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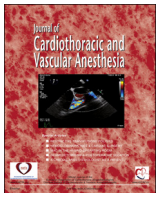

ORIGINAL ARTICLE

Left Ventricular Assist Device Thrombosis is Associated With an Increase in the Systolic-to-Diastolic Velocity Ratio Measured at the Inflow and Outflow Cannulae

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Objective: To determine whether the ratio of peak systolic-to-nadir diastolic velocity (S/D ratio) measured using Doppler at the left ventricular assist device (LVAD) inflow and outflow cannulae is associated with pump thrombosis and to determine whether there is an absolute decrease in the diastolic cannula velocities in LVAD thrombosis.

Design: Retrospective chart review.

Setting: University hospital.

Participants: Patients who underwent LVAD exchange.

Interventions: None.

Measurements and Main Results: Transesophageal echocardiograms were reviewed from all patients with the HeartMate II device (Thoratec Corporation, Pleasanton, CA) over a 6-year period and who underwent LVAD exchange for pump thrombosis. The following 3 time points were evaluated: (1) initial LVAD placement (prethrombosis), (2) thrombosis, and (3) exchanged LVAD placement (postthrombosis). Systolic and diastolic flow velocities were examined using pulse-wave spectral Doppler at the inflow and outflow cannulae, and the S/D ratio for each was determined. Statistical analysis was performed with SAS, version 9.4 (SAS Institute, Cary, NC), using 2-tailed tests and alpha = 0.05. Thirteen patients were included in the study. Significant differences were observed in S/D ratios among the 3 phases at both the inflow ($p = 0.0234$) and outflow ($p = 0.0047$) cannulae. Pairwise tests of the inflow cannulae showed that the mean S/D ratio at the time of thrombosis (mean $\pm$ standard deviation [SD], 4.29 ± 1.74) was significantly greater than the prethrombosis ratio (2.49 ± 0.65; $p = 0.0069$). Among outflow measurements, the mean S/D ratio at thrombosis (3.94 ± 1.34) was significantly higher than both the prethrombosis (2.63 ± 0.56; $p = 0.0025$) and postthrombosis (2.74 ± 0.83) ($p = 0.0093$) ratios. Decreases in diastolic velocities were not statistically significant at the inflow cannula. At the outflow cannula, there was a significant difference in diastolic velocity among the phases ($p = 0.0233$). Specifically, the postthrombosis diastolic measurements (41.50 ± 9.94) were significantly higher than both the prethrombosis (26.85 ± 10.13; $p = 0.0140$) and thrombosis (26.7 ± 15.35; $p = 0.0151$) values.

Conclusions: An increased S/D ratio measured with Doppler at the LVAD inflow and outflow cannulas may be associated with pump thrombosis. Decreased diastolic cannula velocities were not observed in LVAD thrombosis.

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Key Words: left ventricular assist device; thrombosis; echocardiography; Doppler

LEFT VENTRICULAR ASSIST DEVICES (LVADs) have become an increasingly important therapeutic tool for treating patients with advanced heart failure.[1,2] Today, LVADs are becoming more common not only for bridge-to-transplantation but also for destination therapy. Continuous-flow LVADs have demonstrated increased durability compared with their pulsatile predecessors.[3]

In this evolving clinical context, early detection and management of LVAD-related complications are essential to the care of LVAD patients. Complications of LVAD therapy include bleeding, infection, pump thrombosis, right heart failure, device malfunction, and stroke.[4] Pump thrombosis after LVAD occurs in 2% to 6% of cases.[5] In addition to increasing the risk of stroke and mortality, pump thrombosis leads to prolonged hospital readmissions.[2,4,5] Various changes have been made in an effort to develop an effective anticoagulation strategy, with special emphasis on maintaining a fine balance between preventing bleeding complications and pump thrombosis. This problem has been complicated by the advent of newer anticoagulants and their insufficient experience with continuous-flow assist devices.[5]

