Heart Failure: Definition

A clinical syndrome that results from impairment of ventricular filling or ejection of blood. Manifestations include dyspnea and fatigue, exercise intolerance, fluid retention, which may lead to pulmonary +/- splanchnic congestion +/- peripheral edema. Some patients have exercise intolerance but little fluid retention, others complain primarily of edema, dyspnea, or fatigue.

There is no single diagnostic test for HF. It is a clinical diagnosis based on a the history and physical examination.

Yancy et al 2013 ACCF/AHA Heart Failure Guideline
Heart Failure: Prevalence

- Estimated 23 million people with HF worldwide
- In the US: 670,000 cases diagnosed/year
- 1 million hospitalizations and 3.4 million outpatient visits
- Rate of rise in HF cases has outpaced the rate of transplantation

Death from specific cardiovascular, Lung and Blood Diseases, U.S., 2004 NHLBI report

Mechanical Assist Devices

A valuable option for patients with end stage systolic heart failure (Stage D)

ESC Definition of Advanced HF

1. Severe symptoms of HF with dyspnea and/or fatigue at rest or with minimal exertion (NYHA class III or IV)
2. Episodes of fluid retention (pulmonary and/or systemic congestion, peripheral edema) and/or reduced cardiac output at rest (peripheral hypoperfusion)
3. Objective evidence of severe cardiac dysfunction shown by at least 1 of the following:
   a. LVEF <30%
   b. Pseudonormal or restrictive mitral inflow pattern
   c. Mean PCWP >16 mmHg and/or SAP >12 mmHg by PA catheterization
   d. High BNP or NT-proBNP plasma levels in the absence of noncardiac causes
4. Severe impairment of functional capacity shown by 1 of the following:
   a. Inability to exercise
   b. 6-Minute walk distance ≤300 m
   c. Peak VO2 <12 to 14 mL/kg/min
5. History of ≥1 HF hospitalization in past 6 mo
6. Presence of all the previous features despite “attempts to optimize” therapy, including diuretics and CABG, unless these are poorly tolerated or contraindicated, and CRT when indicated
Why offer an LVAD?

- Wait times for cardiac transplantation are long
- Large numbers of patients with end-stage heart failure
- 1-y survival on LVAD support awaiting transplant ~55-85%
- >30 000 LVADs are implanted world-wide

LVADs: Clinical Indications

1. Bridge-to-Transplantation (BTT)
   - Duration of Support: 6 ~ 12 months
   - Maximize survival until transplant
2. Destination Therapy (DT)
   - Duration of support is indefinite
   - Purpose: maximize functional capacity and quality of life
   - 1-y survival approaching 80%
3. Myocardial Recovery + Potential Explant
   - Maximize LV reverse remodeling
**LVAD Circuit**

**Removal of blood from LV apex return blood to aorta via graft**

Three main internal components to LVAD:
1. Inflow cannula at LV apex
2. Mechanical impeller
3. Outflow graft connected to the ascending aorta

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**HeartMate II**

**HVAD (HeartWare)**

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ECHO: Clinical Indications

1. Surveillance
   - Drift from baseline echo

2. Determine optimal device settings
   - With or without speed changes
   - To select the optimal LVAD speed setting

3. Assess complications
   - Thrombosis
   - Inflow/outflow cannula obstruction

4. Assessment of LV recovery

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The Surveillance Echo
LVAD Parameters

LVAD Evaluation

1. LV size
2. Aortic valve opening
3. Aortic insufficiency
4. Inter-ventricular septum position
5. Right ventricle size and function
6. Mitral regurgitation
7. Inflow cannula
8. Outflow cannula
9. Thrombosis
10. Pericardium
Inter-ventricular septum
Position of Inter-ventricular Septum

- **Rightward Shift**: Inefficient LV unloading
- **Midline**: Efficient LV compression
- **Leftward Shift**: Markedly unloaded LV

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**Aortic Valve Opening**
Aortic valve opening: 2D Echo

- Closed
- Intermittent opening
- Opening normally

Aortic valve opening: M-mode Echo

- Closed
- Intermittent opening
- Opening every beat
Impact of Aortic valve opening

Aortic Insufficiency

Aortic Insufficiency

1) Often occurs during both systole and diastole (pan-cyclical) and not only during diastole
2) Overall volume load that the ventricle sees is greater
3) Eccentric and often poorly measured by traditional echocardiographic measures such as vena contracta and PISA

