33 Management of Decompensated Right Ventricular Failure in the Intensive Care Unit

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Case Presentation

A 64 year old woman with a history of COPD (FEV1 of 1.1 L, 35 % predicted) on supplemental oxygen of 2 L/min by nasal cannula, obesity hypoventilation syndrome, and hypertension, was admitted with a 3-day history of worsening shortness of breath, increased productive cough, and pleuritic chest pain. On admission the patient had an increased white blood cell count (14.5 K), increased oxygen requirement to 6 L/min, and evidence of right lower lobe consolidation on computed tomographic pulmonary angiography (CTPA) (Fig. 33.1). No evidence of pulmonary embolism was seen. Twenty-four hours after admission, the patient developed increased work of breathing, worsening hypoxemia, and bilateral infiltrates on chest radiograph. She was intubated and transferred to the intensive care unit for mechanical ventilation and hemodynamic monitoring.

In the intensive care unit, a central venous catheter was placed which demonstrated central venous pressure (CVP) of 3 cm H_2O and a mixed venous oxygen saturation ($ScvO_2$) of 65 %. She was begun on intermittent sedation, and initial ventilator settings of FiO_2 60 %, tidal volume 450 cc (8 cc/kg ideal body weight), respiratory rate of 16 breaths per minute, and PEEP of 5 mmHg. At these settings, plateau pressure was 24 mmHg and there was no detectable autopeep. A point-of-care ultrasound performed by the intensivist demonstrated preserved left ventricular systolic function, however enlarged right ventricle and septal flattening were noted (Video 33.1). A plethoric inferior vena cava was noted to be discordant with the low CVP.

Question What approach should guide this patient's fluid management?

Answer Proper fluid management is critical for successful management of RV failure.

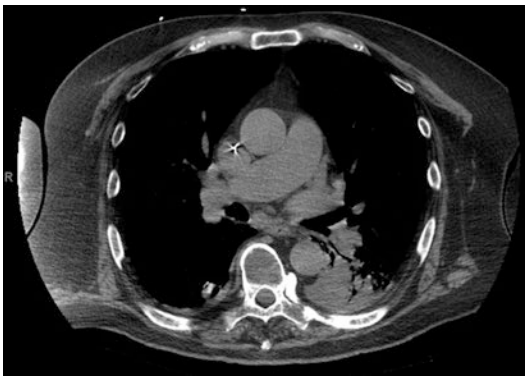

Fig. 33.1 CT scan demonstrating pneumonia in the left lower lobe a Pulmonary to Aorta ratio greater than 1

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In this case, given the ongoing infection, vigilance for a decreased intravascular volume must be maintained. With the increased vascular permeability, decreased oral intake and insensible losses related to fever, our patient is at high risk of hypovolemia and ensuing shock. This is accentuated by use of analgesics and sedative medications that are utilized for ventilator synchrony, which contribute to decreased venous tone and reduced right-sided preload [1]. Adequate right-sided filling pressure is a prerequisite for adequate cardiac output and in this patient volume resuscitation should be instituted as quickly as possible, with strict attention to RV parameters and end-organ perfusion.

Review of the patient's outpatient records revealed that she had undergone a work-up for pulmonary hypertension the year prior to presentation, when an echocardiogram performed in the evaluation of worsening lower extremity edema revealed a pulmonary artery systolic pressure (PASP) of 55 mmHg and dilated right ventricle. She subsequently underwent a V/Q scan, which was negative for chronic thromboembolic disease. Screening autoimmune serology was negative. Following diuresis, a right heart catheterization in euvolemic state was reported as: mean right atrial pressure (mRAP) of 14 mmHg, pulmonary artery pressure (systolic/diastolic/mean) 65/22/32 mmHg, PCWP 15 mmHg, cardiac output/cardiac index by Fick of 4.2 Lmin/1.8 L/min/m^2. The patient's pulmonary hypertension was judged to be primarily Group 3 in nature, related to chronic lung disease and hypoxemia and efforts focused on optimizing underlying comorbid conditions. Her baseline hemodynamics were useful in establishing her mRAP or right-sided filling pressures as being elevated. This gave a target for resuscitation, namely a CVP > 14 mmHg. Given the addition of positive pressure mechanical ventilation, an increased right-ventricular afterload, a target filling pressure of 16–18 mmHg would be an appropriate initial target, though multiple endpoints of perfusion should still be monitored.

