Biventricular (BiV) failure is associated with a high rate of in-hospital mortality despite advances in therapeutic interventions.\textsuperscript{1} Multiorgan system dysfunction (MOSD) is a frequent complication of BiV shock and often prohibits surgical ventricular assist device (VAD) placement. Patients with refractory cardiogenic shock may benefit from temporary BiV support to allow for organ recovery and to assess right ventricular (RV) function better with mechanical decompression of the left ventricle (LV).\textsuperscript{2} We report 2 cases of percutaneous BiV circulatory support with refractory cardiogenic shock.

**Case 1**

A 67-year-old man with a nonischemic dilated cardiomyopathy presented with acutely decompensated heart failure. An echocardiogram showed an LV ejection fraction of 10\%, moderately depressed RV function, and moderate tricuspid regurgitation (Movie I in the online-only Data Supplement). Right heart catheterization demonstrated a severely reduced cardiac output, elevated BiV filling pressures, and pulmonary hypertension (Table). The patient eventually developed MOSD refractory to dual inotropes, vasopressors, and a Mega (50 mL) intra-aortic balloon pump (Maquet, Inc). Because of MOSD, the patient was deemed a poor candidate for surgical VAD implantation. An Impella 5.0 axial-flow device was then deployed via the right axillary artery into the LV (Figure 1) to allow for organ recovery and improve RV function (Movie II in the online-only Data Supplement). Despite improved hemodynamics, the patient required increasing inotropic support (Table). Within 48 hours of Impella deployment, a TandemHeart centrifugal flow pump was implanted via the femoral veins as a right atrial to pulmonary artery bypass circuit to support RV function (Movie III in the online-only Data Supplement; Figure 1). Within 24 hours of BiV support, the patient’s systemic perfusion improved, inotropic requirements decreased, and renal function normalized (Table). Definitive surgical biventricular assist device (BiVAD) placement was discussed with the patient’s family, who decided that long-term support was not consistent with the patient’s wishes and requested withdrawal of care.

**Case 2**

A 53-year-old woman presented with new onset acutely decompensated heart failure. An echocardiogram showed severe BiV failure with an LV ejection fraction of 10\%. Right heart catheterization confirmed the diagnosis of cardiogenic shock despite dual inotropes and an intra-aortic balloon pump (Table). Within 24 hours of admission, the patient developed MOSD. An Impella 5.0 device was deployed via the right femoral artery into the LV and a TandemHeart pump deployed to support RV function. Within 12 hours of BiV support, her hemodynamic parameters and MOSD improved, thereby permitting successful implantation of a surgical HeartWare BiVAD (Figure 2). Pathological specimens confirmed extensive giant cell myocarditis. Within 3 months, the patient was discharged in stable condition and is currently awaiting transplantation.

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Discussion
BiV failure is a primary determinant of poor outcomes in cardiogenic shock. Persistent MOSD often complicates BiV failure and is a relative contraindication for surgical VAD placement. The use of percutaneous BiV support is relatively new. No reports have described the combined use of an Impella 5.0 and TandemHeart pumps to support LV and RV function, respectively. Our report has several potentially important clinical implications. First, we identify the potential advantage of stabilizing hemodynamics and improving MOSD with percutaneous support instead of direct surgical BiVAD placement. As illustrated by case 1, despite improved hemodynamics, percutaneous support provided critical time for the patient’s family to make an informed decision about surgical BiVAD placement. Second, we show that implantation of a percutaneous LV device may clarify the need for a right ventricular assist device by simulating the hemodynamic conditions when on LV support. In both cases, RV support was necessary despite LV support. Third, we demonstrate that BiV support may be achieved by either axillary or femoral deployment of an Impella 5.0 device with concomitant TandemHeart RV support. Finally, we demonstrate that stepwise evaluation of BiV function using hemodynamic variables may aid in determining the need for concomitant percutaneous RV support. In both cases, an elevated central venous pressure >16 mmHg, right atrial:pulmonary capillary wedge pressure ratio >0.8, Pulmonary Artery Pulsatility Index <1.0, and evidence of RV dilatation and impaired RV systolic function indicated the potential need for mechanical RV support. The clinical utility of these criteria after deployment of an LV support device has not been established and highlights the importance of examining all clinical variables when considering concomitant mechanical RV support. In conclusion, percutaneous circulatory support devices may serve as an additional therapeutic option for patients with BiV failure refractory to medical therapy. Further study is required to clarify the role of these device-based approaches for BiV failure.

