Case Series

Tolerance of Sustained Ventricular Fibrillation

During Continuous-Flow Left Ventricular Assist Device Support

Andrew C.W. Baldwin, MD
Courtney J. Gemmato, MD
Elena Sandoval, MD
William E. Cohn, MD
Jeffrey A. Morgan, MD
O.H. Frazier, MD

The widespread use of continuous-flow left ventricular assist devices for mechanical circulatory support has shown that long-term hemodynamic support is possible, even when a clinical "pulse" cannot be detected. We present the incidental discovery of ventricular fibrillation in 6 alert, hemodynamically stable patients supported only by a continuous-flow device (HeartMate II, n=5; Jarvik 2000, n=1). Ventricular fibrillation was found in 3 patients during routine outpatient follow-up visits and in 3 awaiting discharge from the hospital after device placement. Diagnosis was confirmed by electrocardiographic and echocardiographic studies.

The average duration of mechanical circulatory support before ventricular fibrillation occurred was 221 ± 362 days (range, 5–864 d). All patients were conscious and ambulatory at the time of the arrhythmia. Three patients reported symptoms—primarily fatigue, nausea, and exertional dyspnea—that prompted evaluation. Serum chemistry analysis of blood drawn immediately after diagnosis showed no changes that suggested end-organ dysfunction. Three patients died of unrelated complications an average of 3.9 yr (range, 360–2,270 d) after the event. Two of the remaining 3 patients eventually underwent successful pump explantation, and one is on ongoing support.

Our experience shows that it is possible for patients with continuous-flow left ventricular assist devices to remain hemodynamically stable while in ventricular fibrillation. Additional investigation is needed to determine whether defibrillator settings for these patients should be adjusted to limit delivery of shock therapy. ***(Tex Heart Inst J 2017;44(5):357-60)***

Key words: *Arrhythmias, cardiac; assisted circulation/instrumentation/methods; disease-free survival; heart failure/therapy; heart-assist devices; recovery of function; survival rate; time factors; ventricular fibrillation/physiopathology*

From: *Texas Heart Institute, CHI Baylor St. Luke's Medical Center, Michael E. DeBakey Department of Surgery, Division of Cardiothoracic Transplant and Mechanical Circulatory Support, Baylor College of Medicine, Houston, Texas 77030*

Address for reprints: *Jeffrey A. Morgan, MD, Texas Heart Institute, Suite C-355N, 6770 Bertner Ave., Houston, TX 77030*

E-mail: *Jeffrey.Morgan@bcm.edu*

In the treatment of heart failure, efforts to duplicate nature's design of an organ that beats more than 40 million times each year have proved impractical and have forced investigators to reconsider the physiologic necessity for pulsatile blood flow. The engineering advantages afforded by continuous-flow pumps have led to their widespread use in mechanical circulatory support (MCS), and the success of these devices has shown that long-term hemodynamic support is possible, even when a clinical "pulse" cannot be detected. Surprisingly, however, ventricular fibrillation (VF) was incidentally discovered in alert, ambulatory patients at our institution who were being supported only by a continuous-flow left ventricular assist device (LVAD).

Patients and Methods

Six clinically stable patients (4 men, 2 women; average age, 45 yr [range, 21–65 yr]) were incidentally found to be in VF while being supported by a continuous-flow LVAD. Five of these patients had been implanted with a HeartMate II® LVAD (Thoratec, now part of St. Jude Medical, Inc.; Pleasanton, Calif) and one with a Jarvik 2000® (Jarvik Heart, Inc.; New York, NY). The patients needed MCS for the treatment of advanced heart failure (New York Heart Association functional class IV) caused by nonischemic (n=4) or ischemic (n=2) cardiomyopathy. Two patients had a history of ventricular arrhythmias before implantation of the device. Ventricular fibrillation was incidentally diagnosed in 3 patients during routine outpatient follow-up visits and in 3 patients who were awaiting discharge from the hospital after device placement. In each case, VF was confirmed by means of electrocardiographic and echocardiographic studies (Fig. 1). After diagnosis, sinus rhythm was restored through direct-current cardioversion, and blood was obtained for laboratory analysis. This review was conducted with the approval of our institutional review board.

