Right Heart Catheterization and Risk Stratification in Advanced Heart Failure

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Right heart catheterization (RHC) has remained the gold standard in diagnosing elevated cardiac filling pressures. Despite advances in medical therapy, patients with persistent volume overload and heart failure (HF) have a poor prognosis. The diagnosis of volume overload can be difficult in advanced HF with clinical symptoms and signs often lacking sensitivity and specificity. Hemodynamic measurements at rest, especially pulmonary capillary wedge pressure and change in pulmonary capillary wedge pressure, have been closely linked to prognosis. However, RHC is invasive with attendant risks of complications. Noninvasive models without using catheterization-derived values have been shown to be equally predictive of survival. In selected clinical situations, especially the cardiorenal syndrome, RHC continues to play an important role. Newer invasive and noninvasive techniques to assess volume status are available, but large prospective trials are lacking. The advantage with continuous hemodynamic monitoring could be the development of an early warning system prior to the onset of symptomatic decompensation.

Introduction

In advanced heart failure (HF), patients are symptomatic with minimal exertion despite optimal medical therapy. Medical therapy in the modern era comprises the use of pharmacologic and electric therapy [1]. Drug therapy includes angiotensin-converting enzyme (ACE) inhibitors or angiotensin receptor blockers (ARBs), β-blockers, aldosterone antagonists (in appropriate patients), and diuretics to achieve euvolemic status. Electric therapy for appropriate New York Heart Association class III and IV patients is in the form of cardiac resynchronization. Volume overload is the hallmark of patients with advanced HF and it explains their symptomatic state in a vast majority of cases. The methods to detect persistent volume overload in chronic HF are outlined in Table 1.

Patients with chronic HF may limit activity with increasing symptoms, therefore making symptoms of dyspnea unreliable. Due to well developed pulmonary lymphatics, patients may not typically have rales on clinical examination. Dependent on the expertise of the physician performing a physical examination, volume overload may be missed in 50% to 60% of patients with volume overload with possible adverse consequences [2]. The sensitivity and specificity of elevated jugular venous pressures (JVP) and edema in the diagnosis of HF has been stated to be 17% and 98% and 20% and 86%, respectively. However, the persistent presence of orthopnea and elevated JVP has been predictive of mortality [3]. Limitations of the history and physical examination have resulted in a search for a more reliable marker of elevated filling pressures and volume overload. B-type natriuretic peptide (BNP) was initially thought to correlate with high filling pressures, but it may not be reliable in patients with advanced HF, as demonstrated in a study of patients followed in a HF clinic [4]. Among patients with chronic HF who were symptomatic, 21% had BNP levels in the 100 pg/mL or "normal" range. Moreover, the change in BNP levels with therapy may not correlate with change in hemodynamic variables as measured with a pulmonary artery catheter (PAC). However, persistently elevated BNP levels are predictive of increased hospitalizations and mortality in HF [5]. Echocardiography, especially Doppler techniques using peak initial velocity across the mitral valve (E wave), deceleration time, color M-mode echocardiography, calculated E/Vp ratio, in which Vp is the propagation velocity of transmitral flow during early ventricular diastole, have been used to estimate pulmonary capillary wedge pressure (PCWP). Tissue Doppler imaging has been used to measure the early diastolic velocity of the mitral valve annulus (Ea), and the ratio E/Ea obtained correlates closely with PCWP [6].

Noninvasive methods of evaluating thoracic impedance and cardiac output are commercially available. Pearson correlations between bioimpedance and thermodilution derived cardiac outputs have been determined to be in the

Table 1. Methods to detect persistent volume overload in chronic heart failure

Signs and symptoms
Orthopnea
Edema
Weight gain
Elevated jugular venous pressures
Square-wave response to bedside Valsalva maneuver
Ascites
Hepatomegaly
Noninvasive methods
B-type natriuretic peptide and N-terminal pro–B-type natriuretic peptide levels
Echocardiography
Impedance cardiography
^{131}I-tagged albumin
Invasive methods
Intrathoracic Impedance
Pulmonary artery catheter
Implantable hemodynamic monitor*

*Investigational device

range of 0.76 to 0.89, and accuracy is influenced by sensor placement [7]. The two limitations of impedance cardiography (ICG) are the inability to measure right atrial (RA) and PCWPs and the unreliable correlation of measured thoracic impedance with PCWP; however trends in a given patient have been reported to be useful. Retrospective analysis from the PREDICT study demonstrated by multivariable analysis that ICG parameters (ie, velocity index, thoracic fluid content index, LV ejection time) were strong predictors of HF hospitalizations [8]. However, this technique has not been compared and proven to be superior with clinical assessment in predicting HF events.

