Early planned institution of biventricular mechanical circulatory support results in improved outcomes compared with delayed conversion of a left ventricular assist device to a biventricular assist device

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Objective: It is generally accepted that patients who require biventricular assist device support have poorer outcomes than those requiring isolated left ventricular assist device support. However, it is unknown how the timing of biventricular assist device insertion affects outcomes. We hypothesized that planned biventricular assist device insertion improves survival compared with delayed conversion of left ventricular assist device support to biventricular assist device support.

Methods: We reviewed and compared outcomes of 266 patients undergoing left ventricular assist device or biventricular assist device placement at the University of Pennsylvania from April 1995 to June 2007. We subdivided patients receiving biventricular assist devices into planned biventricular assist device (P-BiVAD) and delayed biventricular assist device (D-BiVAD) groups based on the timing of right ventricular assist device insertion. We defined the D-BiVAD group as any failure of isolated left ventricular assist device support.

Results: Of 266 patients who received left ventricular assist devices, 99 (37%) required biventricular assist device support. We compared preoperative characteristics, successful bridging to transplantation, survival to hospital discharge, and Kaplan–Meier 1-year survival between the P-BiVAD ($n = 71$) and D-BiVAD ($n = 28$) groups. Preoperative comparison showed that patients who ultimately require biventricular support have similar preoperative status. Left ventricular assist device ($n = 167$) outcomes in all categories exceeded both P-BiVAD and D-BiVAD group outcomes. Furthermore, patients in the P-BiVAD group had superior survival to discharge than patients in the D-BiVAD group (51% vs 29%, $P < .05$). One-year and long-term Kaplan–Meier survival distribution confirmed this finding. There was also a trend toward improved bridging to transplantation in the P-BiVAD ($n = 55$) versus D-BiVAD ($n = 22$) groups (65% vs 45%, $P = .10$).

Conclusion: When patients at high risk for failure of isolated left ventricular assist device support are identified, proceeding directly to biventricular assist device implantation is advised because early institution of biventricular support results in dramatic improvement in survival.

Early morbidity and mortality in mechanical circulatory support device recipients results primarily from multiple organ failure, postoperative hemorrhage, pulmonary complications, and thromboembolic events.^{1–9} Rates of these complications are significantly higher in patients who require biventricular support. In fact, right ventricular (RV) failure

requiring right ventricular assist device (RVAD) placement is the most significant risk factor for mortality in left ventricular assist device (LVAD) recipients.⁹

Numerous investigators have reported poor outcomes in LVAD recipients with significant RV dysfunction. Santambrogio and colleagues¹⁰ reported an 85% transplantation rate among LVAD recipients without RV failure and only a 25% transplantation rate in LVAD recipients with RV failure. Dang and associates¹¹ showed similarly poor survival to transplantation among patients receiving RVADs after LVADs (35.7%) compared with that seen in LVAD recipients without RV failure (89.9%). Farrar and coworkers¹² reported a 58% transplantation rate with Thoratec BiVADs compared with a 74% transplantation rate among Thoratec LVAD recipients. Finally, Kormos and colleagues¹³ reported a 100% transplantation rate in LVAD recipients without RV failure, whereas their BiVAD recipients survived to transplantation in only 40% of cases. These studies had relatively small sample sizes, with the exception of the

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Abbreviations and Acronyms

BiVAD	= biventricular assist device
D-BiVAD	= delayed biventricular assist device
DBP	= diastolic blood pressure
HR	= heart rate
LVAD	= left ventricular assist device
P-BiVAD	= planned biventricular assist device
RV	= right ventricular
RVAD	= right ventricular assist device

multicenter Thoratec study,¹² which was obviously subject to significant variability in practice and outcomes between sites.

Clearly, the increased morbidity and mortality in patients with post-LVAD RV failure mandates preoperative identification of patients who require biventricular support. A small number of studies have attempted to characterize preoperative parameters that can be used to predict which patients require biventricular assist device (BiVAD) support.¹⁰⁻¹⁶ In total, the published literature identifies at least 25 different potential predictors of severe RV failure in LVAD recipients, including but not limited to low right ventricular stroke work index, preoperative mechanical ventilation, increased creatinine values, female sex, and small body surface area. To enhance the understanding of this problem, we studied our LVAD and BiVAD cohorts at the Hospital of the University of Pennsylvania to identify preoperative predictors of BiVAD need. We found and reported that low cardiac index, low right ventricular stroke work index, echocardiographic evidence of severe pre-ventricular assist device RV dysfunction, increased creatinine values, previous cardiac surgery, and low systolic blood pressure are independently associated with BiVAD use.¹⁷ Although a widely accepted consensus does not yet exist, these studies establish that it is possible to preoperatively identify patients who require biventricular mechanical circulatory support.

