Left Ventricular Assist Device: What Should I Report?

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Disclosures

Speakers Bureau (Philips, Medtronic)
Advisory Board (Siemens)

ASE GUIDELINES & STANDARDS

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.)
The heart is a pump.

Erasistratus | Ἑρασίστρατος
(304 BC – 250 BC)
Greek physician from Alexandria

He was the first to establish that the heart is a pump, a concept unknown to Hippocrates (c. 460 BC – c. 370 BC). He was also the first to describe heart valves (ὑμένης | hymens).

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The heart is an example of a positive displacement pump.

Most artificial hearts are an example of an impeller pump.

A volume of fluid is periodically trapped into a chamber and then expelled. The periodic fluid displacement results in a direct increase in pressure.

Positive displacement pumps

Inertial (impeller) pumps

A rotating propeller-like device called impeller continuously expels the fluid from the pump.
### Ventricular Assist Devices (VAD)

Partial replacement of ventricular function (Booster pumps)

- **VADs**
- **Pulsatile**
  - Pumps that emulate the natural heart.
- **Continuous**
  - Pumps with no direct resemblance to natural heart

#### Bulky valved devices
- Blood pressure variations and pulse still present

#### Smaller valveless devices
- No palpable pulse; BP detectable by Doppler

### Ventricular Assist Devices (VAD)

<table>
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<tr>
<th>Generation</th>
<th>Long-Term Use</th>
<th>Short-Term Use</th>
<th>Valves</th>
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<tr>
<td>Pulsatile</td>
<td>1 HeartMate XVE</td>
<td></td>
<td>Valved</td>
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<tr>
<td>Continuous</td>
<td>2 HeartMate II (Coaxial)</td>
<td>Impella</td>
<td>Valveless</td>
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<td></td>
<td>3 HeartWare HeartMate 3</td>
<td>CentriMag</td>
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*Most clinical experience is with HeartMate II*
Short-Term VADs

Impella LVAD

- Continuous flow pump
- Placed non-surgically in the cath lab through the femoral artery
- Used to stabilize critically ill patients who require short term LV support that cannot be adequately achieved with an intra aortic balloon pump
**Impala**  
A Zulu word for a medium-sized African antelope

**Impella**  
Impeller is the rotator of a centrifugal pump

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**TTE: Proper Impella Placement**

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![Diagram of Impella catheter and TTE image showing proper placement.](image)
Impella: Color Doppler

CORRECT Impella Placement

INCORRECT Impella Placement

Too far into the LV or entangled in papillary muscle.

TTE: Impella on A4C View

No mosaic color pattern below the aortic valve.
(Correct placement of Impella)
TTE: Impella on Spectral Doppler

All spectral recordings will normally have this regular wavy pattern.

Long-Term VADs
HeartMate II LVAD

- **Batteries**: Sends power and operating signals to the pump and receives information from the pump.

**Outside the Body**
- **Outflow Graft**
- **Outflow Cannula**

**Inside the Body**
- **Pump**
- **Inflow Cannula**
Newest LVADs

**HEARTWARE**
3rd generation centrifugal pulsatile pump

**HEARTMATE 3**
3rd generation centrifugal pulsatile pump

**HEARTWARE**
Third-generation pulsatile pump

HeartMate II Control Unit Display

**PUMP FLOW (Q)**
- Estimated from pump power
- Range: 3 - 20 L/min

**ACTUAL PUMP SPEED**
- May vary from programmed speed
- Normal variation: ±150 rpm

**PULSATILITY INDEX**
- Calculated as \((Q_{\text{max}} - Q_{\text{min}})/Q_{\text{avg}}\)
- Typical range: ± 5

**Programed Pump Speed**
- Theoretical range: 6000 – 15000 rpm
- Typical range: 8,000 – 10,000 rpm

**Pump Flow**
- Displayed as 4.5 L/min

**Pump Speed**
- Displayed as 9600 rpm

**Pulse Index**
- Displayed as 3.6

**Pump Power**
- Measured by control unit
- Typical range: 5 – 8 Watts

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**Echocardiography of VADs**

Apply **standard** echocardiographic techniques to the specific requirements of a VAD environment.
Echocardiographic Views

