Managing Right Ventricular Failure in PAH: An Algorithmic Approach

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Pulmonary arterial hypertension (PAH) is a disorder characterized by progressive elevation of pulmonary artery pressure (PAP) and vascular resistance in the absence of left-sided cardiac disease, pulmonary vein compression, respiratory disorders, or thromboembolic disease. It is defined by a mean PAP over 25 mmHg at rest or over 30 mmHg with exercise and a pulmonary artery occlusion pressure (PAOP) of less than 15 mmHg. PAH is associated with a poor prognosis. The estimated median survival from diagnosis is 2.8 years and the 1-year and 5-year survival rates are only 68% and 34%, respectively. More than 70% of PAH patients will die as a result of right ventricular failure and most of the remainder from dysrythmia. Predictors of a poor prognosis in PAH are related to the development of right ventricular failure. The objectives of this review are to examine the pathophysiologic mechanisms leading to the development of right ventricular failure due to PAH, the diagnostic features of right ventricular failure, and the management of chronic right ventricular failure with emphasis on acute decompensation in this setting.

Pathophysiology
Clinical Manifestations and Hemodynamic Derangements
The normal right ventricle is a thin-walled (less than 0.6 cm), trabeculated, roughly triangular structure that weighs less than 65 g in men and less than 50 g in women. It is designed to empty its volume into a low-impedance, high-capacitance, pulmonary circulation by contracting sequentially from inflow to outflow. The pulmonary circulation can tolerate three- to fourfold increases in right-sided cardiac output without significant increases in PAP. In healthy individuals, pulmonary vascular resistance (PVR) decreases as the cardiac output rises with exercise. In the setting of PAH, PVR does not sufficiently decrease with exercise, resulting in dyspnea and poor exercise capacity.

Progressive PAH presents a pressure overload state to the right ventricle, increasing right ventricular workload leading to concentric hypertrophy (Figure 1). The right ventricle compensates: the walls hypertrophy while maintaining a normal or smaller chamber size, resulting in normal or reduced right ventricular wall stress. During this compensated phase of adaptive hypertrophy and normal to reduced wall stress, the ventricle is able to eject blood against the high PVR while maintaining an adequate right-sided cardiac output and normal right atrial pressure. During this phase patients exhibit few symptoms.

The right ventricle can compensate only so long, initiating the symptomatic/declining phase (Figure 1). During this phase, with marked, maladaptive right ventricular hypertrophy and variable degrees of interstitial fibrosis, diastolic function may be impaired, altering the right ventricular diastolic pressure-volume relationship and leading to increases in right ventricular end-diastolic and right atrial pressures. With persistent pressure overload, the right ventricle undergoes a remodeling process eventually leading to right ventricular failure. The right ventricular chamber dilates and the concentric hypertrophy transitions to eccentric hypertrophy, resulting in increased wall stress and systolic dysfunction. Increased heart rate and right ventricular wall stress lead to significant increases in right ventricular myocardial oxygen consumption. This, in combination with reduced right ventricular endomyocardial coronary perfusion (due to reduced right coronary artery pressure, rising right ventricular end-diastolic pressure, and increased right ventricular mass), leads to right ventricular ischemia and worsening right ventricular diastolic and systolic function. The right ventricular ischemia may be clinically manifest as chest pain. As the right ventricle and the tricuspid valve annulus dilate, functional tricuspid regurgitation progressively worsens. Tricuspid regurgitation further compromises right ventricular forward output, and ultimately, left ventricular filling. During this phase of right ventricular remodeling, cardiac output does not meet peripheral demands and right atrial pressure rises further as reflected clinically by exercise intolerance, progressive dyspnea, elevated jugular venous pressure, and fluid retention with edema (the hallmarks of right ventricular failure). These clinical signs reflect both a low cardiac output and the detrimental activation of neurohormones and other mediators. Natriuretic peptide levels become significantly elevated in patients with right heart failure even in the absence of left ventricular dysfunction. B-type natriuret-
Advances in Pulmonary Hypertension

ic peptide (BNP) levels increase in proportion to the extent of right ventricular dysfunction in PAH and are predictive of mortality in right ventricular failure.10,11

