Survival After Left Ventricular Assist Device With and Without Temporary Right Ventricular Support

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Background. Right ventricular (RV) failure after the insertion of a left ventricular assist device (LVAD) historically results in poor outcomes. Patients requiring temporary RV support after LVAD insertion are a heterogeneous group of patients consisting of those in cardiogenic shock after myocardial infarction, to those with chronic decompensated heart failure. For patients requiring biventricular support, we have used a hybrid system consisting of a HeartMate II LVAD and CentriMag right ventricular assist device (RVAD). The purpose of this study was to determine the 1-year survival in patients requiring isolated LVAD and patients requiring biventricular support.

Methods. All patients who underwent HeartMate II LVAD alone or in conjunction with a temporary CentriMag RVAD were examined from 2006 to 2011. Preoperative demographics, operative outcomes, and survival were analyzed.

Results. A total of 139 patients required HeartMate II insertion; 34 (24%) required biventricular support at the time of HeartMate II implantation. The mean duration of biventricular support was 17 ± 11.9 days (range, 6 to 56 days) with 91.8% (n = 31) of RVADs successfully explanted. Survival to hospital discharge was not different between groups (95.2 versus 88.2%; p = 0.2). However, 1-year survival was significantly greater in patients who required isolated HeartMate II LVAD (87% versus 77%; p = 0.03).

Conclusions. Biventricular support using a HeartMate II LVAD and CentriMag RVAD resulted in limited mortality at hospital discharge. However biventricular dysfunction does not have a favorable outcome at 1 year when compared with patients requiring isolated HeartMate II.

Right ventricular (RV) failure is a common and devastating problem after left ventricular assist device (LVAD) insertion [1], significantly increasing the morbidity and mortality [2]. Although in some patients RV failure can be treated conservatively using inotropic agents, inhaled nitric oxide, or delayed chest closure, approximately 15% will require an RV assist device (RVAD) [3]. Unfortunately, the insertion of an RVAD is the number one risk factor for mortality after LVAD insertion, which can be as high as 50% to 70% [3].

The identification of risk factors to predict patients necessitating an RVAD after LVAD insertion has been proposed by many groups [1–5]. However, patients with biventricular dysfunction requiring biventricular assist device (BiVAD) support represent a heterogeneous group ranging from patients in cardiogenic shock after a myocardial infarction to those with a known history of chronic heart failure who experience acute decompensation. Therefore, although some of these measures are useful, it can be difficult to clearly delineate which markers for RV failure may be most important for each patient. Therefore, we believe it is not only the prediction of patients who will require RVAD support that is important but also the optimization of RVAD therapy.

We have used a hybrid ventricular assist device system consisting of a Thoratec HeartMate II (Thoratec Corp, Pleasanton, CA) and CentriMag (Thoratec Corp) temporary RVAD for patients requiring BiVAD support. Using this hybrid system we are able to close the sternum, subsequently extubate the patient, and eventually remotely remove the cannula from the RVAD. We hypothesized that (1) using our hybrid system we would demonstrate a reduction in hospital mortality as compared with previously published results, (2) there would be no significant difference in hospital mortality between patients requiring isolated LVAD compared with our hybrid system, and (3) 1-year mortality would be greater within the hybrid group versus isolated LVAD group as a consequence of impaired RV function.

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Dr Massey discloses that he has a financial relationship with Thoratec Corporation.
Material and Methods

Review

After institutional review board approval, patients who underwent either implantation of an isolated HeartMate II LVAD or a HeartMate II LVAD in conjunction with a CentriMag RVAD were reviewed. Data were examined between 2006 and 2011 to ensure a 1-year follow-up period. Preoperative demographics, operative outcomes, and survival were analyzed. The timing for LVAD or BiVAD insertion was classified into three different presentations: (1) chronic heart failure in which patients had New York Heart Association functional class IIIB or IV heart failure but were not in cardiogenic shock; (2) acute-on-chronic heart failure patients, who have acutely decompensated cardiac function with a known history of chronic heart failure; and (3) acute heart failure, defined as patients who had no history of cardiovascular disease who were in cardiogenic shock. The timing of the operation was defined as emergent if the patient required ventricular assist device (VAD) therapy in less than 24 hours, urgent if between 24 and 48 hours, and elective if greater than or equal to 48 hours.