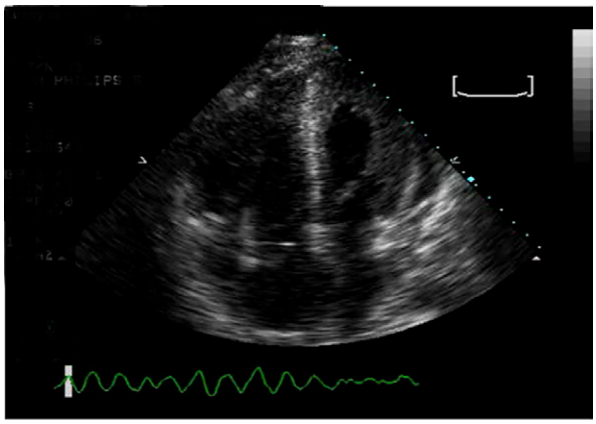

Fig. 1 *Transesophageal echocardiogram confirms ventricular fibrillation in a patient supported entirely by a continuous-flow left ventricular assist device.*

Statistical Analysis

Statistical comparisons were 2-sided, and laboratory data were subjected to between-subjects analysis. A P value <0.05 was considered significant. All analyses were performed with R statistical software, version 3.0.2 (R Foundation for Statistical Computing; Vienna, Austria). Laboratory data are presented as mean ± SD.

Results

The 6 patients survived a prolonged fibrillation event without evidence of hemodynamic compromise. Each patient had previously undergone automated implantable cardioverter-defibrillator implantation; however, these devices were not turned on to treat tachyarrhythmias. Each patient was conscious and ambulatory at the time of the arrhythmia. Four patients reported symptoms that prompted evaluation: 3 had dizziness and fatigue within 24 hours of the diagnosis. In one of these 3 patients, the symptoms were presumably related to kinking of the left ventricular outflow tract while the patient squatted. The 4th patient exhibited symptoms of occasional presyncope. When asked, a 5th patient reported mild nausea and lightheadedness during the 10 days before a scheduled clinic appointment. In the asymptomatic patient, VF was identified during a routine postoperative echocardiogram before discharge from the hospital.

The average duration of MCS before the VF event was 221 ± 362 days (range, 5–864 d). It was not possible to establish how long each of the 3 outpatients had been in VF before their presentation; the duration of each episode could only be approximated based on the onset of symptoms (when present). Upon physical examination, no patient had a palpable pulse, and 3 had plethoric neck veins. No patient showed evidence of end-organ dysfunction as a result of the fibrillation episode, and serum chemistry analysis of blood drawn after diagnosis showed no significant changes from previous values (Table I).

All 6 patients remained stable after cardioversion and were discharged after a brief hospital stay (range, 2–24 d after diagnosis). There were no recurrent episodes of VF, and all patients were cared for on a routine outpatient basis. Three patients survived, 2 of whom ultimately underwent successful pump explantation. Three patients died an average of 3.9 years (range, 360–2,270 d) after the VF event: one of a hemorrhagic stroke the next year, and 2 after eventual transplantation more than 5 years after the VF event. One patient is still on LVAD support.

Discussion

In this study, we describe the cases of 6 patients who survived sustained periods of VF during dependence on a continuous-flow pump as the sole source of cardiac output. The patients, some of whom reported mild symptoms, were conscious and ambulatory, and they exhibited no evidence of end-organ dysfunction at the time of diagnosis. In addition, none had signs or symptoms of right-sided heart failure. All underwent successful cardioversion, which was performed not to restore hemodynamic stability, but to reduce the risk of right-sided heart failure consequent to prolonged dysrhythmia.

