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Effects of Left Ventricular Assist Device Therapy on Ventricular Arrhythmias

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OBJECTIVES In a retrospective study, we sought to evaluate the effect of left ventricular assist device (LVAD) therapy on ventricular tachyarrhythmias in patients with advanced congestive heart failure.

BACKGROUND Despite the increasing use of LVAD as a bridge to cardiac transplantation, our knowledge regarding its effect on ventricular arrhythmias is currently limited to small series. Little is known about the prevalence, predictors, and clinical consequences of ventricular arrhythmias in LVAD recipients.

METHODS We reviewed the pre- and post-LVAD course of the last 100 consecutive adult patients to receive a HeartMate LVAD (Thoratec Laboratories Corp., Pleasanton, California) at our institution. All ventricular arrhythmias sustained for at least 30 s or requiring defibrillation were analyzed. All documented pre- and post-LVAD sustained ventricular arrhythmias were classified either as monomorphic ventricular tachycardia (MVT) or polymorphic ventricular tachycardia (PVT)/ventricular fibrillation (VF).

RESULTS Our population had an average age of 51 years, had predominately ischemic cardiomyopathy (63%), and a mean left ventricular ejection fraction of 20 ± 10%. New-onset MVT was observed in 18 patients who did not have MVT before LVAD placement. After LVAD, new-onset MVT was 4.5 times more likely than elimination of previously present MVT ($p = 0.001$), whereas the effect of LVAD on incidence of PVT/VF was not significant. In a multivariate Cox proportional hazards regression analysis, serum electrolyte abnormality was an independent predictor of post-LVAD ventricular arrhythmias. Preoperative MVT did not predict postoperative MVT.

CONCLUSIONS After LVAD placement, there is a significant rise in the incidence of de novo MVT. By contrast, the incidence of PVT/VF was unaffected by LVAD placement. (J Am Coll Cardiol 2005;45:1428–34) © 2005 by the American College of Cardiology Foundation

As the prevalence of advanced heart failure continues to increase, the left ventricular assist device (LVAD) has become an excellent bridge to cardiac transplantation and to possible other future alternative therapies (1,2). Our understanding of post-LVAD ventricular arrhythmias is currently limited to clinical data from a few small case series (3,4), and little is known about the prevalence, predictors, and clinical significance of post-LVAD ventricular arrhythmias. Even fewer data are available with regard to the effects of LVAD therapy on the prevalence and the electrophysiologic characteristics of pre-existing ventricular arrhythmias. In this retrospective study, we investigated the prevalence, predictors, electrocardiography, and clinical outcomes of ventricular arrhythmias in LVAD recipients.

METHODS

Subjects. We reviewed the last 100 consecutive available charts of patients to receive a HeartMate LVAD (Thoratec Laboratories Corp., Pleasanton, California) at the Columbia University Medical Center between July 1997 and March 2001. All but two patients received a LVAD for medically unresponsive advanced heart failure, whereas two patients received LVADs for uncontrollable ventricular tachyarrhythmias. All LVADs were implanted by the cardiothoracic surgical staff at our institution and placed at a left ventricular (LV) apical site as previously described (5). The majority of the patients received a LVAD as a bridge to cardiac transplantation. Eighteen of the 100 patients had biventricular assist devices placed at other institutions for stabilization, until transfer to our institution for biventricular assist device explantation followed by HeartMate LVAD implantation. Another 12 patients required right ventricular assist device (RVAD) placement at our institution for severe right heart failure after LVAD implantation.

Ventricular arrhythmia analysis. All available past medical records, physician and nurse notes, telemetry tracings, retrieved implantable cardioverter-defibrillator (ICD) tracings, and 12-lead electrocardiograms (ECGs), both preoperatively and postoperatively, generated during the admission before LVAD implantation and during any subsequent admissions, were reviewed. All available preoperative and postoperative ventricular tachyarrhythmias lasting for at least 30 seconds or requiring transthoracic defibrillation or an ICD shock for termination were analyzed. Ventricular arrhythmias were classified as monomorphic ventricular tachycardia (MVT), using the constancy of cycle length from one beat to the next, and the reproducibility of ECG or rhythm strip QRS morphology or ICD local signal

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Abbreviations and Acronyms

ECG = electrocardiogram
ICD = implantable cardioverter-defibrillator
LV = left ventricular
LVAD = left ventricular assist device
LVEF = left ventricular ejection fraction
MVT = monomorphic ventricular tachycardia
PVT = polymorphic ventricular tachycardia
RVAD = right ventricular assist device
VF = ventricular fibrillation

morphology from one beat to the next, based on separate review by two electrophysiologists, each blinded to the classification of the other. Sustained ventricular arrhythmias not meeting the criteria for MVT were classified as polymorphic ventricular tachycardia (PVT), or ventricular fibrillation (VF). No distinction was made between sustained PVT and VF, (henceforth, PVT/VF) for analysis of the results.