Criteria for Left Ventricular Assist Device Insertion

Our criteria for HeartMate II LVAD insertion are similar to previously published reports [6]. Briefly, all patients must have symptoms corresponding to New York Heart Association class IIIB or IV failure. In addition patients must have a left ventricular ejection fraction less than 0.25, peak oxygen consumption of less than 12 mL · kg⁻¹ · min⁻¹ or inotropic dependence, body metabolic index of less than 35 kg/m², and symptoms that have failed to respond to optimal medical management for greater than 60 of the past 90 days. In addition, our contra-indications for HeartMate II insertion included worsening liver and kidney function, ankle–brachial index less than 0.6, active infection, or a hypercoagulable syndrome.

Preoperative Right Ventricle Assessment

In all patients a right heart catheterization is performed before HeartMate II insertion to evaluate the RV function. In particular, when the ratio between the pulmonary capillary wedge pressure and central venous pressure (CVP) is less than 1.5 or the RV stroke work index less than 400 mm Hg · m⁻² · L⁻¹ or pulmonary capillary wedge pressure to CVP ratio less than 1.5; or (3) failure of isolated HeartMate II LVAD implant with VAD index less than 2.2 with elevated filling pressures (CVP >18 mm Hg) on inotropic and pulmonary vasodilatory therapy (eg, nitric oxide or epoprostenol sodium).

Cannulation for RVAD therapy was performed using one of two techniques: (1) standard central cannulation using direct right atrial and pulmonary artery cannulation (performed from 2002 to 2008); or (2) remote cannula removal approach using a percutaneous femoral venous cannula (25F Quickdraw, Medtronic Inc, Minneapolis, MN) and a percutaneous pulmonary arterial cannula (19F Biomedicus, Medtronic Inc) exiting through the left chest (2008 to present). Using the remote cannula removal approach, the RVAD inflow cannula is percutaneously placed into the right femoral vein, with the cannula tip placed within the mid–right atrium. Outflow cannulation is achieved after two pursestring sutures have been placed on the main pulmonary artery. The outflow cannula is brought through the fifth to sixth intercostal space after the pulmonary pleura has been dissected laterally. This ensures that the left pleural space will not have been violated on cannula insertion, allowing for minimal adhesions at the time of cannula removal. An 8-mm Hemashield graft (Maquet, Wayne, NJ) is placed around the outflow cannula. After placement of 2.5 cm of the cannula into the pulmonary artery, the pursestring sutures are tied, and the graft is brought down to the main pulmonary artery. The adventitia of the pulmonary artery is then sewn to the graft using two 5-0 Prolene sutures (Ethicon). The cannula is then tightly secured within the graft using three silk ties placed near the chest wall (Fig 1). Both cannulas undergo adequate removal of air and are connected to the CentriMag pump. Once LVAD and RVAD therapy has started and adequate hemostasis is achieved, the sternum is closed and the patient is taken to the intensive care unit. If the patient requires RVAD therapy for greater than 2 weeks, the femoral venous inflow cannula is replaced using a right internal jugular cannula (19F Biomedicus, Medtronic Inc) to allow for ambulation and easy transfer from the bed to the chair.

Postoperative Wean

After placement of a transesophageal echocardiogram probe, the patient is given 150 U/kg of heparin. The HeartMate II speed is decreased by 200 to 400 rpm, and
the RVAD flows are decreased in 1-L increments. Attention is continuously given to the ventricular septum to ensure that it remains midline. If the septum begins to shift toward the left ventricle demonstrating increased RV volume, the weaning process is stopped, with return to the previous LVAD and RVAD settings. Further variables necessary to assess are a CVP of 20 mm Hg or less without an increase of 15% from baseline, and a decrease in LVAD flows greater than 1.0 L/min with a cardiac index of at least 2.2. Once the RVAD is no longer used, the patient is monitored for 1 hour to identify any instability. Once it has been determined that it is safe to remove the RVAD, a 5-cm left anterior thoracotomy is performed to visualize the outflow graft. The graft is identified, the cannula is removed, and the remaining graft is stapled.

Statistical Analysis
All data are presented as mean ± standard deviation unless otherwise stated. Univariate statistical analysis was performed after ensuring equality of variables. Qualitative variables were compared using $\chi^2$ analysis. Kaplan-Meier survival curves were constructed and compared using the log-rank test. All statistics were performed using GraphPad Prism version 5.0, (GraphPad Software, San Diego, CA). In all cases, a probability value of less than 0.05 was considered significant.

