Evaluation of Patients with LVADs and Percutaneous Support Devices

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Case # 1

A 74-year-old male

- Ischemic cardiomyopathy, LVEF 22%
- Hospitalized with NYHA Class IV symptoms
- Plan: HeartMate III implantation (DT)
Surgical implantation

- HeartMate II
- HeartMate III
- HeartWare HVAD
- Berlin Heart Incor
- Jarvik 2000
- HeartAssist 5
- DuraHeart

Non-surgical implantation

- Centrimag
- Abiomed
- Impella LD 5.0
- Abiomed BVS 5000
- Abiomed AV 5000

Continuous flow pump

- Abiomed Impella LP 5.0/2.5
- Tandem heart pVAD

Pulsatile pump

- IABP
- Short
- Long

Duration of use

- HeartMate XVE
- Thoratec IVAD
- CardioWest TAH-t
- Thoratec pVAD
- Berlin Heart Excor
- Berlin Heart Excor ped
- Abiomed BVS 5000
- Abiomed AV 5000
- Impella LD 5.0
- Impella LP 5.0/2.5
- Tandem heart pVAD
Ventricular Assist Device Innovation

1st Generation
- Pulsatile Technology

2nd Generation
- Continuous Flow Technology
  - Axial Design
- Continuous Flow Technology
  - Centrifugal Design
- 3rd Generation
  - Experimental
  - FDA Approved
  - BTT 2008
  - DT 2010
- Bearingless with Magnetic levitation
- Bearings with stator
- Bearings

Slide courtesy Dr. Mandeep R. Mehra
Echocardiography in the Management of Patients with Left Ventricular Assist Devices: Recommendations from the American Society of Echocardiography

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(J Am Soc Echocardiogr 2015;28:853-909.)

Keywords: Echocardiography, mechanical circulatory support, left ventricular assist devices, comprehensive examination
Red Flag Signs

Pre-operative

Any congenital heart disease
Mobile mass
Acute endocarditis

> Mild PS or
≥ moderate PR

PFO/ASD*

RV*

≥ Moderate TR or
> mild TS

RV dilation
RV systolic dysfunction

LV*

> Mild AR*

Aortic aneurysm, dissection, atheroma, PDA, Coarctation

LAA thrombus

≥ Moderate MS

Any congenital heart disease
Mobile mass
Acute endocarditis
LV Size pre-LVAD implantation

n=83, CF-LVAD,
RV Failure after LVAD

Survival Curve

Survival Probability

Days

Remaining at Risk

386 348 206 105
65 52 30 18

No RVF
0.94 ± 0.01
0.87 ± 0.02
0.89 ± 0.04
0.78 ± 0.03

RVF
0.66 ± 0.06
0.59 ± 0.07
Pre-LVAD RV assessment

- Literature does NOT support the use of any “single” echocardiographic RV parameter
- Echo parameters should not be used in isolation
- RV absolute peak longitudinal strain of <9.6% and RV:LV end-diastolic diameter ratio of > 0.75 were identified as potential independent predictive echocardiographic parameters
Case #1
Case #1
# Case #1

<table>
<thead>
<tr>
<th>LV size</th>
<th>LV diameter</th>
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<tbody>
<tr>
<td></td>
<td>-LVIDD</td>
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<tr>
<td></td>
<td>7.5 cm</td>
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<tr>
<td></td>
<td>-LVIDS</td>
</tr>
<tr>
<td></td>
<td>6.7 cm</td>
</tr>
<tr>
<td></td>
<td>Interventricular septal thickness (cm)</td>
</tr>
<tr>
<td></td>
<td>LVEF</td>
</tr>
<tr>
<td>Aortic regurgitation</td>
<td>None</td>
</tr>
<tr>
<td>Aortic root size</td>
<td>3.1 cm</td>
</tr>
<tr>
<td>Mitral regurgitation</td>
<td>Mild (1+)</td>
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<tr>
<td>PFO/ASD</td>
<td>Positive agitated NSS bubble study consistent with PFO</td>
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<tr>
<td>Thrombus</td>
<td>Suspected LV apical mural thrombus</td>
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# Case #1

