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A simplified echocardiographic technique for detecting continuous-flow left ventricular assist device malfunction due to pump thrombosis

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BACKGROUND: Malfunction of a continuous-flow left ventricular assist device (CF-LVAD) due to device thrombosis is a potentially life-threatening event that currently presents a diagnostic challenge. We aimed to propose a practical echocardiographic assessment to diagnose LVAD malfunction secondary to pump thrombosis.

METHODS: Among 52 patients implanted with a CF-LVAD from a single center who underwent echocardiographic pump speed-change testing, 12 had suspected pump thrombosis as determined by clinical, laboratory, and/or device parameters. Comprehensive echocardiographic evaluation was performed at baseline pump speed and at each 1,000-rpm interval from the low setting of 8,000 rpm to the high setting of 11,000 rpm in 11 of these patients.

RESULTS: Receiver operating characteristic curves and stepwise logistic regression analyses showed that the best diagnostic parameters included changes in the LV end-diastolic diameter (<0.6 cm), aortic valve opening time (<80 msec), and deceleration time of mitral inflow (<70 msec) from lowest to highest pump speed. One parameter was predictive of pump malfunction, with 100% sensitivity and 89% specificity, whereas 2 of 3 parameters increased the sensitivity to 100% and specificity to 95%.

CONCLUSIONS: The 3 echocardiographic variables of measured changes in LV end-diastolic diameter, aortic valve opening time, and deceleration time of mitral inflow between the lowest (8,000 rpm) and highest pump speed settings (11,000 rpm) during echo-guided pump speed-change testing appear highly accurate in diagnosing device malfunction in the setting of pump thrombosis among patients supported with CF-LVAD. Further investigation is warranted to create and validate a prediction score.

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Registry data show that more than 6,000 patients with advanced heart failure (HF) are currently supported by continuous-flow left ventricular assist devices (CF-LVADs), representing most of the devices implanted for mechanical circulatory support.[1–4] Although 1-year and 2-year survival rates have progressively improved to approximately 80% and 70%, respectively, CF-LVAD use is not without risks.[3–5] One such important post-implant complication is thrombus formation in the LVAD system that can result in hemolysis

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and malfunction, with one or more clinical consequences, including HF, stroke, renal failure, and death.

Thrombosis leading to LVAD failure is a medical emergency, yet management of this condition can be compounded by the challenge of making a definitive diagnosis.[5] Although objective testing with different imaging techniques and management algorithms has been recently reported, only one report has been published on the role of echocardiography to define LVAD malfunction, and there remains a lack of consensus on the most practical imaging protocol to detect this potentially fatal condition.[6–9]

Two-dimensional and Doppler echocardiography can be useful in detecting thrombus formation and turbulent flow suggestive of cannula obstruction.[10] However, its capacity to evaluate the inflow and outflow cannula is limited by acoustic windows/shadowing and cannula artifact. Multidetector cardiac computed tomography (CT) can better visualize cannulas and surrounding anatomy, yet it is unable to detect thrombus within the LVAD pump itself, is incapable of diagnosing LVAD malfunction, and involves some radiation and contrast exposure.[10,11] Recently, Uriel et al[12] demonstrated that their echocardiographic speed optimization "ramp" test protocol reliably detected LVAD thrombosis and malfunction. They found that in 9 patients with suspected device thrombosis, attenuated reduction in LV dimensions by echo with increasing LVAD pump speed and increased power detected by the LVAD console were diagnostic of flow obstruction secondary to LVAD-related thrombosis. However, the Columbia echo ramp-up protocol is partly limited by its use of 11 different pump speed measurements and the need to derive linear slope calculations to screen for a LV end-diastolic diameter (LVEDd) slope > -0.16.