If it is possible to predict which patients require BiVADs, then it is plausible that early planned institution of biventricular support will result in better outcomes than delaying insertion of the RVAD. Two studies have reported results with patients who received planned BiVADs. Magliato and associates¹⁸ showed 59% survival to transplantation among 17 Thoratec BiVAD recipients, whereas Tsukui and coworkers¹⁹ reported an exceptional 84% transplantation rate in select patients who received planned BiVADs. These results represent substantial improvements over reported outcomes in patients who had delayed conversion of LVAD to BiVAD support.¹⁰⁻¹³

The reports by Magliato and associates¹⁸ and Tsukui and coworkers¹⁹ lead us to believe that timely institution of bi-

ventricular support is the most effective strategy for patients at risk for LVAD support failure. Unfortunately, neither of these reports compares planned BiVAD outcomes with unplanned BiVAD outcomes at their institutions. Accordingly, we studied our cohort of 266 LVAD recipients, 99 of whom also required mechanical support of the right ventricle, to compare outcomes between LVAD, planned BiVAD, and delayed BiVAD recipients. This represents the largest single-institution series to address this question.

We hypothesized that patients at high risk for LVAD support failure can achieve improved outcomes with early planned BiVAD insertion as opposed to delayed conversion of LVAD to BiVAD support.

MATERIALS AND METHODS**Patients**

We performed a retrospective review on all patients who underwent LVAD implantation at the Hospital of the University of Pennsylvania from April 1995 to June 2007. Patients were assigned to separate LVAD and BiVAD groups for comparison. Based on the timing of device insertion, the BiVAD group was further divided into 2 subgroups: (1) preplanned BiVAD support (P-BiVAD group) or (2) delayed conversion of LVAD to BiVAD support (D-BiVAD group).

The P-BiVAD group included only patients who were taken to the operating room with a predetermined plan to place biventricular support devices. The devices were implanted concurrently, and no attempt to use isolated LVAD support was made. The D-BiVAD group was defined as any failure of isolated LVAD support requiring conversion to BiVAD support. This included patients who had LVADs converted to BiVADs (1) during 2 separate operations or (2) during the same operation because they could not be weaned from cardiopulmonary bypass and taken to the intensive care unit on LVAD support alone. Although these scenarios differ somewhat, they both represent unplanned conversion of an LVAD to a BiVAD.

The decision to implant an RVAD was made by the individual cardiac surgeon in consultation with the heart failure cardiologist. Multiple factors influenced this decision. In addition to clinical status, preoperative considerations include patient size, transplant eligibility, device availability, and expected duration of support. At our institution, transplant-ineligible patients are considered inappropriate for long-term RVAD use. However, if a brief period of RV support is anticipated, a temporary RVAD can be used. Furthermore, the choice of LV device influences the use of an RV device by potentially altering the need for anticoagulation or the patient's eligibility for outpatient therapy.

Thirty-seven percent of our cohort required biventricular support. Two published series report similar or greater proportions of patients who required BiVADs,^{12,13} although most series have a smaller percentage. In our institution all LVAD recipients at risk for RV failure are started on a milrinone infusion and inhaled prostacyclin to optimize the function of the RV before weaning from cardiopulmonary bypass. If, on weaning from bypass, the hemodynamic situation is still not satisfactory, we proceed to RVAD implantation. The higher proportion of RVAD use in our cohort is explained by multiple factors. First, most series report only patients in whom LVAD support failed and who then required RVAD support, thereby excluding patients who received preplanned BiVADs. Additionally, our BiVAD cohort might represent a population more likely to require RV support than those reported in other studies, as evidenced by the high proportion of female subjects (37%), subjects receiving preoperative mechanical ventilation (71%), subjects with an intra-aortic balloon pump (61%), and subjects requiring extracorporeal membrane oxygenation (21%) in our cohort.