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<tr>
<th>RV size</th>
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<tr>
<td>RV diameter</td>
<td></td>
</tr>
<tr>
<td>- Base</td>
<td>3.8 cm</td>
</tr>
<tr>
<td>- Mid</td>
<td>2.8 cm</td>
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<tr>
<td>- Long axis</td>
<td>8.5 cm</td>
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<tr>
<td>RV FAC</td>
<td>42%</td>
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<tr>
<td>RV volume</td>
<td></td>
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<tr>
<td>- RVEDV</td>
<td>144.8 mL (&lt;200 mL)</td>
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<tr>
<td>- RVESV</td>
<td>61.3 mL (&lt;177 mL)</td>
</tr>
<tr>
<td>- RV 3D ejection fraction (%)</td>
<td>57.7%</td>
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<tr>
<td>Tricuspid regurgitation</td>
<td>Trace</td>
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<tr>
<td>TAPSE</td>
<td>2.3 cm</td>
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<tr>
<td>Myocardial performance (Tei) Index</td>
<td>0.6 (by TDI) (Normal &gt;0.54)</td>
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<tr>
<td>RV S’</td>
<td>13 cm/sec</td>
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Case #1

EDV: 144.8 ml
ESV: 61.3 ml
SV: 83.5 ml
EF: 57.67 %
RVLS (Septum): -9.15 %
RVLS (Freewall): -20.84 %
Peri-operative

- Preimplantation TEE
  - Confirm TTE findings
    - PFO/ASD
    - TR, RV function
    - Thrombus

- Peri-operative TEE during LVAD implantation
  - Septal position
  - Cannula position
  - Cannula orientation

- Peri-operative TEE during LVAD activation/speed optimization
  - Air, Unmasked PFO
  - LV/RV size
  - AV opening
  - Inflow/outflow cannula
  - Aortic regurgitation
  - Tricuspid regurgitation

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Inflow Cannula Position
Inflow Cannula Position
Inflow cannula directed toward interventricular septum
LVAD Doppler Flow

Nadir diastolic velocity
Peak systolic velocity (Typical ≤ 1.5 m/sec)

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Cannula Velocity Changes

Typical response to increased pump speed: smaller S/D ratio
LVAD Doppler Flow

CW

Hybrid signal from overlapping of continuous diastolic inflow-cannula flow and diastolic MV inflow

Inflow cannula systolic flow

MR Doppler

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Outflow Cannula Position

[Image of echocardiography showing outflow cannula position]

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Outflow Cannula Position

Peak systolic velocity
(Typical < 2.0 m/sec)

Nadir diastolic velocity
Outflow Cannula Position

CW

Peak systolic velocity (Typical < 2.0 m/sec)

Nadir diastolic velocity
Screening for Outflow Cannula Malfunction of Left Ventricular Assist Devices (LVADs) With the Use of Doppler Echocardiography: New LVAD-Specific Reference Values for Contemporary Devices

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Chicago, Illinois; Houston, Texas

Highlights:
Establish normal reference ranges
- LVAD outflow graft Vpeak > 2 m/sec poorly predicts malfunction
- HM-II Velocity > 2.7 m/sec
- HVAD Velocity > 3.4 m/sec have improved specificity for detecting malfunction
Unmasked PFO after LVAD with RA to LA shunt
HVAD Suction event
HVAD Suction event
To detect complication

- Aortic dissection
- Intracardiac thrombus (RA, LA, LV and aortic root)
- Conduit kinking/obstruction
- Aortic insufficiency
- LV Suction/overpumping
- Inflow cannula thrombosis
- Pericardial eff/tamponade
- Progressive RV failure
- Pump malfunction
Case #1
Low flow Alarm
Low flow Alarm

- LVAD suction events
- RV failure
- Hypovolemia
- Cardiac tamponade
- Inflow / outflow cannula obstruction
- Malignant hypertension
- Atrial and ventricular arrhythmias
Post-operative Optimization

Definition varies among centers

Consensus: “optimal speed” lies between a minimum and maximum speed

Minimum Speed - below this speed
- LVIDd increased relative to baseline
- Ventricular septum shifted rightward
- AV opening more frequent/sustained
- Increased RAP, PASP, clinical congestion, low BP, decreased end-organ function (recurrent heart failure)

Maximum Speed - above this speed
- Ventricular septum shifted leftward
- TR may worsen (increased RV size, RV annular distortion)
- AV ceases opening (if previously opening)
- Increased AR (when present) - observe for HTN or hyphenation
- Some or all of these may constitute a Suction event

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LVAD Optimization worksheet

**Appendix G** Speed Changes: LVAD Optimization or Problem-Focused (Ramp) Protocol Worksheet

### Speed Changes: LVAD Optimization or Problem-Focused (Ramp) Protocol Worksheet

- **CF-LVAD type:**
- **Implant date:**
- **[PT INR = ______ PTT = ______]**

Previous echo exam date and significant findings:

- **Optimization protocol.** Optimal speed based on MCS center’s own standard; sample order sets include the following: (a) Attain at least intermittent AV opening, or (b) attain neutral IVS position and/or mild or less MR, or (c) attain complete AV closure to maximize LV unloading or (d) adjust speed to below the maximum speed associated with complete AV closure and the minimum speed associated with more prominent MR and rightward IVS.