Progressive right ventricular dilation in the setting of pericardial constraint and diastolic ventricular interdependence compromise left ventricular filling via several mechanisms.7,12,13 A shift of the ventricular septum during diastole toward the left ventricle reduces left ventricular compliance and diastolic filling. As the right ventricle dilates in association with increases in right ventricular and right atrial diastolic pressure, a marked rise in intrapericardial pressure ensues. The transmural left ventricular end-diastolic pressure (end-diastolic pressure minus intrapericardial pressure), the true preload of the left ventricle, is reduced and by the Frank-Starling relationship results in low systemic cardiac output. Furthermore, with marked elevation in right atrial pressure the coronary sinus pressure also rises, resulting in left ventricular myocardial congestion and wall dimensions that limit left ventricular compliance. This mechanism appears to act independently of diastolic ventricular interaction due to pericardial constraint.14 As a consequence of decreased left ventricular preload, systemic cardiac output is further compromised, first with exercise only but eventually even at rest. It should be noted that with extreme right ventricular failure and dilation, left ventricular compliance can be so severely impaired that at a certain point the left ventricular end-diastolic pressure (LVEDP) and PAOP may rise due to a shift of the left ventricular diastolic pressure volume relationship upward and to the left such that even with low left ventricular volume the left ventricular pressure is increased.

The decompenated phase of right ventricular systolic failure is manifest as symptoms with minimal activity or at rest. It is marked by elevation in right atrial pressure and systemic venous hypertension leading to hepatic congestion, which combined with tricuspid regurgitation, leads to an enlarged, pulsatile liver and ascites. A right ventricular S3 gallop may be audible and renal and splanchnic congestion can cause diuretic resistance. Renal venous congestion combined with decreased renal arterial perfusion will be exhibited as diuretic resistance, reduced urine output, and prerenal azotemia.15 Also evident is a low cardiac output state resulting in fatigue and syncope or pre-syncope. In acute decompenated right ventricular failure (ADRVF) reduced cardiac output is evident by a narrow pulse pressure and hypotension with peripheral tissue and vital organ hypoperfusion. The latter increases the arterio-venous oxygen difference. Hypoxemia may also be the consequence of right to left shunting in PAH patients with a patent foramen ovale and elevated right atrial pressure. Further, the destruction of the cross-sectional pulmonary vascular bed (a pathologic consequence of protracted PAH) also contributes to

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Figure 1.—Progressive PAH presents a pressure overload state to the right ventricle, increasing right ventricular workload leading to concentric hypertrophy.
hypoxemia and with reduction in peripheral oxygen delivery, acidosis, which can lead to life-threatening dysrhythmias, may ensue.

**Diagnostic Findings in Right Ventricular Failure in PAH**

Chest radiographs typically show enlarged pulmonary arteries and distal tapering of the peripheral vessels and on lateral view an enlarged right ventricle can be visualized by filling of the retrosternal space. The electrocardiogram in advanced stages of pulmonary hypertension and right ventricular failure may reveal right axis deviation, RBBB, p wave amplitude of more than 2.5 mm, and/or S1, Q3, T3 pattern reflective of pressure overload state on the right ventricle. The R wave will be prominent in V1 with deep S waves in the lateral precordial leads indicating right ventricular hypertrophy. Increased p wave amplitude in lead II, qR pattern in lead V1, and right ventricular hypertrophy are associated with an increased risk of death.

