Waveform-guided management of implantable ventricular assist device in a small child

Jiyong Moon, MD, Hari Tunuguntla, MD, and Iki Adachi, MD, Houston, Tex

Ventricular assist device (VAD) support with a small left ventricular (LV) cavity poses a challenge. This is frequently encountered in children without cardiac dilation, particularly when using a device designed for adults, resulting in patient–device size mismatch. We present a case of a 4-year-old female patient (13.0 kg, body surface area 0.58 m²) with a remote history of congenital acute myeloid leukemia who developed chemotherapy-induced cardiomyopathy with restrictive physiology and pulmonary hypertension supported with HVAD (Medtronic, Inc, Minneapolis, Minn). Her clinical course is described to highlight the utility of the HVAD waveform in her management.

Our patient was evaluated for heart transplant due to worsening heart failure with progressive biventricular systolic and diastolic dysfunction. Hemodynamic catheterization demonstrated significantly elevated pulmonary vascular resistance (10.7 Woods × U/m²) with high LV end-diastolic pressures (24 mm Hg) (Tables E1 and E2). The decision was made to proceed with HVAD implant to induce reverse remodeling of the pulmonary vasculature and allow for further optimization of pulmonary hypertension therapies. The primary concern was her small LV cavity size, which would get even smaller once decompressed. Nonetheless, given the uncertainty in the duration of VAD support to improve her pulmonary vasculature, we chose a device that could offer an opportunity for outpatient management, rather than a pediatric paracorporeal VAD intended for inpatient management. Due to her small chest size and big pump housing, atrial cannulation was excluded.

The HVAD implant was performed via median sternotomy. The pulmonary artery pressure before sternal closure was at 60% systemic pressure (Figure 1, A).

Postoperatively, the HVAD pump speed adjustment was challenging. There was little margin between “excessive” and “insufficient” speed; when excessive, suction events ensued and when insufficient, the trough of the flow waveform approached “zero” or even became negative (Figure 2, A). A negative trough indicates flow reversal in the pump during the diastolic phase, resulting in stagnation and risk for pump thrombosis. With optimization of pulmonary vasodilator therapy post-VAD implant, there was gradual improvement in right heart cardiac output and preload to the HVAD demonstrated by the increased pulsatility in flow waveform. This favorable trend allowed for the pump speed to be increased from 2200 to 2260 rpm on postoperative day 10 (Figure 2, B). Repeat cardiac catheterization on day 47 showed an adequately decompressed left heart with low LV end-diastolic pressure (5 mm Hg) and improved pulmonary vascular resistance (4.7 Wood × U/m²) (Tables E1 and E2). She was activated on the transplant list and discharged home on day 65 without major complications.
After discharge, however, she developed 3 episodes of thromboembolic ischemic stroke despite appropriate anticoagulation and antiplatelet therapy. Her initial stroke occurred 3 months post-VAD implant, likely secondary to her small LV cavity with further decompression by VAD. The last 2 events were rapidly rescued with percutaneous embolectomy, resulting in minimal neurologic sequela. Of note, the second stroke induced persistent sinus bradycardia, resulting in diminished pump preload and suction events. This waveform abnormality resolved after providing an appropriate heart rate with atrial pacing (Figure 2, C). Subsequently, she received heart transplant on day 189, with uneventful recovery. Direct inspection of the explanted heart confirmed that the LV cavity was mostly occupied by the pump inflow (Figure 1, B and C). There was small organized thrombus around the LVAD inflow cannula.

This report highlights the current reality of pediatric VAD support; the choices are to use either adult devices (despite size mismatch and associated risks) or pediatric devices necessitating inpatient management. This also underscores the critical importance of the graphical display of flow waveform information. This information was crucial to the management of this patient. The graphic monitoring system can be an important compliment to a pediatric continuous flow VAD system.