An accurate analysis of blood volume is now commercially available and can be performed in an automated fashion using albumin-iodine 131. Hypervolemia measured by this technique has been shown to correlate with increased PCWP and subsequent risk of death and urgent heart transplantation [2]. Implantable hemodynamic monitors are also being investigated as early warning systems for decompensated HF. The COMPASS-HF trial is a single-blinded, randomized trial evaluating HF management of class III and IV patients using an intracardiac monitoring system versus a control group. Initial results suggest that patients randomized to the continuous hemodynamic monitoring strategy had greater symptomatic improvement and fewer hospitalizations [9].

An implantable cardioverter-defibrillator device equipped with a minute ventilator sensor that has been modified to measure intrathoracic impedance is now available. A deviation from an established reference baseline is considered abnormal and has been shown in a small study to be 77% sensitive in detecting HF exacerbations requiring hospitalizations approximately 12 days prior to each admission [10]. FAST is a prospective, multicenter, nonrandomized study evaluating the utility of measuring ambulatory intrathoracic impedance by the InSync Marquis System (Medtronic, Inc., Minneapolis, MN) downloaded with the OptiVol Thoracic Fluid Status Monitoring feature (Medtronic, Inc., Minneapolis, MN) [11]. Hemodynamic correlation by right heart catheterization (RHC) with this system is available in limited animal and human studies showing that an increase in impedance correlates with a decrease in PCWP.

Figure 1 is a proposed algorithm outlining the various methods described earlier to detect persistent volume overload known to be a sign of poor prognosis, the presence of which could help determine referral to an advanced HF center.

RHC in HF

Standard guidelines for RHC in HF

The 2005 American College of Cardiology (ACC)/American Heart Association (AHA) practice guidelines state that "there is no established role for periodic invasive or noninvasive hemodynamic measurements in the management of HF, nevertheless it may assist in the determination of volume status and in distinguishing HF from other disorders that may cause circulatory instability" [12]. Although the guidelines recognize that aggressive control of volume overload in patients with advanced HF is important being a class I recommendation, PAC placement to guide therapy is a class IIb recommendation with level of evidence being C. The 2006 Heart Failure Society of America practice guidelines state that "the routine use of invasive hemodynamic monitoring in patients with acute decompensated HF is not recommended (strength of evidence A)" but should be considered in patients in whom the response to initial therapy is inadequate, volume status and filling pressures are unclear, clinically significant hypotension is present, renal function is declining, or outpatient inotropic therapy is being considered (strength of evidence C) [13]. The 2005 Task Force on Acute Heart Failure of the European Society of Cardiology echoes these recommendations by stating that "the use of the PAC is recommended in hemodynamically unstable patients who are not responding in a predictable fashion to traditional treatments and in patients with a combination of congestion and hypoperfusion (class IIb recommendation, level of evidence C)" [14].

Indications for RHC in advanced HF

The ESCAPE trial has shown that routine RHC did not significantly affect outcomes in advanced HF when compared with expert clinical assessment [15••]. There are certain indications, however, that justify the use of a PAC.