Transthoracic echocardiography is the most useful and readily available noninvasive tool to evaluate right ventricular failure due to PAH. Typically the right ventricle is hypertrophied and dilated with poor systolic function and the right atrium is enlarged while the left ventricle is small and underfilled. In a cross-sectional view, the left ventricle appears “D” or crescent shaped as the ventricular septum displaces or “flattens” toward the left ventricle. Septal flattening during systole suggests right ventricular pressure overload, whereas septal flattening during diastole occurs with volume overload (tricuspid regurgitation). Typically in right ventricular failure, septal flattening occurs throughout the cardiac cycle due to both right ventricular pressure and volume overload. The left ventricle contracts normally or is hyperdynamic. However, the diastolic transmitral filling characteristics are abnormal due to reduced left ventricular compliance. Patients with right ventricular failure have Doppler evidence of significant tricuspid regurgitation and moderately to severely elevated pulmonary artery systolic pressure (PAPs). The PAPs is estimated from the peak tricuspid regurgitant velocity and an estimate of right atrial pressure based on inferior vena cava size and respiratory dynamics. In right ventricular failure, the inferior vena cava is plethoric and does not collapse with inspiration, indicative of high right atrial pressure. Pulse wave Doppler in the right ventricular outflow tract typically reveals a reduced velocity-time integral suggestive of low forward output. Agitated saline contrast not only will aid in the diagnosis of some congenital systemic-to-pulmonary shunts, but may also detect a patent foramen ovale in one third of patients. Echocardiographic predictors of a poor prognosis include an enlarged right atrium, the presence of a pericardial effusion, and a higher Doppler global right ventricular index.

**Pulmonary Artery Catheterization**

In right ventricular failure associated with PAH pulmonary artery catheterization will reveal high right atrial, right ventricular, and pulmonary arterial pressures with a PAOP of greater than 15 mmHg. The cardiac and stroke volume indices are reduced and the mixed venous oxygen saturation is generally markedly reduced. With end-stage right ventricular failure, paradoxically the PAP may not be severely elevated and may actually fall as right ventricular ejection and the cardiac output are so compromised that the right ventricle cannot generate a high pulmonary pressure in the setting of high PVR. Ultimately in the throes of severe right ventricular dilation and failure, the PAOP may be elevated as left ventricular compliance is severely compromised with perturbation of the left ventricular diastolic-pressure volume relationship.

Pulmonary artery catheterization is useful not only for the diagnosis of right ventricular failure due to PAH but also for its management. In the case of systemic hypoperfusion and hypotension, catheterization can often identify the hemodynamic mechanism for the hypotension. Blood pressure is the product of cardiac output and SVR and hypotension in patients with PAH may be a result of either low cardiac output from right ventricular failure or reduced SVR from overvasodilation or infection. Precise identification of the operative hemodynamic derangement will guide therapy in right ventricular failure due to PAH.

**Chronic and Acute RV Failure in PAH**

**Goals of Therapy**

The goals of treating chronic right ventricular failure due to PAH are to 1) relieve symptoms, improve exercise capacity, and quality of life; 2) reduce morbidity and mortality; and 3) improve cardiopulmonary hemodynamics to prevent worsening of right heart failure (ie, delay disease progression). The immediate goals of treating acute decompensated right ventricular failure (ADRVF), especially with hemodynamic compromise, are to 1) restore oxygenation; 2) treat volume overload; and 3) restore vital organ perfusion. The intermediate and long-term goals are to optimize the medical regimen to alleviate symptoms, prevent further disease progression, reduce morbidity and mortality, and successfully bridge the patient to lung or heart-lung transplantation in appropriate individuals.

**Chronic RV Failure: Medical Therapies**

The long-term goals of managing chronic right ventricular failure in PAH can be reached by applying the approaches delineated in Table 1 that have been reviewed elsewhere. Strategies to prevent and treat chronic right ventricular failure are aimed at reducing right ventricular wall stress, thereby minimizing myocardial oxygen consumption and ischemia, and to improve the inotropic state of the right ventricle. To reduce wall stress, one must lower right ventricular afterload. This is accomplished with chronic pulmonary arterial vasodilators: O2 therapy, endothelin receptor antagonists, prostanoids, and phosphodiesterase V inhibitors as described in recent reviews. Calcium channel blockers should be avoided in patients with marginal blood pressure and significant right heart failure as manifest by right atrial pressures greater than 15 mmHg and low cardiac index (less than 2.0 L/min/m2). Chronic anticoagulation is recommended to prevent pulmonary arterial thrombosis in situ, which contributes to narrowing and remodeling of the pulmonary arterial bed, consequently increasing right ventricular outflow impedance.

