

# Anesthesia for Left Ventricular Assist Device Insertion: A Case Series and Review

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## ABSTRACT

From October 2008 to June 2010, a total of 42 patients had the HeartMate II left ventricular assist device inserted surgically at Ochsner Medical Center in New Orleans, LA. A retrospective electronic record review was conducted on this series of patients to analyze elements of perioperative anesthetic care, including general anesthetic care, echocardiographic considerations, and blood product usage. Etomidate was used to induce anesthesia for 34 of 42 patients (81%) in this series, with an average dose of 16.5 mg ( $\pm 6$  mg). The average intraoperative fentanyl dose was 1,318  $\mu$ g ( $\pm 631$   $\mu$ g). On average, patients were extubated 91 hours ( $\pm 72$  hours) after arrival to the intensive care unit and left on day 9 ( $\pm 5$  days). The average left ventricular ejection fraction of the patients in this series was 13% ( $\pm 5$ %). Sixteen patients were evaluated as having severe right-heart dysfunction preoperatively. Two of 42 patients required surgical closure of echocardiographically identified patent foramen ovale. Twelve of 42 patients underwent surgical correction of tricuspid regurgitation. On average, 3 units ( $\pm 2.6$  units) of fresh frozen plasma were transfused intraoperatively and 10 units postoperatively. Intraoperative red blood cell usage averaged 1.1 units (maximum, 7 units), with an average 9.3 units administered in the first 48 hours postoperatively.

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## INTRODUCTION

A heart transplant remains the ultimate surgical therapy for advanced heart failure. The ongoing national shortage of available donor hearts, coupled with the design limitations (and associated 1-year survival of 53%) of older generations of pulsatile left ventricular assist device (LVAD) pumps, has necessitated continuing evolution of these complex devices.<sup>1</sup> The HeartMate II LVAD (Thoratec, Pleasanton, CA) was approved for clinical use in patients with severe heart failure by the US Food and Drug Administration on April 21, 2008. This newer-generation LVAD is an axial-flow device placed via median sternotomy with an outflow cannula that is inserted into the ascending aorta.

The anesthetic management of these cases differs from that with previous generations of LVADs as most patients receiving the HeartMate II have delayed surgical chest closure. Delayed chest closure is optimal for this extremely preload-sensitive device to avoid compression on the right heart and to allow time for correction of postoperative coagulopathy and bleeding. Patients are typically brought back to the operating room after 48 hours in the intensive care unit (ICU) for sternotomy closure. Occasionally, select low-risk patients may undergo primary closure. While earlier axial-flow ventricular assist devices (VADs, such as the Jarvik 2000) may have been equally preload sensitive, technical differences in device insertion made delayed closure less appropriate, as these earlier devices were often placed via thoracotomy.<sup>2</sup>

From October 2008 to June 2010, a total of 42 patients had the HeartMate II device inserted surgically at Ochsner Medical Center in New Orleans, LA. The anesthetic management of this series of patients is outlined here with a focus on 3 major dimensions of care: (1) general anesthetic management, (2) echocardiographic considerations, and (3) bleeding and coagulation disorders.

## METHODS

Institutional review board approval was obtained for this retrospective anesthetic case series report.

Preoperative patient data were extracted from the Ochsner Clinical Workstation electronic record. The

preoperative data collected included the last preoperative 2-dimensional echocardiography left ventricular ejection fraction, the degree of coexisting right ventricular dysfunction, the degree of valvular tricuspid regurgitation (TR), and the degree of aortic insufficiency.

Intraoperative and postoperative patient data were extracted from the Horizon Patient Folder electronic record. The intraoperative data collected included the anesthetic drugs given, such as the induction drug and dose, the volatile anesthetic agent used, intraoperative fentanyl dosing, and the muscle relaxant chosen. Intraoperative intravenous (IV) access, including any peripheral and central lines placed, was recorded. Also extracted from the intraoperative records were the total blood red blood cells (RBCs) and fresh frozen plasma (FFP) administered, as well as any platelets, cryoprecipitate, or factor VII. All vasoactive medications the patient was receiving upon exiting the operating room were recorded. Any additional surgical procedures performed, including valvular TR or patent foramen ovale (PFO) closure, were noted.