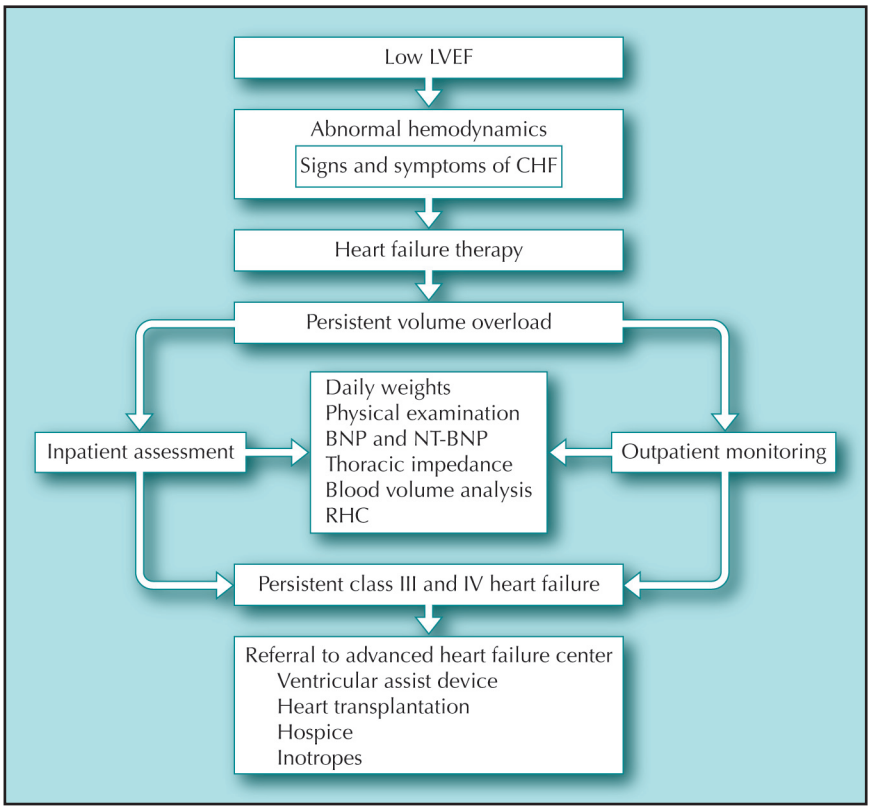

Figure 1. Proposed management algorithm for patients with advanced heart failure based on volume status. BNP—B-type natriuretic peptide; CHF—congestive heart failure; LVEF—left ventricular ejection fraction; NT-BNP—N-terminal B-type natriuretic peptide; RHC—right heart catheterization.

Persistent volume overload, despite aggressive attempts at diuresis, may identify patients in need of inotropic therapy for palliative purposes or as a bridge to heart transplantation. The PAC in these circumstances also enables minimal, effective dosing of these drugs and subsequent weaning (if possible) when a euvolemic state is achieved. RHC may also be justified with the development of concomitant renal insufficiency to assess renal perfusion by measurement of cardiac output. In addition, because physical examination may not be helpful in some patients to assess volume status accurately, a PAC may be able to provide an accurate dry weight that can be clinically used in these patients to manage diuretic dosing. Advanced HF centers routinely use RHC to assess candidacy for heart transplantation for various reasons. First, by demonstrating the presence of persistently elevated intracardiac filling pressures, despite adequate medical therapy, a determination of poor outcome can be made and thus the need for heart transplantation. Secondly, acceptable pulmonary vascular resistance (PVR) at rest or during vasoreactivity studies ensures a safer outcome after heart transplantation. Objective hemodynamic criteria by RHC are also used to demonstrate an indication for the use of ventricular assist devices in advanced HF. Hemodynamic criteria that support the use of mechanical circulatory support are right atrial (RA) pressures of 12 mm Hg or greater, PCWP greater than 20 mm Hg, and cardiac index (CI) less than 2 L/min/m^2 with at least one inotrope or vasoactive drug. The expected survival of these patients at 6 months with medical therapy is typically less than 50% [16].