Time Course of Aortic Insufficiency

N = 237 patients with HeartMate II CF-LVADs
32 patients had mod or severe AI
Histopathological Changes Leading to AI in cf-LVADs

1. Increased local fibrosis and thrombus formation
2. Aortic root remodeling and dilatation
3. AV degeneration and remodeling
4. AV commissural fusion
5. AV leaflets malcoaptation

Thrombosis
50 year-old man 1 month status post HeartMate II LVAD. He was ready to go home after a lengthy admission. This echo was done prior to discharge.
Other Thrombosis

- Malposition
- Occlusion
- Thrombosis

Inflow cannula
The Normal Inflow Cannula

Inflow cannula is usually positioned in the LV apex and oriented within the LV toward the mitral valve.

The Abnormal Inflow Cannula

**Mechanisms** of inflow cannula obstruction
- Thrombus
- Inlet occlusion by trabeculations
- Cannula angulation into the myocardium
- Malposition due to LV under-filling
The Abnormal Inflow Cannula

74 year-old F with an LVAD complains of shortness of breath, fatigue and exercise intolerance

The Abnormal Inflow Cannula

74 year-old female with an LVAD complains of shortness of breath, fatigue and exercise intolerance
The Abnormal Inflow Cannula

Outflow cannula

- Kink
- Obstruction
- Thrombosis
The Normal Outflow Cannula

Normal reference for outflow cannula peak velocities depend on LVAD type

- 57 patients with LVADs:
  - Thoratec HeartMate II (HMII) (N= 44)
  - HeartWare (HW) (N= 13)
- LVAD outflow peak velocities were measured with Doppler echocardiography (TTE) from the right parasternal window to establish the average velocity as well as the upper and lower normal reference limit (defined as ± 2SD around the mean).
- The upper reference limit was then used as a screening threshold for outflow cannula malfunction.
Abnormalities in the outflow cannula: Case 1

61 year-old man s/p HMII for ICM. Peak outflow cannula velocity of 3.9 m/s on 13d follow-up echo

Outflow cannula velocity 3.9 m/s
Kink/bend in the outflow graft

Abnormalities in the outflow cannula: Case 2
Stenosis in the outflow graft

Abnormalities in the outflow cannula: Case 3

48 yo woman status post HeartWare LVAD for ICM as BTT. Admitted with shortness of breath/chest pain

RHC:
RAP = 23 mmHg
PAP = 52/34
mPAP = 40 mmHg
PCWP = 29 mmHg
SVR = 1644 dynes/sec/cm-5

Outflow velocity 3.4 m/s
Abnormalities in the outflow cannula: Case 3

Turbulence
Parasternal long-axis

Rt. supra sternal

Abnormalities in the outflow cannula: Case 3

Aortogram
Balloon
Stent
Abnormalities in the outflow cannula: Case 3

Post stent echo

LVAD speed optimization
Cardiac Output

Lie  Run

Walk

The Ramp Study

The RAMP study is stopped if suction events occur and/or if the LVEDD < 3.0 cm

Increasing LVAD speed (in RPM)
The RAMP Study

1. Optimize device speed without compromising cardiac function:
   i. Mean arterial BP > 65 mmHg
   ii. Maintain inter-ventricular septum position in midline
   iii. Intermittent aortic valve opening
   iv. No more than mild mitral regurgitation

2. Evaluate for LVAD malfunction such as device-related thrombosis

Pre-RAMP Considerations

Ensure:
- INR > 1.8
- PTT > 60
- No LV thrombus
- No aortic root thrombus

![Aortic root clot](image)
RAMP test protocol

**Table 1: Ramp Test Protocol (for HeartMate II)**

<table>
<thead>
<tr>
<th>Speed, rpm</th>
<th>PI</th>
<th>Power</th>
<th>Flow</th>
<th>BP</th>
<th>HR</th>
<th>LVEDD</th>
<th>LVESD</th>
<th>AV Opening</th>
<th>AI</th>
<th>MR</th>
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LVAD parameters
Patient parameters
Echo parameters

Inotropic ramp test protocol was developed for the HeartMate III.

LV = left ventricular; RV = right ventricular; IS = isovolumic systolic; E = ejection fraction; EF = ejection fraction; LVEDD = left ventricular end-diastolic diameter; LVESD = left ventricular end-systolic diameter; MR = mitral regurgitation; AI = aortic insufficiency; AV = aortic valve; BP = blood pressure; HR = heart rate; RVSP = right ventricular systolic pressure.