Of the 100 consecutive patients initially selected into our study, medical chart reviews identified 9 patients whose problem lists included ventricular tachyarrhythmia but for whom no actual documentation of any ventricular arrhythmia was available. These cases were not included in the analysis because without proper documentation, these arrhythmias could not be classified. Moreover, the distinction between MVT and PVT/VF was one of the main points of our analysis. The remaining 91 patients either did not have a history of any ventricular tachyarrhythmia, or had documented MVT, or PVT/VF, or both.

Available 12-lead ECGs were also analyzed in a blinded fashion by two separate cardiac electrophysiologists, for estimation of the approximate site of origin of MVTs, using a previously published algorithm (6). There was a 95% agreement rate between the two cardiac electrophysiologists. In cases of disagreement, a third, blinded electrophysiologist was asked to review the data for a final decision.

Several clinical and hemodynamic data, including blood test results and postoperative LVAD flows, were also analyzed. For laboratory data, the last recorded values within the 24 h before the ventricular tachyarrhythmia and the first recorded values within 24 h after the ventricular tachyarrhythmia were used. Serum electrolyte abnormalities analyzed as correlates of ventricular tachyarrhythmias included hypokalemia, hyperkalemia, hypomagnesemia, and hypocalcemia. These were defined as serum potassium concentration <3.5 mEq/l, >5.2 mEq/l, serum magnesium concentration <1.5 mEq/l, and corrected serum calcium concentration <8.0 mEq/l, respectively, in accordance with the normal ranges of our hospital laboratory.

Statistical analysis. Proportions from different subgroups were compared by chi-square test. For comparisons within small groups in which the total data points were <40, a Fisher exact test was used. In comparing the prevalence of arrhythmias before and after LVAD therapy, McNemar's chi-square test was used. Continuous variables were compared using a Student t test. To investigate the association of postoperative ventricular arrhythmia and all-cause mortality, a Cox proportional hazards survival analysis was used. Once the transplant was complete, the patients were censored from survival analysis. A Cox proportional hazards analysis was also constructed to demonstrate the strength and independence of predictors of postoperative ventricular arrhythmias. Based on the number of ventricular arrhythmia events observed after LVAD, we selected and tested five clinical factors for MVT and four for PVT/VF, as potential predictors of post-LVAD ventricular arrhythmia. In this analysis, time to event was defined as time to onset of ventricular arrhythmia after LVAD implantation. The patients who underwent cardiac transplantation or died before a ventricular tachyarrhythmia event were censured from this analysis. A p value <0.05 was considered statistically significant.

RESULTS

Clinical characteristics. Of the initial 100 patients whose charts were reviewed, our population consisted of 91 patients who had either no pre-LVAD ventricular arrhythmias or documented pre-LVAD ventricular arrhythmias. Their clinical characteristics are shown in Table 1. Only the two patients whose indication for LVAD was uncontrollable ventricular arrhythmias were not receiving intravenous inotropic therapy before LVAD.

Arrhythmia prevalence. One hundred eighteen episodes of documented sustained clinical ventricular arrhythmia occurred in 30 patients (3.9 episodes per patient) from 3 years to 1 day before LVAD implantation. One hundred seventy-nine episodes of sustained ventricular arrhythmia occurred in 32 patients (5.6 episodes per patient) from 1 day to 126 days after LVAD placement. Of the 30 patients with ventricular arrhythmia before LVAD, 9 had documented MVT, 23 had documented PVT/VF, and 2 had both (Table 2). Of the 32 patients with post-LVAD ventricular arrhyth-

Table 1. The Clinical Characteristics of the Patient Population

Characteristics	Total N = 91 (%)
Age (yrs)	51 ± 10
Male	74 (81)
Ischemic heart disease	57 (63)
LVEF (%)	20 ± 10
Patients on amiodarone therapy before LVAD	38 (42)
Patients with cardiac arrest prior to LVAD	28 (30)
Patients with MVT or PVT/VF before LVAD	30 (33)
Patients with MVT or PVT/VF after LVAD	32 (35)
Patients with ICD implanted prior to LVAD	17 (19)
Patients with NYHA functional class IV before LVAD	81 (89)
Patients on inotropic support prior to LVAD	89 (98)
Patients on inotropic support after LVAD	91 (100)

ICD = implantable cardioverter-defibrillator; LVAD = left ventricular assist device; LVEF = left ventricular ejection fraction; MVT = monomorphic ventricular tachycardia; NYHA = New York Heart Association; PVT = polymorphic ventricular tachycardia; VF = ventricular fibrillation.