RHC versus expert clinical assessment in the management of advanced HF

The ESCAPE trial was the first and only randomized clinical trial to evaluate the utility of RHC in the management of advanced HF [15••]. In the era of modern pharmacologic therapy, between January 2000 and November 2003, 433 patients with severe symptomatic HF were randomized to receive either medical therapy guided by a PAC and clinical assessment or clinical assessment alone. The clinical goal in both groups was optimization of volume status to relieve congestion. Despite hemodynamic goals of a RA pressure of 8 mm Hg and PCWP of 15 mm Hg being defined for the PAC group, the use of inotropes with or without vasodilator therapy was not significantly different in the two groups. Patients in both groups achieved similar weight loss, reduction in JVP and edema, improvement in global symptom score, and orthopnea. The primary end point was days alive out of the hospital over the first 6 months, with secondary end points being BNP levels, peak oxygen consumption, 6-minute walk distance, and the Minnesota Living with Heart Failure questionnaire. There was no difference in the primary endpoint with the use of the PAC and no significant improvement in any of the secondary endpoints. In addition, there were no significant differences in death or length of hospitalization. The limitations of the study were the failure to define a consistent treatment strategy and the applicability of these results to community hospitals inexperienced in the treatment of severe HF. However, the lesson learned

is that hemodynamic information provided by the PAC may add little to the clinical assessment of the expert HF physician in managing decompensated chronic HF patients. The trial excluded patients requiring RHC emergently, and therefore results cannot be extrapolated to patients with cardiogenic shock or patients requiring ventricular assist device therapy or heart transplantation. These results have been supported by findings in a randomized, controlled trial using the PAC in patients primarily with septic shock [17] and a large meta-analysis that evaluated the use of the PAC in the management of critically ill patients in both medical and surgical populations, demonstrating no reduction in morbidity and mortality with RHC [18••].

Persistent Volume Overload Portends Poor Prognosis in HF

Persistent volume overload (despite medical therapy) demonstrated either by clinical examination [3], BNP levels [5], or RHC is a marker of recurrent hospitalizations and death.

RHC and Survival

The limitations of many prognostic studies in HF are the lack of prospective data, small numbers of patients, inhomogeneous patient populations, different treatment regimens, and lack of dynamic measurements. With this caveat, hemodynamics obtained during RHC have been variably linked to mortality. The FIRST database was retrospectively analyzed to assess the prognostic importance of various hemodynamic measurements in patients with severe HF. By multivariable analysis, with adjustment for age and New York Heart Association class, a decrease in PCWP was the only hemodynamic variable predictive of survival [19]. In a more recent study of patients referred for heart transplantation on current HF therapy, N-terminal proBNP and PCWP remained the only independent predictors of all-cause mortality and the need for urgent transplantation [20]. Exercise hemodynamics were not found to be helpful in predicting mortality except for peak exercise stroke work index in a small population of patients with chronic HF. PCWP at rest and not during exercise was identified as an independent predictor of mortality by multivariable analysis in this study [21]. However, a larger study involving 185 HF patients demonstrated that cardiac output response to exercise was the most powerful and independent predictor of 1-year survival. [22]. The alteration of hemodynamics in the early days of so-called "tailored therapy" using vasodilators and diuretics proved to be more reliably accurate in predicting survival than static measurements [23]. Patients who achieved a PCWP greater than 16 mm Hg during such treatment had a 1-year survival of 83% as compared with 38% in those with persistent PCWP greater than 16 mm Hg [24]. Similar results of improved survival linked to a reduction in PCWP were observed in the ESCAPE trial [25•]. One-year outcomes in a group of patients listed for heart transplantation were found to be dependent primarily on RA pressures, survival being worse in patients with RA pressures greater than 12 mm Hg [26]. Perhaps the elevated RA pressures reflect the extent of RV dysfunction, which in turn has been a predictor of mortality in chronic HF [27]. Pulmonary artery systolic pressure was found to be the only predictive hemodynamic parameter in a diverse group of patients with idiopathic dilated cardiomyopathy by multivariable analysis in another study [28]. One of the few studies to show a link between cardiac output (CO) and survival was conducted prior to the routine use of vasodilator therapy [29], but in general, a low measured CO is not considered an important determinant of survival in this population. Inherent inaccuracies in the measurement of CO and the narrow range of values obtained may be some of the reasons that CO has not been statistically shown to be a prognostic predictor in advanced HF [30•]. Table 2 summarizes these and other studies [31,32] that have linked hemodynamic criteria to prognosis in patients with HF.

