Right Ventricular Support Options

An overview of acute RV failure, the importance of adequate support, and advancements in therapeutic devices.

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The management of acute right ventricular (RV) failure continues to be a major challenge for cardiac surgeons, with an incidence of 5% to 20% depending on the level of severity of RV dysfunction.[1] RV failure increases short-term mortality and can occur in patients via a number of mechanisms, including acute ischemia from RV myocardial infarction, refractory left-sided heart failure, pulmonary hypertension, and cardiogenic shock.[2-7] Medical management is generally the first-line approach for these patients and has shown some success; however, in refractory cases, mechanical support is the only option to augment the failing right ventricle. Failure of the right ventricle is often thought of as a secondary effect of a faltering circulatory system, primarily driven by left ventricular (LV) failure. Thus, the majority of the device options for ventricular support have been created for LV support. Given a recent appreciation for the high in-hospital morbidity and mortality associated with RV failure,[8-10] there has been considerable emphasis placed on the importance of adequate RV support with the use and creation of new device options.

PATHOPHYSIOLOGY OF RV FAILURE

RV function plays a critical role in heart failure prognosis, yet due to its complicated geometry and high sensitivity to fluctuations in loading conditions, assessing and treating RV dysfunction remain challenging.[11] Normal RV function is marked by low peak systolic function and < 20% the stroke work of the left ventricle, maintaining forward flow against a high-compliance, low-resistance pulmonic circulation.[7,12] This normal RV steady state is interrupted under pathophysiologic conditions such as acute RV contractile failure due to infarction, which is manifested by increased end-diastolic volume, reduced peak systolic pressure, and reduced stroke volume.[7] Independent of the intrinsic contractile function of the right ventricle are the forces that the right ventricle must contract against, and increased afterload is a major cause of RV failure.[13-15] Pulmonary hypertension, pulmonary embolism, and LV failure are all causes of RV failure and result in increased afterload with rising RV filling pressures and reduced stroke work.

MEDICAL MANAGEMENT

Medical management is the first-line option for reversible causes of RV failure and is tailored to mitigate the pathophysiologic strain placed on the right ventricle. Options include percutaneous coronary intervention for acute RV infarction, catheter-based thrombolysis for pulmonary embolism, aggressive diuresis in the setting of volume overload with a dilated right ventricle, and pulmonary vasodilators (eg, epoprostenol, nitric oxide) in the setting of pulmonary artery hypertension. If RV failure is refractory to medical management, the remaining options entail mechanical circulatory support (MCS).

MECHANICAL CIRCULATORY SUPPORT

Stabilization with MCS plays a critical role in treating the acutely failing right ventricle that has not responded to treatment of reversible causes with medical management. In the setting of cardiogenic shock, MCS unloads the heart and allows the right ventricle time to recover. Historically, MCS for the right ventricle has been limited to surgically implantable pulsatile pumps with inflow and outflow valves.[7] Currently, second- and third-generation RV assist devices (RVADs) use rotodynamic pumps that function from the transfer of rotational kinetic energy. MCS device options for RV failure can be subcategorized as "durable" or surgically implanted and percutaneous options.

PERCUTANEOUS DEVICES FOR RV SUPPORT

Intra-Aortic Balloon Pump

The use of an intra-aortic balloon pump (IABP) for counterpulsation successfully augments diastole and

increases coronary perfusion during balloon inflation, while simultaneously causing a sink effect during balloon deflation in systole with a resultant reduction in LV afterload. IABP use has been proven efficacious in the setting of acute decompensated LV failure. However, its use has limited utility in the setting of isolated RV failure. The theoretical benefits of IABP use in RV failure include improved right coronary perfusion via diastole augmentation and reduction in LV filling pressure, in effect, reducing RV afterload.[1,7]