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Table 2. Specific Ventricular Tachyarrhythmias Before and After LVAD Placement

Ventricular Arrhythmia	Patients With Ventricular Arrhythmia Before LVAD	Patients With Ventricular Arrhythmia After LVAD	Patients With Ventricular Arrhythmia Pre-LVAD But Not Post-LVAD	Patients With Ventricular Arrhythmia Pre-LVAD As Well As Post-LVAD	Patients With Ventricular Arrhythmia Post-LVAD But Not Pre-LVAD	Ratio of New-Onset Arrhythmia/ Eliminated Arrhythmia
MVT	9	23	4	5	18	18/4 = 4.5 p = 0.001
PVT/VF	23	17	16	7	10	10/16 = 0.63 p = 0.17

Abbreviations as in Table 1.

mia, 23 patients had documented MVT, 17 had documented PVT/VF, and 8 patients had both (Table 2). After LVAD, MVT was no longer observed during the follow-up period in four patients with documented pre-LVAD MVT, whereas the other five patients with pre-LVAD MVT continued to have MVT after LVAD implantation. New-onset MVT was documented after LVAD implantation in 18 patients who had no preoperative MVT (Table 2). Furthermore, 12 of these 18 patients had no pre-LVAD ventricular arrhythmia of any type. Thus, new-onset MVT was 4.5 times more likely than elimination of previously present MVT ($p = 0.001$) (Table 2). This finding remained statistically significant in the subgroup of patients with ischemic heart disease and in the group with LVEF between 15% and 40%. The presence of pre-LVAD amiodarone therapy did not influence the significance of this finding; among the patients with no prior amiodarone therapy, and among those with prior amiodarone treatment, there were equal numbers of new-onset post-LVAD MVT.

After LVAD, PVT/VF was no longer observed in 16 patients who had this type of ventricular arrhythmia before LVAD placement, whereas PVT/VF occurred as a new-onset ventricular arrhythmia in 10 patients who had not had these ventricular arrhythmias documented preoperatively (Table 2). The ratio of new-onset PVT/VF to the previously present PVT/VF, which disappeared after LVAD, was not statistically significant (Table 2).

Repeating this analysis after excluding the two patients who received LVAD support for intractable ventricular tachyarrhythmias did not change our results. In this analysis, the number of patients with pre-LVAD MVT was 7; however, the number of patients with new-onset MVT after LVAD placement remained 18, and the number of patients with pre-LVAD MVT, who no longer had MVT after LVAD implantation also remained 4. Thus new-onset MVT remained 4.5 times more likely than the elimination of previously present MVT.

The majority of the 32 patients who had post-LVAD ventricular arrhythmia had experienced the first episode of ventricular arrhythmia by the end of the first postoperative week (Fig. 1). All but 1 of the 32 patients had experienced post-LVAD ventricular arrhythmia by day 14 after LVAD implantation (Fig. 1), and after this period, no new-onset ventricular tachyarrhythmia in any of the remaining patients was observed until transplant or death.

Electrocardiographic site of origin of monomorphic ventricular tachycardia. An approximate left ventricular (LV) site of origin was defined for 11 post-LVAD MVTs, for which, the 12-lead ECGs were available, using the ECG algorithm (6). Seven of these 11 MVTs (64%) were assigned an LV apical site of origin (Fig. 2). Two of the remaining 11 patients had an inferior LV site of origin, 1 patient had an anteroseptal site of origin, and 1 patient had a basal-septal site of origin. Five of the 11 available 12-lead ECG tracings had been recorded in patients who had new-onset MVT after LVAD implantation. Three (60%) of these five MVTs had an LV apical site of origin by the ECG algorithm used. Pre-LVAD MVT had a mean cycle length of 355 ± 82 ms; in general, post-LVAD MVT was faster than preoperative MVT, manifesting a mean cycle length of 308 ± 88 ms ($p = 0.04$).