Table. Hemodynamic Variables

<table>
<thead>
<tr>
<th>Devices</th>
<th>Systemic BP</th>
<th>CVP</th>
<th>PCWP</th>
<th>PAP</th>
<th>SVR</th>
<th>Cl</th>
<th>PAPI</th>
<th>RA-PCWP</th>
<th>Creatinine</th>
<th>AST</th>
<th>Total Bilirubin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 1</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IABP</td>
<td>76/42 (53)</td>
<td>27</td>
<td>44</td>
<td>64/44 (50)</td>
<td>1030</td>
<td>1.7</td>
<td>0.74</td>
<td>0.61</td>
<td>2.0</td>
<td>483</td>
<td>2.8</td>
</tr>
<tr>
<td>After Impella 5.0 LP</td>
<td>124/52 (76)</td>
<td>15</td>
<td>23</td>
<td>46/23 (30)</td>
<td>678</td>
<td>2.9</td>
<td>...</td>
<td>...</td>
<td>2.5</td>
<td>480</td>
<td>2.6</td>
</tr>
<tr>
<td>After Tandem RVAD</td>
<td>120/60 (80)</td>
<td>8</td>
<td>28</td>
<td>32/28 (31)</td>
<td>933</td>
<td>3.1</td>
<td>...</td>
<td>...</td>
<td>1.5</td>
<td>370</td>
<td>2.1</td>
</tr>
<tr>
<td>Case 2</td>
<td></td>
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</tr>
<tr>
<td>IABP</td>
<td>75/50 (58)</td>
<td>24</td>
<td>30</td>
<td>44/36 (38)</td>
<td>1470</td>
<td>1.9</td>
<td>0.3</td>
<td>0.8</td>
<td>3.3</td>
<td>1203</td>
<td>2.1</td>
</tr>
<tr>
<td>After Impella 5.0 LP and Tandem RVAD</td>
<td>95/72 (80)</td>
<td>18</td>
<td>22</td>
<td>45/28 (31)</td>
<td>952</td>
<td>2.3</td>
<td>...</td>
<td>...</td>
<td>2.7</td>
<td>1128</td>
<td>1.7</td>
</tr>
</tbody>
</table>

AST indicates aspartate aminotransferase; BP, blood pressure; Cl, cardiac index; CVP, central venous pressure; IABP, intra-aortic balloon pump; PAP, pulmonary artery pressure; PAPI, pulmonary artery pulsatility index; PCWP, pulmonary capillary wedge pressure; RA, right atrial; RVAD, right ventricular assist device; and SVR, systemic vascular resistance.
Disclosures
Dr Kapur receives preclinical research support from Cardiac Assist, Abiomed, and HeartWare and has received speaker honoraria from Maquet. Dr Pham receives preclinical research support from Cardiac Assist and HeartWare. The other authors have no conflicts to report.

References

Key Words: cardiogenic shock ■ heart failure ■ mechanical support
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Supplemental Material

**Video Clip 1.** 2D-echocardiogram demonstrating a left ventricular ejection fraction (LVEF) of 10% and moderate RV systolic failure.

**Video Clip 2.** Cine-angiography showing placement of an Impella 5.0 LP axial-flow device under fluoroscopic guidance via the right axillary artery, across the aortic valve, into the left ventricle.

**Video Clip 3.** Cine-angiography showing deployment of the Tandemheart outflow cannula via the femoral vein into the pulmonary artery using a J-tipped wire.