RHC and risk stratification in heart transplantation candidates

Risk stratification in chronic HF is perhaps most important in determining heart transplantation eligibility. A HF survival score has been developed and prospectively validated to predict survival in patients referred to heart transplantation centers [33]. The noninvasive model using variables such as presence of ischemic cardiomyopathy, resting heart rate, LVEF, mean blood pressure, intraventricular conduction delay, peak oxygen consumption, and serum sodium, performed as well as the invasive model that incorporated mean PCWP at rest. There was no added benefit of using RHC parameters. RHC is particularly important in determining the presence of pulmonary hypertension and its reversibility in patients with HF prior to heart transplantation. Increased post-transplantation mortality primarily due to RV failure has been well described in patients with preoperative fixed pulmonary hypertension [34]. Several retrospective analyses identified pulmonary vascular resistance (PVR) index measured during RHC as the only reliable and independent predictor of mortality in the post-transplantation population [35,36]. Some studies have demonstrated that an elevated trans-pulmonary gradient or TPG (difference in the mean pulmonary artery [PA] and PCW pressures) and not PVR may be of greater value in predicting early post-transplantation mortality [37,38]. Reversibility of baseline pulmonary hypertension in chronic HF patients during RHC using various vasodilator drugs has been shown to be an important tool in predicting survival after heart transplantation. Patients who had elevated PVR that could be reduced to less than 2.5 Wood units with sodium nitroprusside while maintaining systemic blood pressures greater than 85 mm Hg had a similar prognosis to patients

with a normal PVR after heart transplantation [39]. More recently, pulmonary artery systolic pressure, especially values over 50 mm Hg remains the only independent predictor of adverse outcome after heart transplantation despite demonstrating reversibility by reducing PVR to 2.5 Woods units or less [40].

Hemodynamic Alterations and Prognosis

An important aspect of therapy in advanced HF has been to improve congestive symptoms such as dyspnea, and to achieve this goal, improving hemodynamics has been felt to be a critical component of therapy. However, all contemporary life-saving therapies in HF, such as ACE inhibitors and β-blockers, in large multicenter trials have been administered without attention to hemodynamic effects. Second, drugs that may improve hemodynamics, such as the imidazoline receptor agonist moxonidine [41] and inotropes, are actually linked to increased mortality [42]. Third, the biologically beneficial effect of the drug is distinct and separate from the ability of the drug to improve hemodynamics in the acute phase. The improvement in survival that has been reported with decreased PCWP in HF may be a marker of a subset of patients whose disease state is not advanced to the point of not being able to respond to conventional therapy, or response may primarily be seen in patients who have common reversible causes of HF such as medication noncompliance with resumption of therapy.

Complications of RHC

The complications associated with the placement of a PAC have been well described and include those associated with the placement of the introducer, as well as floatation and maintenance of the catheter. Complications such as bleeding, infection, vascular damage, venous thrombosis, air embolism, pneumothorax, and hemothorax may occur with the insertion of any central venous catheter. There has been some interest in the past decade in the use of real-time, two-dimensional ultrasound to assist in vessel identification and catheter placement, with several studies suggesting decreased placement failure and risk of complication [43]. Complications resulting from floatation of the PAC include atrial and ventricular arrhythmias, right bundle branch block, complete heart block, catheter knotting, PA rupture, and thromboembolic events. Although the incidence of right bundle branch block is estimated at less than 5%, PACs should not be floated in patients with pre-existing left bundle branch block unless the ability to institute transthoracic or transvenous pacing is immediately available [44]. Life-threatening complications such as PA rupture fortunately are infrequent with an incidence of less than 0.1% [45], and in the ESCAPE trial, the incidence of PAC infection was 2%. Despite an earlier observational report of increased mortality in critically ill patients with the use of a PAC [46], a meta-analysis of 5051 patients in 13 randomized clinical trials showed the use of a PAC not to be associated with an increase in mortality and an overall neutral effect with an odds ratio of 1.04 [18••].

Case Studies

The cases listed help illustrate the several important indications for RHC in the management of advanced HF.