Treatment of post-LVAD ventricular arrhythmias. One hundred twelve episodes (63%) of post-LVAD ventricular arrhythmia were terminated immediately by an ICD shock or transthoracic direct current cardioversion or defibrillation. Another 5% of the episodes were terminated by cardioversion after 7.5 ± 1.0 h of sustained ventricular tachyarrhythmia, and 14% of the MVTs were interrupted by antitachycardia ventricular pacing. Post-LVAD ventricular tachyarrhythmia was nearly incessant (continuous through-

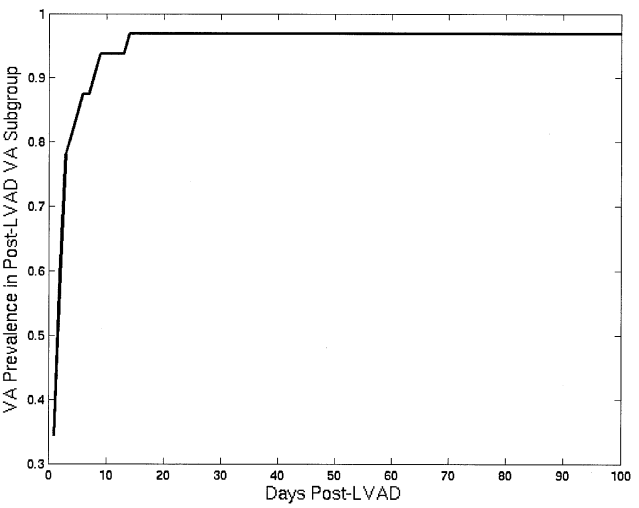

Figure 1. Of the 32 patients with post-left ventricular assist device (LVAD) ventricular tachyarrhythmias, prevalence of arrhythmia onset is shown as a function of days post-LVAD. VA = ventricular arrhythmia.

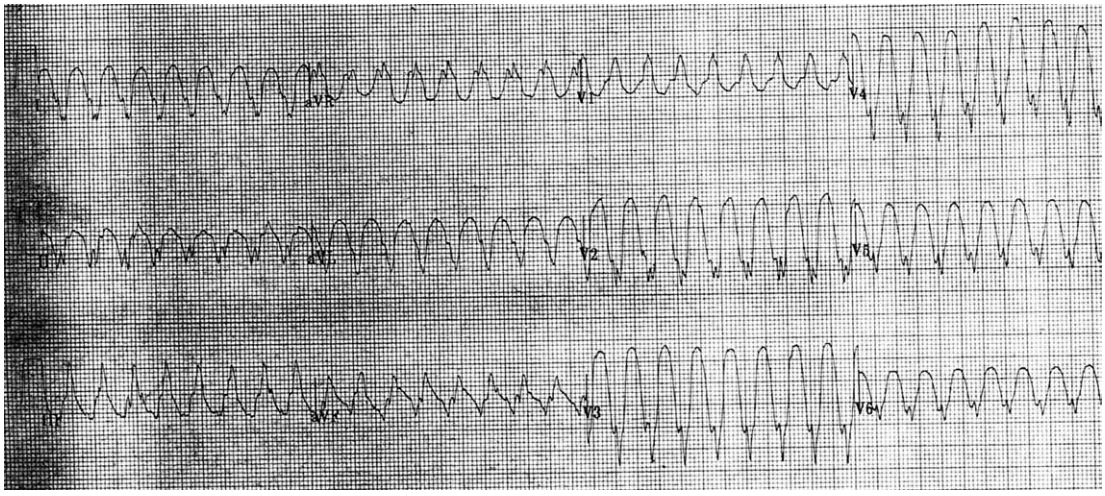

Figure 2. An example of a 12-lead electrocardiogram tracing recorded during post-left ventricular assist device monomorphic ventricular tachycardia. The electrocardiogram algorithm applied to the frontal and the horizontal axes and the QRS morphology suggests a left ventricular apical site of origin.

out the day with brief interruptions) in nine patients and highly frequent (>5 episodes/day) in seven patients.

Ninety-three percent of ventricular tachyarrhythmia episodes were treated with antiarrhythmic agents. Seventy-one percent of patients with ventricular tachyarrhythmias required two or more antiarrhythmic agents to prevent recurrence. The most common agent used was amiodarone (75%). Lidocaine was the second most commonly used agent (41%). Procainamide, mexilitine, bretylium, and beta-blockers were all used less commonly to control ventricular tachyarrhythmias.

