Imaging the VAD Patient

Duke Advanced Heart Failure Symposium

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Duke Heart Center
Disclosures

• None
Echocardiographic Structural Assessment Pre-LVAD

- LVEF (≤ 25% for DT LVAD)
- Right ventricle
- Valvular disease
- Intra-cardiac shunts
- Intra-cardiac thrombi
- Ascending aorta
Case 1

50 yo M transferred from OSH with acute decompensated HF and cardiogenic shock

– 2 Prior bypass surgeries
– Stage III CKD with a baseline Cr 1.7
– Renal failure and volume overload on inotropes
– Transferred for consideration of advanced heart failure therapies
Case 1

HM II BTT LVAD with post-op CentriMag RVAD support
Case 1

- HM II BTT LVAD
- Prophylactic post-op CentriMag RVAD support
- Post-operative course:
  - RVAD weaned
  - Milrinone for 2 weeks
  - Stable, persistent RV failure
- Listed for Heart Transplant
Consequences of Post LVAD RV Failure

- Increased perioperative mortality
- Worse end-organ function
- Increased cost of hospitalization and LOS
- Decreased survival to transplantation

Predicting RV Failure?

- Clinical and biochemical characteristics
- Echocardiographic characteristics
- Pre-procedure hemodynamics
Sample Risk Scores

RV Failure Risk Score (Michigan)

- Vasopressors (4 points)
- AST > 80 (2 pts)
- Bilirubin > 2 (2.5 pts)
- Scr > 2.3 (3 pts)
- OR of 7.6 (95% CI 3.4 to 17.1) with score > 5.5

Heartmate 2 Risk Score

- CVP/PCWP > 0.63
- Pre-op ventilatory support
- BUN > 39


*J Thorac Cardiovasc Surg* 2010;139:1316-1324.
2010 JASE Guidelines for RV Systolic Function Assessment

- Visual
- RV dP/dt
- Tei index
- TAPSE
- Tissue Doppler
- Strain

*J Am Soc Echocardiogr* 2010;23:685-713.
Tricuspid Annular Motion as a Predictor of Severe Right Ventricular Failure After Left Ventricular Assist Device Implantation

Sarinya Puwanant, MD, a Karen K. Hamilton, MD, a Charles T. Klodell, MD, b James A. Hill, MD, MS, a Richard S. Schofield, MD, a Timothy S. Cleeton, ARNP, a Daniel F. Pauly, MD, PhD, a and Juan M. Aranda Jr, MD a

- Retrospective of 33 patients – 11 patients with RV failure
- TAPSE < 0.75 cm significant predictor
- Elevated RVSP also significant
Right-to-left ventricular end-diastolic diameter ratio and prediction of right ventricular failure with continuous-flow left ventricular assist devices

- 137 patients – 13% developed RV failure
- RVEDD/LVEDD ratio of 0.72 predictive (OR 11.4)

JHLT 2010
Addition of Strain Imaging to Risk Prediction

With RV Failure

Grant, et al. JACC 2012; 60:521-528.
LVAD Management
TEE: LVAD off CPB

Thunberg et al. J Cardiothorac Vasc Anesth 2010
Apical cannula position
Apical cannula position
Selecting an Optimal LVAD Speed
## HeartMate II Display

<table>
<thead>
<tr>
<th>Clinical</th>
<th>Settings</th>
<th>Alarms</th>
<th>Save Data</th>
<th>History</th>
<th>Admin</th>
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<tr>
<th>Pump Flow</th>
<th>Pump Speed</th>
<th>Pulse Index</th>
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<tbody>
<tr>
<td>5.7</td>
<td>9600</td>
<td>3.5</td>
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</tbody>
</table>

- **Fixed Mode - Speed Setpoint:** 9600 rpm
- **Pump Power:** 7.0
Flow: 5-6 L/min

Speed: 8600-9800 rpms

Power: 6-7 W

Pulsatility Index: 3.5-5.5

Adopted from Figure 8. J Heart Lung Transplant 2010;29:S1-S39
## Selecting Optimal Speed