Devices

Multiple devices were used throughout the study period. These include the BioMedicus Perfusion System (Medtronic, Inc, Littleton, Mass), TCI IP (Thermo Cardiosystems, Inc, Woburn, Mass), TCI VE (Thermo Cardiosystems), HeartMate XVE (Thoratec Corp, Pleasanton, Calif), Abiomed BVS-5000 (Abiomed, Inc, Danvers, Mass), Thoratec PVAD (Thoratec), and HeartMate II (Thoratec). We define the BioMedicus and Abiomed as short-term devices, whereas the Thoratec PVAD, TCI IP, TCI VE, and HeartMate ventricular assist devices are defined as long-term devices. In the BiVAD subcohorts the use of short- and long-term devices was statistically equivalent, eliminating an inferior device as an explanation for poor outcomes among the D-BiVAD group.

Data

The study protocol was approved by the Institutional Review Board of the University of Pennsylvania. Data were collected retrospectively from the medical records. Preoperative data, including demographics, clinical factors, hemodynamic parameters, and laboratory values, were entered into a database. These data were used to establish the baseline characteristics of the 2 BiVAD groups. Date of device implantation, date of transplantation, date of initial hospital discharge, current status (alive or deceased), and date of death were also collected. These data points allowed us to compare survival to hospital discharge, survival to transplantation, and 1-year and long-term Kaplan–Meier survival distribution among the LVAD, P-BiVAD, and D-BiVAD groups. After accrual of data, identifying information was removed from the database, and a unique code number was assigned to each record.

Statistical Analysis

SAS 9.1.3 software (SAS Institute, Cary, NC) was used to perform statistical analysis. Preoperative parameters were compared with χ^2 tests for categorical variables and unpaired Student *t* tests for continuous variables. Patients requiring preoperative mechanical circulatory support were excluded from analysis of hemodynamic variables.

Survival to hospital discharge and survival to transplantation were compared among the LVAD, P-BiVAD, and D-BiVAD groups by using χ^2 tests. Kaplan–Meier survival distribution was compared among the 3 groups by using XLSTAT version 2007.6 statistical analysis add-in software (Addinsoft USA, New York, NY) for Microsoft Excel.

RESULTS

There were 266 patients who received LVADs at the Hospital of the University of Pennsylvania during the 12-year study period. Of these, 167 (63%) patients tolerated isolated LVAD support, whereas 99 (37%) patients required biventricular support. Of the 99 patients who received BiVADs, 71 underwent preplanned BiVAD insertion (the P-BiVAD group), and 28 underwent delayed conversion of LVAD to BiVAD support (the D-BiVAD group).

Of the 28 D-BiVAD patients, 14 underwent RVAD insertion during the LVAD operation primarily because of severe RV failure in the setting of hemodynamic instability with isolated LVAD support. The remaining 14 D-BiVAD patients underwent RVAD implantation during a later operation primarily because of progressive multiorgan dysfunction resulting from severe RV failure. The median time to RVAD implantation in this subgroup was 2 days. Outcomes in all parameters were equivalent in these 2 D-BiVAD subgroups.

Results of univariate analysis comparing the P-BiVAD and D-BiVAD subgroups are shown in Table 1. Of the 35

TABLE 1. Univariate comparison of preoperative characteristics between planned BiVAD and delayed BiVAD recipients