Of the 32 patients with postoperative ventricular tachyarrhythmias, adequate suppression of arrhythmias could not be achieved in 12 patients. Six of these patients died and the other six had cardiac transplantation. The mean number of days from the last documented ventricular tachyarrhythmia to the end of follow-up was 4.9 ± 1.2 in these 12 patients. By contrast, of the remaining 20 patients in whom ventricular tachyarrhythmias were suppressed, 3 patients died, and 17 patients underwent cardiac transplantation ($p = 0.049$). The mean number of days from the last documented ventricular tachyarrhythmia to the end of follow-up was 55.2 ± 11.3 in these 20 patients. Furthermore, of these 20 patients, the ventricular arrhythmia came under control a mean of 17.9 ± 6.8 days after onset in patients with post-LVAD MVT, and 7.1 ± 3.2 days after onset in patients with PVT/VF. Amiodarone was more often the first drug to be started and the last to be used in the group that achieved ventricular arrhythmia suppression.

Predictors of post-LVAD ventricular arrhythmias. We generated two separate multivariate models for predictors of MVT and PVT/VF. A Cox proportional hazards analysis showed that pre-LVAD MVT was not a predictor of post-LVAD MVT (Table 3). Postoperative serum electrolyte abnormality, as defined in the Methods section, was an independent predictor of both post-LVAD MVT and PVT/VF (Tables 3 and 4). Among the parameters analyzed (Table 3), the multivariate model identified only ischemic heart disease as an additional independent predictor for post-LVAD MVT (Table 3). The same analysis applied to post- LVAD PVT/VF showed an inverse correlation between immediate postoperative LVAD flows and post-LVAD PVT/VF (Table 4).

Clinical consequences of post-LVAD ventricular arrhythmias. Of the 32 patients with post-LVAD ventricular arrhythmias, 6 (18%) required implantation of an RVAD for severe right heart failure, whereas 6 (10%) of the 59 patients without post-LVAD ventricular arrhythmias required implantation of an RVAD. This difference was not significant. In the entire group with post-LVAD ventricular arrhythmias, there was no significant change in laboratory indicators of inadequate systemic perfusion (blood urea nitrogen, creatinine) or right-sided heart failure (liver enzymes, prothrombin time) after termination of post-LVAD ventricular arrhythmias. The risk of embolic events was 23% higher in patients with post-LVAD ventricular arrhythmias (5 of 32), compared with those who did not have post-LVAD ventricular arrhythmias (8 of 59). This increase was not statistically significant.

Over a follow-up period of one year after LVAD implantation, 9 of the 32 (28%) patients with post-LVAD ventricular arrhythmias died compared with 8 deaths in the group of 59 (14%) patients with no post-LVAD ventricular arrhythmias (unadjusted hazard ratio = 2.16, 95% confi-

Table 3. Clinical Parameters Analyzed as Potential Predictors of Post-LVAD MVT

	Hazard Ratio (CI)	p Value
Presence of MVT before LVAD	1.6 (0.48–5.4)	0.44
Postoperative electrolyte abnormality	5.2 (2.1–12.9)	0.0004
LVAD flow immediately post-LVAD	1.1 (0.74–1.7)	0.54
Ischemic heart disease as etiology of heart failure	4.6 (1.4–16)	0.015
LVEF (%)	0.98 (0.93–1.04)	0.52

CI = confidence interval; other abbreviations as in Table 1.

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Table 4. Clinical Parameters Analyzed as Potential Predictors of Post-LVAD PVT/VF

	Hazard Ratio (CI)	p Value
Postoperative electrolyte abnormality	3.2 (1.3–8.2)	0.015
LVAD flow immediately post-LVAD	0.62 (0.43–0.89)	0.010
Ischemic heart disease	0.40 (0.072–2.2)	0.29
LVEF (%)	1.0 (0.97–1.1)	0.72

Abbreviations as in Tables 1 and 3.

dence interval 0.83 to 5.62, p = 0.11). Figure 3 shows the survival curves in these two groups. None of these deaths were sudden, because LVAD provided adequate cardiac output, at least temporarily, even when ventricular tachyarrhythmias were intractable. The majority of the deaths were caused by low output states, with or without sepsis or bleeding, whereas two patients died of fatal stroke.

