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Left Ventricular Assist Device Malfunction

An Approach to Diagnosis by Echocardiography

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OBJECTIVES A protocol using transthoracic echocardiography was designed to diagnose the common malfunctions of patients on chronic support with a left ventricular assist device (LVAD).

BACKGROUND Mechanical circulatory support, primarily with a LVAD, is increasingly used for treatment of advanced heart failure as a bridge to transplant and for long-term treatment of heart failure. The LVAD dysfunction is a recognized complication. To date, no studies have defined the role of transthoracic echocardiography in evaluating long-term mechanical complications of chronic LVAD support.

METHODS Transthoracic echocardiography was used in a protocol designed to detect the common types of mechanical malfunction. Patients were followed up with serial echocardiograms, and clinical validations were made with findings from a catheter-based protocol and inspection at the time of cardiac transplant or corrective surgery.

RESULTS Thirty-two patients with 44 LVADs were followed up during a four-year period using this protocol that correctly identified 11 patients with inflow valve regurgitation, 2 with intermittent inflow conduit obstruction, 1 with severe kinking of the outflow graft, and 9 with new insufficiency of the native aortic valve.

CONCLUSIONS As LVAD use for end-stage heart failure becomes widespread, and durations of support are extended, dysfunction will be increasingly prevalent. Transthoracic echocardiography provides a practical method to accurately identify the causes of mechanical dysfunction with patients on chronic LVAD support. (J Am Coll Cardiol 2005;45:1435–40) © 2005 by the American College of Cardiology Foundation

Mechanical circulatory support, primarily with a left ventricular assist device (LVAD), is used increasingly to treat advanced heart failure. The LVADs are able to bridge patients with end-stage heart failure to cardiac transplantation (1,2). The Randomized Evaluation of Mechanical Assistance for the Treatment of Congestive Heart Failure (REMATCH) trial demonstrated that patients with New York Heart Association functional class IV congestive heart failure, who were ineligible for heart transplantation, received a longer-term survival benefit from the LVAD compared with optimal medical therapy (3). Thus, LVAD technology has also proven effective for long-term heart failure treatment, referred to as *destination therapy*. Given the substantial number of patients with end-stage heart failure, it appears that LVAD usage is likely to increase.

The LVAD malfunction is an important cause of morbidity and mortality. Device failure was the second most common cause of death in the REMATCH trial; at 24 months' post-implant, 35% of patients suffered device failure (3). As cardiologists provide care for more LVAD patients, it is important that they be able to troubleshoot a malfunctioning device.

Diagnosis of LVAD component malfunction remains a challenge. Diagnostic studies have not been standardized. A systematic catheter-based approach for the diagnosis of LVAD system malfunction has been reported but not one principally utilizing echocardiography (4).

Transesophageal echocardiography (TEE) is ideal for defining LVAD dysfunction in both the pre-operative and intra-operative setting (5–7). However, no studies have used echocardiography, especially the less invasive transthoracic echocardiography (TTE), to evaluate the long-term mechanical complications of discharged patients with chronic LVAD support.

Therefore, we prospectively followed up with patients discharged from the hospital with the HeartMate LVAD (Thoratec Corp., Pleasanton, California) and performed serial examinations with TTE to see if this noninvasive test could identify the common types of LVAD dysfunction.

METHODS

We studied 35 patients (30 male; age 52 years [range 20 to 77 years]) undergoing implantation of the HeartMate VE or XVE (Thoratec Corp.) LVAD between September 1999 and October 2003 at the LDS Hospital, of which, 26 were as a bridge to transplant and 9 as destination therapy. Forty-five LVADs were implanted with nine patients receiving a second LVAD and one patient receiving four. Three patients underwent transplantation before echocardiography could be performed, 2 died after receiving repeat LVAD implants, and 32 were followed with serial TTEs (Table 1).

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Abbreviation and Acronyms

IVR	= inflow valve regurgitation
LV	= left ventricle
LVAD	= left ventricular assist device
REMATCH	= Randomized Evaluation of Mechanical Assistance for the Treatment of Congestive Heart Failure
TEE	= transesophageal echocardiography
TTE	= transthoracic echocardiography
VTI	= velocity time integral

The mechanical functioning of the Thoratec Corp. LVAD is described in Figure 1. Patients beyond the early postoperative period were evaluated routinely with TTE, generally every three months, and more frequently if mechanical dysfunction was suspected. Studies were performed with the Hewlett-Packard Sonos 5500 (Andover, Massachusetts) and a S3 transducer. Standard transthoracic windows evaluated native heart function and anatomy, and special measurements were performed of the LVAD components including the inflow cannula, outflow graft, and native aortic valve, which can malfunction with the chronically indwelling LVAD.