Variable	P-BiVAD (n = 71)	D-BiVAD (n = 28)	P value
Age (y)	52.4 ± 10.9	49.3 ± 13.2	.2787
Sex (% female)	37	39	.8050
Body surface area (m ²)	1.92 ± 0.25	1.95 ± 0.29	.7104
Ischemic cardiomyopathy	59	53	.6127
COPD (%)	8	7	.8297
Diabetes (%)	25	29	.7430
Mechanical ventilation (%)	70	71	.9211
Acute myocardial infarction (%)	27	21	.5823
Previous cardiac surgery (%)	38	54	.1587
Severe preoperative RV dysfunction (%)*	75	68	.4753
Intra-aortic balloon pump (%)	56	71	.1664
Preoperative circulatory support (%)	20	25	.5626
Nonseparation from cardiopulmonary bypass (%)	23	21	.9051
Heart rate (beats/min)	100.1 ± 21.6	113.9 ± 22.4	.0299
Systolic blood pressure (mm Hg)	96.9 ± 17.5	92.2 ± 11.5	.2010
Diastolic blood pressure (mm Hg)	57.5 ± 12.5	51.2 ± 10.2	.0389
Mean arterial blood pressure (mm Hg)	70.6 ± 13.0	64.9 ± 9.9	.0565
Central venous pressure (mm Hg)	22.5 ± 8.2	21.6 ± 6.5	.6824
Pulmonary artery systolic pressure (mm Hg)	46.0 ± 11.8	41.1 ± 10.2	.1151
Pulmonary artery diastolic pressure (mm Hg)	26.5 ± 8.7	26.2 ± 7.4	.8793
Mean pulmonary artery pressure (mm Hg)	33.0 ± 9.0	31.2 ± 7.9	.4278
Cardiac index (L · min ⁻¹ · m ⁻²)	1.77 ± 0.44	1.85 ± 0.36	.4774
SvO ₂ (%)	56.8 ± 13.0	54.5 ± 9.3	.4842
Right ventricular stroke work index (mm Hg · L/m ²)†	0.195 ± 0.201	0.209 ± 0.178	.8046
LV ejection fraction (%)	15.0 ± 11.9	14.0 ± 17.0	.7601
White blood cell count (10 ⁹ /L)	14.0 ± 7.4	11.5 ± 5.1	.0788
Hemoglobin (g/dL)	11.3 ± 1.9	11.2 ± 2.0	.7989
Platelet count (10 ⁹ /L)	183.9 ± 109.9	165.0 ± 79.5	.3692
International normalized ratio	1.76 ± 0.86	1.87 ± 1.11	.6510
Partial thromboplastin time (s)	56.3 ± 33.7	53.8 ± 32.8	.7500
Creatinine (mg/dL)	2.08 ± 1.39	1.92 ± 1.46	.6271
Total bilirubin (mg/dL)	1.56 ± 1.48	1.85 ± 1.68	.4898
Alanine aminotransferase (U/L)	626.4 ± 1632.8	253.5 ± 687.8	.1993
Aspartate aminotransferase (U/L)	632.2 ± 1732.7	268.7 ± 309.9	.1460
Albumin (g/dL)	2.7 ± 0.6	2.7 ± 0.8	.8395

BiVAD, Biventricular assist device; P-BiVAD, planned biventricular assist device group; D-BiVAD, delayed biventricular assist device group; COPD, chronic obstructive pulmonary disease; SvO₂, mixed venous oxygen saturation; LV, left ventricular. *Right ventricular dysfunction was graded as none, mild, moderate, or severe and was based on the final report of the preoperative echocardiogram. †Right ventricular stroke work index = (Mean pulmonary artery pressure – Central venous pressure) × Cardiac index/Heart rate

FIGURE 1. Comparison of survival to transplantation among the left ventricular assist device (LVAD), planned biventricular assist device (P-BiVAD), and delayed biventricular assist device (D-BiVAD) groups.

parameters compared between the 2 groups, only heart rate (HR) and diastolic blood pressure (DBP) were significantly different. Unexpectedly, HR was slightly higher and DBP was slightly lower in the group that received unplanned BiVADs. This is counterintuitive if one presumes that patients exhibiting higher HRs and lower DBPs would be considered more ill and would therefore receive BiVADs in a planned fashion. Multivariate comparison of the P-BiVAD and D-BiVAD groups was not performed because of the lack of significant preoperative differences between the populations.

Transplant-eligible patients in each of the 3 study groups were identified by excluding patients who received LVADs as destination therapy or who successfully recovered from ventricular assist device support. All other patients were considered transplant eligible, irrespective of whether they were ever listed for transplantation. Of 141 transplant-eligible patients in the LVAD group, 111 (79%) ultimately underwent transplantation. This proportion was not significantly higher than the transplantation rate in the P-BiVAD group (65% [36/55], $P = .0539$). Expectedly, the 79% transplantation rate in the LVAD group was significantly greater than the 45% survival to transplantation achieved in the D-BiVAD group (10/22, $P = .0009$). Importantly, patients who underwent planned BiVAD insertion trended toward better survival to transplantation than patients undergoing delayed BiVAD insertion (65% vs 45%, $P = .1$). Survival to transplantation among the 3 groups is shown in Figure 1.

Survival to hospital discharge (Figure 2) was highest among the LVAD group (71% [119/167]). This was significantly higher than survival to hospital discharge in both the P-BiVAD (51% [36/71], $P = .0023$) and D-BiVAD (29% [8/28], $P < .0001$) groups. Most importantly, when P-BiVAD patients (51% survival) were compared with

FIGURE 2. Comparison of survival to hospital discharge among the left ventricular assist device (LVAD), planned biventricular assist device (P-BiVAD), and delayed biventricular assist device (D-BiVAD) groups.

