheterization in the intensive care units has been for the management of patients with ARDS. It has been postulated that monitoring both right and left ventricular filling pressures (right atrial and pulmonary capillary wedge pressures) and cardiac output will facilitate the maintenance of volume status and regulation of vasopressor and inotropic therapy. It has also been suggested that such hemodynamic monitoring with the use of balloon flotation catheters is superior to the use of central venous catheters to monitor central venous pressure alone and is likely to produce better outcome. Indeed, many nonrandomized clinical studies have recommended, for routine bedside hemodynamic monitoring, the use of balloon flotation catheters for management of ARDS.³¹

However, a large National Heart, Lung, and Blood Institute-sponsored randomized clinical trial has reported that pulmonary artery catheterization is not associated with a better outcome compared with central venous catheterization in patients with ARDS. In both pulmonary artery catheterization-guided and central venous catheterization-guided groups, the numbers of patients with shock and on vasopressors were similar.³² The mortality and the number of days in the intensive care units in the 2 groups were not different. However, the complications with pulmonary artery catheterization were higher. It was concluded that "PAC [pulmonary artery catheterization]-guided therapy did not improve survival or organ perfusion and complications were higher than CVC [central venous catheterization]-guided therapy." It appears, therefore, that routine pulmonary artery catheterization should not be practiced for management of patients with ARDS.

In another large National Heart, Lung, and Blood Institute-sponsored randomized clinical trial, aggressive fluid resuscitation in patients with acute lung injury with hemodynamic monitoring and the use of balloon flotation catheters were associated with deleterious outcome.³³ In this study, aggressive fluid resuscitation appears to be the cause of adverse outcome, not the use of Swan-Ganz catheters.

One of the major criticisms of these studies is that it was forgotten that Swan-Ganz catheters are diagnostic and not therapeutic tools. Another problem is that prolonged catheterization was frequently performed in patients with no known reversible therapy. Furthermore, the misinterpretation of the hemodynamic data obtained frequently led to inappropriate therapy.

Severe Chronic Heart Failure

As in patients after acute myocardial infarction, hemodynamic prognostic indices were developed in patients with chronic heart failure. It was reported that pulmonary capillary wedge pressure >25 mm Hg, cardiac index <2.2 L $\cdot$ min⁻¹ $\cdot$ m², left ventricular stroke work index <45 gm/m², and systemic vascular resistance >1800 dyne $\cdot$ s $\cdot$ cm⁻⁵ are associated with poor prognosis.^{34,35} However, these indices were developed before the modern therapies of heart failure were available. Furthermore, careful clinical assessment, along with measurement of B-type natriuretic peptide and echocardiographic

assessment of the severity of systolic and diastolic dysfunction, provides adequate evaluation of the prognosis of patients with chronic heart failure, and determination of invasive hemodynamic indices is not necessary.

In patients with severe chronic heart failure it is often necessary to use intravenous diuretic, inotropic, and vasoactive drugs. It has been suggested that assessment of response to such therapy is facilitated by bedside hemodynamic monitoring. The proposed hemodynamic-tailored therapy was also reported to decrease hospital readmission rates.³⁶ Clinical subsets based on hemodynamics were introduced as in patients with acute myocardial infarction.³⁷ The hemodynamic goals for heart failure-tailored therapy, based on retrospective studies, were proposed.³⁸ These hemodynamic goals were widely accepted by the heart failure specialists, and in most institutions patients with severe chronic heart failure underwent bedside pulmonary artery catheterization with the use of balloon flotation catheters.

However, to assess the necessity and effectiveness of pulmonary artery catheterization in the management of severe chronic heart failure, a prospective randomized trial was performed.³⁹ The primary end point of this study was to detect the differences in mortality and number of days in the hospital, which were not different between patients who received pulmonary artery catheterization-guided therapy and whose treatment was based on clinical assessment alone. The conclusion was that the addition of pulmonary artery catheterization to careful clinical assessments did not affect overall mortality and hospitalization.⁴⁰

The results of these randomized clinical trials have established that routine bedside pulmonary artery catheterization is not indicated even in high-risk acute coronary syndrome and non-acute coronary syndrome patients. It is seldom necessary for diagnosis or to assess prognosis and response to therapy. For the management of critically ill patients, use of pulmonary artery catheterization does not increase overall mortality or days in the hospital, nor does it confer benefit.⁴⁰ It can be associated with serious adverse complications, including death, particularly if it is not used properly.

The potential life-threatening complications such as pneumothorax, hemothorax, pulmonary artery perforation, and inadvertent insertion of the catheter into the carotid artery, causing bleeding and even stroke, should not occur if proper precautions are taken and the procedure is done after some training.