### Development of a Novel Echocardiography Ramp Test for Speed Optimization and Diagnosis of Device Thrombosis in Continuous-Flow Left Ventricular Assist Devices

**The Columbia Ramp Study**

Nir Uriel, MD,* Kerry A. Morrison, BA,* Arthur R. Guran, MD,* Tomoko S. Kato, MD,* Melana Yucelpekaysa, MD,* Farhana Latif, MD,* Susan W. Restaino, MD,* Donna M. Mancini, MD,* Margaret Flannery, NP† Hirono Takayama, MD;† Ranjit John, MD;‡ Paolo C. Colorado, MD,* Yoshifumi Naka, MD, PhD;§ Ulrick P. Jurde, MD

*New York, New York, and Minneapolis*

### Objectives

This study sought to develop a novel approach to optimizing continuous-flow left ventricular assist device (CF-LVAD) function and diagnosing device malfunctions.

### Background

In CF-LVAD patients, the dynamic interaction of device speed, left and right ventricular decompression, and valve function can be assessed during an echocardiography monitored speed ramp test.

### Methods

We devised a unique ramp test protocol to be routinely used at the time of discharge for speed optimization and/or if device malfunction was suspected. The patient’s left ventricular end-diastolic dimension, frequency of aortic valve opening, mitral insufficiency, blood pressure, and CF-LVAD parameters were recorded in increments of 400 rpm from 8,000 rpm to 12,000 rpm. The results of the speed designations were plotted, and linear function slopes for left ventricular end-diastolic dimension, pulsatility index, and power were calculated.

### Results

Fifty-two ramp tests for 39 patients were prospectively collected and analyzed. Twenty-eight ramp tests were performed for speed optimization, and speed was changed in 17 (65%) with a mean absolute valve adjustment of 424 ± 313 rpm. Seventeen patients had ramp tests performed for suspected device thrombosis, and 10 tests were suspicious for device thrombosis; these patients were then treated with intensified anticoagulation and/or device exchange/emergent transplantation. Device thrombosis was confirmed in 8 of 10 cases at the time of emergent device exchange or transplantation. All patients with device thrombosis, but none of the remaining patients had a left ventricular end-diastolic dimension score > 0.16.

### Conclusions

Ramp tests facilitate optimal speed changes and device malfunction detection and may be used to monitor the effects of therapeutic interventions and need for surgical intervention in CF-LVAD patients. (J Am Coll Cardiol 2012;69:1704–78) © 2012 by the American College of Cardiology Foundation.

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- **28 Optimization Studies**
  - 61% changes
- **17 Ramp Studies**
  - 10 Abnl (8/9 Exchanges)
Selecting Optimal Speed

- BP
- LV Size
- AV Opening
- MR Severity
- AR Severity
- RVSP
- Speed Setting
- Power
- PI
- Estimated Flow

Adapted from Figure 2 from *J Am Coll Cardiol* 2012;60:1764-75
Figure 3  Graphs of Normal Example Versus Device Thrombosis Example of LVEDD, PI, and Power

(A) LVEDD slope, PI slope, and power slope of a patient with normal device function. (B) LVEDD slope, PI slope, and power slope of a patient with device thrombosis.

AV = aortic valve; LVAD = left ventricular assistive device; LVEDD = left ventricular end-diastolic dimension; PI = pulsatility index.
Selecting Optimal Speed

Development of a Novel Echocardiography Ramp Test for Speed Optimization and Diagnosis of Device Thrombosis in Continuous-Flow Left Ventricular Assist Devices

The Columbia Ramp Study

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Objectives
This study sought to develop a novel approach to optimizing continuous-flow left ventricular assist device (CF-LVAD) function and diagnosing device malfunctions.

Background
In CF-LVAD patients, the dynamic interaction of device speed, flow, and right ventricular decompression, and valve function can be assessed during an echocardiographically monitored speed ramp test.