D-BiVAD patients (29% survival), the result remained statistically significant ($P = .0459$). In a further subgroup analysis survival to hospital discharge was determined for the most commonly used devices. When the HeartMate I (TCI IP, TCI VE, or HeartMate XVE) was chosen as the LVAD, survival to discharge was 74.4% (87/117 patients) for isolated LVAD recipients, 71.4% (5/7) for P-BiVAD patients, and 28.6% (4/14) for D-BiVAD patients. When a Thoratec was chosen as the LVAD, survival to discharge was 63.2% (24/38) for isolated LVAD recipients, 56.0% (28/50) for P-BiVAD patients, and 36.4% (4/11) for D-BiVAD patients. These results further support the assertion that survival is primarily determined by the initial decision to implant univentricular or biventricular devices rather than the choice of device type.

Analysis of Kaplan–Meier 1-year survival distribution likewise showed the best results in the LVAD group (65%). When compared with the P-BiVAD group, which had 48% one-year survival, this result was statistically significant ($P = .003$). One-year survival was lowest in the D-BiVAD group, at 25%, which was also significantly lower than that seen in the LVAD group ($P < .0001$). Importantly, comparison between the 2 BiVAD groups showed statistically higher 1-year survival among P-BiVAD patients ($P = .025$). Finally, long-term survival distribution curves (Figure 3) mirrored the findings at 1 year among the 3 study groups (LVAD vs P-BiVAD, $P = .014$; LVAD vs D-BiVAD, $P < .0001$; P-BiVAD vs D-BiVAD, $P = .019$).

DISCUSSION

Patients who require mechanical circulatory support face the risk of life-threatening postoperative complications, which

FIGURE 3. Long-term survival distribution curves for the left ventricular assist device (LVAD; A), planned biventricular assist device (P-BiVAD; B), and delayed biventricular assist device (D-BiVAD; C) groups.

they must overcome to achieve long-term survival. The development of severe RV failure after LVAD implantation is a serious complication, resulting in end-organ dysfunction in multiple organ systems. Multiorgan failure subsequently results in dramatically increased mortality in this group.

The most effective therapy for these patients is biventricular mechanical support. However, it is now well recognized that BiVAD recipients have higher morbidity and mortality rates than LVAD recipients in nearly all categories. Because destination therapy is generally not an option for BiVAD recipients, long-term survival among BiVAD recipients is closely tied to their ability to survive to transplantation or recover from VAD support.

Fortunately, posttransplantation survival does not appear to be linked to the use of univentricular or biventricular preoperative support. Farrar and coworkers¹² showed equivalent posttransplantation survival through hospital discharge between the Thoratec LVAD and BiVAD recipients, and the Columbia University group has shown that pretransplantation RVAD support was not a risk factor for posttransplantation mortality in their cohort.^{11,14} Additionally, Magliato and associates¹⁸ reported 90% posttransplantation survival to hospital discharge in planned BiVAD recipients.

Therefore if cardiac transplantation is the event that equalizes survival between LVAD and BiVAD recipients, we must improve the rate at which BiVAD recipients survive to transplantation. Because their morbid illness results from severe biventricular failure, it is logical to assume that timely restoration of cardiac output will improve the ability of BiVAD recipients to survive the perioperative period. Magliato and associates¹⁸ and Tsukui and coworkers¹⁹ have reported favorable results in patients who underwent planned BiVAD insertion; however, the current literature does not adequately address how the timing of BiVAD placement affects patient outcomes.

The current study is the largest to directly compare results at a single institution between planned BiVAD outcomes and delayed BiVAD outcomes. In addition, no other study has examined whether unplanned RVAD insertion immediately after LVAD insertion (during the same operation) has a deleterious effect on patient outcomes.

Our previous study established that preoperative demographics, clinical factors, hemodynamic data, and laboratory values can be used to readily distinguish between patients who tolerate isolated LVAD support and those who ultimately require biventricular support.¹⁷ In the current study we compared preoperative parameters between P-BiVAD patients and D-BiVAD patients to determine whether the D-BiVAD group exhibited characteristics suggesting they would tolerate LVAD support. Surprisingly, the 2 groups were nearly equivalent because only HR and DBP showed statistically significant differences. Additionally, the small HR increase and DBP decrease observed in D-BiVAD patients are probably not meaningful clinically. In summary, patients who require biventricular support can be clearly distinguished based on preoperative characteristics from those who tolerate isolated LVAD support. Furthermore, there is reason to believe that all patients who ultimately require

BiVADs are equally identifiable before ventricular assist device insertion based on critical analysis of preoperative data.¹⁷