Principles of Management

Diagnosis

This patient is manifested clinical and echocardiographic evidence of right ventricular dysfunction, which given the patient's history and negative CTPA is likely acute on chronic. Determining the causes of RV failure, specifically whether it is the result of established pulmonary vascular disease and secondary to concomitant disease states or a result of an acute increase in RV afterload versus RV ischemia is a critical step for patients presenting to the ICU with evidence of RV dysfunction. Also critical, though often difficult, is differentiating pressure overload from volume overload. If echocardiographic and CT imaging indicate an acute pulmonary embolism as a cause, relieving the increase in pressure/afterload attributed by the PE is the first and most critical treatment. If RV ischemia is identified, the treatment algorithm similarly shifts to reperfusion strategies. In situations where RV failure is acute on chronic as is the case with this patient, the conditions responsible for the chronic RV failure cannot be readily reversed and management options are limited to optimizing RV function.

In order to optimize RV function, it is necessary to first have accurate assessment of filling pressures and baseline hemodynamics. The utility of invasive monitoring for this purpose is controversial and will be addressed below. In addition to bedside echocardiography performed by the intensivist [2], formal assessment with transthoracic echocardiography (TTE) offers added utility [3]. In addition to assessing filling pressures, TTE can contribute to the quantification of degree of contribution of LV dysfunction and valvular heart disease. Estimates of pulmonary artery systolic pressure PASP on TTE are not indicative of severity of dysfunction as PASP falls with fall in cardiac output and attention is best directed at other surrogates of severity. RV systolic function can be assessed via the tricuspid annular plane systolic excursion (TAPSE) by measuring the systolic displacement of the RV base toward the

RV apex [4]. This has been shown to correlate well with RV ejection fraction, and values below 1.8 cm indicate a low RV stroke volume index with high sensitivity, though utility in acute settings is not well validated [5]. In addition to low TAPSE, prognostic indicators of poor prognosis in pulmonary hypertension are right atrial enlargement, pericardial effusion [6], and septal displacement, but this is not well studied in critically ill patients [7]. Though TTE estimates of PASP generally correlates with invasive measurements, the frequency of variance increases in patients with chronic lung disease [8], and similarly positive pressure ventilation can contribute to inaccurate assessment of pressure.

CTPA, though often obtained to exclude other causes of respiratory failure, may suggest the presence of right ventricular dysfunction. A ratio of main pulmonary artery to aortic diameter of greater than 1 correlates with elevated pulmonary artery pressure generally (Fig. 33.1) [9]. Alternatively, a pulmonary artery with a diameter greater than 2.9 cm has a high specificity for the presence of PH [9]. Other radiographic signs include increased right ventricular wall thickness (>4 mm), right ventricular dilation defined as right ventricle ventricle–to–left ventricle diameter ratio of more than 1:1 at the midventricular level on axial images, dilatation of the inferior vena cava and hepatic veins; and pericardial effusion [10, 11].

Monitoring of End-Organ Perfusion

Monitoring of endpoints of perfusion in patients with RV failure is critical, as acidemia that results from hypoperfusion and elevated lactate can worsen hypoxemic vasoconstriction in the pulmonary vascular bed, thus increasing afterload [12]. That said, monitoring for these patients can be accomplished by modalities utilized in the care of any critically ill patient. A central venous catheter that allows serial measurement of $ScvO_2$ and CVP is a valuable tool. By accurately assessing $ScvO_2$ and monitoring for values lower than 70%, the SvO_2 can be both an indicator of reduced cardiac output and provide a measure of current filling pressure. Superior vena cava central access is favored for this, as it is felt to be a more reliable surrogate of SvO_2 if well-positioned [13]. Similarly, serum lactate and urine output remain important indicators of tissue perfusion.