Postoperative data included chest tube drainage recorded over a 48-hour postoperative period in patients having primary chest closure. For patients undergoing delayed closure, all instances of drainage between device insertion and return to the operating room for closure, as well as in the first 24 hours following closure, were recorded. Blood product usage, times to extubation, and postoperative day of discharge from the ICU were extracted from the ICU record as well. Data were collected on all 42 patients having the HeartMate II LVAD inserted from October 2008 through June 2010.

## STATISTICS

Continuous data are presented as mean  $\pm$  standard deviation. Discrete variables are presented as percentages and total number where appropriate.

## RESULTS

Etomidate was used to induce anesthesia for 34 of 42 patients (81%) in this series, with an average dose of 16.5 mg ( $\pm$ 6 mg). The remaining patients (8 of 42) were induced with IV midazolam and fentanyl. All patients received pulmonary artery (PA) catheters, and 31 of 42 (74%) had 2 or more central lines in place for the surgical procedure. For 19 patients (45%), peripheral IV access was achieved via 16-gauge or larger catheters. Twenty of 42 patients (48%) were managed intraoperatively without peripheral IV access.

Thirty-two patients received isoflurane as the volatile anesthetic for the procedure, while 9 re-

ceived sevoflurane. One patient was maintained on desflurane. The average intraoperative fentanyl dose was 1,318  $\mu$ g ( $\pm$ 631  $\mu$ g). On average, patients were extubated 91 hours ( $\pm$ 72 hours) after arrival to the ICU and left the ICU on day 9 ( $\pm$ 5 days). The muscle relaxant vecuronium was given to 24 of 42 patients (57%) and rocuronium to only 4 of 42. Pancuronium was used to achieve neuromuscular blockade in 12 of 42 patients, while the final two received other relaxants.

With regard to inotropic therapy postbypass, epinephrine was given to 40 of 42 patients (95%) and milrinone to 39 (93%). Twenty-three patients were also given inhaled nitric oxide postbypass. Fifteen of 42 (36%) were given vasodilator support with either nicardipine or nitroglycerin. The vasoconstrictor norepinephrine was administered to 14 of 42 patients and vasopressin to 15.

The average left ventricular ejection fraction of the patients in this series was 13% ( $\pm$ 5%). Sixteen patients were evaluated with severe right-heart dysfunction preoperatively, while moderate and mild dysfunction was found in 9 and 17 patients, respectively. Two of 42 patients required surgical closure of echocardiographically identified PFO. Severe TR was noted in 10 of 42 patients, while moderate TR was observed in 7. Twelve of 42 patients underwent surgical correction of TR, while 2 patients underwent surgical intervention for aortic insufficiency.

Eleven patients underwent primary closure and the remaining 31 delayed closure.

On average, 3 units ( $\pm$ 2.6 units) of FFP were transfused intraoperatively and 10 units postoperatively. Platelet transfusions were performed, with an average of 4.6 units administered intraoperatively and 5.4 in the intensive care unit. Intraoperative RBC usage averaged 1.1 units (maximum, 7 units), with an average 9.3 units administered in the first 48 hours postoperatively. The postoperative blood loss for patients undergoing primary closure averaged 4,031 mL ( $\pm$ 2,310 mL) in the first 48 hours, while that for patients undergoing secondary closure averaged 3,845 mL before closure and 2,694 mL in the first 24 hours after closure. Three of the 42 patients were given recombinant factor VII during their surgical course.

## DISCUSSION

### General Anesthetic Care

Because of the impaired left ventricular function in patients receiving LVADs, anesthetic induction is approached with caution. Etomidate was used to induce anesthesia for 34 of 42 patients (81%) in this series. The use of etomidate is common practice in cardiac anesthesia because of reduced myocardial

depression effect when compared to other IV induction drugs. In one classic laboratory study supporting this practice,<sup>3</sup> isolated dog papillary muscles were exposed to equianesthetic doses of thiopental and etomidate. Whereas thiopental decreased developed tension by 33%, etomidate decreased it by 17%. The average dose of etomidate used in this series was 16.5 mg ( $\pm 6$  mg), which, on a weight basis, is closer to the lower end of the standard-textbook induction dose of 0.2 to 0.4 mg/kg. There were no reported instances of awareness with these lower doses in this small series. One drawback to the use of etomidate, noted anecdotally in this group, has been the frequent occurrence of myoclonus. Instances of this generally benign side effect were reported to be 86% in 1 study.<sup>4</sup> The 8 remaining patients who were not induced with etomidate received IV premedication drugs, such as midazolam and fentanyl, before initiation of muscle relaxation for intubation.

