Biventricular Circulatory Support With Two Miniaturized Implantable Assist Devices

Background—Up to 30% of patients with end-stage heart failure experience biventricular failure that requires biventricular mechanical support. For these patients, only bulky extracorporeal or implantable displacement pumps or the total artificial heart have been available to date, which enables only limited quality of life for the patients. It was our goal to evaluate a method that would allow the use of 2 implantable centrifugal left ventricular assist devices as a biventricular assist system.

Methods and Results—Seventeen patients have been implanted with 2 HeartWare HVAD pumps, 1 as a left ventricular assist device and 1 as a right ventricular assist device. Seventy-seven percent of the patients had idiopathic dilated or ischemic cardiomyopathy. Their age ranged from 29 to 73 years (mean 51.8 ± 14.5 years), and 11 (64.7%) received intravenous catecholamine support preoperatively. The right ventricular assist device pump was implanted into the right ventricular free wall. The afterload of this pump was artificially increased by local reduction of the outflow graft diameter, and the effective length of its inflow cannula was reduced by the addition of two 5-mm silicon suture rings to the original HVAD implantation ring. All right ventricular assist device devices could be operated in appropriate speed ranges and delivered a flow of between 3.0 and 5.5 L/min. Thirty-day survival was 82%, and 59% of the patients could be discharged home after recovering from the operation. There was no clinically relevant hemolysis in any of the patients.

Conclusions—Two HeartWare HVAD pumps can be used as a biventricular assist system. This implantable biventricular support gives the patients more comfort and mobility than usual biventricular ventricular assist devices with large and noisy displacement pumps. (Circulation. 2011;124[suppl 1]:S179–S186.)

Key Words: cardiomyopathy ventricular assist device heart failure
the successful use of 2 Jarvik 2000 Flowmaker pumps. However, this device did not become widely accepted, probably because the Jarvik 2000 is designed for connection to the descending aorta and therefore is difficult to explant during subsequent heart transplantation. Furthermore, at least in the United States, the device was only approved for left ventricular use.

It was our goal to evaluate a method that would allow the use of 2 implantable centrifugal LVADs of the type HeartWare HVAD (HeartWare Inc, Framingham, MA) as a biventricular assist system. In making this attempt, 3 issues had to be solved:

1. Because the HeartWare HVAD is designed for use in the systemic circulation, in the pulmonary circulation without systemic afterload, even with the lowest recommended pump speed of 2400 rpm, the flow delivered by the HVAD would be too high, theoretically resulting in severe pulmonary edema.

2. The inflow cannula of the HVAD is 35 mm in length. Although the right ventricular (RV) dimensions are usually increased in RV failure, this might be too long.

3. Because there was little experience with connecting continuous-flow ventricular assist devices (VADs) to the right side of the heart, the optimal anatomic site for this connection had to be determined.

### Methods

#### Patients

After individual consent for the operation, especially for the off-label use of the HeartWare HVAD pump as an RV assist device (RVAD), was obtained from every patient and the study was approved by our institutional review committee, 17 patients (2 women, 15 men) received implantation of 2 HeartWare HVAD pumps, 1 as LVAD and 1 as RVAD. Their age ranged from 29 to 73 years (mean 51.8 ± 14.5 years) and their body mass index from 18 to 32 kg/m² (mean 25.3 ± 6.0 kg/m²). Eleven (64.7%) of the patients were on intravenous catecholamine support. The mean Philadelphia score for assessment of RV function and feasibility of LVAD versus BVAD support was 50.5 ± 14.0. Preoperative data are summarized in Table 1.