Serial point-of-care ultrasound may also be helpful, both for assessing hypovolemic states as well as identifying optimal timing to offload the RV [14]. For example, if TTE reveals RV dilation and impingement on LV filling this would suggest reduction in preload through diuresis may be needed. However, with hypovolemia, the inferior vena cava may not collapse, as pressure overload can predominate, even in settings of low intravascular volume (Video 33.2).

Pulse pressure variation (PPV) and stroke volume variation (SVV) are well-established modalities in the ICU, however the utility in pulmonary hypertension is not well established [15]. Small studies have demonstrated that PPV is in fact not predictive of increased stroke volume in patients with pulmonary hypertension [16, 17]. This is likely because in pulmonary hypertension, PPV and SVV are related to an inspiratory increase in RV afterload rather than a decrease in RV preload, and thus do not reliably indicate fluid responsiveness. Conceptually, lack of response to a volume challenge in the setting of high PPV or SVV may actually serve as an indicator of RV dysfunction.

Optimization of Right-Sided Filling Pressures

The CVP is a reliable surrogate of right atrial pressure [18]. The CVP pressure tracing consists of three positive waves (a, c, and v) and two descents (termed x and y) (Fig. 33.2). The CVP is measured immediately prior to the c wave when there is continuity with the right ventricle and gives an accurate estimate of preload. Optimally, the CVP is measured at end-expiration, when there is a net neutral pleural pressure and respiratory effect on central pulmonary vasculature is minimized [19]. Patients with chronic

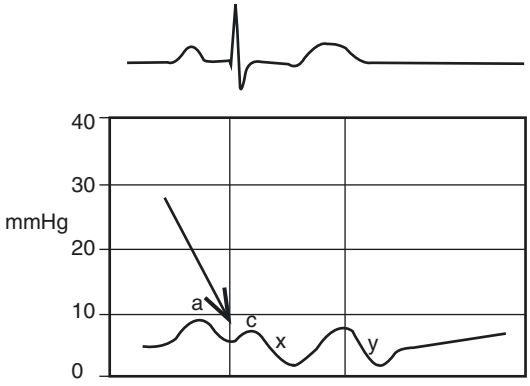

Fig. 33.2 The CVP is measured directly before the c wave (*arrow*)

compensated RV dysfunction generally have higher CVP at baseline and tend to be dependent on higher right-sided preload. Though there is considerable variation not only between individual patients, but also in varying states of afterload, in general preload goals should be targeted to maintain a moderately elevated filling pressure. Initial targets of 8–12 mmHg, with adjustment for observations of surrogates of low cardiac output or hypoperfusion are prudent. Should one have access to baseline hemodynamics for any individual patient, whether mRAP from right heart catheterization or estimate of CVP from TTE in a steady-state, these values can guide fluid management in a far more individualized way, allowing of course for variability and progression over time.

Reversal of Conditions that Heighten Pulmonary Vascular Tone

Many of the diseases that affect patients in the intensive care unit can worsen pulmonary vascular resistance (PVR). These conditions must be aggressively addressed in the setting of acute on chronic RV failure as they have a deleterious effect on the RV by increasing afterload. Perhaps most commonly implicated is hypoxic pulmonary vasoconstriction that occurs as a response to decreased oxygen saturation. Though the vasoconstriction is most pronounced in the setting of low alveolar oxygen tension, it is also affected by hypoxemia in the pulmonary and bronchial artery beds. Standard intensive care monitoring adequately assesses systemic oxygenation, but pulmonary arterial oxygenation is less easy to assess without invasive monitoring device. Measuring $ScvO_2$ can be a useful surrogate. Situations that worsen the vasoconstrictive response and PVR include hypercapnea and acidemia, and efforts to avoid each must be made [20, 21]. This is difficult when patients progress to ARDS and standard of care would mandate low-tidal volume ventilation and permissive hypercapnea. This unique situation will be elaborated upon below.