Venous access via a large-bore catheter is particularly important for patients undergoing LVAD insertion because of the high incidence of postoperative coagulopathy and bleeding from multiple suture lines. With regard to central venous access in this series, all patients had at least one 9 French introducer, and 31 of 42 (74%) had 2 or more central lines. For all patients, Swan-Ganz catheters were floated into the appropriate position, with the primary purpose of postoperative SvO<sub>2</sub> monitoring as a marker of volume status and the need for transfusion of RBCs. For 19 of 42 patients (45%), peripheral IV access was also obtained via 16-gauge or larger catheters. Many patients had limited options for peripheral access, probably as a result of recurrent hospital admissions and because of long-term IV access for pharmacologic inotropic support at home. In fact, 20 of 42 patients (48%) in this series were managed intraoperatively without peripheral IV access.

Regarding volatile anesthetic use, some controversy exists as to whether the choice of agent affects care. Isoflurane has the longest track record of use in the cardiac anesthesia arena and was the only agent used in 1 case series of patients with LVADs reported in 2003.<sup>2</sup> In our case series, all patients (except for 1) received either isoflurane or sevoflurane as the inhaled anesthetic, usually in low doses, 0.25 to 0.5 minimum alveolar concentration (MAC). One clear differentiating feature between these 2 agents is the blood-gas partition coefficients, known to be 0.68 and 1.4 for sevoflurane and isoflurane, respectively.<sup>5</sup> As the less soluble of the 2 agents, sevoflurane can be titrated more quickly to allow for more rapid return of myocardial contractility and sympathetic tone in the event of adverse hemodynamic effects in this fragile

population. Some laboratory evidence points to a possible advantage of sevoflurane over isoflurane, although it is controversial as to whether this benefit translates to the clinical setting. All volatile anesthetics are known to depress myocardial contractility in a dose-dependent fashion. The mechanism of this depression is thought to be partly caused by decreases in intracellular calcium levels. However, in 1 ferret model of right ventricular pressure overload hypertrophy, peak intracellular calcium levels rose above baseline levels when exposed to 0.5 MAC of sevoflurane; this result was statistically significant when compared to the decrease observed with isoflurane.<sup>6</sup> These findings may be particularly relevant for the LVAD population's high incidence of coexisting pulmonary hypertension secondary to left ventricular dysfunction.

As an adjunct to the lower volatile anesthetic doses used, IV fentanyl was given intraoperatively to all patients in this series. Fentanyl can help to prevent excessive increases in systemic afterload during periods of intense surgical stimulation or during direct laryngoscopy, which is often poorly tolerated by the failing left ventricle of the patient with LVAD. Trends in narcotic use during cardiac surgery have varied significantly across decades, with large fentanyl doses (50  $\mu$ g/kg) used throughout the 1980s and reduced doses used in the mid-1990s (15  $\mu$ g/kg) and with the rising popularity of fast-track cardiac anesthesia.<sup>7</sup> Because patients receiving the HeartMate II LVAD are often brought to the ICU with an open sternum, fast-tracking is not an issue. Nevertheless, fentanyl doses for this series of patients were similar to the so-called fast-track doses, with the average dose being 1,318  $\mu$ g ( $\pm 631$   $\mu$ g). On average, patients were extubated 91 hours ( $\pm 72$  hours) after arrival to the ICU and left the ICU on day 9 ( $\pm 5$  days).

Neuromuscular blocking drugs were given to all patients to prevent movement during the surgical procedure. The use of neuromuscular blocking drugs is necessary for these patients because of the lighter volatile anesthetic doses used, as described above. The most common class of relaxants was the intermediate-acting drugs. Vecuronium was given to 24 of 42 patients (57%) and rocuronium to only 4 of 42. The preferential use of vecuronium may result from its historically lower cost. The longer-acting muscle relaxant pancuronium was given to 12 of 42 patients. This drug may have been preferentially given to those patients who were most likely to have delayed closure. Paralysis is often continued postoperatively in the ICU until after sternotomy closure.