Investigators have previously examined ventricular arrhythmias after LVAD implantation, particularly those instances related to interruption of the native conduction system and cannula positioning.[1] However, prolonged episodes of VF in patients supported by LVADs have been reported only 4 times in the literature: all patients had a pulsatile system in place.[2-4] In this study, we present the largest series of patients who were supported by continuous-flow pumps while in sustained VF, and we report the longest duration of continuous-flow support during active fibrillation.

The application of continuous-flow technology in MCS has created a new physiology, of which little is known. Patients with continuous-flow LVADs may or may not have a clinically detectable pulse, depending on variables such as pump speed, ventricular chamber size, and aortic valve status. Thus, a pump may function in series as the sole source of cardiac output, leading to nonpulsatile blood flow; or it may work in parallel with native ejection through the aortic valve, leading to pulsatile blood flow.

Despite the widespread use of continuous-flow devices in treating heart failure, the consequences of sustained periods of nonpulsatility are poorly understood. Although laminar flow in the capillary beds does not appear to be a substantial risk to end-organ perfusion, evidence does suggest that pulsatile blood flow is ben-

TABLE I. Laboratory Values Before and After Ventricular Fibrillation in 6 Patients

Variable	Before Event	After Event	*P* Value
White blood count ($\times 10^3$/mL)	8 ± 3.8	7.9 ± 2	0.9
Hemoglobin (g/dL)	12 ± 1.5	12.1 ± 1.1	0.9
Hematocrit (%)	36.5 ± 4.6	37.3 ± 4.7	0.8
Potassium (mEq/L)	3.9 ± 0.6	3.9 ± 0.5	1
Magnesium (mEq/L)	2 ± 0.1	2.2 ± 0.5	0.3
Blood urea nitrogen (mg/dL)	20.3 ± 5.5	20.8 ± 5.5	0.9
Creatinine (mg/dL)	1.1 ± 0.03	1.1 ± 0.4	0.6
Bicarbonate (mEq/L)	27.5 ± 3.1	26.3 ± 2.4	0.4
Aspartate aminotransferase (U/L)	58 ± 12	67 ± 25	0.4
Alanine aminotransferase (U/L)	36 ± 31	64 ± 52	0.2
Total bilirubin (mg/dL)	1.5 ± 0.6	1.5 ± 0.6	0.8
Troponin I (ng/mL)	—	2.6 ± 3.4	—
Creatine kinase-MB isoenzyme (ng/mL)	—	1.8 ± 0.9	—
International normalized ratio	2.1 ± 0.9	1.8 ± 0.6	0.5
Plasma hemoglobin (g/dL)	8.6 ± 4.3	139 ± 267	0.2
Lactate dehydrogenase (U/L)	552 ± 208	589 ± 292	0.8

Data are presented as mean ± SD. $P < 0.05$ was considered statistically significant.

eficial.[5] Ultrasonographic studies at our institution have revealed thrombus formation along the aortic cusps and carotid bulb in LVAD patients with nonpulsatile flow.[6,7] Thus, intermittent pulsatility may reduce the risk of thromboembolic events by enabling arterial washout in areas susceptible to stasis. Investigators have also suggested an increased incidence of aortic insufficiency[8] and gastrointestinal bleeding[9] in patients with continuous-flow devices; however, the mechanisms by which these effects occur is not yet fully understood.