### Table 1. Preoperative Data

<table>
<thead>
<tr>
<th>Patient</th>
<th>Sex</th>
<th>Weight, kg</th>
<th>BMI, kg/m²</th>
<th>Age at Implantation, y</th>
<th>INTERMACS</th>
<th>Heart Disease</th>
<th>Previous Procedures</th>
<th>Creatinine, mg/dL</th>
<th>LVEF, %</th>
<th>LVEDD, mm</th>
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</thead>
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<td>1</td>
<td>M</td>
<td>63</td>
<td>21.8</td>
<td>57</td>
<td>4</td>
<td>ICM</td>
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<td>M</td>
<td>84</td>
<td>24.5</td>
<td>60</td>
<td>2</td>
<td>DCM</td>
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<td>0.70</td>
<td>15</td>
<td>77</td>
</tr>
<tr>
<td>3</td>
<td>M</td>
<td>95</td>
<td>32.1</td>
<td>57</td>
<td>2</td>
<td>ICM</td>
<td>Mechanical MVR + CABG</td>
<td>1.30</td>
<td>20</td>
<td>80</td>
</tr>
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<td>4</td>
<td>M</td>
<td>50</td>
<td>19.5</td>
<td>32</td>
<td>2</td>
<td>Congenital</td>
<td>Mechanical AVR + VSD closure LVAD, short-term RVAD</td>
<td>0.36</td>
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<td>87</td>
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<td>M</td>
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<td>26.2</td>
<td>58</td>
<td>1</td>
<td>Postcardiomy heart failure</td>
<td>MVRp, ECMO, LVAD, short-term RVAD</td>
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<td>10</td>
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</tr>
<tr>
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<td>M</td>
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<td>17.5</td>
<td>44</td>
<td>1</td>
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<td>LVAD, short-term RVAD</td>
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<td>15</td>
<td>57</td>
</tr>
<tr>
<td>7</td>
<td>F</td>
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<td>22.4</td>
<td>63</td>
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<td>DCM</td>
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<td>Permanent</td>
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<td>25</td>
</tr>
<tr>
<td>8</td>
<td>M</td>
<td>90</td>
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<td>70</td>
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<td>ICM</td>
<td>CABG</td>
<td>Permanent</td>
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<td>15</td>
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<td>28</td>
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<td>DCM</td>
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<td>BTT</td>
<td>0.77</td>
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<td>BTT</td>
<td>1.90</td>
<td>10</td>
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<tr>
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<td>39.4</td>
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<td>DCM</td>
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<td>BTT</td>
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<tr>
<td>12</td>
<td>F</td>
<td>47</td>
<td>17.4</td>
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<td>RCM</td>
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<td>BTT</td>
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<td>60</td>
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<td>73</td>
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<td>BTT</td>
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<td>M</td>
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<td>27.0</td>
<td>59</td>
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<td>M</td>
<td>116</td>
<td>33.2</td>
<td>56</td>
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<td>ICM</td>
<td>CABG + MVRp</td>
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<td>25</td>
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<td>86</td>
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<td>DCM</td>
<td>None</td>
<td>BTT</td>
<td>1.20</td>
<td>10</td>
</tr>
</tbody>
</table>

Mean ± SD 80.2 ± 22.4 25.3 ± 6.0 51.8 ± 14.5 2.2 ± 0.77 1.51 ± 1.0 20.2 ± 12.4 65.8 ± 12.9

BMI indicates body mass index; INTERMACS, Interagency Registry for Mechanically Assisted Circulatory Support; VAD, ventricular assist device; LVEF, left ventricular ejection fraction; LVEDD, left ventricular end-diastolic diameter; M, male; ICM, ischemic cardiomyopathy; BTT, bridge to transplantation; DCM, dilative cardiomyopathy; MVR, mitral valve replacement; CABG, coronary artery bypass grafting; AVR, aortic valve replacement; VSD, ventricular septal defect; LVAD, left ventricular assist device; RVAD, right ventricular assist device; MVRp, mitral valve repair; ECMO, extracorporeal membrane oxygenation; F, female; N/A, not available; and RCM, restrictive cardiomyopathy.
Fourteen of the patients in the present study presented with severe chronic biventricular failure that required BVAD support according to our institutional guidelines. S/L axis indicates ratio of short-axis diameter to long-axis diameter; RVEDD, right ventricular end-diastolic diameter; RVEF, right ventricular ejection fraction; RA, right atrium; PVR, pulmonary vascular resistance; BVAD, biventricular assist device; and LVAD, left ventricular assist device.