Reduction in right ventricular preload and tricuspid regurgi-
Diet and lifestyle considerations
- Sodium restriction
- Smoking cessation
- Weight loss
- Avoidance of physical exertion in setting of pre or frank syncope
- Avoidance of pregnancy
- Avoidance of high altitude

Interventions for treatment of pulmonary arterial hypertension
- Pulmonary vasodilators (endothelial receptor antagonists, prostanoids, PDE-5 inhibitors)
- Supplemental oxygen
- Anticoagulation (maintain INR 2-3)

Pharmacologic interventions for right ventricular failure
- Reduction of wall stress by decreasing excessive preload
  - Diuretics: loop, thiazide, and aldosterone antagonists
- Improve inotropy and reduce neurohormonal activation
  - Digitalis glycosides

Invasive interventions
- Lung transplantation
- Heart-lung transplantation for complex congenital heart disease
- Percutaneous blade-balloon atrial septostomy

Table 1. Management of Chronic Right Ventricular Failure in Pulmonary Arterial Hypertension.

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Interventions for treatment of pulmonary arterial hypertension
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ADRVF: Identification and Correction of Precipitating Factors
Factors that may precipitate ADRVF in patients with chronic right ventricular failure must be sought and corrected (Figure 2). These include dietary indiscretion, intercurrent infection, anemia/erythrocytosis, thyroid disorders, concomitant pulmonary embolus, and dysrhythmias. Infection must be considered in patients presenting with decompensated right ventricular failure and hemodynamic compromise, especially in patients with an indwelling central venous catheter for epoprostenol infusion. Infection is poorly tolerated in patients with right ventricular failure and limited right ventricular contractile reserve. The increase in right ventricular work associated with reduction in SVR will result in systemic hypotension. This scenario, beta- and alpha- agonists such as dopamine or norepinephrine are indicated as initial therapy to stabilize hemodynamics. Anemia also increases right ventricular work and it has been shown to be associated with worse quality of life and increased mortality in patients with PAH.2,29

Chronic RV Failure: Surgical and Interventional Therapies
Atrial septostomy. It is well known that patients with PAH and a patent foramen ovale have a better prognosis compared to those without a patent foramen ovale.25 The interatrial communication allows right to left shunting, thus reducing right atrial pressure and improving left ventricular filling and cardiac output, delaying progression of right ventricular failure. Percutaneous blade-balloon atrial septostomy is a catheter-based technique that allows the creation of a perforation in the atrial septum allowing shunting of blood from right to left. It has been utilized in select patients with right ventricular failure and syncope.21,26 Atrial septostomy has been shown to improve clinical status and produce beneficial long-lasting hemodynamic effects.26 The procedure is limited by systemic arterial oxygen desaturation, spontaneous closure of the atrial septal aperture, the potential for paradoxical embolic events, and a high procedure-related mortality. This investigational procedure should be performed only by experienced operators. It should not be performed in moribund patients or in those who have severe right ventricular failure and are on maximal cardiopulmonary support. A right atrial pressure greater than 20 mmHg, a PVR index greater than 55 um2/m2 and a predicted 1-year survival less than 40% are significant predictors of procedure-related death. Furthermore, patients should have an acceptable baseline systemic oxygen saturation (greater than 90% on room air). The procedure is indicated for recurrent syncope or right ventricular failure, despite maximal medical therapy, when no other options exist and/or as a bridge to lung transplantation.27 Extracorporeal membrane oxygenator systems in conjunction with atrial septostomy in a low cardiac output patient with hypoxemia have not been studied, but could theoretically be of value.

Transplantation. Bilateral lung transplantation or heart-lung transplantation for patients with complex congenital heart disease may be indicated for suitable candidates with chronic right ventricular failure who continue to deteriorate with poor quality of life despite aggressive pharmacologic therapy. With bilateral lung transplantation, survival is 70%, 45%, and 20%; with heart-lung transplantation, survival is 65%, 40%, and 25% at 1 year, 5 years, and 10 years, respectively.21 Long-term survival is predominantly limited by the development of post-transplant bronchiolitis obliterans.