Methods
We developed a unique ramp test protocol to be routinely used at the time of discharge for speed optimization and/or if device malfunction was suspected. The patient’s left ventricular end-diastolic volume, frequency of aortic valve opening, ventricular insufficiency, blood pressure, and CF-LVAD parameters were recorded in increments of 400 rpm from 8,000 rpm to 12,000 rpm. The results of the speed desensitizations were plotted, and linear function slopes for left ventricular end-diastolic volume, pulsatility index, and power were calculated.

Results
Fifty-two ramp tests for 39 patients were prospectively collected and analyzed. Twenty-eight ramp tests were performed for speed optimization, and speed was changed in 17 (50%) with a mean absolute value adjustment of 414 ± 213 rpm. Seventeen patients had ramp tests performed for suspected device thrombosis, and 10 tests were suspicious for device thrombosis; these patients were then treated with intensified anticoagulation and/or device exchange/emergent transplantation. Device thrombosis was confirmed in 6 of 10 cases at the time of emergent device exchange or transplantation. All patients with device thrombosis, but none of the remaining patients had a left ventricular end-diastolic dimension scope ≥0.50.

Conclusions
Ramp tests facilitate optimal speed changes and device malfunction detection and may be used to monitor the effects of therapeutic interventions and need for surgical intervention in CF-LVAD patients.

28 Optimization Studies
- 61% changes
17 Ramp Studies
- 10 Abnormal (8/9 Exchanges)

Conclusions
- Safe procedure
- Changes in speed
- Ramp studies may be helpful diagnostic study
Selecting Optimal Speed: Mayo Experience

Measurements

- AV Opening
- Interatrial septum
- Cannula flow
- TR velocity
- Estimated P_right Atrium
- Estimated CO
Figure 3. Systemic Cardiac Output Assessment

(A) Right ventricular outflow tract diameter assessment. (B) Time velocity integral by pulsed Doppler in the right ventricular outflow tract. The calculated stroke volume (86 cc) at a heart rate of 80 beats/min equates to a cardiac output of 6.8 l/min. RVOTd = right ventricular outflow tract diameter; SV = stroke volume; TVI = time velocity integral.

Figure 3 from J Am Coll Cardiol Img 2010;3:1049-64
PARTIAL SUPPORT
- HF Symptoms
- Embolic Risk
- Pump Thrombosis

FULL SUPPORT
- Ventricular Arrhythmias
- Aortic Valve Damage
- Increased Hemolysis
- Heyde’s Syndrome
LVAD Troubleshooting
LVAD Troubleshooting

- Pericardial effusions +/- tamponade
- RV dysfunction
- Under-filled LV
- Inflow cannula malposition
- AV Insufficiency
- Intra-cardiac thrombus
- Pump failure

Adopted from Table 3 from *J Am Coll Cardiol Img* 2010;3:1049-64
LVAD Troubleshooting

- Heart Failure
  - HF with increased power
  - HF with normal power
- High Flows with Normal Power
  - Aortic Insufficiency
- Arrhythmias
  - Cannula Position
  - Suction Events
- GI Bleeding
LVAD Troubleshooting

- Heart Failure
  - HF with increased power
  - HF with normal power
- High Flows with Normal Power
  - Aortic Insufficiency
- Arrhythmias
  - Cannula Position
  - Suction Events
- GI Bleeding
Heart Failure with Increased Power

- Increased MAP
- Pump Thrombus
- Kink in the Outflow Cannula
Case 2
Heart Failure with Increased Power

41 yo M with NICM s/p HM II LVAD in 2011 doing well for 2 years until he develops new heart failure symptoms, power spikes to 13W, and dark urine. LDH 1728.
Sub-Acute Pump Thrombosis

2011

2013
Sub-Acute Pump Thrombosis
Pump Thrombosis

Figure 2 from Meyer, et al. J Thorac Cardiovasc Surg 2008
Outflow cannula kinking
Outflow cannula kinking
LVAD Troubleshooting