At our institution, patients are considered for primary biventricular support mainly on the basis of echocardiographic parameters. The degree of tricuspid regurgitation, RV end-diastolic diameter, RV ejection fraction, right atrial diameter, and the sphericity index of the RV together with the pulmonary resistance form the basis for the decision for biventricular support (Figure 1). Furthermore, clinical parameters of secondary renal or liver dysfunction are taken into consideration. These data are summarized in Table 2.

**Implantation Procedure**

In all 17 patients after implantation of 1 HeartWare HVAD device as an LVAD as described elsewhere, a second pump was implanted into the RV free wall as an RVAD (Figure 2). To allow for a "physiological" flow range of 3 to 6 L/min within a pump speed setting of between 2400 and 3500 rpm, as is usually set when the HVAD is used as an LVAD and as recommended by the manufacturer, the afterload of the right pump was increased artificially. After investigating this in a mock circulation model, we decided to reduce the outflow graft diameter to such a degree that the afterload of the RVAD would reach the normal levels of the systemic circulation. In accordance with our mock circulation data, we decided to reduce the outflow graft to an inner graft diameter of approximately 5 mm in patients with normal pulmonary vascular resistance and to 6 to 7 mm in patients with elevated pulmonary vascular resistance. This was achieved by side clamping and narrowing the graft with a suture (6 × 0 Prolene). To ensure definite and reproducible reduction of the diameter, Hegar bars were used for calibration. The length of the narrowed section was 35 mm.

To reduce the effective length of the inflow cannula, we added two 5-mm silicon suture rings covered with Dacron velour (in-house product of the Deutsches Herzzentrum Berlin, made by Berlin Heart GmbH, Berlin, Germany) to the original HVAD implantation ring. The 2 rings were fixed to the original "apical" fixation ring with Bioglue (CryoLife, Atlanta, GA). These additional rings prevented the cannula from penetrating deeply into the RV cavity (Figure 3).

In all 17 patients, the right pump was connected to the anterior free wall of the RV just below the RV outflow tract. This implantation site yields the greatest distance between the tip of the inflow cannula and the opposite interventricular septum. In 1 patient, the pump was later switched to the right atrium (see below). All patients intra-

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**Table 2. Preoperative Data, Including Parameters of Right Ventricular Function**

<table>
<thead>
<tr>
<th>Patient</th>
<th>RVEDD, mm</th>
<th>RVEF, %</th>
<th>Bilirubin, mg/dL</th>
<th>AST, U/L</th>
<th>GGT, U/L</th>
<th>INR</th>
<th>CVP, mm Hg</th>
<th>TR Grade</th>
<th>S/L Ratio</th>
<th>PA Pressure</th>
<th>RL Ratio</th>
<th>Philadelphia Score</th>
<th>Signs of Chronic RV Failure</th>
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<td>526</td>
<td>1</td>
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<td>2</td>
<td>0.50</td>
<td>80/NA/31</td>
<td>0.64</td>
<td>34</td>
<td>Ascites</td>
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<td>64</td>
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<td>13</td>
<td>2–3</td>
<td>0.60</td>
<td>44/26/34</td>
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<td>47</td>
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<td>10</td>
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<td>30/11/19</td>
<td>0.66</td>
<td>32</td>
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<td>933</td>
<td>751</td>
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<td>10</td>
<td>3</td>
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<td>Ascites</td>
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<td>54</td>
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<td>1.5</td>
<td>23</td>
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<td>0x RVAD</td>
<td>0.64</td>
<td>NA</td>
<td>Ascites</td>
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<td>36</td>
<td>20</td>
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<td>24</td>
<td>226</td>
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<td>18</td>
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<td>12</td>
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<td>61/35/43</td>
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<td>Chronic renal failure</td>
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<td>51/28/38</td>
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</table>