DISCUSSION

This study presents the largest series to date, evaluating the effect of LVAD therapy on the presence and characteristics of ventricular tachyarrhythmias. While ventricular tachyarrhythmias were common in our population, present in approximately one-third of the patients, both preoperatively and postoperatively, LVAD therapy itself appeared to promote MVT in this group of patients. This conclusion is supported by the significant increase in the new-onset MVT after LVAD therapy compared with the post-LVAD absence of previously present MVT in a small number of patients. By contrast, LVAD therapy did not have a similar effect on PVT/VF. Furthermore, whereas the total number of patients with ventricular tachyarrhythmias of any kind before and after LVAD was similar, post-LVAD ventricular tachyarrhythmia was more frequent, often incessant, and resistant to multiple drug treatments. Our study did not show a statistically significant relationship between post-LVAD ventricular tachyarrhythmias and all-cause mortality or stroke. However, because this study was not powered to show even a 50% relative risk increase in all-cause mortality, our data are inconclusive on these issues.

Two previously published series investigated the pre- and post-LVAD prevalence of ventricular tachyarrhythmias (3,4). Both studies were small and included fewer than 30 patients. The incidence of post-LVAD ventricular tachyarrhythmias in these small series was 43% and 18%, respectively, compared with 35% incidence we encountered in our population. The conclusions of these two studies were discordant, one suggested a two-fold increase in ventricular tachyarrhythmia prevalence post-LVAD (3), whereas the other suggested a 36% reduction in ventricular tachyarrhythmia prevalence (4). Our study has twice the power of these previous investigations, evaluated the changes in the prevalence of MVT and PVT/VF separately, and showed a clear-cut increase in the incidence of MVT after LVAD. It is important to emphasize that the increase in the incidence of MVT we observed in LVAD recipients was not the result of transformation of PVT/VF into MVT by LVAD because the majority of the de novo MVTs occurred in patients who had no pre-LVAD ventricular tachyarrhythmia of any kind.

Several previous case reports describe the use of LVAD to treat frequent, drug-refractory ventricular tachyarrhythmias (7–10), similar to the two patients in our study, who received a LVAD for uncontrollable MVT. These cases show that ventricular tachyarrhythmias may or may not continue after LVAD, but the clinical deterioration may be halted with LVAD even in patients with continuing ventricular tachyarrhythmias. Two small series have reported the relative stability of LVAD patients despite recurrent sustained ventricular tachyarrhythmias (3,11). One of these reported a significant decrease in LVAD flow, by up to 1.4 l/min, during sustained ventricular arrhythmias with prompt return to baseline LVAD flow values after the cessation of ventricular arrhythmias without any evidence of significant vital organ damage (3). Our observations corroborate this lack of end-organ damage with prolonged episodes of ventricular arrhythmias in the presence of LVAD support. Prolonged periods of right ventricular PVT/VF or MVT may, in theory, predispose to marked right heart failure; however, our study did not show an increased incidence of severe right heart failure in patients with post-LVAD ventricular tachyarrhythmias.

There was a trend, which did not reach statistical significance, suggesting a possible association of post-LVAD ventricular tachyarrhythmias and all-cause mortality. However, our study was not powered to prove or disprove such an association, and further investigation in a larger group of patients is needed to determine whether this association can achieve statistical significance. This is especially important since the temporary hemodynamic stability, provided by the LVAD, may result in prolonged periods of untreated sustained ventricular arrhythmias. Any association of prolonged episodes of ventricular arrhythmias with adverse outcome, either increased incidence of stroke or increased

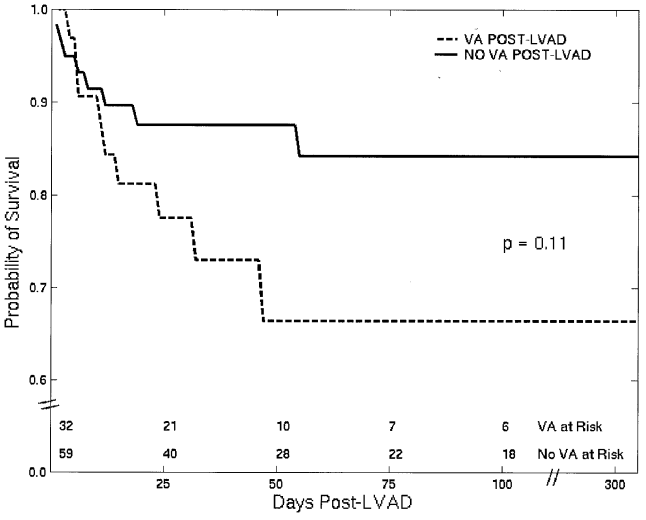

Figure 3. Cumulative survival curves show all-cause mortality after left ventricular assist device (LVAD) implantation in the group with and the group without post-LVAD ventricular tachyarrhythmia (VA).

risk of mortality, would result in a more aggressive policy of detection and treatment of post-LVAD ventricular arrhythmias.