Advances in Pulmonary Hypertension 21
Erythrocytosis is associated with higher viscosity and more cardiovascular events in patients with Eisenmenger syndrome and cor pulmonale from respiratory disorders. Specifically, higher hemoglobin levels are associated with worse cardiopulmonary function. Ventricular dysrhythmias usually occur in end-stage right ventricular failure. Atrial tachyarrhythmias should be slowed with digoxin, amiodarone, or diltiazem. The use of beta-blockers or the calcium blocker verapamil should be avoided as their negative inotropic effects may exacerbate the low cardiac output state while vasodilatory effects may reduce the SVR and cause hypotension. Amiodarone is relatively safe in this setting and is useful for the management of atrial fibrillation with rapid ventricular response to slow the rate as well as to facilitate electrical or chemical cardioversion to sinus rhythm. With symptomatic bradydysrhythmias, temporary and/or permanent pacemaker insertion should be considered in the appropriate situation. Ventricular dysrhythmias usually occur in end-stage right ventricular failure.

ADRVF: Restoration of Oxygenation and Prevention of Acidemia
Oxygen is a pulmonary vasodilator and maintenance of adequate oxygenation in right ventricular failure due to PAH is of paramount importance. High-flow oxygen has been shown to reduce PVR and increase cardiac index even in normoxic patients with pulmonary hypertension and should be applied liberally in patients with right ventricular failure or hypoxemia. Vapotherm is a high-flow oxygen delivery device that heats and humidifies oxygen for use with a nasal cannula, face mask, or tracheostomy mask at flow rates of 6 to 14 L/min that may provide adequate oxygen delivery without having to use positive pressure. Mechanical ventilation may be required for cardiorespiratory collapse due to ADRVF in order to maintain adequate oxygenation. However, by increasing transpulmonary pressures, especially with positive end expiratory pressure (PEEP), mechanical ventilation may increase right ventricular afterload and decrease right ventricular stroke volume, aggravating right ventricular failure and potentially exacerbating hepatic, splanchnic, and renal congestion. The ventilator should be set to the lowest possible PEEP and acidemia, a potent pulmonary vasoconstrictor, should be avoided.
avoided. Small degrees of alkalemia may be beneficial.  

**ADRVF: Restoration of Vital Organ Perfusion**

In the setting of ADRVF with hypotension once emergent measures have been applied to stabilize the patient, pulmonary arterial catheterization should be considered to identify the hemodynamic mechanism for the hypotension and to guide therapy. Pharmacologic therapy to reduce right ventricular afterload and/or increase inotropy should be promptly and aggressively administered to avoid vital organ damage. Inhaled nitric oxide (via endotracheal tube or by face mask) up to 40 ppm can be administered. Inhaled nitric oxide is a selective pulmonary vasodilator that reduces the PVR via the cyclic guanosine monophosphate system without affecting the SVR as it is quickly inactivated by hemoglobin. With the reduction in pulmonary afterload the cardiac output increases and the blood pressure can stabilize. Alternatively, inhaled epoprostenol or iloprost may be considered, but unlike inhaled nitric oxide, these agents can exert systemic vascular effects. Once stabilized patients can be transitioned to intravenous epoprostenol which has pulmonary vasodilator properties and may exert inotropic effects on right ventricular function. Continuous intravenous infusion of epoprostenol should be started at 1 ng/kg/min and titrated by 0.5 to 1 ng/kg/min every 30 minutes while maintaining a systolic blood pressure of greater than 80 mmHg, until a maximum tolerated dose is reached. This point is usually marked by the development of hypotension or other dose-limiting side effects such as headache, nausea/vomiting, diarrhea, myalgias, arthralgias, and trismus. If the patient maintains an adequate systemic blood pressure and cardiac output, inhaled nitric oxide can be weaned slowly by 5 ppm increments until a dose of 5 ppm is reached. Thereafter, nitric oxide should be weaned by 1 ppm increments until off to prevent rebound increases in pulmonary hypertension. While administering nitric oxide, methemoglobin levels must be monitored every 6 hours and maintained at less than 5% of methemoglobin to avoid methemoglobin toxicity.