**Mean ± SD**  
38.6 ± 6.4, 29.9 ± 11.7, 2.2 ± 3, 255 ± 721, 199 ± 200, 1.3 ± 0.2, 15.3 ± 6.8, 2.4 ± 0.8, 0.57 ± 0.05, 0.74 ± 0.13, 50.5 ± 14.0

RVEDD indicates right ventricular end-diastolic diameter; RVDD, right ventricular ejection fraction; AST, aspartate transaminase; GGT, gamma glutamyl transferase; INR, international normalized ratio; CVP, central venous pressure; TR, tricuspid regurgitation; S/L ratio, short-axis diameter divided by long-axis diameter of right ventricle; PA, pulmonary artery; R/L ratio, RVEDD divided by left ventricular end-diastolic diameter; RV, right ventricular; NA, not available; ECMO, extracorporeal membrane oxygenation; and RVAD, right ventricular assist device. The 2 rings were fixed to the original "apical" fixation ring with Bioglue (CryoLife, Atlanta, GA). These additional rings prevented the cannula from penetrating deeply into the RV cavity (Figure 3).

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**Figure 1. Algorithm for decision between left ventricular and biventricular support in patients with terminal heart failure at our institution.**

S/L axis indicates ratio of short-axis diameter to long-axis diameter; RVEDD, right ventricular end-diastolic diameter; RVEF, right ventricular ejection fraction; RA, right atrium; PVR, pulmonary vascular resistance; BVAD, biventricular assist device; and LVAD, left ventricular assist device.

Three of 4 criteria apply:

- Tricuspid insufficiency grade III or IV?
- No
- PVR < 4 Wood units?
- Yes

**Figure 2. Algorithm for decision between left ventricular and biventricular support in patients with terminal heart failure at our institution.**

S/L axis indicates ratio of short-axis diameter to long-axis diameter; RVEDD, right ventricular end-diastolic diameter; RVEF, right ventricular ejection fraction; RA, right atrium; PVR, pulmonary vascular resistance; BVAD, biventricular assist device; and LVAD, left ventricular assist device.

**Figure 3. Algorithm for decision between left ventricular and biventricular support in patients with terminal heart failure at our institution.**

S/L axis indicates ratio of short-axis diameter to long-axis diameter; RVEDD, right ventricular end-diastolic diameter; RVEF, right ventricular ejection fraction; RA, right atrium; PVR, pulmonary vascular resistance; BVAD, biventricular assist device; and LVAD, left ventricular assist device.
eratively received a left atrial catheter for direct pressure measurement during the first postoperative days.

Postoperative Patient Management and Anticoagulation

All patients received standard postoperative care for VAD patients according to our institutional guidelines. Postoperative catecholamine support consisted of noradrenaline in cases with low systemic resistance only, because the 2 mechanically supported ventricles do not need further inotropic therapy. No nitric oxide ventilation was applied. Patients were weaned from the respirator after complete hemodynamic stability was achieved and they became wide awake. Anticoagulation with intravenous heparin was started no earlier than 8 hours postoperatively, after blood loss via drainage tubes reached less than 50 mL/h. Target activated partial thromboplastin time levels were increased from 50 to 55 seconds on postoperative day 1 to 55 to 65 seconds on postoperative day 4. After removal of the mediastinal drainage tubes and pacing wires, oral anticoagulation with coumarin or warfarin was initiated. The target international normalized ratio was set at 2.8 to 3.5. Additional platelet inhibition with 100 mg of acetylsalicylic acid was used. To detect any clinically significant hemolysis due to the use of 2 HVAD pumps, free hemoglobin, bilirubin, haptoglobin, and lactate dehydrogenase blood levels were analyzed on a daily basis during the hospital stay and then for up to 6 months during outpatient visits.