Ventilation Strategy

In general, when faced with RV dysfunction, attention to avoiding exposure to hypoxemia primarily and secondarily to hypercapnea and ensuing acidosis is prioritized [22]. As high lung volumes and associated distending pressures can worsen RV afterload, ventilating near functional residual capacity is favored [23, 24]. Though respiratory therapist driven ventilator liberation protocol is still relevant in this group, the presence of higher degrees of hypoxemia may be tolerated as many will have right to left shunting through patent foramen ovale (PFO). Should worsening hypoxemia be noted with increasing levels of PEEP, a dedicated bubble study for identification of occult PFO should be obtained for confirmation. Generally, high levels of PEEP should be avoided as autopsy studies suggest greater than 30 % of the population has PFO [25] and in the setting of right ventricular dysfunction and increased afterload there may be increased right to left shunting. APRV is discussed below.

Supportive Care

Early, broad-spectrum antibiotics, adherence to proven ventilator bundle strategies to minimize risk of ventilator associated events and complications are of equal importance in patients with RV dysfunction. Additionally, compliance with ABCDE protocol to ensure timely liberation of patients from mechanical ventilator support is essential [26].

Evidence Contour

Several aspects of management in the patient with acute decompensated RV failure remain without consensus in the face of available clinical trials. There are theoretical benefits to certain therapeutic options, and animal models support pathophysiologic rationale behind these choices.

Pulmonary Artery Catheter Use in Decompensated RV Failure

When reliable measurement of pulmonary hemodynamics is needed, pulmonary artery catheterization (PAC) provides valuable information on cardiac output, pulmonary artery pressure and filling pressures. Although the routine use of a PAC has not been well studied in the management of RV failure in the intensive care unit, serial measurement of hemodynamics can add value particularly in complex cases [24]. For example, in situations in which RV function is highly variable and dependent on small changes in volume or preload, then having serial measurements of cardiac output as fluid resuscitation is effected can be critical. Should the patient progress to require inotropic support, a PAC may be of value in titration of effect. Because of the complexity and small but real risk of complications such as pulmonary artery rupture, the benefit of PAC placement should be felt to outweigh the risks when used [27].

Choice of Vasopressor

Patients with chronic RV dysfunction often tolerate infection poorly, as systemic vasodilation and decreased preload impair already compromised RV function [28]. As such, even with appropriate fluid management and optimization of filling pressures, they may progress to shock and require vasopressor support. There is no ideal vasopressor, as none increases systemic pressure and RV contractility without increasing PVR [18]. However, norepinephrine is favored for patients with RV dysfunction who require pressor support [29]. Norepinephrine has predominantly α1 effects, with limited β1 receptor stimulation. In a small study of patients with sepsis with right heart failure, norepinephrine use was associated with improved RV myocardial oxygen delivery. Phenylephrine is not favored as it can cause reflex bradycardia, which is especially troubling for patients in whom tachycardia may be their sole means of increasing cardiac output, when stroke volume is relatively fixed [30]. Epinephrine is a mixed α/β receptor agonist that can induce vasoconstriction and increase inotropy [31]. Vasopressin at high doses causes pulmonary and coronary artery vasoconstriction [32]. Taken in aggregate, norepinephrine is a reasonable choice in these difficult clinical scenarios.

Selective Use of Inotropic Agents

Inotropic agents should be considered only when there is clear evidence of inadequate tissue perfusion despite optimization of volume status, preload and afterload. The risk of all inotropes is the incidence of tachyarrhythmias. Low-dose dopamine is a reasonable option to improve cardiac output without increasing PVR in patients with RV failure [33]. Dobutamine acts via β1 receptor, but can cause vasodilatation due to β2 effects and as such, higher doses should be avoided [34]. Milrinone is often the agent of choice, as it is the only non-adrenergic inotrope, and can improve inotropy while promoting pulmonary arterial vasodilatation [35].