With respect to outcomes, LVAD recipients survived to transplantation at the highest rate (79%). However, P-BiVAD patients in our cohort survived to transplantation in 65% of cases, a result that was not significantly lower than the transplantation rate in LVAD recipients. This bridge to transplantation rate among P-BiVAD patients is at least comparable with, if not better than, rates published by Morgan and colleagues,¹⁴ Magliato and associates,¹⁸ and Tsukui and coworkers.¹⁹ Similarly, our 45% bridge-to-transplantation rate among D-BiVAD patients compares with the poor results in other published series. The fact that survival to transplantation among P-BiVAD patients was not significantly higher than that among D-BiVAD patients is likely due to the small number of transplant-eligible patients in the D-BiVAD group ($n = 22$). Nonetheless, these results clearly argue in favor of a strategy of P-BiVAD placement for patients who require biventricular support.

Not unexpectedly, survival to hospital discharge was highest in the LVAD group (71%). Importantly, P-BiVAD patients survived to hospital discharge at a significantly higher rate (51%) than those who had BiVADs placed in a delayed fashion (29%). This represents a relative in-hospital mortality reduction of 31% in the P-BiVAD group compared with that seen in the D-BiVAD group. The fact that survival to hospital discharge was significantly higher among P-BiVAD patients than among D-BiVAD patients, even though the transplantation rate was not significantly different, is explained by the fact that a high proportion of P-BiVAD patients (23% [16/71]) successfully recovered from ventricular assist device support and therefore did not require transplantation.

Survival distribution rates demonstrate similar results. Kaplan–Meier 1-year survival again was highest in the LVAD group (65%). Notably, 1-year survival was significantly higher in the P-BiVAD group (48%) than in the D-BiVAD group (25%). Again, this represents a 31% relative risk reduction for 1-year mortality in the P-BiVAD group compared with the D-BiVAD group. Most importantly, long-term Kaplan–Meier survival distribution mirrored the findings at 1 year. Importantly, if one examines BiVAD recipients at our institution, those who were appropriately identified as requiring biventricular support before initial ventricular assist device placement survived to hospital discharge and to 1 year at nearly twice the rate as those who were not initially believed to require BiVADs. This study therefore provides strong evidence that a strategy of early planned BiVAD insertion for patients who require biventricular mechanical circulatory support results in higher transplantation rates and improved long-term survival.

The factors that result in the increased mortality in the BiVAD groups should ideally be determined. Because ventricular assist device recipients have complications in multiple organ systems and the definition of these can vary, it was difficult in this retrospective review to definitively identify every complication. Nonetheless, reoperation rates (P-BiVAD, 62% [44/71]; D-BiVAD, 75% [21/28]) and the need for postoperative hemodialysis (P-BiVAD, 31% [22/71]; D-BiVAD, 39% [11/28]) were similar between the BiVAD subcohorts. The majority of reoperations were attributed to bleeding. In the BiVAD subcohorts patients who died in the hospital had similar survival time (P-BiVAD: mean, 20.2 days; median, 15 days; D-BiVAD: mean, 22.4 days; median, 14.5 days). Although many factors were involved in the survival time of these patients, causes of death were likewise similar between the BiVAD subcohorts. Patients who died early after BiVAD placement generally died of progressive multiorgan dysfunction, whereas those who survived longer died as a result of infection, stroke, and debilitation. These facts demonstrate that P-BiVAD and D-BiVAD patients have similar postoperative complications, but patients who receive planned BiVADs have a tendency to survive at a higher rate.

LIMITATIONS

This was a retrospective study performed at a single institution. The timing of device implantation and the device type were based on the clinical judgment of the surgeon in consultation with the heart failure cardiologists, as opposed to a defined protocol. Additionally, there are innumerable factors that influence the decision to use univentricular versus biventricular support. Finally, some percentage of RV failure is related to intraoperative events that might not be predictable preoperatively. These include lung injury, massive transfusion, and poor intraoperative RV protection. There was no way to correct for the presence of these factors in this study.

CONCLUSIONS

Exceedingly high postoperative morbidity and mortality present a significant challenge to long-term survival in patients who require biventricular mechanical circulatory support. These poor outcomes result primarily from end-organ dysfunction because of the severity of the biventricular failure. This study strongly supports a strategy of early planned institution of biventricular mechanical circulatory support to improve survival in patients with morbid heart failure. In fact, with this strategy, it might be possible for patients who receive planned BiVADs to achieve outcomes comparable with those of isolated LVAD recipients. Furthermore, this study highlights the importance of establishing widely accepted criteria to preoperatively identify patients who require biventricular support so they can receive appropriate support devices.

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