Case # 1

A 55-year-old male with ischemic HF, with a remote 20-pack year history of smoking, previous coronary artery bypass surgery, patent grafts to native vessels, moderate mitral regurgitation, and LVEF of 23% presents with significant dyspnea on mild exertion, despite optimal medical therapy including high-dose diuretics. He was referred for heart transplantation and RHC was performed. Hemodynamics were as follows: RA 12, PA 75/32, PCWP 17, CI 2.5 L/min/m^2, PVR 19 units, TPG 29. A chest CT demonstrated diffuse central lobular nodularity and emphysematous changes. Pulmonary function tests confirmed severe obstructive lung disease.

Discussion

The hemodynamics in this patient with heart and lung disease were invaluable in assessing the contribution of lung disease and secondary pulmonary hypertension to the patient's symptoms. In a patient with low LVEF and coronary artery disease, diagnosing emphysematous lung disease as a cause of dyspnea would have been clinically challenging, especially with just elevated JVP. The patient (due to significant pulmonary hypertension diagnosed by RHC) was not a candidate for solitary heart transplantation due to a PVR and TPG greater than 6 and 15 respectively.

Case # 2

A 21-year-old female with new onset nonischemic HF, due to a familial dilated cardiomyopathy, presented as an inpatient with persistent symptoms of dyspnea despite initial medical therapy consisting of diuretics and ACE inhibitors. The patient was started on β-blockers and subsequently developed sustained, symptomatic hypotension without overt clinical signs of congestion. She was started on dopamine and transferred to the intensive care unit for placement of a PAC. Hemodynamics obtained on inotropes were as follows: RA 13 mm Hg, PA 43/23 mm Hg, PCWP 25 mm Hg, CI 2.4 L/min/m^2. ACE inhibitors and β-blockers were held, the patient was diuresed significantly, and inotropes were discontinued because of stabilization of blood pressures. Hemodynamics on discontinuation of dopamine were as follows: RA 8 mm Hg, PA 35/22 mm Hg, PCWP 16, CI 1.7 L/min/m^2. Due to stable blood pressure and renal

Table 2. Summary of trials assessing the prognostic value of hemodynamics in patients with heart failure

Source (*N*)	Population	Design	Hemodynamics assessed	End points (Follow-up)	Hemodynamic goals	Treatment strategies	Results
Binanay et al. [15••] (433)	Severe symptomatic and recurrent HF	Patients randomized to PAC vs no PAC to determine if the PAC is safe and affects clinical outcomes in hospitalized patients with advanced HF	RAP, PCWP, CIx, CO, SVR	Days alive out of hospital (6 mo)	Yes PCWP < 15 mm Hg and RAP < 8 mm Hg	No	Use of the PAC did not significantly affect the primary end point (133 d vs 135 d; HR, 1.00 [95% CI, 0.82–1.21], $P = 0.99$) or mortality (43 patients vs 38 patients; OR, 1.26 [95% CI, 0.78–2.03], $P = 0.35$)
Gardner et al. [20] (97)	Class III and IV, EF < 35%	Compare prognostic value of hemodynamics vs NT-proBNP	RAP, PASP, PCWP, TPG, CO, CIx, PVR, SVR	Mortality (1 y)	No	No	Univariate predictors of mortality were PASP > its median value (HR, 4.1 [95% CI, 1.2–13.6], $P = 0.02$) and SVR < its median value (HR, 5.9 [95% CI, 1.2–30.2], $P = 0.02$)
Shah et al. [19] (471)	Class IIIb and IV, EF < 25%, CI < 2.2, PCWP > 15	Identify hemodynamic variables predictive of survival in patients receiving epoprostenol	HRt, MAP, PASP, PADP, RAP, CIx, CO, PCWP	Mortality (1 y)	No	No	After adjustment for age and NYHA class, decreased PCWP predicted survival (HR, 0.96 [95% CI, 0.94–0.99], $P = 0.003$).
Saxon et al. [31] (528)	Advanced HF, mean EF 20%, ischemic and nonischemic etiologies	Identify predictors of HF death, hospitalization, or urgent transplantation in patients admitted for treatment of advanced HF and transplantation evaluation	RAP, PASP, PADP, PCWP, CIx, SBP, HRt	Mortality (mean 1 y)	Yes PCWP ≤ 15 mm Hg and SVR ≤ 1200 dynes-sec/m-5 while maintaining SBP > 80 mm Hg	No	After treatment and stabilization, PCWP and PADP were the only univariate hemodynamic predictors of HF death or urgent transplantation ($P = 0.08$). In multivariate analysis, PADP > 19 mm Hg was the only significant predictor. No hemodynamic variable was predictive of sudden death.
Morley et al. [26] (138)	Class III and IV, mean EF 16%, listed for transplantation	Identify hemodynamic variable most predictive of survival in patients awaiting cardiac transplantation	RAP, PASP, TPG, CO, CIx, PVR	Mortality (1 y)	No	No	In univariate analysis, predictors of survival included RAP ($P = 0.0009$), CO ($P = 0.005$), PCWP ($P = 0.02$) and PVR ($P = 0.05$). In multivariate analysis, RAP was the only hemodynamic variable predictive of survival ($P < 0.05$).