Regardless of the need for further study of the effects of nonpulsatile flow, the ability of continuous-flow pumps to support patients without functional cardiac reserve has tremendous implications in the field of MCS. The development of a durable, long-term total artificial heart has been a logical, yet elusive, goal for addressing the needs of the growing pool of patients with heart failure who are awaiting cardiac transplantation. The most common total artificial heart devices to date have been pulsatile systems that require large extracorporeal pneumatic consoles, which create considerable physical limitations and durability concerns. Continuous-flow pumps offer several engineering advantages over the traditional volume-displacement approach. Substantially smaller, these pumps are more anatomically appropriate and simpler to implant and to operate, and they enable patient mobility. Furthermore, the continuous-flow design eliminates the potential for mechanical wear because there are no points of mechanical contact. A report of a patient who survived 7 years with a single-axial flow LVAD illustrates the clinical durability of continuous-flow devices.[10]

The use of dual continuous-flow assist devices for the management of concomitant right-sided heart failure further suggests the physiologic tolerance of nonpulsatile blood flow. After our first description of the use of paired Jarvik 2000 pumps,[11] the use of biventricular continuous-flow ventricular assist devices has been reported with increasing frequency for both short- and long-term support.[12] This approach appears to be well tolerated by many patients, and preservation of the ventricles theoretically enables transmission of native contractility through the pump. Patients whose native hearts are not pumping and who are discovered to be in prolonged VF closely approximate a truly nonpulsatile system, such as that provided by a continuous-flow total artificial heart.

In conclusion, our study illustrates the ability of patients with continuous-flow LVADs to remain hemodynamically stable while in VF. This raises the question of whether defibrillator settings should be altered to limit delivery of shock therapy in patients who are supported with continuous-flow LVADs. Additional investigation is required to answer this question.

References

1. Bedi M, Kormos R, Winowich S, McNamara DM, Mathier MA, Murali S. Ventricular arrhythmias during left ventricular assist device support. Am J Cardiol 2007;99(8):1151-3.
2. Fasseas P, Kutalek SP, Kantharia BK. Prolonged sustained ventricular fibrillation without loss of consciousness in patients supported by a left ventricular assist device. Cardiology 2002;97(4):210-3.
3. Salzberg SP, Lachat ML, Zund G, Turina MI. Left ventricular assist device (LVAD) enables survival during 7 h of sustained ventricular fibrillation. Eur J Cardiothorac Surg 2004;26(2):444-6.
4. Gibbon JH Jr. Application of a mechanical heart and lung apparatus to cardiac surgery. Minn Med 1954;37(3):171-85; passim.
5. Saxton GA Jr, Andrews CB. An ideal heart pump with hydrodynamic characteristics analogous to the mammalian heart. Trans Am Soc Artif Intern Organs 1960;6:288-91.
6. Frazier OH, Wampler RK, Duncan JM, Dear WE, Macris MP, Parnis SM, Fuqua JM. First human use of the Hemopump, a catheter-mounted ventricular assist device. Ann Thorac Surg 1990;49(2):299-304.
7. Reul JT, Reul GJ, Frazier OH. Carotid-bulb thrombus and continuous-flow left ventricular assist devices: a novel observation. J Heart Lung Transplant 2014;33(1):107-9.
8. Cowger J, Pagani FD, Haft JW, Romano MA, Aaronson KD, Kolias TJ. The development of aortic insufficiency in left ventricular assist device-supported patients. Circ Heart Fail 2010;3(6):668-74.
9. Crow S, John R, Boyle A, Shumway S, Liao K, Colvin-Adams M, et al. Gastrointestinal bleeding rates in recipients of nonpulsatile and pulsatile left ventricular assist devices. J Thorac Cardiovasc Surg 2009;137(1):208-15.
10. Westaby S, Siegenthaler M, Beyersdorf F, Massetti M, Pepper J, Khayat A, et al. Destination therapy with a rotary blood pump and novel power delivery. Eur J Cardiothorac Surg 2010;37(2):350-6.
11. Frazier OH, Myers TJ, Gregoric I. Biventricular assistance with the Jarvik FlowMaker: a case report. J Thorac Cardiovasc Surg 2004;128(4):625-6.
12. Strueber M, Meyer AL, Malehsa D, Haverich A. Successful use of the HeartWare HVAD rotary blood pump for biventricular support. J Thorac Cardiovasc Surg 2010;140(4):936-7.