Bispectral index is used to monitor for awareness in all cases requiring cardiopulmonary bypass at our institution. Concerns regarding awareness during

LVAD insertion are especially relevant in light of the lower volatile anesthetic doses used. A review of cases in our occurrence-reporting database revealed no reported instances of awareness in the 42 patients with LVADs who comprised this series, which is not surprising owing to the low overall incidence of awareness (1%) even in the high-risk cardiac surgical population.<sup>8</sup>

The use of pharmacologic inotropic support is a critical element in successful discontinuation of cardiopulmonary bypass in the patient undergoing LVAD insertion. Whereas the LVAD assumes the work of the left ventricle (LV) immediately after placement, the right ventricle (RV) can worsen after insertion. This deterioration occurs as the substantial septal contribution to RV contractility is lost.<sup>9</sup> This is especially true in cases of excessive LVAD flow rates with coexisting intravascular hypovolemia, as the interventricular septum will shift leftward toward the under-filled LV. The immediate worsening of RV function can occur despite a relative decrease in right-sided filling pressures, as typically occurs with left ventricular decompression. Previous studies<sup>10</sup> have outlined the preoperative risk factors for RV failure after LVAD implantation, including female gender and heart failure of nonischemic etiology. All patients in this series required some form of inotropic support upon exiting the operating room, with epinephrine being the most common inotrope, given to 40 of 42 patients (95%), followed closely by milrinone, given to 39 of 42 patients (93%). The high rate of inotropic support is similar to that reported in previous LVAD case series. In a previous study of 113 patients receiving the HeartMate II,<sup>11</sup> 13% of patients required extended inotropic support, defined as a period of more than 14 days. Despite the initial postbypass concerns regarding right heart function, evidence exists to support improvement of the right heart in the intermediate and long term after LVAD placement.<sup>12</sup> In our series, no patients required inotropes for more than 14 days, and at the time of discharge, no patients required home inotropic therapy. There was no requirement for mechanical right heart support in any patient from this group.

Fifty-five percent of patients (23 of 42) were given nitric oxide to augment forward flow through the RV. Pharmacologic support of systemic vascular tone varied widely in these 42 patients. Fifteen of 42 (36%) were given vasodilator support with either nicardipine or nitroglycerin. These drugs were used for excessive vascular tone in the immediate postbypass period, as VAD flows are often best facilitated with mean systemic pressures ranging from 65 to 75 mmHg. On the other hand, 55% of patients (23 of 42) required significant vasopressor support: norepinephrine for

33% of patients (14 of 42) and vasopressin for 36% (15 of 42). The need for vasopressors may have been increased somewhat by the high incidence of milrinone use (93%) to support RV contractility in this series.

### Transesophageal Echocardiography for LVAD

For patients undergoing LVAD placement, transesophageal echocardiography (TEE) is an essential component of anesthetic care. Before LVAD insertion, TEE is necessary for diagnosing cardiac structural and functional abnormalities. After insertion, TEE is used to monitor cardiac function as well as assist device function. The examination includes the standard general TEE examination in addition to special considerations associated with the device.

Preimplantation echocardiography in the patient presenting for LVAD insertion will, by definition, show severely depressed systolic LV function. This is often accompanied by significant diastolic dysfunction. The principal diagnosis for our patients (62%) was dilated cardiomyopathy, with 37% having ischemic cardiomyopathy. Our patient population had an average ejection fraction of 13% ( $\pm 5\%$ ), very close to the left ventricular ejection fraction of 17 reported in another similarly sized study.<sup>13</sup> LV mural thrombi can form in the low-flow state, typically at the apex of the LV. This is the placement site for the LVAD's inflow cannula. Thrombi, when present, can be visualized on TEE in the midesophageal views and can be surgically removed before device placement.

The presence of intracardiac shunts can be assessed with intraoperative TEE. A PFO should be identified, when present, as part of the predevice insertion examination. This is best performed by bubble study with agitated saline or blood injected via central line after release of a Valsalva breath. A previously undetectable PFO can be revealed after initiation of LVAD support, secondary to decreases in left-sided pressures and unmasking of the septal defect. In our cohort, 2 of 42 patients required surgical closure of echocardiographically identified PFO. The presence of an unrepaired PFO can lead to systemic hypoxemia from right-to-left shunt and even failure of separation from bypass. Immediate identification is helpful to facilitate reinitiation of bypass for repair of the defect.