**Right Parasternal Views**
For imaging of outflow graft connection to aorta

**Parasternal Views**
Most important for LV size, MR & AI

**Apical Views**
Often difficult due to inflow cannula

**Subcostal Views**
May be difficult in acute setting due to bandages

**Chest X-Ray**
HeartMate II

Indications for Echocardiography of VADs

<table>
<thead>
<tr>
<th>Acute LVAD Complications</th>
<th>Chronic LVAD Management</th>
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<tbody>
<tr>
<td>1. Pericardial effusion</td>
<td><strong>Objective</strong></td>
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<tr>
<td>2. VAD obstruction</td>
<td>‘Optimal’ LV Decompression</td>
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<tr>
<td>3. RV failure</td>
<td>1. Middle interventricular septum position</td>
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<tr>
<td>4. Miscellaneous</td>
<td>2. Intermittent AV opening</td>
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</table>

3. No more than mild MR.
LVAD Uses

1. Bridge to Heart Transplant
2. Destination Therapy
3. Bridge to Recovery

Maximize LV Decompression
Gradually minimize LV Support

Case Presentation
Case Presentation

47-y/o woman with severe nonischemic cardiomyopathy

Clinical Course

Echo #1
Class IV heart failure despite IV inotropes

Echo #2
HeartMate II LVAD implanted
Marked improvement in symptoms (Class II heart failure)

Echo #3
Few months post LVAD
Recurrence of severe symptoms

LVAD Case

Echo #1
Prior to LVAD Implantation
Echo #1: Prior to LVAD Implantation

- Severely dilated and hypokinetic LV
- Marked functional mitral regurgitation
- No aortic regurgitation

Prior to LVAD implantation, aortic regurgitation needs to be corrected but aortic stenosis often does not.
Aortic Regurgitation & LVAD Function

Significant aortic regurgitation interferes with LVAD function by creating an endless loop:

LV >> inflow cannula >> LVAD >> outflow graft >> AR

If aortic regurgitation is present prior to LVAD, aortic valve is surgically repaired, oversewn or replaced.

‘Park Stitch’

Figure 2. Pledged 4-0 Prolene sutures are applied to approximate the fibrous annulus of Aorticus to create a coaptation stitch.

LVAD Case

ECHO #2
IMMEDIATELY POST LVAD IMPLANTATION
Echo #2: Immediately Post LVAD Placement

- No aortic regurgitation
- Aortic valve does NOT open

There is no firm agreement on how frequently aortic valve should open in LVAD patients.

- Marked decrease in LV size
- Marked decrease in functional regurgitation

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Impact of LVAD rpms on Echo Parameters

<table>
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<tr>
<th>Less LV Decompression</th>
<th>More LV Decompression</th>
</tr>
</thead>
<tbody>
<tr>
<td>8,000 rpms</td>
<td>12,000 rpms</td>
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</tbody>
</table>

- Larger LV Size
- More functional MR
- Less AR
  - More AV opening

- Smaller LV Size
- Less functional MR
- More AR
  - Less AV opening
Ramp study = Measurement of Echo Parameters with Varying rpm LVAD Settings

LVEDD = 6.9 cm
LVEDD = 6.1 cm
LVEDD = 5.8 cm

AV opens with every beat

AV opens intermittently

AV does not open at all
HeartMate II LVAD: Intermittent AV Opening

HeartMate II LVAD: No AV Opening
LVAD Case

Echo #3
Serial Imaging
Post LVAD Implantation

Echo Series Post LVAD Implantation

One Month Post LVAD
Aortic regurgitation mild and intermittent (diastolic).

Three Months Post LVAD
Aortic regurgitation more pronounced and continuous (diastolic and systolic).
Echo Series Post LVAD Implantation

Six Months Post LVAD
Systolic and diastolic aortic regurgitation is now more severe.

Echo Series Post LVAD Implantation

Color M Mode in PLAX View
Continuous (systolic & diastolic) aortic regurgitation
Echo Series Post LVAD Implantation

LVAD Patient
Continuous (systolic & diastolic) aortic regurgitation

Non-LVAD Patient
Usual diastolic aortic regurgitation

Learning Points

POINT #1
Progressive de novo aortic regurgitation may develop post LVAD placement.

In one retrospective study, significant aortic regurgitation developed in 14% (9 out 63) patients with HeartMate II LVAD (J Heart Lung Transplant. 2010; 29: 1172-1176)

POINT #2
Aortic regurgitation post LVAD is continuous (systolic and diastolic).