Nitric oxide and epoprostenol may be used together in refractory cases, given that the combination may be additive as they exert their effects via different cyclic nucleoside pathways. It must be emphasized that if an acute effect to epoprostenol is not apparent, the therapy should not be abandoned (provided multiorgan failure has not occurred) as its benefits may be delayed. The effects of epoprostenol on the pulmonary circulation will take time (weeks) and prove to be effective while the cardiac output and blood pressure are supported with inotropic agents to avoid vital organ hypoperfusion. In addition to its pulmonary vasodilator effects epoprostenol may exert positive right ventricular inotropic effects via activation of the cyclic adenosine monophosphate pathway. It should replace or be added to any chronic oral or inhalational pulmonary vasodilator agent the patient may already be receiving for PAH when ADRVF supervenes. Intravenous epoprostenol can assist with the weaning process from inhaled nitric oxide and beta-adrenergic inotropes in severe right ventricular failure.

In ADRVF, low dose beta-adrenergic agents such as dobutamine or dopamine at 1 to 2 mcg/kg/min may improve cardiac output and restore vital organ perfusion. In the initial treatment of hypotension/hypoperfusion, dopamine or norepinephrine should be considered to restore right ventricular function, systemic hemodynamics and coronary perfusion. These agents may be more beneficial than phenylephrine alone, which is a selective alpha-agonist. Phenylephrine with low-dose dobutamine is a combination that may be desirable in tachycardic patients with vital organ hypoperfusion. Manipulating these drugs separately will allow the clinician to attain specific hemodynamic effects. The institution of inotropic and vasopressor agents is a double-edged sword as they can increase right ventricular work and exert vasopressor effects on the pulmonary circulation. However, in the appropriate clinical situation they are essential to restore and maintain systemic perfusion. The lowest possible dose of these drugs should be utilized to minimize tachycardia, proarrhythmia, myocardial oxygen consumption and ischemia, and pulmonary vasoconstriction.

In patients with ADRVF, central venous congestion, and hypotension volume infusion should not be employed. The failing right ventricle is operating on the flat to descending portion of its Frank-Starling curve and further increase in right ventricular preload will not improve cardiac output and blood pressure. Volume loading will further dilate the right ventricle, resulting in worsening tricuspid regurgitation and right ventricular wall stress. In addition, as a result of diastolic ventricular interdependence imposed by pericardial constraint, volume loading will exacerbate the low systemic cardiac output state due to compromised left ventricular filling as previously discussed. The phosphodiesterase-3 inhibitor, milrinone, is an intravenous inodilator that should be avoided in right ventricular failure from PAH as its vasodilatory properties may overwhelm its inotropic effect. Milrinone may reduce the SVR without affecting the PVR in this patient population and may exacerbate systemic hypotension. By the same token, nitric oxide donors such as nitropusside or nitrates should not be used in ADRVF due to PAH as they can exacerbate systemic hypotension.

Although the recombinant B-type natriuretic peptide nesiritide is effective in pulmonary hypertension due to left-sided heart failure, it has not been shown to decrease PVR when administered acutely in patients with PAH with or without right ventricular failure. Data are lacking for this agent in PAH and concerns for systemic hypotension do not support use of nesiritide in this patient population at this time.

**ADRVF: Treatment of Volume Overload**

In severe right heart failure when diuretic resistance is operative, aggressive intravenous and combination diuretic therapy should be instituted. Diuretic resistance may result from 1) poor intestinal absorption of oral diuretic secondary to bowel wall edema; 2) pre-existing renal disease; 3) low cardiac output with renal arterial hypoperfusion and inadequate delivery of solute to the distal renal tubule; 4) renal arterial hypoperfusion combined with renal venous congestion resulting in reduced glomerular filtration; 5) tubular cell hypertrophy due to chronic diuretic use; 6) intense neurohormonal activation; and/or 7) concomitant administration of nonsteroidal anti-inflammatory agents or COX-2 inhibitors. Intravenous bolus loop diuretic therapy or a continuous infusion of loop diuretic (furosemide 5 to 20 mg/h, bumetanide 0.5 to 1 mg/h, and torsemide 5 to
10 mg/h) after a priming bolus dose often overcomes the diuretic resistance. The constant infusion strategy will maintain a continuous renal threshold of drug without the peak and valleys of the higher dose intermittent bolus administration and effect a constant diuresis with less ototoxicity. If loop diuretic drip alone is ineffective, then intermittent intravenous chlorthalidone (not to exceed 2 gm over a 24 hour period) can be instituted. Intermittent metolazone can also be administered provided that absorption of the oral drug is felt to be adequate. The use of an aldosterone antagonist in conjunction with loop or thiazide diuretics will often be effective. Aldosterone antagonists should be avoided in patients with hyperkalemia and significantly compromised renal function. Electrolytes should be monitored closely with these agents.