BP—blood pressure; CI—confidence interval; CIx—cardiac index; CO—cardiac output; EF—ejection fraction; HF—heart failure; HRt—heart rate; LVEDP—left ventricular end diastolic pressure; MAP—mean arterial pressure; NT-proBNP—N-terminal proB-type natriuretic peptide; OR—odds ratio; PAC—pulmonary artery catheter; PADP—pulmonary artery diastolic pressure; PAM—pulmonary artery mean pressure; PASP—pulmonary artery systolic pressure; PCWP—pulmonary capillary wedge pressure; PVR—pulmonary vascular resistance; RAP—right atrial pressure; SBP—systolic blood pressure, SVI—stroke volume index; SVR—systemic vascular resistance; TPG—transpulmonary gradient.

Table 2. Summary of trials assessing the prognostic value of hemodynamics in patients with heart failure

Source (*N*)	Population	Design	Hemodynamics assessed	End points (Follow-up)	Hemodynamic goals	Treatment strategies	Results
Griffin et al. [21] (49)	Class II, III, and IV, mean EF 23%, ischemic and nonischemic etiologies	Determine the prognostic value of hemodynamic variables at rest and during exercise	HRt, MAP, RAP, PCWP, CIx, SVR, SVI, SWI	Mortality (1 y)	No	No	In univariate analysis, PCWP of nonsurvivors was significantly different than that of survivors at rest (22 mm Hg ± 10 mm Hg vs 15 mm Hg ±10 mm Hg; $P = 0.01$) and during exercise (32 mm Hg ±9 mm Hg vs 24 mm Hg ± 9 mm Hg; $P = 0.003$.
Stevenson et al. [24] (152)	Class III and IV, EF < 20%, ischemic and nonischemic etiologies	Identify patients with EF < 20% on tailored therapy most likely to survive after referral for transplantation	HRt, BP, RAP, PASP, PCWP, CIx, SVR	Mortality (1 y)	Yes PCWP ≤ 15 mm Hg and SVR ≤ 1200 dynes-sec/cm-5	Yes Nitroprusside and diuretics with transition to oral vasodilators	Elevation of initial filling pressures were not predictive of survival. However, 1-y survival of patients with reduction of PCWP to ≤ 16 mm Hg during tailored therapy was 79% vs 33% ($P = 0.0012$).
Komajda et al. [28] (201)	Class I, II, III, and IV, nonischemic etiology	Identify factors of poor prognosis in order to select a subgroup of patients with idiopathic dilated cardiomyopathy at high risk of mortality	SBP, DAP, PASP, PADP, PCWP, LVEDP, CIx	Mortality (mean 57 mo)	No	No	In univariate analysis, RAP, PASP, PADP, PCWP, LVEDP and CI were all significantly predictive of mortality. In multivariate analysis, only PASP was predictive of mortality ($P = 0.005$)
Keogh et al. [32] (232)	Class I, II, III, and IV, ischemic and nonischemic etiologies	Identify clinical and investigational parameters measure at assessment that most accurately predict survival in advanced HF	PAM, PASP, PADP, PCWP, CO, PVR	Mortality (2 wk–5.5 y)	No	No	In multivariate analysis, PCWP was the only hemodynamic variable predictive of survival ($P = 0.008$). There was also a difference between survival for a PCWP > 12 mm Hg and ≤ 12 mm Hg ($P = 0.01$), but significance was lost when viewed around the mean of 25 mm Hg ($P = 0.08$)