Possible mechanisms of post-LVAD ventricular arrhythmias. Previous clinical observations have shown a strong correlation between myocardial scar and MVT (12). The factors that promote PVT/VF may not necessarily be the same as those that promote MVT, although usually there is an overlap between the etiologies of these morphologically different ventricular arrhythmias (13). Therefore, hemodynamic benefit from the LVAD support might have played a major role in the 20 patients in whom the ventricular arrhythmias were finally suppressed. Improved hemodynamic conditions may reverse myocardial ischemia and decrease ventricular wall tension, thereby exerting an antiarrhythmic effect. However, these factors may influence MVT and PVT/VF differently. For example, factors such as myocardial ischemia, poor hemodynamic state, and ongoing intravenous pressor requirement, may play a more important role in triggering PVT/VF compared with MVT, which may be more dependent on the presence of old, but perhaps also newly acquired myocardial scar. This view is supported by our observation that low LVAD flows, which may cause myocardial ischemia and may also be associated with unstable hemodynamic conditions, predicted PVT/VF but did not predict MVT. By contrast, the scar produced by the apical insertion of the LVAD in-flow cannula may create a new substrate for MVT, thereby increasing the incidence of MVT even in the absence of myocardial ischemia or unstable hemodynamic conditions. This possible explanation is supported by the fact that the LV apex was the likely site of origin in three of the five de novo post-LVAD MVTs, for which 12-lead ECG documentation was available. Furthermore, PVT/VF came under control in a shorter period, 7.1 ± 3.2 days after LVAD implantation, compared with MVT, which took longer, 17.9 ± 6.8 days, to subside. These observations suggest, but do not prove, that factors such as hemodynamic improvement with LVAD support and discontinuation of intravenous pressors may have had a greater impact on PVT/VF, compared with MVT, which may have required the antiarrhythmic effect of amiodarone to a greater extent before coming under control. Finally, LVAD may have had an indirect effect on MVT by increasing the efficacy of the antiarrhythmic agents resulting from the improvement in hemodynamic conditions.

It is not surprising that derangements in serum electrolyte concentrations correlated with the presence of any sustained ventricular arrhythmia after LVAD implantation, because regardless of the nature of the arrhythmia substrate, these serum electrolyte abnormalities may serve as initiating triggers.

Treatment of post-LVAD ventricular arrhythmias. Based on our experience, the following methodical approach may be reasonable for the treatment of post-LVAD ventricular arrhythmias. Regardless of the type of ventricular tachyarrhythmia, the first step should be the immediate assessment of their hemodynamic consequences. Those that result in systemic clinical signs of hypoperfusion such as oliguria, a decrease in LVAD flows by 1.5 or more, or acute right heart failure should be terminated promptly by transthoracic cardioversion or ICD shock if there is one in place. As a second step, serum electrolyte derangements should be corrected promptly, again regardless of the type of ventricular arrhythmia. Our results suggest that meticulous monitoring of serum electrolytes as early as possible is warranted as a measure to possibly avoiding post-LVAD ventricular arrhythmias. Our data also show that the majority of patients who develop ventricular tachyarrhythmias after LVAD placement have them very early after the operation (Fig. 1), when there is prodigious intravenous pressor use. Especially for those patients with PVT/VF, weaning off pressor support promptly, whenever possible, should be the goal. Finally, in patients with MVT, amiodarone therapy should be started early, because it takes longer for this ventricular arrhythmia to come under control, which may not happen solely by improvement of hemodynamic conditions, myocardial ischemia, and other reversible conditions.

Study limitations. Our study was limited by its retrospective nature. This was especially a concern with regard to the pre-LVAD documentation of ventricular arrhythmias. Despite our efforts to carry out a very comprehensive clinical review of all available clinical material generated before LVAD implantation, it is possible that few patients had ventricular arrhythmias months or years before LVAD placement with no available documentation. Such lack of documentation may result in underestimation of pre-LVAD MVT, or PVT, or both. Lack of documentation is a lesser problem for the duration of hospital stay, because the patients are watched closely, and their cardiac rhythms are monitored on telemetry. However, when the cardiac rhythm of an LVAD patient is no longer monitored continuously, for example, after discharge from the hospital, episodes of self-terminating latent ventricular arrhythmias may go undetected because of the hemodynamic stability provided by the LVAD support. Such occurrences would underestimate the incidence of post-LVAD late ventricular arrhythmias.