In the patient who is markedly volume overloaded and not responding adequately to aggressive diuresis, or in whom the blood urea nitrogen and creatinine are rising, low dose dobutamine and dopamine should improve renal perfusion and potentiate diuresis. If diuretic manipulation with inotropic assistance fails to adequately deal with the volume overload, mechanical fluid removal usually with continuous venous-venous hemodialysis or other methods of ultrafiltration should be promptly employed to decompress the right ventricle, improve right ventricular performance and left ventricular preload, and reduce vital organ congestion.

Once hemodynamic stabilization has been achieved with the maneuvers delineated above, optimization of chronic therapy should be instituted. For patients who are suitable candidates for lung or heart-lung transplantation, strategies should be put in place to successfully bridge them to surgery. For those who are unstable and/or have refractory right ventricular failure and are not candidates for transplantation, the emphasis of care should shift to palliation of symptoms and hospice care when appropriate.

Conclusions

In patients with PAH, right ventricular failure is associated with a poor prognosis. Established therapies for PAH should be instituted early and optimized to prevent right ventricular failure. Diuretics are the mainstay of therapy for right ventricular failure and should be optimized. For patients who present with ADRF an aggressive approach should be undertaken. Pharmacologic therapy including oxygen, inhalational nitric oxide, epoprostenol, and inotropic support must be instituted rapidly to prevent vital organ hyperperfusion. Volume overload must be treated promptly to decompress the right ventricle and promote left ventricular filling. Sequential nephron blockade with intravenous loop and thiazide diuretics as well as aldosterone antagonists should be instituted. Mechanical fluid removal should be applied if diuretic therapy fails. In suitable patients who continue to deteriorate despite optimal medical therapy, prompt evaluation and listing for lung or lung-transplantation is indicated. At specialized centers, atrial septostomy should be considered for severe right ventricular failure, recurrent syncope, or as a bridge to lung transplantation. Intravenous epoprostenol and beta-adrenergic inotropic agents may be utilized in combination as a bridge to transplantation. For end-stage right ventricular failure, when all treatment options are exhausted or are inappropriate, the focus of management should transition to palliative care.

References

Jack Reeves, MD, Remembered as ‘Renaissance Ideal,” in Stellar Career Spanning Diverse Pulmonary Research

It is rare for a clinician to be described as someone who came “as close as any of us will see to the Renaissance ideal.” Yet this is the praise earned by John “Jack” Reeves, MD, who died last September in a motor vehicle-bicycle accident in Colorado where he earned a reputation as a preeminent clinician and scholar..

The description of Dr Reeves came in a tribute to him from Richard Krugman, MD, Dean of the School of Medicine at the University of Colorado Health Sciences Center, Denver. Dr Reeves made exceptional contributions in teaching, mentoring, research, administration, and leadership to the Colorado Center for Altitude Medicine and Physiology. “He was a scientist of international stature. He made major advances at the molecular, cellular, animal, and human level with regard to the pulmonary circulation and adaptation to high altitude,” added Dr. Krugman.

For many years Dr Reeves was a senior member of the Cardiovascular Pulmonary Laboratory of the School of Medicine within the Department of Medicine and most recently played a significant role in the establishment of the Colorado Center for Altitude Medicine and Physiology in the Department of Surgery. In recent years Dr Reeves was an integral part of the pulmonary vascular biology group in the Department of Pediatrics and, according to Dr Krugman, was “a friend, counselor, mentor, scientific advisor and inspiration to a generation of pediatric pulmonologists, critical care physicians, cardiologists, neonatologists, and their colleague PhD investigators.”

Returning to the theme of Dr Reeves as the embodiment of the Renaissance ideal, Dr Krugman called him an internationally renowned investigator, a deeply compassionate physician, an athlete, an accomplished photographer, and a literary scholar.” Pursuing a strong interest in the formation and guidance of medical education groups,

(continued on page 29)