Hypoxemia in a patient with biventricular HeartWare® ventricular assist devices

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Abstract
We present the case of a 59-year-old Caucasian man with a nonischemic cardiomyopathy who underwent implantation of HeartWare® (HeartWare Inc., Framingham, MA) ventricular assist devices (HVAD) for biventricular support due to refractory cardiogenic shock after attempted ventricular tachycardia ablation. After implantation of biventricular HVADs, he developed hypoxemia that failed to correct with administration of supplemental oxygen. A patent foramen ovale (PFO) was discovered on postoperative transesophageal echocardiogram (TEE). Speed adjustment of both the right and left HVADs under TEE guidance allowed for spontaneous closure of the PFO and resolution of the hypoxemia.

Keywords: biventricular mechanical support; advanced heart failure; biventricular assist devices; HeartWare®; hypoxemia

Case report
We present the case of a 59-year-old Caucasian man with sick sinus syndrome and high-grade atrioventricular block requiring dual chamber pacemaker implantation in 2010. He was diagnosed with a dilated cardiomyopathy after presenting in March 2012 with sustained ventricular tachycardia (VT), which terminated spontaneously. Coronary angiography demonstrated no coronary artery disease. He was subsequently upgraded to a biventricular pacemaker–defibrillator in April 2012 in the setting of VT and severely reduced left ventricular systolic function (LVSF).

He was stable on medical therapy until December 2012 when he experienced frequent implantable cardio defibrillator (ICD) shocks. An initial VT ablation was performed in January 2013. His procedure was complicated by ventricular fibrillation (VF) requiring several external defibrillations. His VT recurred a month later with multiple ICD discharges despite treatment with anti-arrhythmics. He was referred to our institution for further management. Echocardiogram showed moderately reduced LVSF with ejection fraction of 32%. There was borderline right ventricular (RV) enlargement with mildly reduced RV function.

A second attempt at VT ablation was performed with the hemodynamic support of an Impella® 2.5L (Abiomed Europe GmbH, Aachen, Germany) device. During the procedure, transient hypoxemia, hypotension, and low Impella® flows developed. On transesophageal echocardiogram (TEE), the RV was noted to be markedly dilated and hypokinetic. The ablation procedure was aborted and he was transferred to the intensive care unit intubated and requiring vasoactive medications. End-organ function was also compromised with acute renal failure and metabolic acidosis requiring continuous renal replacement therapy.
He was urgently taken to the operating room for biventricular HeartWare® ventricular assist devices (HVAD) implantation. Intraoperative TEE was notable for severe biventricular dysfunction. The interatrial septum bowed towards the left atrium but no patent foramen ovale (PFO) was identified. The left HVAD inflow cannula was placed in the standard LV apical position and the outflow conduit was anastomosed to the mid-ascending aorta. The right HVAD inflow cannula was bolstered with multiple felt washers and placed on the diaphragmatic surface of the RV. The outflow graft was narrowed over a #6 Hagar dilator for approximately 3-4 cm using titanium clips and anastomosed to the main pulmonary artery (PA).

The inotropic and vasoactive medications were dramatically weaned initially; however, multiple attempts at weaning the inhaled nitric oxide resulted in refractory hypoxemia. Arterial blood gas (ABG) at the time was as follows: 7.48/30/63/91% on 80% fraction of inspired oxygen (FiO₂) and a positive end-expiratory pressure (PEEP) of 10 mm Hg. We hypothesized that the HVADs were causing an iatrogenic PFO with right-to-left shunting. A TEE demonstrated a small collapsed LV, a dilated RV, and a thin interatrial septum with bowing towards the left atrium. There was the new finding of a tunneled PFO with color Doppler indicating a right-to-left shunt (Fig. 1). The right HVAD speed was then increased in an attempt to decrease right-sided filling pressures and avoid right-to-left shunting. Simultaneously, the left HVAD speed was decreased slightly to help prevent drawing blood directly from the right atrium into the systemic circulation. Direct visualization of the PFO after increasing the right HVAD speed confirmed closing of the flap and resolution of right-to-left shunting (Fig. 2). His hypoxia resolved allowing the slow wean of FiO₂ and PEEP and he was extubated successfully 2 days later without recurrence of hypoxia (ABG after extubation: 7.5/35/131/99% on 40% FiO₂ Venturi mask).