One of the author's fellows in training did not recognize that the balloon flotation catheter was in the right common carotid artery, and each time the balloon was inflated, the patient had a transient ischemic attack. The problem, however, was recognized promptly and corrected. Another potentially fatal complication is pulmonary artery perforation, which also can be avoided if recommended techniques are followed.⁴¹

It should be appreciated, however, that only because of the invention of balloon flotation catheters and their introduction for bedside hemodynamic monitoring has our knowledge of hemodynamic correlates of clinical, echocardiographic, and other noninvasive investigations been possible. It should also be realized that pulmonary artery catheterization is a diag-

nostic rather than a therapeutic tool. To avoid complications, some experience is necessary. Furthermore, some knowledge is mandatory for the proper interpretation of hemodynamic data. The fact that pulmonary artery catheterization with the use of balloon flotation catheters can be performed easily does not mean that it should be performed without a proper indication.

Are There Any Residual Indications for Pulmonary Artery Catheterization?

Although routine bedside catheterization with balloon flotation catheters in the coronary, medical, or surgical intensive care units is not indicated, many indications exist for its use. In patients with cardiogenic shock after acute myocardial infarction, hemodynamic monitoring with the use of balloon flotation catheters is necessary during supportive therapy after reperfusion treatment. For example, in patients with acute right ventricular myocardial infarction, hemodynamic monitoring is useful to maintain appropriate ventricular filling pressures by volume expansion therapy and adjustment of the dose of vasopressors and inotropic agents. In patients with mechanical complications of acute coronary syndromes, hemodynamic monitoring is indicated both preoperatively and postoperatively.

Pulmonary artery catheterization is necessary for the hemodynamic differential diagnosis of pulmonary arterial hypertension.⁴² For example, presently no noninvasive tests are available for the accurate diagnosis of precapillary, postcapillary and mixed hemodynamic types of pulmonary arterial hypertension.

Determination of hemodynamics is often necessary in patients with heart failure complicated by chronic obstructive pulmonary disease or other comorbid conditions. In patients with severe diastolic or systolic heart failure, with or without cardiogenic shock, unexplained hemodynamic abnormalities can be uncovered, such as low systemic vascular resistance despite hypotension and low cardiac output, as in cardiac amyloidosis. Similarly, in chronic systolic heart failure, "pseudosepsis syndrome" due to excessive vasodilatation therapy can be diagnosed. It is important to recognize these uncommon causes or complications of heart failure because treatments are different and complicated and cannot be achieved without hemodynamic monitoring with the use of balloon flotation catheters. Treatment of potentially reversible systolic heart failure, such as fulminant myocarditis or peripartum cardiomyopathy, is facilitated with the use of Swan-Ganz catheters. In patients with discordant right and left ventricular failure, monitoring of central venous pressure alone is likely to produce underestimation or overestimation of the severity of right or left ventricular failure. In these patients, determination of both right and left ventricular filling pressures with the use of Swan-Ganz catheters is useful.

During workup for heart, lung, and heart and lung transplantation, bedside hemodynamic monitoring with the use of balloon flotation catheters is routinely employed. In many institutions, pulmonary artery catheterization is performed to exclude portopulmonary hypertension before liver transplantation is undertaken. It should not be forgotten that without

Table. Current Indications for Use of the Swan-Ganz Catheter

Not indicated as routine pulmonary artery catheterization in high-risk cardiac and noncardiac patients
Indicated in patients with cardiogenic shock during supportive therapy
Indicated in patients with discordant right and left ventricular failure
Indicated in patients with severe chronic heart failure requiring inotropic, vasopressor, and vasodilator therapy
Indicated in patients with suspected "pseudosepsis" (high cardiac output, low systemic vascular resistance, elevated right atrial and pulmonary capillary wedge pressures)
Indicated in some patients with potentially reversible systolic heart failure such as fulminant myocarditis and peripartum cardiomyopathy
Indicated for the hemodynamic differential diagnosis of pulmonary hypertension
Indicated to assess response to therapy in patients with precapillary and mixed types of pulmonary hypertension
Indicated for the transplantation workup

balloon flotation catheters in the cardiac catheterization laboratory, proper training in hemodynamics would not have been possible for a large number of trainees. The potential current indications for the use of Swan-Ganz catheters are summarized in the Table.

Conclusion

Pulmonary artery catheterization with the use of balloon flotation catheters is an easy and rapid technique for bedside hemodynamic monitoring. However, its abuse has been associated with complications that can be avoided if it is used by experienced operators. The randomized clinical trials in patients with acute coronary syndrome, noncoronary high-risk patients (including noncardiac surgical patients and patients with sepsis and ARDS), and patients with chronic heart failure have established that its routine use is not necessary and may be associated with increased complications, including death. However, it is still necessary in patients with cardiogenic shock, for the differential diagnosis of pulmonary arterial hypertension, and for diagnosis and treatment of uncommon causes and complications of heart failure.

In patients with severe chronic heart failure requiring inotropic, vasopressor, and vasodilator therapy, hemodynamic monitoring is essential. For heart and lung transplantation workup, hemodynamic monitoring is always necessary. In many institutions, hemodynamic studies are conducted before liver transplantation.

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Disclosures

None.

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