The aortic valve should be evaluated before bypass for significant aortic insufficiency (AI). AI reduces the forward systemic flow of the device by creating a continuous loop of flow from the aorta back into the LV (Figure 1). AI may be underestimated before VAD placement owing to high LV pressures and low diastolic aortic pressures, thus decreasing the gradient across the regurgitant valve. AI should be



**Figure 1. Doppler in a long-axis view of the aortic valve demonstrates aortic insufficiency. This can result in a circular loop of flow back into the ventricular assist device instead of the desired systemic perfusion.**

reevaluated upon initiation of cardiopulmonary bypass when conditions may more closely mimic those following device placement. A subset of our patient population (2 of 42) required surgical correction of AI. For patients needing long-term LVAD support, the aortic valve may be surgically closed. For patients for whom LVAD explantation is planned, replacement of the valve may be necessary. Mechanical valves should be avoided because of the increased risk of thromboembolism. If a mechanical valve is present, it should be replaced with a bioprosthetic valve.

Mitral regurgitation (MR) secondary to ventricular dilation with heart failure is commonly seen in LVAD candidates. LV sphericity, as well as displacement of the papillary muscles, leads to incomplete leaflet coaptation and a central MR jet. Although MR will often be moderate to severe before implantation of the device, a properly functioning LVAD will decompress the LV and decrease the degree of MR significantly. Finding of MR rarely requires surgical intervention before LVAD placement. Mitral stenosis (MS) is rare, but devastating, if undiagnosed in this population. MS will restrict LV filling and device preload, ultimately leading to decreased VAD output. MS should be addressed surgically with either commissurotomy or mitral valve replacement.

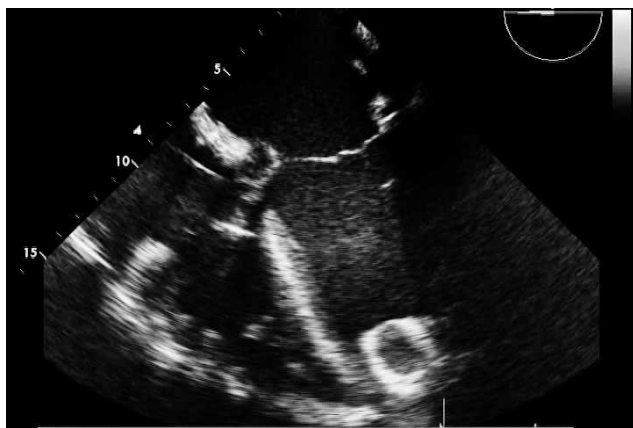
Evaluation of RV function is essential before LVAD placement. RV dysfunction is almost universally present in this patient population.<sup>13</sup> In this series, 16 patients were evaluated with severe right heart dysfunction preoperatively, while moderate and mild dysfunction were found in 9 and 17 patients, respectively. LV filling and VAD preload are dependent on RV function. TEE determines the extent of RV dysfunction by evaluating the excursion of the

tricuspid valve annulus toward the apex, free-wall motion, and presence of ventricular dilation. Assessing the degree of RV dysfunction is important in formulating a plan for separation from cardiopulmonary bypass. There is a strong association between preplacement poor RV function and the need for an RV assist device (RVAD). This abnormality has been correlated with low preoperative PA pressures and low RV stroke work index.<sup>14</sup>

If the right heart is only moderately depressed, the anesthesiologist can maximize inodilators and select pulmonary vasodilators, decreasing afterload to the RV while increasing contractile function. After placement and initiation of VAD support, the LV will be decompressed. TEE evaluation at the time of separation from bypass is essential in monitoring volume status of the LV, which equates to preload for the VAD. A rightward shift of the interventricular septum could denote inadequate VAD function. Evaluation for inflow cannula obstruction should also be considered. Leftward shift of the septum may denote high pump speeds, inadequate volume status, or RV dysfunction hindering the filling of the LV. The management goal for the anesthesiologist is to achieve a neutral position for the ventricular septum, indicating adequate LV filling and appropriate pump speeds.

The presence of significant TR can hinder post-implantation RV function. It is important to evaluate the severity of TR before device placement to determine if repair of the valve is warranted. Severe TR was noted in 10 of 42 patients, while moderate TR was observed in 7. The most common additional surgical intervention in our patient population was tricuspid valvuloplasty. Twelve of 42 patients in this series underwent tricuspid repair. Typically, TR is caused by increased RV preload and afterload, which leads to RV enlargement and dilation of the tricuspid annulus. Although LVAD placement alone decreases right-sided pressures, it has not been shown to consistently decrease the degree of TR present postimplantation.<sup>15</sup> Tricuspid repair should be considered in cases of prebypass RV dysfunction or structural abnormality of the tricuspid valve associated with moderate to severe TR.