Optimization of LV unloading

Increasing LVAD pump speed

- **8000 RPM**: 74 mm
- **9600 RPM**: 69 mm
- **10400 RPM**: 63 mm

- **8000 RPM**: Rightward
- **9600 RPM**: Rightward
- **10400 RPM**: Rightward
Optimization of Ao valve opening

Increasing LVAD pump speed

8000 RPM  9200 RPM  11600 RPM

Optimization of Aortic Insufficiency

Increasing LVAD pump speed

8000 RPM  9600 RPM  11200 RPM
Optimization of Mitral Regurgitation

Increasing LVAD pump speed

Example RAMP Study

<table>
<thead>
<tr>
<th>RPM</th>
<th>LVEDD</th>
<th>AVO</th>
<th>AI</th>
<th>MR</th>
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<tbody>
<tr>
<td>8000</td>
<td>77 mm</td>
<td>10/10</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>8800</td>
<td>75 mm</td>
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<td>3</td>
</tr>
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<tr>
<td>11600</td>
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Example RAMP Study

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<th>Power</th>
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<th>PAsys</th>
<th>PAd</th>
<th>mPAP</th>
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<td>26</td>
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<table>
<thead>
<tr>
<th>Speed</th>
<th>LVEDD</th>
<th>Septum</th>
<th>AVO</th>
<th>AI</th>
<th>MR</th>
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<tbody>
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<td>77</td>
<td>Midline</td>
<td>10/10</td>
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<td>3</td>
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<tr>
<td>8800</td>
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<td>3</td>
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<tr>
<td>9600</td>
<td>69</td>
<td>Midline</td>
<td>3/10</td>
<td>2.5</td>
<td>3</td>
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<tr>
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<td>69</td>
<td>Midline</td>
<td>Closed</td>
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<td>2</td>
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<tr>
<td>11600</td>
<td>62</td>
<td>Leftward</td>
<td>Closed</td>
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LVAD Malfunction: Case
LVAD Malfunction: A Case

50 year-old female
- Idiopathic CM
- HMII 6 months ago
- 2-d history of shortness of breath and fatigue
- Labs consistent with hemolysis
- A RAMP study was performed

Recall: Normal LVAD Function

<table>
<thead>
<tr>
<th>RPM</th>
<th>8000</th>
<th>9600</th>
<th>10800</th>
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<tbody>
<tr>
<td>AV opening</td>
<td><img src="6.5cm.png" alt="Image" /></td>
<td><img src="5.4cm.png" alt="Image" /></td>
<td><img src="4.9cm.png" alt="Image" /></td>
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<tr>
<td>AV closed</td>
<td><img src="6.5cm.png" alt="Image" /></td>
<td><img src="5.4cm.png" alt="Image" /></td>
<td><img src="4.9cm.png" alt="Image" /></td>
</tr>
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</table>

- Increasing aortic regurgitation
- Decreasing mitral regurgitation
- Shift in interventricular septum to the left
RAMP Study in our patient

<table>
<thead>
<tr>
<th>RPM</th>
<th>8000</th>
<th>9600</th>
<th>11200</th>
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</thead>
<tbody>
<tr>
<td>6.0 cm</td>
<td>6.0 cm</td>
<td>5.8 cm</td>
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Visible thrombus in the inlet stator

Consider LVAD thrombosis:
1. Worsening HF
2. Signs of hemolysis
   - Elevated LDH
   - Low haptoglobin
3. Device malfunction (power spikes/flow alarms)
4. Echo-Ramp test demonstrates lack of change in LVEDD with increasing LVAD speeds

Device inspection in this patient
Inflow cannula:
- Malposition
- Occlusion
- Malfunction
- Thrombosis

Right ventricle:
- Failure
- Tricuspid regurgitation
- Thrombosis

Aortic valve:
- Opening
- Regurgitation
- Thrombosis

Mitral valve:
- Regurgitation
- Thrombosis

Septum:
- Malposition
- LV dimension

Pericardium:
- Atypical Effusion
- Tamponade
- Hemorrhage

Outflow cannula:
- Kink
- Obstruction
- Thrombosis

Death from specific cardiovascular, Lung and Blood Diseases, U.S., 2004 NHLBI report

Thank-you for your attention