BP—blood pressure; CI—confidence interval; CIx—cardiac index; CO—cardiac output; EF—ejection fraction; HF—heart failure; HRt—heart rate; LVEDP—left ventricular end diastolic pressure; MAP—mean arterial pressure; NT-proBNP—N-terminal proB-type natriuretic peptide; OR—odds ratio; PAC—pulmonary artery catheter; PADP—pulmonary artery diastolic pressure; PAM—pulmonary artery mean pressure; PASP—pulmonary artery systolic pressure; PCWP—pulmonary capillary wedge pressure; PVR—pulmonary vascular resistance; RAP—right atrial pressure; SBP—systolic blood pressure, SVI—stroke volume index; SVR—systemic vascular resistance; TPG—transpulmonary gradient.

function, excellent urine output without clinical signs of hypoperfusion, inotropes remained discontinued. The patient was reinstated on ACE inhibitors and β-blockers at a much lower dose with continued aggressive diuresis. Hemodynamics did not significantly change and CI remained low. The patient was discharged home in stable condition and seen 1 and 6 months post-hospitalization with improved functional status.

Discussion

This patient likely had an adverse reaction to β-blockers. The PAC was initially useful in diagnosing clinically unrecognized hypervolemia that resulted in aggressive diuresis and enabled identification of a dry weight. This allowed reinitiation and tolerance of β-blocker therapy. However, the CI measurement obtained after discontinuation of inotropes was confusing. Based on this measurement alone inotrope use could have been justified and resumption of β-blockers could have been deferred, but based on clinical parameters inotrope use did not appear warranted and β-blocker use, with adequate diuresis and at a lower dose, was well tolerated. The decrease in PCWP correctly identified a good outcome for this patient. For present neurohormonal blockade drugs used in the treatment of HF, improvement in cardiac output does not appear to be an important prognostic endpoint. This case illustrates the use of RHC to diagnose volume overload accurately but was not useful in directing appropriate drug therapy except diuretics.

Case # 3

A 49-year-old male with idiopathic dilated cardiomyopathy, dependant on the inotrope milrinone and listed for heart transplantation, was admitted with increasing dyspnea, hypotension, and worsening renal insufficiency. He was felt to be "cool and wet" on clinical examination, and aggressive intravenous diuretics with addition of dobutamine was initiated. He lost approximately 7.3 kg within a week, with improved renal function and blood pressures. BNP level was 120 pg/mL. A PAC was placed to assess true inotrope requirement, and he was considered clinically euvolemic. Hemodynamics on dobutamine and milrinone revealed RA 8, PA 42/24, PCWP 28, CI 2.3 L/min/m^2. He was referred for LV assist device implantation.

Discussion

Despite dramatic clinical improvement, PAC helped determine that patient had a persistently elevated PCWP and volume overload indicating poor prognosis. BNP level was not helpful or indicative of true volume status in this patient. The PAC also demonstrated the requirement for dual inotropes to maintain adequate cardiac output and peripheral perfusion, prompting a decision to provide mechanical support.

Conclusions

RHC remains the gold standard in diagnosing elevated intracardiac pressures and can be used to determine and maintain volume status in patients with advanced HF. Although medical therapy based on catheterization-derived information may not be superior to therapy directed by expert clinical assessment, there are specific clinical situations that RHC plays an invaluable role in the diagnosis, management, and assessment of prognosis in advanced HF.

Clinical Trial Acronyms

COMPASS-HF—Chronicle Offers Management to Patients With Advanced Signs and Symptoms of Heart Failure; ESCAPE—Evaluation Study of Congestive Heart Failure and Pulmonary Artery Catheter Effectiveness; FAST—Fluid Accumulation Status Trial; FIRST—The Flolan International Randomized Survival Trial; PREDICT—Prospective Evaluation of Cardiac Decompensation in Patients with Heart Failure by ICG Test.

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