Our institution has used pump speed-change testing for several years to bracket the extent of pump speed support to screen for device malfunction, myocardial recovery, and detect pulmonary hypertension before heart transplantation. In addition, we perform it to detect optimal LV unloading based on LV size measurements and aortic valve (AV) opening in persistently symptomatic patients.[13] The aims of this study were to

- perform comprehensive echocardiography-guided ramp-up speed testing to determine the association between standard 2-dimensional (2D) and spectral Doppler echo parameters and LVAD malfunction,
- examine serologic markers of hemolysis with LVAD malfunction secondary to pump system thrombosis, and
- examine those parameters with the strongest association with pump thrombosis in an attempt to further define and improve the diagnosis of LVAD malfunction in this potentially life-threatening condition.

Methods

The Methodist DeBakey Heart & Vascular Center Investigational Review Board approved this study.

Patient population

Between January 2008 and July 2013, a HeartMate II (Thoratec Corp, Pleasanton, CA) CF-LVAD was implanted in 201 patients at our center. We identified retrospectively from our LVAD database 12 patients who had suspected or confirmed pump thrombosis according to the following criteria:

1. suspected pump thrombosis with evidence of significant hemolysis, defined as a lactate dehydrogenase (LDH) level >2.5 upper limit of normal, associated decrease in baseline hemoglobin, hematuria, evidence of HF without another explanation, and acute renal failure and/or stroke and/or death;
2. confirmed pump thrombosis by direct visualization at the time of surgery or unequivocal evidence by cardiac CT.

From the remaining 189 patients, we randomly selected 40 clinically stable patients for the control group who had an echo pump speed-change test as part of a prospective echo surveillance protocol. Patients in the control group who had a mitral valve annuloplasty ring ($n = 2$), significant mitral annular calcification ($n = 1$), or sub-optimal images ($n = 1$) were excluded. None of the patients included in the study had greater than moderate aortic insufficiency or underlying atrial fibrillation.

Echo pump speed-change protocol

An echo pump speed-change protocol was performed prospectively in all patients as part of surveillance testing for evaluation of myocardial recovery and pre-heart transplant pulmonary pressure assessment and for those with a change in clinical status (i.e., residual HF or suspected pump thrombosis). Complete transthoracic echocardiographic studies were performed by standard fashion and were reviewed by an independent reader blinded to the patient's clinical outcomes (pump thrombosis vs control stable LVAD cohort). Images were initially acquired at each patient's baseline pump speed, typically at 8,800 to 10,200 rpm. The LVAD pump speed was then decreased to the lowest setting of 8,000 rpm and successively ramped up at 1,000-rpm intervals to the highest setting of 11,000. At each interval, we allowed 2 minutes before acquiring a complete set of 2D and Doppler parameters.

From the parasternal window, LVEDd, pulmonic annulus diameter, and right ventricular outflow tract (RVOT) velocity were measured per guidelines.[14,15] RVOT stroke volume was derived as the RVOT cross-sectional area × RVOT time-velocity integral flow by pulsed-wave Doppler. Systemic cardiac output (CO) was calculated as RV stroke volume × heart rate.

In addition, 2D echo and M-mode were used from the parasternal window to record AV function per institutional guidelines in patients on LVAD support.[13] AV opening time was measured from M-mode images and averaged over 3 cardiac cycles.

From the apical window, pulsed-wave Doppler was used to record mitral inflow at the level of the mitral valve leaflet tips. Doppler signals were analyzed for peak early (E) and late (A) diastolic velocities, E/A ratio, and deceleration time (DT) of mitral E velocity.[16] Tissue Doppler was applied to measure mitral annular early (e′) velocities at the lateral and septal sides of the annulus.[16] The resulting annular velocities by pulsed-wave Doppler were recorded for 3 to 5 cardiac cycles at a sweep speed of 100 mm/sec. E/e′ ratios were computed.

Valvular regurgitation signals were recorded and interpreted in accord with standard recommendations.[17] Inferior vena caval diameter and its collapse and hepatic venous flow were recorded in the sub-costal view.[18] Pulmonary artery (PA) systolic pressure was derived using the modified Bernoulli equation as PA systolic pressure in mm Hg $= 4(v)^2$ of peak tricuspid regurgitation velocity in m/sec + right atrial pressure in mm Hg. Right atrial pressure was