Use of Selective Pulmonary Vasodilators

There are situations in which a patient has met endpoints in terms of preload, volume status, and oxygenation but there is not an appreciable improvement in RV function. Though vasodilating agents are an appealing choice, it is important to remember that no pulmonary vasodilator has been approved for the treatment of RV failure in critically ill patients [18]. In the setting of associated lung disease, administration can worsen gas exchange by blunting hypoxic pulmonary vasoconstriction and impairing V/Q matching. In the

setting of left heart disease, the influx of volume accomplished through pulmonary vasodilation may be poorly tolerated by the LV and result in worsening of hypoxemic respiratory failure [36].

Despite the inherent risks, there are times when attempting to offload the RV is the last best option. There is variability in the risks of each vasodilating agent. Inhaled nitric oxide (iNO) is a potent pulmonary vasodilator with an extremely short half-life, making it an appealing option. Importantly, because it preferentially affects the areas of the lung that are well ventilated, it can improve oxygenation by decreasing shunt fraction. There is evidence that iNO improves RV function and mixed venous oxygen saturation in patients with acute RV failure, though again it is difficult to extrapolate to acute on chronic RV failure [37]. Similarly, there are prostacyclin derivatives available by inhalation, but little is known about their use in critical illness.

Phosphodiesterase 5 (PDE5) inhibitors reduce PVR and may improve RV contractility, but little is known about their use in critical illness. These agents increase pulmonary vasodilation via the nitric oxide pathway. There is evidence in animal models that these agents may improve RV function in patients with chronic pulmonary hypertension who develop acute RV failure [38]. In contrast to the inhaled agents, PDE5 inhibitors can cause systemic hypotension and must be used cautiously in patients who are hemodynamically unstable [39]. This combined with their longer half-life makes their use particularly best suited for a pulmonary hypertension specialist. And this is true of the remainder of the available agents including intravenous prostacyclin analogues.

Ventilatory Considerations in the Face of ARDS

Principles surrounding the ventilator management of these patients are confounded in the face of ARDS. Acute hypoxia as a cause of pulmonary vasoconstriction is well described and is worsened by many factors, including acidosis and hypercapnia [40]. The evidence for benefit for a low tidal volume strategy is sound, and should be undertaken in a manner so as to avoid permissive hypercapnia, which will worsen pulmonary vasoconstriction. More straightforward perhaps is the recommendation that in refractory hypoxemia, a high PEEP strategy should be avoided. First, high PEEP leads to RV dilatation and reduced cardiac output in severe ARDS. Second, as many patients have occult PFO, which in the setting of chronic RV dysfunction manifest right to left shunting, increasing levels of PEEP can worsen shunting. Both atelectasis and ventilation at high lung volumes should therefore be avoided in patients with RV dysfunction as both worsen RV afterload. Prone ventilation may also reduce plateau pressures and pCO_2 sufficiently to improve acute RV failure, but evidence is limited [41, 42].

Airway pressure release ventilation (APRV) is sometimes employed for refractory hypoxemic respiratory failure [43]. As such, the setting required to successfully oxygenate a patient who has been refractory to conventional mechanical ventilation involve relatively high pressure settings. In patients with PH, APRV can increase PVR by prolonging the time exposed to high distending pressures. This increases afterload through compression of the alveolar vessels and likely outweighs the benefits conferred by reversing hypoxemia.

Extra Corporeal Membrane Oxygenation (ECMO)

Patients with refractory RV failure may benefit from support with ECMO as a bridge to transplantation. At centers with the expertise in this modality of support, the decision to proceed hinges upon whether the patient has been optimized with medical therapy and whether the patient is a reasonable candidate for lung or heart-lung transplantation. In order to provide hemodynamic and ventilatory support veno-arterial ECMO is preferred [44]. Use of this modality is contingent upon the patient's ability to tolerate intense anticoagulation and the possibility to achieve transplant within a reasonable amount of time.

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