Statistical Analysis

Statistical analysis was performed with SPSS version 10.0.0 for Windows (SPSS, Inc, Chicago, IL). Results are given as mean±SEM.

Results

Between September 2009 and November 2010, 17 patients received implantation of a BVAD using 2 HVAD devices at our institution, representing a cumulative experience with biventricular HVAD support of 7.9 patient-years. The majority of patients had idiopathic dilated cardiomyopathy (53%) or ischemic cardiomyopathy (24%). Sixty-five percent of the patients in the present study were in INTERMACS (Interagency Registry for Mechanically Assisted Circulatory Support) class I or II before BVAD implantation.

Perioperative survival (30 days) was 82%. Three patients died perioperatively, 1 of progressive multiorgan failure, 1 of intractable bronchial hemorrhage, and 1 of Candida sepsis with mediastinitis. Postoperative bleeding that required early surgical reexploration was the predominant postoperative complication (6 patients). Two cases of gastrointestinal bleeding, no stroke, and no pulmonary embolism occurred (Table 3). All RVAD devices could be operated in a pump speed range of between 2400 and 3800 rpm. With these settings, the RVADs delivered a flow of between 3.0 and 5.5 L/min. The right pump speed was adjusted according to central venous pressure levels. The LVAD pump speed was set to ensure the maximum possible flow with left atrial pressure values of between 8 and 13 mm Hg. During the first postoperative week, daily echocardiographic evaluation was performed so that the pump speed settings could be adjusted according to the filling status of both ventricles, the position of the interventricular septum, and the frequency of aortic valve openings, which resulted in LVAD flows of between 3.8 and 6.9 L/min.

In 1 patient (patient 9), after primary chest closure, stable hemodynamics could not be achieved. The patient was brought to the intensive care unit, and his volume status and mechanical ventilation were optimized; however, pump flows remained low, with 3.0 L/min on the right and 3.8 L/min on the left side. Transesophageal echocardiography revealed a compressed RV, with the tip of the right inflow cannula in close proximity to the interventricular septum. Because this situation could not be solved by changes in medical management, the patient was taken to the operating room again, and the right pump was switched to a right atrial connection (Figure 4). This maneuver resulted in an increase in the flows delivered to 4.0 L/min (right) and 5.5 L/min (left) and complete hemodynamic stability. The patient was discharged.
home after 53 days (Figure 5) and received successful heart transplantation after 230 days of biventricular support. Data on the postoperative outcome of the patients are given in Table 3.

Ten (59%) of the patients in the present study could be discharged home after they recovered from the operation (8 [67%] of 12 after primary operations (67%) and 2 [40%] of 5 after redo operations or secondary implantations). The mean

![Figure 4. Chest roentgenogram of patient 9 after switch of the right HeartWare HVAD pump from the anterior free wall of the right ventricle to the right atrium.](image-url)
length of postoperative hospital stay was 39 days, which reflects the preoperative severity of illness with organ dysfunction due to biventricular heart failure in these patients. After 3 weeks in a rehabilitation center, they joined our outpatient program, with regular visits to our outpatient department every 4 to 8 weeks.

In long-term patients in the present study who had elevated pulmonary artery pressures after BVAD implantation, we experienced a steady decline of pulmonary resistance during the support period. Therefore, occasionally a reduction of pump flow on the right side was necessary. Pump speed was reduced when the indicated RVAD flow was equal to or exceeded the LVAD flow. No adverse events of continuous RVAD flow with regard to the lungs were observed.

In 2 patients (patients 2 and 11), after 370 and 60 days of BVAD support, respectively, both RV function and the RV end-diastolic diameter normalized, which resulted in frequent suction events between the inflow cannula and the opposite interventricular septum. Subsequently, thrombosis of the right VAD pump occurred in both patients. The pumps were stopped without any hemodynamic consequences, and the 2 patients remained on left ventricular support only. In patient 2, we cut the driveline close to the pump and sealed it with a silicone cap. The distal part of the cable was removed to eliminate the possibility of infection and provide increased comfort for the patient, who at that time had been at home for almost 10 months. In patient 11, who was still in the intensive care unit at the time, only the controller and batteries were disconnected from the cable.