**Discussion**

The use of permanent biventricular assist devices has become more common recently. Newer, smaller pumps are more compact and easily-implantable as opposed to previous generation paracorporeal devices. These newer continuous-flow devices have demonstrated excellent results (1,2). In some cases, they allow for both RV and LV mechanical support (3). These permanent devices also allow for reduced hospital stays as patients can become ambulatory and rehabilitate faster with improved quality of life as opposed to bulkier devices such as the total artificial heart (4) and other paracorporeal devices for temporary RV support (5). Concurrent RV support is often needed as RV failure post-LVAD placement is a frequent and highly-morbid complication. Its incidence ranges between 9 and 44% depending on the definition of right heart failure being used (6). Furthermore, long-term outcomes are worse in patients with RV failure post-LVAD placement (7).
Hypoxemia caused by PFOs in patients supported by mechanical assist devices has been well-reported in the literature. PFOs are quite common in the general population with an incidence of 25-30% (8). Any condition causing elevated right-sided filling pressure that exceeds left atrial pressure in the presence of a PFO can cause transient right-to-left shunting and hypoxemia. It has previously been noted that after LVAD implantation there is a reversal of the atrial pressure gradient with right atrial pressure being higher than left atrial pressure (9). Therefore, it is critically important to understand the potential development of hypoxemia in the presence of a PFO in patients being considered for mechanical circulatory support.

There are several reports describing hypoxemia post-LVAD placement especially in the setting of mechanical ventilation and PEEP (10). Some case reports describe the use of TEE in the diagnosis of a PFO as the cause of right-to-left shunting post-LVAD implantation. TEE has been employed in the adjustment of PEEP in order to minimize shunting (10,11), as well as to aid in the percutaneous closure of a PFO (12,13).

The timing of when to diagnose a PFO during LVAD placement has been addressed in the literature. In a small study by Liao and colleagues, the pre- and post-LVAD implantation TEEs were evaluated in their ability to detect PFOs (14). They noted that the pre-cardiopulmonary bypass TEE missed all three surgically-confirmed PFOs. As a result, they perform a TEE with contrast bubble study intraoperatively once the patient is on LVAD support in order to assess for the presence of a PFO. Intraoperative manual compression of the PA has also been performed under TEE guidance in order to elicit the presence of an undiagnosed PFO (15). Guidelines in the clinical management of continuous flow devices strongly recommend either direct inspection or a bubble study after implantation in order to make the diagnosis of a PFO allowing for closure at the time of surgery (16).

Balancing the two in-series circulatory systems in the setting of biventricular mechanical support can be challenging. Since these HVADs were meant to withstand the afterload of the systemic circulation, some centers either perform a ‘banding’ procedure at the outflow graft of the right HVAD or reduce the diameter of the outflow graft in order to avoid excessive pulmonary circulation that could lead to pulmonary edema (3). Often the pulmonary vascular resistance of a patient with biventricular failure is elevated at the time of implant precluding the need for such modifications. In our patient, we elected to downsize the RV outflow graft as described previously (17,18).

This case highlights the importance of achieving a balanced circulation when managing biventricular assist devices. The initial speed settings allowed for blood to be pulled from the right atrium into the systemic circulation via an iatrogenic PFO. Spontaneous closure of the PFO was achieved by simultaneously increasing the right HVAD speed while decreasing the left HVAD speed under TEE guidance until PFO flap closure was demonstrated. As the use of intrapericardial HVADs becomes more widespread, the utilization of these devices for biventricular support will increase. Understanding the unique physiology that is created and the potential pitfalls in management are of utmost importance.

Conflicts of interest and funding

There is no conflict of interest in the present study for any of the authors.

References