In a properly aligned inflow cannula (Fig. 2), intracavitary flow was considered normal if it was laminar and unidirectional. Inflow valve regurgitation (IVR) was defined as turbulent flow originating at the inflow cannula during LVAD ejection (Fig. 3). A semiquantitative value was assigned based on the area of turbulent flow seen within the left ventricle (LV). Pulsed Doppler flow patterns delineated the timing, direction of cannula flow, and flow variation relative to the native cardiac cycle (Fig. 4).

Inflow valve regurgitation was quantified further by assessing the flow through the outflow graft. Right parasternal views were used. Peak velocities, velocity time integral (VTI), and the outflow graft diameter were measured (Fig. 5). The stroke volume within the outflow graft was calculated as the product of the area of the outflow graft and the VTI. The stroke volumes of stable LVAD patients were compared with those in patients with IVR.

Inflow cannula obstruction was defined as interrupted flow at the mouth of the inflow cannula occurring during LVAD diastole. Outflow valve regurgitation was defined as retrograde flow seen within the outflow graft occurring during LVAD diastole. Outflow graft distortion was defined by an acceleration of Doppler velocities proximal in the graft compared with the values measured more distally. The native aortic valve was observed in the parasternal views for thickening, systolic opening, and the presence of aortic insufficiency by color flow Doppler.

Twelve (38%) of the patients followed up with echocardiography underwent 17 angiographic evaluations for suspected LVAD dysfunction. Echocardiograms were performed within a 30-day window of the angiographic studies. All patients had their findings correlated at the time of corrective surgery. Eighteen patients with stable functioning LVADs underwent cardiac transplantation, and LVAD components were examined at that time.

Statistical analysis Data for discrete variables are presented as percentages with sample sizes, and data for continuous variables are presented as mean with standard deviations or mean with range in the case of time periods. For tests of significance, the chi-square test was used for discrete variables and the *t* test was used for continuously distributed variables.

RESULTS

Image quality. A total of 244 TTEs were performed with 71 TTEs utilizing the protocol. Of these studies, the inflow conduit was imaged adequately in 68 (96%). In all patients, the outflow graft velocities were obtained, but in one case (2%), the outflow graft diameter could not be measured.

IVR. Eleven of the 42 LVADs (26%) had findings of IVR, with 3 of the LVADs developing new IVR during the study period. By the end of the study period, 9 of the 11 LVADs had progressed to having severe IVR. Doppler-echocardiography identified all eight patients with IVR by angiography and confirmed by surgery to have severely deformed inflow valves. Eighteen patients (56%) found to be IVR-free on echocardiography had successful cardiac transplantation. The inflow valves were inspected at explant. Seventeen patients had normal inflow valves, and one had only a minor gap between two inflow valve leaflets. Thus, absence of IVR was correctly identified in 100% of cases.

Pulsed Doppler at the inflow cannula found significant variability of the IVR flow relative to the native cardiac cycle. The IVR waveforms were denser with higher velocities when they occurred during native left ventricular (LV) diastole (Fig. 4).

Table 2 depicts the differences found in patients with IVR compared with patients without IVR. Normal function is associated with an outflow graft peak velocity of about 2.1 m/s and a calculated stroke volume of approximately 76 cc. Outflow graft velocities, VTI, and stroke volume were all significantly reduced in patients with IVR. Consistent with a decompressed heart, LV diastolic dimensions were generally normal in patients without IVR, and significantly dilated in patients with IVR.

With a poorly contracting native LV and with a normally functioning LVAD allowing for decompression, the aortic valve would be expected to open sparingly. Inflow valve regurgitation was associated with frequent aortic valve opening (65%) compared with 19% in patients without IVR.

Outflow valve regurgitation. No cases of outflow valve regurgitation were found in the 71 TTEs. Absence of outflow regurgitation was confirmed in the 15 angiographic studies, and no deformities of the outflow valve were seen at surgery.