The institutional review board or equivalent ethics committee of the Baylor College of Medicine did not approve this study because case reports on 3 or fewer patients do not meet the definition of research as a systematic investigation designed to contribute to generalizable knowledge. Patient written consent for the publication of the study was not received because all the patient’s information was deidentified.
FIGURE 2. HVAD wave form POD1 (A), POD 10 (B), and at heart rate in the 50 beats per minute range with sinus bradycardia (C). A, HVAD setting was minimum with 2160 rpm due to low LVAD filling. VAD flow was 1.0 L/min with the minimal pulsatility of waveform. Trough level was close to zero L/min (red arrow). B, With improving right heart cardiac output and resultant increase in left heart preload, HVAD speed was increased to 2260 rpm. This speed change not only increased the VAD flow to 2.3 L/min but also trough level above 1 L/min (red arrow). C, The waveforms were biphasic (blue arrow) during systolic phase, with the trough reaching below zero (red arrow), indicating partial inflow obstruction during systole phase and regurgitant flow to the VAD pump during diastole phase. POD, Postoperative; LVAD, left ventricular assist device; VAD, ventricular assist device.
References

1. Patel SR, Saeed O, Naftel D, Myers S, Kirklin J, Jorde UP, et al. Outcomes of restrictive and hypertrophic cardiomyopathies after LVAD: an INTERMACS analysis. J Card Fail. 2017;23:859-67.

2. Grupper A, Park SJ, Pereira NL, Schettle SD, Gerber Y, Topilsky Y, et al. Role of ventricular assist therapy for patients with heart failure and restrictive physiology: improving outcomes for a lethal disease. J Heart Lung Transpl. 2015;34:1042-9.

3. Miera O, Kirk R, Buchholz H, Schmitt KR, VanderPluym C, Rebeyka IM, et al. A multicenter study of the HeartWare ventricular assist device in small children. J Heart Lung Transpl. 2016;35:679-81.

4. Adachi I, Guzmán-Pruneda FA, Jeewa A, Fraser CD Jr, McKenzie ED. A modified implantation technique of the HeartWare ventricular assist device for pediatric patients. J Heart Lung Transpl. 2015;34:134-6.

5. Adachi I, Spinner JA, Tunuguntla HP, Elias BA, Heinle JS. The miniaturized pediatric continuous-flow device: a successful bridge to heart transplant. J Heart Lung Transpl. 2019;38:789-93.
### TABLE E1. Hemodynamic evaluation by echocardiogram before and after VAD implantation

|                     | Pre-VAD implantation | Post-VAD implantation (2 mo after VAD) |
|---------------------|----------------------|----------------------------------------|
|                     | Value                | Z score                  | Value     | Z score                  |
| LVEDV               | 42 mL                | 1.5                      | 26 mL     | –2.0                     |
| LVEDD               | 49 mm                | 0.5                      | 27 mm     | –2.3                     |
| LVEDA               | 10.2 cm²             | 1.8                      | 6.7 cm²   | –2.0                     |
| LVEF                | 25%                  | –7.6                     | 64%       | 0                        |

VAD, Ventricular assist device; LVEDV, left ventricle end-diastolic volume; LVEDD, left ventricle end-diastolic diameter; LVEDA, left ventricle end-diastolic area; LVEF, left ventricle ejection fraction.

### TABLE E2. Hemodynamic evaluation by catheter examination before and after VAD implantation

|                     | Pre-VAD implantation | Post-VAD implantation (47 d after VAD) |
|---------------------|----------------------|----------------------------------------|
|                     | Room air             | O₂ + iNO 40 ppm | Room air             | O₂ + iNO 40 ppm   |
| LVEDP               | 24 mm Hg            | 42 mm Hg       | 5 mm Hg (PCWP)      | 4 mm Hg (PCWP)   |
| mPAP                | 53 mm Hg            | 40 mm Hg       | 20 mm Hg            | 18 mm Hg         |
| TPG                 | 37 mm Hg            | 6 mm Hg        | 15 mm Hg            | 14 mm Hg         |
| PVR                 | 10.7 Wood × U/m²     | 2.2 Wood × U/m² | 4.7 Wood × U/m²     | 4.0 Wood × U/m²  |

VAD, Ventricular assist device; iNO, inhaled nitric oxide; LVEDP, left ventricle end-diastolic pressure; PCWP, pulmonary capillary wedge pressure; mPAP, main pulmonary artery pressure; TPG, transpulmonary gradient; PVR, pulmonary vascular resistance.