Pump thrombosis is diagnosed by the clinical sign of left ventricular failure, biochemical sign of hemolysis, and increased device power levels with decreased pump flow. Echocardiography is an important tool for clinicians caring for patients with LVADs.[6] The Uriel et al[7] "ramp" study, which originally examined 17 patients with suspected device thrombosis, has gained popularity in aiding in the diagnosis of LVAD thrombosis. Doppler examination of LVAD cannula flow also may be valuable in detecting device thrombosis. Using transthoracic echocardiography (TTE) in thrombosed LVADs, Fine et al[8] demonstrated in 14 patients with thrombosed LVADs that while systolic velocities in the cannulae were preserved, the diastolic velocities were relatively decreased. The result was an increase in the ratios of systolic/diastolic (S/D) velocity measured with spectral Doppler in both the inflow and outflow cannulae.[8]

The purpose of this exploratory study was to replicate the observations of previous authors with respect to the S/D ratio and diastolic cannula velocities in patients with thrombosed LVADs while using transesophageal echocardiography (TEE) during general anesthesia.[8,9] Specifically, the authors hypothesized that (1) increased S/D ratios would be associated with the presence of LVAD thrombosis and (2) decreased diastolic cannula velocities would be associated with LVAD thrombosis.

Methods and Study Design

Patient Selection, Definition, and Management of LVAD Thombosis

After institutional review and approval, the cases of all patients with the HeartMate II device (Thoratec Corporation, Pleasanton, CA) who underwent LVAD exchange due to pump thrombosis were reviewed between January 2009 and August 2015. A total of 265 patients underwent LVAD placement at Tufts Medical Center during the selected time period; of these, 130 had the HeartMate II, 111 had the HeartWare (HeartWare International, Framingham, MA), and 24 had a biventricular assist device. Of the 130 patients with HeartMate II devices, 27 presented to the operating room for device exchange due to thrombosis. Of these, 13 (mean age 59.9 $\pm$ 10.5 years, 3 female, 6 bridge-to-transplantations) had pulse-wave Doppler profiles available for analysis.

Device thrombosis was suspected on the basis of one of the following: (1) transient increases in pump power for more than 14 days after device implantation or gradually increasing power requirements of at least 2 watts, (2) lactate dehydrogenase (LDH) levels 3 times the upper limit of normal in the absence of other causes of hemolysis, and (3) presence of overt LVAD dysfunction associated with embolic signs and symptoms. If a patient with suspected LVAD thrombosis was hemodynamically stable, a trial of medical management with thrombolytic therapy was started. A ramp study was performed to assess the effectiveness of management and improvement in hematologic values.[10] Patients who showed no signs of improvement within 72 to 96 hours or who were hemodynamically unstable were referred for device exchange. According to the authors' institutional protocol, every patient who presented for device exchange after initially being suspected of experiencing thrombosis on the basis of clinical and hematologic data was considered to be experiencing LVAD thrombosis.

Of the patients who presented to the operating room for device exchange, TEE images were reviewed using the Philips Xcelera image management system (Philips, Andover, MA). Echocardiographic studies initially were reviewed to confirm the presence of complete inflow and outflow cannula Doppler spectral tracings at the following 3 periods: (1) time of initial LVAD placement (prethrombosis), (2) precardiopulmonary bypass (thrombosis), and (3) postcardiopulmonary bypass after LVAD exchange (postthrombosis). Patients who received the HeartWare as an initial device were excluded from the study due to an inability to examine the LVAD inflow cannula with Doppler and the lack of outflow cannula data.

Echocardiography, Laboratory, and LVAD Pump Data

The TEE images for inflow cannulae were obtained in the standard midesophageal left ventricular views, and the aortic outflow cannulae were imaged in upper esophageal ascending aortic long-axis views (Fig 1).[6] Both the systolic and diastolic flow velocities were recorded using pulse-wave spectral Doppler at the respective inflow and outflow cannulae, with the sample gate placed approximately 0.5 cm into the respective orifices. The systolic-to-diastolic velocities for each were recorded and

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