Analysis of hemolysis parameters revealed no significant increase in free hemoglobin, bilirubin, or lactate dehydrogenase blood levels during the first 6 postoperative months. Only haptoglobin levels were slightly diminished: They dropped from normal preoperative values to 72±49 mg/dL after 2 weeks (P=0.05) and 41±49 mg/dL after 3 months (P=0.048), without any clinical relevance.

No driveline infections have been detected in any of the 17 patients during the entire postoperative course to date. Six-month survival of the patients in the present study who received the BVAD system ≥6 months ago is 50.0%.

**Discussion**

Two HeartWare HVAD VADs can be used to form an implantable biventricular support system. After a few important modifications of the implantation procedure, the second pump can easily be implanted into the right side of the heart. These modifications mainly serve to adapt the pump to the low afterload in the pulmonary circulation. The HeartWare HVAD is constructed for pumping against a systemic vascular resistance of 600 to 3500 dyne·s⁻¹·cm⁻². The normal pulmonary resistance, however, is found between 80 and 200 dyne·s⁻¹·cm⁻². By performing a “banding” procedure at the outflow graft of the RVAD, we added a second resistance that was in serial connection to the patient’s own pulmonary resistance.

An effective way to achieve additional resistance is to reduce the diameter of the outflow graft, because according to the Hagen-Poiseuille equation, its internal radius influences the resistance to the fourth power. However, because native pulmonary resistance is increased in many patients with end-stage biventricular heart failure, a reduction of the outflow graft diameter to 6 mm is appropriate for patients with moderate pulmonary hypertension, and in cases with severe pulmonary hypertension, a reduction to 7 mm is appropriate (Table 4). However, other groups have published preliminary results of the use of 2 HVAD pumps as BVAD without such a banding procedure. These groups run the right-sided HVAD with pump speeds <2400 rpm.

In clinical practice, the patient’s pulmonary resistance is a dynamic value. During the weeks or months of left ventricular assistance, an initially increased pulmonary resistance can fall or can even drop to completely normal values. How far this process can go and which final level of pulmonary resistance will be reached are unpredictable. According to our mock circulation analysis, in the range of possible recovery of the pulmonary circulatory bed, the reserve of the pump speed spectrum after our “banding” procedure should be sufficient to guarantee an appropriate flow within the recommended pump settings. From our measurements, we can calculate that with an outflow graft diameter of 6 mm during pulmonary vascular resistance reduction from 800 to 160 dyne·s⁻¹·cm⁻², a constant pump flow of 6 L/min could be assured by reduction of the pump speed from 3200 to 2400 rpm.

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**Table 4. Recommendation for Inner Graft Diameter of the RVAD Outflow Graft According to Pulmonary Resistance**

<table>
<thead>
<tr>
<th>Pulmonary Vascular Resistance, dyne·s⁻¹·cm⁻²</th>
<th>Recommended Inner Graft Diameter, mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 to 240: Normal</td>
<td>5</td>
</tr>
<tr>
<td>240 to 400: Moderately increased</td>
<td>6</td>
</tr>
<tr>
<td>≥400: High</td>
<td>7</td>
</tr>
</tbody>
</table>

RVAD indicates right ventricular assist device.
Precise assessment of pulmonary pressures is difficult in the presence of a continuous-flow BVAD, because the RVAD cannot be stopped without having backward blood flow through the pump. The repeatedly necessary reduction of pump flow on the right side in the long-term patients in the present study who had elevated pulmonary artery pressures at BVAD implantation, however, can be interpreted as indirect evidence of a decline of pulmonary vascular resistance.