Results
A total of 139 patients underwent VAD placement, 105 with an isolated HeartMate II and 34 who required BiVAD support at the time of the current operation (Fig 2). There was no difference between the preoperative age and sex between the two groups (Table 1). As expected, there were more patients requiring an emergent operation within the BiVAD group, whereas patients requiring isolated HeartMate II were more likely to require an urgent or elective VAD placement. The number of patients presenting in acute, chronic, or acute-on-chronic cardiac failure was similar between groups (Table 2).

Of the 105 patients who underwent isolated HeartMate II implantation, 2 experienced subsequent RV failure demonstrated by decreased RV function on echocardiography with elevated filling pressures (CVP >18 mm Hg), requiring increased inotropic and pulmonary vasodilatory support on postoperative day 1. Both patients were taken back to the operating room for temporary RVAD implantation. Eventually, in both patients, the RV function improved, allowing RVAD removal. Both patients were successfully discharged from the hospital.

Patients who underwent isolated HeartMate II implantation had a greater survival to discharge than patients requiring initial BiVAD therapy (95.2% versus 88.2%); however, this was not statistically significant. However, 1-year survival was significantly greater in patients requiring isolated HeartMate II implantation compared with patients requiring temporary RVAD support (87.6% versus 76.40%; $p = 0.03$; Fig 3). When comparing the reasons for death between the two groups, the only variable that was statistically significant was recurrent RV heart failure, which was greater within the group of patients requiring BiVAD support.

Comment
It has been well documented that RV dysfunction after LVAD insertion results in a high morbidity and mortality [1]. Planned RVAD support at the time of the operation results in an increased 1-year survival when compared with those who require reoperation for RVAD support [8]. However, regardless of the timing, the survival rates are still very low (48% and 25%) [8]. These numbers are in contrast to our findings of an 88.2% 1-year survival rate. We believe this dramatic contrast between the historic
data and our own is reflective of the strategy by which we cannulate and remotely remove the cannulas for RVAD therapy. Using our cannulation strategy, we are able to close the sternum either at the time of RVAD implant or alternatively 1 to 2 days postoperatively depending on the coagulopathy and bleeding status. This is vastly different from previous reports when central RVAD cannulation is used, and the sternum is either left open for the duration of RVAD therapy [9] or is closed, and then subsequently reopened at the time of RVAD cannula removal [10]. We believe that early chest closure reduces the risk of subsequent infections that contribute to the patients’ overall morbidity and mortality. Further, changing the RVAD inflow cannula position from a femoral venous to internal jugular allows the patient to be more effectively mobilized, and results in the ability to sit the patient upright, allowing for a ventilator wean and improved pulmonary function.

The femoral venous inflow approach is our preference at the time of RVAD insertion for several reasons. It is easier to manipulate the position of the femoral venous inflow within the right atrium, and it allows us to continually monitor the mixed venous oxygen saturation from the Swan-Ganz catheter during the early perioperative period.

We believe our remote cannula removal approach using a small anterior left thoracotomy reduces the length of the operation at RVAD cannula removal. When using a central cannula removal approach, oftentimes adhesions, which have formed over the previous weeks, are dissected. Using our approach, in which the left chest has not previously been entered, we are able to easily and quickly identify the pulmonary arterial outflow graft and remove the cannula. Thus far, despite only sewing the outflow graft to the pulmonary adventitia, we have not identified any hemorrhage after cannula removal.

As others have previously identified, patients requiring RVAD insertion after LVAD insertion are a heterogeneous group of patients [1, 2]. This likely accounts for why there was no statistical difference in survival at discharge between groups. The inclusion of more patients would be required to allow for multivariate analysis among all groups to determine whether survival at discharge is different between the LVAD and BiVAD groups. Despite the differences, patients requiring an RVAD at the time of LVAD insertion did have a survival disadvantage at 1 year compared with patients requiring isolated HeartMate II. This advantage is likely the result of continued RV failure after RVAD removal.

We choose to implant an RVAD on any patient who we believed would require mechanical RV support during the postoperative period. Although in some cases we may have unnecessarily implanted an RVAD, there was no difference in survival at discharge between groups. Alternatively, patients with RV dysfunction could leave the operating room without an RVAD. However, the large