Venoarterial Extracorporeal Membrane Oxygenation

The use of venoarterial extracorporeal membrane oxygenation (VA-ECMO) is an indirect method for bypassing the acutely failing right ventricle and has been widely adopted as a first-line option due to its availability and relative ease of use in biventricular failure with cardiogenic shock. Options for cannulation include central right atrial and aortic cannulation, often in the setting of sternotomy with postcardiotomy acute biventricular failure, or peripheral cannulation via the right femoral vein for right atrial drainage along with femoral artery cannulation (in the absence of severe peripheral artery disease). Due to large-diameter arterial inflow cannulas (18–20 F), it is often necessary to place a concomitant distal arterial perfusion cannula in the superficial femoral artery. VA-ECMO reduces RV preload by venous drainage from the right atrium with transfer of blood to the systemic arterial circulation, which results in increased mean arterial pressure and LV afterload. Due to the potential for increased LV strain, LV decompression is often required and can be achieved with an LV vent in the pulmonary vein or left ventricle, an IABP, or an LV Impella device (Abiomed, Inc.).

Impella RP

The Impella RP device (Abiomed, Inc.) is considered a temporary, minimally invasive, percutaneous RVAD composed of a 22-F catheter with a microaxial pump that can be used for up to 14 days.[16] The insertion site is often the femoral vein, and the Impella device is inserted under fluoroscopic and echocardiographic guidance using a peel-away 23-F sheath. The device is advanced to the inferior vena cava–right atrium junction and then carefully positioned across the tricuspid and pulmonic valves with the pump inflow in the inferior vena cava and the pump outflow into the pulmonary artery at a flow rate of up to 4 to 5 L/min, largely bypassing the right ventricle (Figure 1). Recent studies have demonstrated favorable results with Impella RP use, with a reduction in central venous pressure and improvement in cardiac output, including direct augmentation of pulmonary flow.[1,17]

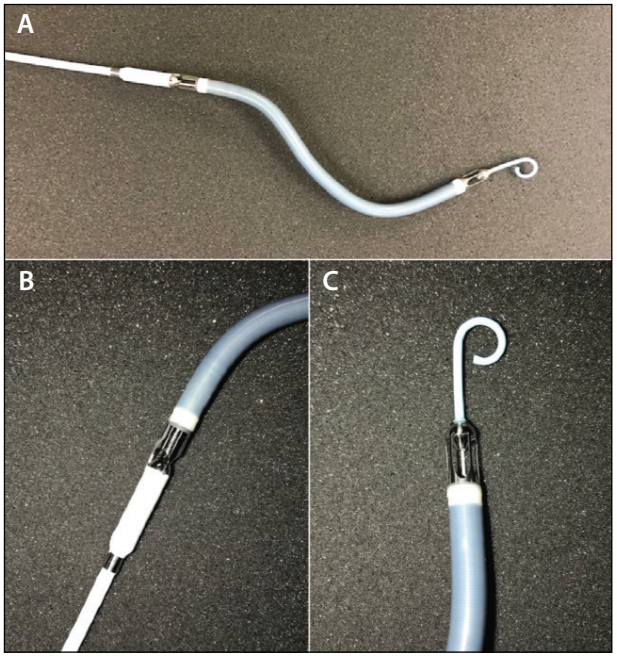

Figure 1. The Impella RP device has a small profile with an 11-F catheter diameter that is capable of generating flows ≥ 4 L/min (A). The blood inlet area sits in the inferior vena cava (B). The blood outlet area enters the right atrium and traverses the tricuspid and pulmonic valves to sit in the pulmonary artery (C).

TandemHeart

The TandemHeart centrifugal flow pump (TandemLife) is another percutaneous direct RVAD similar to the Impella RP device. Typically, there are two venous cannulas—one for drainage from the right atrium that is the inflow and the other that acts as an outflow cannula that is placed in the pulmonary artery (Figure 2). The cannulation sites for the right atrium and the pulmonary artery are generally the left femoral and the right femoral veins, respectively. Although adequate for hemodynamic support with flows up to 4 L/min, both the TandemHeart and the Impella RP devices can limit the patient's mobility due to the frequent need for groin cannulation. However, this limitation is somewhat mitigated by internal jugular venous access. Initial experience with the TandemHeart device for RV support showed favorable results, including increased cardiac output and improved RV hemodynamics but with variable mortality that was lowest in patients who required RV support in the setting of RV failure after LV assist device (LVAD) use.[18]