- **Problem-focused protocol.** Indication for exam: Sample order sets include the following indications:
  a. Smoldering left- and/or right-sided heart failure.
  b. Screen for pump function in setting of hemolysis and suspected pump thrombosis.
  c. Other LVAD-alarm trouble-shooting.

<table>
<thead>
<tr>
<th>Pump Speed (rpm)</th>
<th>BP</th>
<th>AV Opening (y/n/intermittent)</th>
<th>LVIDd (cm)</th>
<th>RVOT VTI (cm)</th>
<th>Signif AR (y/n)</th>
<th>Signif MR (y/n)</th>
<th>Signif TR (y/n)</th>
<th>TR Velocity (m/s)</th>
<th>MV Peak E Velocity (m/sec), DT (ms)</th>
<th>IVS Direction L/R/Neutral</th>
<th>a. Symptoms (y/n)</th>
<th>b. Evidence of Inflow-Cannula Obstruction (y/n)</th>
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Reason for termination: (eg, signs of inflow-cannula obstruction, hypotension, hypertension, worsening RV or LV function, etc.)

**Final speed setting = ____ rpm**

**Final BP = _____ mmHg**
- Optimization testing
- N = 35
- Combined invasive & echo ramp test to “optimize” patient management
- Up to 9 steps (400 rpm HMII, 100 rpm HVAD)
- Results
  - As normal as possible
  - CVP & PCWP (feasible in 56%)
LVAD Surveillance Exam

Indications

- Uncomplicated course
  - no alarms
  - no abnormal clinical signs or symptoms
- Establish baseline Pt-specific parameters
- Detect occult abnormalities
  (deno AR, smoldering HF, early pump malfunction)
Example LVAD Surveillance Echo Schedule

CF-LVAD Implant

- ~2 weeks or prior to Discharge
- 1 month
- 3 months
- 6 months
- 12 months
- Every 6-12 months thereafter
Aortic insufficiency after LVAD

- Mild-to-mod AI developed in 25-30% after cf-LVAD
- AI is continuous / interrupted by LV contraction
- > mod AI 50% progress to HF that requires > med management

**Significant AI**
- VC > 3 mm
- Prox jet/ LVOT diameter > 46%
- Do not reflect “pancyclic” nature of AI
- LV size increase
- Decreased RVOT flow relative to device flow
Aortic insufficiency after LVAD
Continuous AI

Magnitude of flow interruption is a reflector of residual LV contractility
Commissural Fusion of the AV Cusps
Vicious Cycle

LVAD Echo
2016 ASE ASEAN
- N=20 (none to mod-severe AI after cfLVAD)
- RHC
- Traditional measures of AI (RF, VC)
- LVAD outflow graft
  - Diastolic acceleration
  - S/D ratio
  - Correlated well with RF & Left-sided filling
AI Regurgitant Flow = Total Systemic Flow - Flow to Right Side of Heart

= (CO across LVAD Outlet) + (CO across Aortic Valve) - (CO measured by RHC)

= (VTI\text{LVAD Outflow} \times CSA\text{LVAD Outflow} \times HR) + (VTI\text{LVOT} \times CSA\text{LVOT} \times HR \times AoV\text{OF}) - CO\text{RHC}

AI Regurgitant Fraction = AI Regurgitant Flow / Total Systemic Flow
Impact of LVAD Speed Setting

Low

Normal AV opening

45dB M Gain = 0dB
PUMP SPEED = 9,000
FLOW = 6.3

Cal = 20mm

Store in progress
HR = 99bpm
Sweep = 100mm/s
Impact of LVAD Speed Setting

Intermediate
Case #2

![Graph showing flow (L/min) and power (Watts) over 14 days.](image)

Flow (L/min)

Power (Watts)

14 Days
LVAD Thrombosis: Signs and Symptoms

- Asymptomatic
  - Transient or sustained power elevation
  - Isolated LDH elevation

- Symptomatic
  - CHF (left ± right-sided)
  - Hemolysis (pfhbg, bilis, LDH, dark urine)

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Aortic Root Thrombus
LVAD Echo Reporting Protocol

1. Document device type, mode, pump speed setting, BP
2. Standard comprehensive echo exam for heart failure
3. PLAX and PSAX record 3-5 cardiac cycles (2D, M-Mode to assess LV dimension, function and AV opening frequency/duration)
4. Inflow cannula view (off axis A4C or A2C) or modified apical views. Obtain Doppler flow velocity
5. Outflow cannula views : RPS view, obtain Doppler flow velocity
6. Outflow cannula-ascending aorta anastomosis: RPS view obtain Doppler flow
THANK YOU
FOR YOUR ATTENTION

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