• Heart Failure
  – HF with increased power
  – HF with normal power

• High Flows with Normal Power
  – Aortic Insufficiency

• Arrhythmias
  – Cannula Position
  – Suction Events

• GI Bleeding
Heart Failure with Normal Power

- RV failure
- Tricuspid Valve Insufficiency
- Inflow Obstruction
- Mitral Stenosis
Case 3
Heart Failure with Normal Power

53 F with NICM and BMI 48.2 kg/m²
- HM II LVAD implanted 3 months prior
- Admitted from clinic with volume overload despite up-titration of diuretics as an outpatient
- Speed 9200, Power 5.8 W, PI 3.3, Flow 4.6 L/min
Heart Failure with Normal Power

- **Right Heart Cath**
  - RA: 19
  - RV: 33/16
  - PA: 33/15 (25)
  - PCWP: 10
  - Aorta: 140/60 (87)
  - CO 4.4 CI: 2.1 with a PA sat: 42%
LVAD Troubleshooting

• Heart Failure
  – HF with increased power
  – HF with normal power

• High Flows with Normal Power
  – Aortic Insufficiency

• Arrhythmias
  – Cannula Position
  – Suction Events

• GI Bleeding
Aortic Insufficiency

- Greater than moderate disease can result in a “futile” circuit

- Treated with afterload reduction or repair/closure

- Absence pre-implant doesn’t necessarily predict absence after implant
Case 4
High flows with normal power

69 M s/p HM II LVAD for ICM
• Uneventful Peri-Operative Course
• Trivial AR on Pre-Op Echo
Immediately s/p LVAD
3 months s/p LVAD
6 months s/p LVAD
6 months s/p LVAD
Continuous AI
Intra-op TEE prior to AVR
Intra-op TEE post AVR
LVAD Troubleshooting

• Heart Failure
  – HF with increased power
  – HF with normal power
• High Flows with Normal Power
  – Aortic Insufficiency
• Arrhythmias
  – Speed drops / Suction Events
  – Cannula Position
• GI Bleeding
Case 5
Arrhythmia with speed drops

54 yo M with NICM
- Intermittent palpitations and lightheadedness
- HM II LVAD speed drops (9200 → 8000 rpm) multiple times per minute
- ECG shows frequent PVC’s
Arrhythmia: Speed drop / Suction Event

48 bpm  
81 bpm
Case 6
Cannula position and Arrhythmias

67 yo M with NICM

- HM II LVAD planned for Destination Therapy
- 5 months post LVAD implantation
- Recurrent low flow and hypotensive episodes
- INR 1.7 on admission
- Frequent PVC’s and runs of NSVT noted
- NSVT timing correlates with symptoms
Cannula position: Arrhythmias

9200 rpm

FR 62Hz
18cm
2D 63%
C 50
P Off
HPen

JPEG
50 bpm
Cannula Position: Arrhythmias
Case 7
Unexplained VT

72 yo man: DM, MDS
• Severe CAD/LVSD → CABG
• Post CABG Day 7: failing – arrest; HM II
• Complicated post-op course
• VT recurrent: refractory to meds
• Recurrent ICD shocks
• Echo suggests inflow cannula malposition
Cannula Position: VT
Intra-cardiac Shunts

• At baseline masked by left to right shunting with elevated LVEDP/LAP

• Right to left shunting after LV decompression with VAD

• Risk for Paradoxical emboli
Case 8
LVAD and Intra-cardiac Shunts

42 yo M s/p HM II LVAD presents with slurred speech
• Recent DVT
• INR 1.6
• Normal LDH
Conclusions

• Chest xray: overall device positioning visualization
  – Serial evaluation for temporal shifting cannula position
• Echocardiography plays an important role in pre-LVAD implantation and post-LVAD management
  – Evolving use for predicting post-LVAD RV failure
• Echo speed studies and ramp protocols useful tools to evaluate and optimize LVAD function
  – Outcomes data and further studies are necessary
• Echocardiography and CT are pivotal diagnostic tools in LVAD trouble-shooting