SURGICALLY IMPLANTED RVADs

Currently, short-term surgical RVADs are limited to extracorporeal centrifugal pumps requiring surgical access via sternotomy or thoracotomy with right

Figure 2. The TandemHeart device includes an extracorporeal centrifugal pump with venous inflow from the right atrium and outflow to the pulmonary artery.

atrial inflow and pulmonary artery outflow, effectively bypassing the right ventricle. The CentriMag device (Thoratec Corporation) is the primary option for surgically implanted centrifugal pumps and generates flows up to 10 L/min with reported good results in successful device weaning of patients with heart failure requiring temporary RV support (Figure 3).[1,10] Surgically implanted RVADs have the benefit of large-bore cannulation and generally maintain flows ranging from 6 to 8 L/min. For extended use, options include biventricular support with pulsatile VADs,[19] rotary flow RVADs, and isolated pulsatile RVADs.[7] However, RVAD use beyond short-term needs becomes impractical due to the required close clinical surveillance in a hospital setting. Therefore, existing LVADs have been used in the RV position to support the isolated right ventricle or biventricular function in a longer-term setting. Such options include, but are not limited to, the HeartWare (Medtronic) and Jarvik 2000 (Jarvik Heart, Inc.) devices.[20-25] However, the use of LVADs in the RVAD position is suboptimal as LVADs are designed for the high-resistance/high-flow systemic circulation, and the low-flow/low-resistance right atrial–to–pulmonary artery connection is often met by frequent "suck-down" events.

SUMMARY

RV failure continues to be a major cause of morbidity and mortality with limited options for mechanical

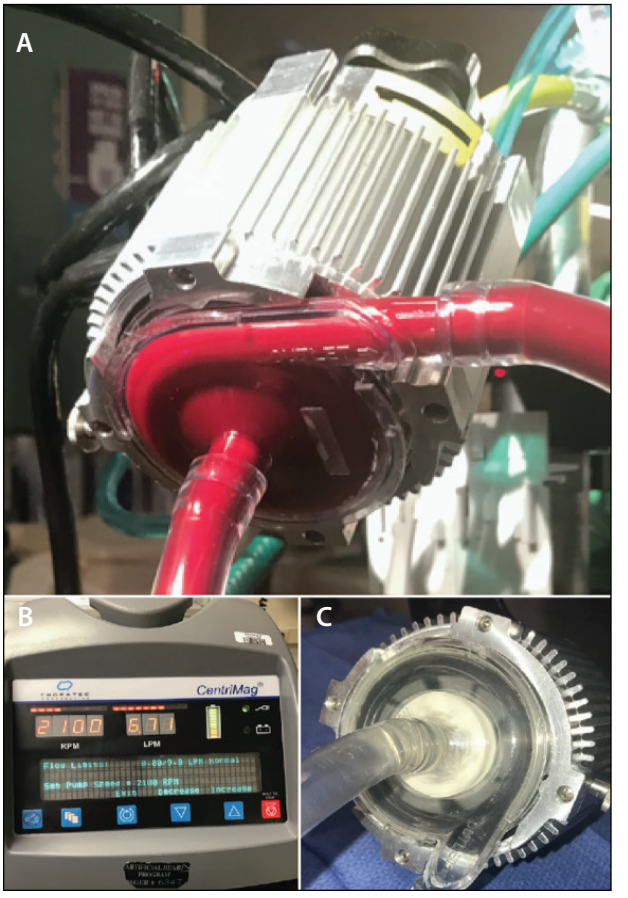

Figure 3. The CentriMag device with inlet from the patient and outlet to the patient (A). CentriMag is an optimal short-term RVAD that can achieve flows of up to 10 L/min (B). The levitating rotor ensures no frictional contact with the surrounding environment, which minimizes turbulent flow (C).

support; however, current advancements in percutaneous techniques have shown encouraging initial results. Patient selection and concomitant management of comorbid conditions, including pulmonary hypertension and left heart failure, are pivotal to successfully supporting the right ventricle in the short term while allowing recovery of acute RV failure. ■

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