This is in contrast to regular aortic regurgitation which is typically only diastolic.
De Novo Aortic Regurgitation Post LVAD

Proposed mechanisms
- Aortic valve remains closed during systole
- Commissural fusion of the aortic valve from disuse
- Subsequent degeneration of valve
- Turbulent blood backflow from small outflow cannula onto a closed valve
- Persistent elevation of aortic root pressure → aortic root dilation and valve incompetence

Treatment
- Lower LVAD speed (but that may worsen mitral regurgitation)
- Aortic valve surgery or percutaneous intervention
- Heart transplant

*Circ. Heart Failure. 2010;3:668-674
Circ J. 2011;75(5):1147-55

Post-LVAD Aortic Regurgitation: Impact of LVAD Speed

LVAD Speed 9200 rpm
Aortic regurgitation is continuous (systolic & diastolic)

LVAD Speed 8000 rpm
Less systolic aortic regurgitation
Case Presentation

76-y/o man

- Moderate native AR prior to LVAD
- At time of LVAD implant, AV was oversewn (Park stitch)
- Aortic regurgitation resolved post LVAD only to recur months later

Percutaneous Treatment of Post-LVAD Aortic Regurgitation

Regurgitant orifices then closed percutaneously with 2 Amplatzer devices.
Images and Case Reports in Heart Failure

Percutaneous Intervention for Recurrent Aortic Insufficiency in a Patient With a Left Ventricular Assist Device and a Centrally Oversewn Aortic Valve

Raymond Biery, MD; Lorna B. Balian, MD; Mohamed Sari, MD; Duff B. McElhinney, MD; Stuart Katz, MD; Abe DeAnda Jr, MD; Alex Bayontovich, MD

Circ Heart Fail. 2013;6:e43-e44.

LVAD COMPLICATION

Aortic Root Thrombosis
71-y/o man; s/p HM II LVAD a year ago; anticoagulation stopped after he developed a stroke

Right middle cerebral artery (MCA) stroke

A few days after cessation of anticoagulation, developed chest pain and markedly elevated troponin I

TEE: Thrombus in left and noncoronary cusps of a surgically ligated aortic valve
A few days after cessation of anticoagulation, developed chest pain and markedly elevated troponin I

TEE: Thrombus in left and noncoronary cusps of a surgically ligated aortic valve

Evaluation of LVAD Inflow Cannula
Heart Mate II Inflow Cannula: A4C View

Normal lamina flow in inflow cannula in LV apex
Heart Mate II Inflow Cannula: PLAX View

On spectral Doppler, normal flow pattern is unidirectional and of low velocity

\[ V_{\text{max}} = 1.0 \text{ – } 2.0 \text{ m/sec} \]

Proper Alignment of Inflow Cannula
LVAD inflow cannula should be in the LV apex, aligned with LV inflow tract and away from surrounding LV walls.

Misaligned LVAD Inflow Cannula

LVAD inflow cannula that is too close to LV walls may get obstructed at higher rpms (LV walls sucked into the cannula).
Misaligned LVAD Inflow Cannula

Flow Pattern in Inflow Cannula

On color Doppler, normal flow pattern in laminar.
Flow Pattern in Inflow Cannula

On spectral Doppler, normal flow pattern is unidirectional and of low velocity $V_{\text{max}} = 1.0 - 2.0 \text{ m/sec}$

The magnitude of pulsatility depends on the degree of LV decompression.

More LV decompression >>> Less pulsatility

VSD: Complication of Misaligned Inflow Cannula
VSD: Complication of Misaligned Inflow Cannula

Evaluation of LVAD Outflow Graft
Outflow graft travels anterior to the right heart.

Outflow graft typically ends in the ascending aorta.

LVAD: Outflow Graft

Flow into the ascending aorta may normally appear somewhat turbulent
(small caliber graft >>> larger caliber aorta)
Flow Pattern in Outflow Graft

On spectral Doppler, normal flow pattern is unidirectional and of low velocity
Vmax = 1.0 – 2.0 m/sec

The magnitude of pulsatility depends e.g. on the degree of LV decompression.
More LV decompression >>> Less pulsatility

3D TEE: LVAD Outflow Graft in Aorta
Abnormal high-velocity aliased flow in outflow graft.