The outflow cannula of the HeartMate II is anastomosed, in an end-to-side fashion, to the ascending aorta. It is important to rule out significant atheroma in the ascending aorta, which is associated with increased risk of cerebral embolic events. Aortic aneurysm, if present, should be repaired at the time of LVAD placement. The outflow cannula of the VAD can then be anastomosed to the ascending aortic graft, if necessary. The aortic arch and descending aorta should also be evaluated for the presence of atheroma, aneurysm, or dissection.

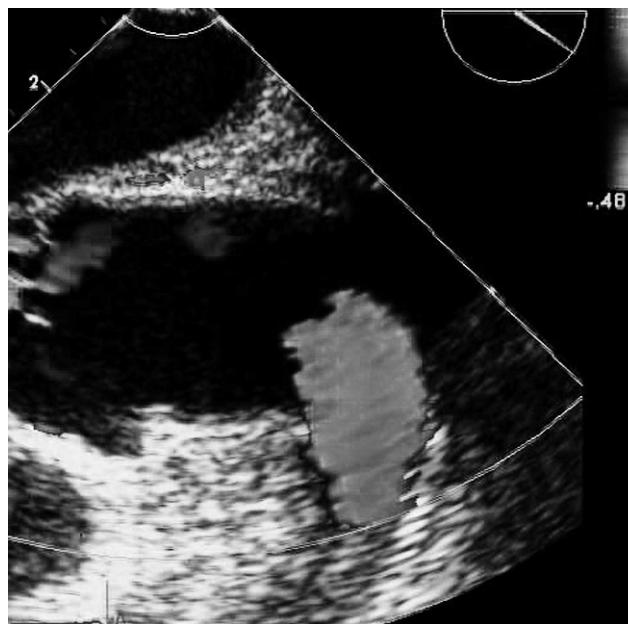


**Figure 2. Left ventricular assist device inflow cannula correctly positioned near the apex of the left ventricle. The cannula should be directed straight up into the middle of the ventricle as is the case here. A cannula directed toward the septum may result in inflow occlusion.**

TEE evaluation of the components of the newly inserted LVAD is necessary after separation from cardiopulmonary bypass. Inflow cannula placement is evaluated with the midesophageal views (Figure 2). The cannula should be in line with the mitral inflow into the LV, without entraining the leaflets of the mitral valve. If the inflow cannula is oriented toward the ventricular septum, inflow cannula obstruction may occur, especially during episodes of hypovolemia. Velocities into the inflow cannula should be measured to assist in ruling out obstruction from surrounding tissues, thrombus, or misalignment. The outflow cannula is visualized with the long axis of the ascending aorta at the level of the right pulmonary artery (Figure 3). Peak velocities should be measured to rule out orifice obstruction or intrinsic obstructing lesions.

### Coagulation Disorders

Patients presenting for LVAD insertion will frequently have preexisting coagulation disorders. These disorders can be broadly categorized as iatrogenic and intrinsic. Most candidates for VADs will already be receiving systemic anticoagulation for prevention of intracardiac thrombus secondary to low cardiac output states. A subset of device recipients will present with acute cardiac failure, with resulting hepatic insufficiency. These patients have coagulopathy secondary to decreased production of coagulation factors by the liver. Other surgical candidates have been prescribed antiplatelet medications that affect platelet function, either reversibly or irreversibly. In addition to the above preoperative concerns, VAD placement is a complicated and surgically challenging



**Figure 3. Left ventricular assist device outflow cannula routed into the ascending aorta.**

procedure that often involves an extended period on cardiopulmonary bypass with resultant coagulopathy. Patients therefore require aggressive replacement of blood components and specific surgical strategies to address this issue.