The average observation periods before and after LVAD were uneven by necessity, because the post-LVAD follow-up period is understandably limited by cardiac transplantation in the majority of patients. Longer follow-up periods might allow observation of new MVT or PVT/VF, thereby changing the incidence of post-LVAD ventricular arrhythmias. This limitation, however, is unlikely to affect the main observation of our study, the emergence of a significant number of de novo MVT after LVAD implantation, during a relatively short period, and mostly in patients who had no pre-LVAD ventricular arrhythmia of any kind.

Other limitations involved the analysis and the interpretation of the 12-lead ECG tracings. Even though the tracings were interpreted in a blinded fashion, our reviewers

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were aware of the fact that these were LVAD recipients. Thus, bias could have been introduced in ECG interpretations. Finally, the difficulty in reviewing all the details during the complex intensive care given to the LVAD recipients limited our ability to report comprehensively on the efficacy of the specific anti-arrhythmic agents used for treatment of ventricular arrhythmias postoperatively. Thus, our study is not able to suggest a definitive pharmacologic treatment strategy for post-LVAD ventricular arrhythmias.

Conclusions. In the largest retrospective study to date investigating the effect of LVAD therapy on ventricular arrhythmias, we showed a significant increase in de novo MVT after LVAD therapy, with no similar increase in post-LVAD PVT/VF. The optimal modalities of anti-arrhythmic therapy for ventricular arrhythmia suppression in LVAD recipients need better definition. Whether post-LVAD ventricular arrhythmias are associated with an increased risk of stroke or all-cause mortality remains unresolved and needs to be investigated further.

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REFERENCES

1. Rose EA, Gellins AC, Moskowitz AJ, et al. Long-term use of a left ventricular assist device for end-stage heart failure. N Engl J Med 2001;345:1435–43.
2. Frazier OH, Rose EA, Oz MC, et al. Multicenter clinical evaluation of the Heartmate vented electric left ventricular assist system in patients awaiting heart transplantation. J Thorac Cardiovasc Surg 2001;122:1186–95.
3. Oz MC, Rose EA, Slater J, Kuiper JJ, Catanese KA, Levin HR. Malignant ventricular arrhythmias are well tolerated in patients receiving long-term left ventricular assist devices. J Am Coll Cardiol 1994;24:1688–91.
4. Arai H, Swartz MT, Penninton DG, et al. Importance of ventricular arrhythmias in bridge patients with ventricular assist devices. ASAIO Trans 1991;37:M427–8.
5. Oz MC, Goldstein DJ, Rose EA. Preperitoneal placement of ventricular assist devices: an illustrated stepwise approach. J Cardiovasc Surg 1995;10:288–94.
6. Kuchar DL, Ruskin JN, Garan H. Electrocardiographic localization of the site of origin ventricular tachycardia in patients with prior myocardial infarction. J Am Coll Cardiol 1989;13:893–900.
7. Fasseas P, Kutalek SP, Samuels FL, Holmes EC, Samuels LE. Ventricular assist device support for management of sustained ventricular arrhythmias. Tex Heart Inst J 2002;29:33–6.
8. Thomas NJ, Harvey AT. Bridge to recovery with the Abiomed BVS-5000 device in a patient with intractable ventricular tachycardia. J Thorac Cardiovasc Surg 1999;117:831–2.
9. Swartz MT, Lowdermilk GA, McBride LR. Refractory ventricular tachycardia as an indication for ventricular assist device support. J Thorac Cardiovasc Surg 1999;118:1119–20.
10. Kulick DM, Bolman RM III, Salerno CT, et al. Management of recurrent ventricular tachycardia with ventricular assist device placement. Ann Thorac Surg 1998;66:571–3.
11. Fasseas P, Kutalek SP, Kanthria BK. Prolonged sustained ventricular fibrillation without loss of consciousness in patients supported by left ventricular assist device. Cardiology 2002;97:210–3.
12. Saxon LA, Wiener I, Natterson PD, Laks H, Drinkwater D, Stevenson WG. Monomorphic versus polymorphic ventricular tachycardia after coronary artery bypass grafting. Am J Cardiol 1995;75:403–4.
13. Brugada J, Boersma L, Allessie M, Navarro-Lopez F. The complexity of mechanisms in ventricular tachycardia. Pacing Clin Electrophysiol 1993;16:680–6.