Abnormal high-velocity nonpulsatile flow in outflow graft.
HeartMate II: Outflow Graft on Suprasternal TTE

On spectral Doppler, normal flow pattern is unidirectional and of low velocity

Vmax = 1.0 – 2.0 m/sec
Evaluation of RV Function

RV Function Evaluation in LVAD Patients

Use all standard echocardiographic techniques including RV fractional area change.
RV Fractional Area Change (RV FAC)

RVFAC is a rough measure of RV systolic function... obtained from the apical 4-chamber view.

\[
RVFAC = \frac{RVEDA - RVESA}{RVEDA}
\]

RVFAC = (13.4 cm² – 6.1 cm²) / 13.4 cm² = 54%
(Normal RVFAC = 35 – 63%)

RV FAC and LVAD

<table>
<thead>
<tr>
<th>Severe RV Dysfunction</th>
<th>Typical LVAD Patient</th>
<th>Normal RV Function</th>
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<tbody>
<tr>
<td>20%</td>
<td>40%</td>
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Typical LVAD Patient

Normal RV Function
Conclusion: LVAD Echo Assessment

LVAD Reporting: LV Function

<table>
<thead>
<tr>
<th>Comment</th>
<th>LV END-DIASTOLIC DIMENSION</th>
<th>MITRAL REGURGITATION</th>
<th>AORTIC REGURGITATION SEVERITY</th>
<th>AORTIC REGURGITATION TIMING</th>
<th>AORTIC VALVE OPENING</th>
</tr>
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<tbody>
<tr>
<td>WHAT TO REPORT</td>
<td>2D or M mode</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>Normal</td>
</tr>
<tr>
<td>LVEDD = cm</td>
<td></td>
<td>Mild</td>
<td>Mild</td>
<td>Mild</td>
<td>Normal</td>
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<tr>
<td></td>
<td></td>
<td>Moderate</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Intermittent</td>
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<tr>
<td></td>
<td></td>
<td>Severe</td>
<td>Severe</td>
<td>Severe</td>
<td>Never opens</td>
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<tr>
<td>WHAT TO EXPECT</td>
<td>LVEDD decreases</td>
<td>MR decreases</td>
<td>AI may increase</td>
<td>AI may become holocyclical</td>
<td>AV opening decreases</td>
</tr>
<tr>
<td>WITH HIGHER RPMS</td>
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## LVAD Reporting: LVAD Cannulae

<table>
<thead>
<tr>
<th>COLOR DOPPLER FLOW PATTERN</th>
<th>INFLOW CANNULA or OUTFLOW GRAFT</th>
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<tbody>
<tr>
<td></td>
<td>Laminar</td>
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<td>Turbulent</td>
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<thead>
<tr>
<th>SPECTRAL DOPPLER PATTERN</th>
<th>Although HeartMate II is a continuous pump, cannula flows are pulsatile</th>
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<tr>
<th>PEAK VELOCITY</th>
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<tr>
<td></td>
<td>Normal &lt; 2.0 m/sec (&lt;1.5 m/sec in many cases)</td>
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<table>
<thead>
<tr>
<th>WHAT TO EXPECT WITH HIGHER RPMs</th>
<th>Velocity may increase</th>
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<tr>
<th>WHAT ELEVATED VELOCITIES MAY MEAN</th>
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<tr>
<td></td>
<td>High flow</td>
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<td>Obstruction</td>
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## LV Reporting: RV Function

<table>
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<tr>
<th>COMMENT</th>
<th>RV SYSTOLIC FUNCTION</th>
<th>RV CARDIAC OUTPUT</th>
<th>ATRIAL SEPTUM</th>
<th>VENTRICULAR SEPTUM</th>
<th>TRICUSPID REGURGITATION</th>
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<tbody>
<tr>
<td>Semi quantitatively</td>
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<tr>
<td>Normal</td>
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<td>Hypokinetic</td>
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<td>Hyperkinetic</td>
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<td>CO = L/min</td>
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<tr>
<td>Higher preload improves RV function (if RV can handle it)</td>
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<td>RV CO increases (if RV can handle it)</td>
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<tr>
<td>Bows to LA</td>
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<td>Bows to LV</td>
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<td>TR increases</td>
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Thank You!

New York University Langone Medical Center