The reduction of the effective length of the inflow cannula by simply increasing the thickness of the implantation ring using additional distance rings leads to increased height of the extraventricular part of the entire device. In this case, the pump is not advanced as deeply into the RV, and therefore, more of the device stays in front of the ventercile. This requires enough space between the chest wall and the anterior wall of the RV. However, the majority of RVs are enlarged in the case of RV failure, and after mechanical unloading by a VAD, their diameter should reduce, which results in some extra space for the pump. In our experience, especially in slim patients with a short distance between the sternum and the vertebral column, this can be critical, and in such cases, atrial connection of the RVAD or implantation through the diaphragmatic RV wall can be a solution.

RV dimensions vary during the postoperative course. Because the left ventricle becomes smaller in most patients after LVAD implantation, this can also be expected for the RV when supported by an RVAD. This could potentially lead to a situation in which even the reduced effective length of the inflow cannula could be too long for the RV diameter. With this in mind, further clinical studies should elaborate on whether an inferior approach to the RV cavity might be better.

All of the patients in the present study showed severe chronic biventricular failure before VAD implantation. This was reflected by a mean RV end-diastolic diameter of 54.1±8.7 mm and a mean RV ejection fraction of 29.9±11.7%. The Philadelphia score, which is known for its ability to predict the feasibility of LVAD support only versus BVAD support, with a mean of 50.5±14.0, is well above the cutoff level of 30, below which sole LVAD support is recommended.7

Four of the patients in the present study died of multiorgan failure. In all of these patients, an appropriate VAD flow was achieved; however, 3 had signs of impaired liver function before the implantation. This was probably the reason for a 75% rethoracotomy rate for bleeding in this patient group (up to 3 times in 2 patients), which led to multiple transfusions, subsequent impairment of lung function, and finally, respiratory failure that triggered multiorgan failure.

Compared with survival rates of LVAD patient populations, both the 30-day and 6-month survival rates of 82.4 and 50.0% in the present study were lower. However, this is not significantly different from data on BVAD patients in the literature, because the recent INTERMACS annual report published a 6-month survival rate of 50% for BVAD patients.4 We consider the advantages of an implantable biventricular system to lie more in the comfort and quality of life of the VAD patients. The 2 systems run completely without noise, and even if the patients have to carry 2 controllers and up to 4 batteries, they experience a higher grade of freedom and mobility. Aortic insufficiency occasionally complicates long-term support with continuous-flow LVADs; however, we have not seen a similar phenomenon displayed on the right side as pulmonary insufficiency.

The versatility of the HVAD has influenced our surgical strategy for VAD candidates. For LVAD candidates with good RV function, a variety of different VAD systems are available. For those with reduced RV function, however, the HeartWare HVAD has become our LVAD system of first choice. Patients with highly diminished RV function who are clear candidates for primary BVAD support receive implantation of an additional HVAD as an RVAD. In all other patients, ie, patients with moderate RV dysfunction and substantial risk for RV failure after LVAD implantation, after implantation of 1 system as an LVAD, we evaluate whether the patient indeed needs additional RV support, and if so, a cost-effective temporary RVAD system (Levitronix CentriMag, Levitronix GmbH, Zurich, Switzerland) is implanted. In the few patients who show no postoperative recovery of RV function within a reasonable period of time, the temporary RVAD can later be replaced by a second HVAD system.

Conclusions

Two HeartWare HVADs VADs can be used to form an implantable biventricular support system. After a few important modifications of the implantation procedure, the second pump can easily be implanted into the right side of the heart.

A reduction of the outflow graft diameter, together with the addition of further rings to the original HeartWare sewing ring to reduce the effective length of the inflow cannula, allows stable pump function as an RVAD. The anterior free wall of the RV can be used as the implantation site in most patients. However, our approach represents a single-center experience and is not an obligatory one for the effective care of these critically ill patients. This implantable biventricular support system gives patients greater comfort and more mobility than the usual biventricular VADs with their large and noisy displacement pumps.

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Disclosures

None.

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