Transfusion requirements varied widely for the patients in this series. Many patients required aggressive intraoperative transfusion of RBCs, FFP, platelets, and cryoprecipitate, while others required little or no transfusion. These considerable variations in transfusion requirements may be attributed, in part, to the varying degrees of preexisting coagulopathy among this surgical population. The primary method of replacement of coagulation factors was with a combination of FFP and platelet transfusion, both intraoperatively and postoperatively. On average, 3 units ( $\pm 2.6$  units) of FFP were transfused intraoperatively and 10 units postoperatively in our patients with HeartMate II devices. Platelet transfusions were performed, with an average of 4.6 units administered intraoperatively and 5.4 units postoperatively. The preoperative use of antiplatelet medications may also contribute to the necessity for platelet transfusion.<sup>16</sup> Transfusion of packed RBCs is also necessary, secondary to surgical blood loss and coagulopathy. Intraoperative RBC usage averaged 1.1 units (maximum, 7 units), with an average 9.3 units administered in the first 48 hours postoperatively.

Our review shows fewer indications for total surgical drainage after LVAD placement for the primary closure group than for patients undergoing secondary

closure. In this series, 11 patients underwent primary closure, while the remaining 31 underwent delayed closure. For patients undergoing primary closure, postoperative blood loss averaged 4,031 mL ( $\pm 2,310$  mL) in the first 48 hours, while for those undergoing secondary closure, blood loss averaged 3,845 mL before closure and 2,694 mL in the first 24 hours after closure. This difference is most likely attributable to patient selection bias. When choosing patients to undergo primary closure, favorable coagulation status, lesser degree of cardiac decompensation, and absence of anticoagulant medications when presenting for surgery were factors that most likely promoted selection. These factors have been shown elsewhere to affect surgical bleeding during LVAD insertion.<sup>17</sup>

The incorporation of novel approaches to coagulopathy with massive transfusion is part of our perioperative management of these patients. Intraoperative and postoperative administration of recombinant factor VII, in the setting of ongoing coagulopathy refractory to aggressive transfusion of blood products, is one example. In our review, 3 of 42 patients who presented for VAD implantation received recombinant factor VII during their surgical course. Recombinant factor VII increases thrombin generation and promotes clot formation.<sup>18</sup> Antifibrinolytic medications are routinely used in these cases, for example,  $\epsilon$ -aminocaproic acid at our institution. This medication is used to prevent activation of the inflammatory cascade as well as fibrinolysis.<sup>19</sup>

### Surgical Outcomes/Right Heart Support

Perioperative survival was 91% in this series of patients. Four deaths occurred in the postoperative period owing to multiorgan failure stemming from hepatic failure. In 2 instances, the patients were critically ill and in multiorgan failure preoperatively owing to cardiogenic shock. The other 2 patients had chronic heart failure with ischemic cardiomyopathy and had received home inotropic therapy for more than 1 year. All remaining patients in this clinical series were discharged home with no major morbidity, including no need for hemodialysis, no strokes, and no need for inotropic infusions. Eight patients were successfully bridged to transplant with 100% survival.

The incidence of right heart dysfunction requiring RVAD support has historically been around 10% with the older-generation HeartMate XVE LVAD. The HeartMate II trial for destination therapy reported a 4% incidence of right heart support with an RVAD.<sup>20</sup> A comparison revealed a similar incidence of preoperative right heart dysfunction between patients receiving the 2 devices. Interestingly, operative mortality

was lower in the HeartMate II group with the lower requirement for RVAD support. Despite the improvements, the authors<sup>21</sup> noted that right heart dysfunction remains a persistent clinical problem after LVAD placement.

The lower-than-expected incidence of postoperative right heart dysfunction requiring RVAD support in our patients could be caused by several factors. All patients in this series were admitted preoperatively to evaluate right heart function. In all cases, the RV function was adequate preoperatively, as measured by central venous pressure less than 15 mmHg, and cardiac index was greater than 2.0 L/m<sup>2</sup>, as measured by pulmonary artery catheter. Patients then received optimized therapy with inotropic support, judicious diuresis to lower right heart filling pressure, and intra-aortic balloon pump if necessary. Sternal closure is delayed for 24 to 48 hours if either coagulopathy or right heart dysfunction is present. Limiting the amount of blood products transfused, allowing the RV the time to recover in an open sternum, and using nitric oxide are all contributing factors in optimizing the performance of an impaired RV. Returning to the operating room to close the sternal incision allows irrigation of any retained thrombus and is an excellent opportunity for adjusting the LVAD speed under guidance of TEE performed by our team of cardiac anesthesiologists.

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