Table 1. Demographics and Outcomes

<table>
<thead>
<tr>
<th>Variable</th>
<th>HeartMate II LVAD (n = 105)</th>
<th>LVAD + RVAD (n = 34)</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (y)</td>
<td>55.5 ± 12</td>
<td>52.2 ± 11.8</td>
<td>0.2</td>
</tr>
<tr>
<td>Male sex</td>
<td>79.0% (83)</td>
<td>64.7% (22)</td>
<td>0.1</td>
</tr>
<tr>
<td>Timing of VAD</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Emergent</td>
<td>11.4% (12)</td>
<td>100% (34)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Urgent</td>
<td>63.8% (67)</td>
<td>0</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Elective</td>
<td>24.7% (26)</td>
<td>0</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Discharge from hospital</td>
<td>95.2% (100)</td>
<td>88.2% (30)</td>
<td>0.2</td>
</tr>
<tr>
<td>Causes of death</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cardiac</td>
<td>3.0% (3)</td>
<td>13% (4)</td>
<td>0.04</td>
</tr>
<tr>
<td>Infection</td>
<td>4.0% (4)</td>
<td>3.0% (1)</td>
<td>0.9</td>
</tr>
<tr>
<td>Neurologic</td>
<td>2.0% (2)</td>
<td>3.0% (1)</td>
<td>0.9</td>
</tr>
<tr>
<td>MOF</td>
<td>2.0% (2)</td>
<td>6.7% (2)</td>
<td>0.2</td>
</tr>
</tbody>
</table>

LVAD = left ventricular assist device; MOF = multisystem organ failure; RVAD = right ventricular assist device; VAD = ventricular assist device.

Table 2. Survival According to Cardiac Failure Presentation

<table>
<thead>
<tr>
<th>Variable</th>
<th>BIVAD Placement</th>
<th>Hospital Discharge</th>
<th>One-Year Survival</th>
</tr>
</thead>
<tbody>
<tr>
<td>AOC</td>
<td>42% (14)</td>
<td>92.8% (13)</td>
<td>85.7% (12)</td>
</tr>
<tr>
<td>Acute</td>
<td>58% (20)</td>
<td>85.0% (17)</td>
<td>70.0% (14)</td>
</tr>
<tr>
<td>Isolated HM II</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AOC</td>
<td>64% (67)</td>
<td>95.5% (64)</td>
<td>91.0% (61)</td>
</tr>
<tr>
<td>Acute</td>
<td>11% (12)</td>
<td>91.6% (11)</td>
<td>91.6% (11)</td>
</tr>
<tr>
<td>Chronic CHF</td>
<td>25% (26)</td>
<td>96.1% (25)</td>
<td>96.1% (25)</td>
</tr>
</tbody>
</table>

AOC = acute-on-chronic; BIVAD = biventricular assist device; CHF = congestive heart failure; HM II = HeartMate II.
fluid shifts and volumes, particularly during a coagulopathy in VAD patients, can in many cases result in subsequent emergent RVAD insertion, which is known to carry a heavy mortality [2].

**Limitations**

This is a retrospective study with all of the limitations inherent in this approach. Further, we choose to only include patients using the CentriMag pump to allow for a more homogeneous patient population, and therefore the number of patients requiring BiVAD therapy is low.

**Conclusions**

We demonstrate that placement of a CentriMag RVAD and HeartMate II LVAD result in excellent hospital and 1-year survival. However, there is a survival advantage for patients requiring isolated HeartMate II LVAD at 1 year. Further study using a multiinstitutional and larger patient cohort will be necessary to validate these results.

**References**


**INVITED COMMENTARY**

There is an ongoing debate for optimal device selection in patients with acute heart failure requiring mechanical cardiac assist systems. Options reach from short-term univentricular support up to complete heart replacement devices. Implantable, durable, continuous-flow pumps have revolutionized left ventricular assist device (LVAD) long-time support by low complication and excellent survival rates.

Heterogeneity of underlying cardiac problems challenge appropriate and optimal device selection or possible device combinations, especially in patients with refractory cardiogenic shock and expected but unknown recovery potential of the right ventricle (RV). In these patients, primary implantation of a pulsatile biventricular assist device or a total artificial heart might be invasive overtreatment, and isolated LVAD support alone might result in undertreatment in both situations, with different, but high risks for possible devastating complications.

Lazar and colleagues [1] show their excellent clinical results over 5 years with temporary biventricular assist devices in a hybrid approach using two different support systems, the HeartMate II (Thoratec, Pleasanton, CA) LVAD in combination with the CentriMag (Levitronix, Waltham, MA) RVAD. They showed in patients with increased risk of right heart failure that short-term RVAD use during LVAD implantation improves survival dramatically, decreases potential postoperative circulatory collapse, and avoids subsequent emergent RVAD implantation with known severely decreased outcome. Their surgical treatment concept with well-defined preoperative and intraoperative assessment of the RV and LV,