Update on Management of Severe Decompensated Heart Failure (with an emphasis on Mechanical Circulatory Support)

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Disclosures

- None pertinent to this talk.
Objectives

- Review epidemiology and pathophysiology of heart failure (HF) and advanced HF.
- Understand the mechanism of action and physiologic effects of various mechanical circulatory support (MCS) devices.
- Understand the potential limitations, contraindications and complications of MCS devices.
Definition(s) of Congestive Heart Failure

- **1933**- Sir Thomas Lewis, “a condition in which the heart fails to discharge its contents adequately.”
- **1980**- Dr. Eugene Braunwald, “a pathophysiological state, in which an abnormality of cardiac function is responsible for the failure of the heart to pump blood at a rate commensurate with the requirements of the metabolizing tissues, or to do so only from an elevated filling pressure.
- **Current**- Clinical syndrome associated with congestive symptoms and/or symptoms of low cardiac output due to impaired ventricular pump function (reduced EF)
5.1 million persons in the United States have clinical manifestations of HF, with continued increasing prevalence.

650,000 new cases of HF are diagnosed annually.

Prevalence of asymptomatic LV dysfunction ranges from 6% to 21%.

50-55% of HF patients have preserved LVEF.

It is projected that by the year 2030, the economic burden of HF will increase approximately 127% to $69.7 billion compared to 2012.
Epidemiology of Heart Failure (HF)

- From 1968 to the early 1990s, HF has increased at least four-fold as the primary cause of death.
- 10-year survival for patients with symptomatic HF remains only 20%, with a median survival of 1.7 years for men and 3.2 years for women.
- Approximately 50% of patients diagnosed with HF die within 5 years.
- As cardiac patients continue to live longer with better treatment, it is expected that the prevalence of HF will continue to rise, thus increasing the lifetime risk of developing HF.
Risk Factors for HF

- CAD
- Hypertension
- Renal dysfunction
- Older age
- Diabetes mellitus
- Obesity
- Arrhythmia (eg: AF)

- Anemia
- Thyroid disorder
- Lower SES
- Valvular disorders
- Nutritional (eg: Thiamine deficiency)
Epidemiology: Advanced HF

- Subgroup of patients who are refractory to guideline-based medical management.
- Patients with advanced HF are identified as those with severe symptoms, commonly classified as New York Heart Association (NYHA) class III and IV.
- These patients may also incur multiple hospitalizations, despite optimal medical therapy.
- Studies have estimated that >200,000 Americans are living with end-stage HF, with a 1-year mortality rate of 70-90%.
Epidemiology: Advanced HF

- Advanced HF patients represent approx. 10% of the total HF population
- These pts utilize advanced and often invasive therapeutic options, including:
  1) Cardiac transplantation
  2) Mechanical circulatory assist devices
  3) Implantable cardioverter-defibrillator and cardiac resynchronization therapies
  4) Intravenous inotropic therapy
  5) Frequent high-acuity admissions (e.g., ICU admissions with hemodynamic monitoring).
- The economic implications of these evolving new therapies for end-stage HF are potentially enormous
HF Epidemiology: Predictors of poor prognosis

- Advanced New York Heart Association (NYHA) functional class
- Ischemic etiology
- High diuretic dose
- Impaired LV ejection fraction (LVEF)
- Reduced systolic blood pressure
- Hyponatremia
- Anemia
- High relative lymphocyte count
- High uric acid
- Low total cholesterol
- Atrial fibrillation
- Appropriate defibrillator shocks
- HF hospitalizations
- High blood urea nitrogen
- Abnormal hemodynamic indices (cardiac output, pulmonary artery pressure)
- Abnormal cardiopulmonary exercise parameters (peak oxygen consumption, ventilatory efficiency as assessed by ventilation/carbon dioxide production [VE/VCO₂]).
**Introduction: Abbreviations/Definitions**

- HF = Heart Failure
- LVAD = Left Ventricular Assist Device
- P-LVAD = Percutaneous Left Ventricular Assist Device
- MCS = Mechanical Circulatory Support
- P-MCS = Percutaneous Mechanical Circulatory Support
- ECMO = ExtraCorpororeal bypass with Membrane Oxygenator
- PCI = Percutaneous Coronary Intervention
- IABP = Intra-Aortic Balloon Pump
- CS = Cardiogenic Shock
Pathophysiology: Frank-Starling Mechanism-
The Length-Tension Relationship

- Increases in end-diastolic volume lead to stretch of ventricular myocytes and increased tension generation leading to stronger contraction.
- This allows the heart to increase stroke volume when there is increased venous return.
- This increase in contractile force in response to myocyte stretch constitutes the length-tension relationship, also known as the "Frank-Starling mechanism."
- However, increasing chamber volume beyond a certain point does not result in further increases, but rather in decreases in tension generation.

![Sarcomere Diagram]
Pathophysiology: Frank-Starling Curve

- **Stroke volume (mL)**
  - Y-axis: 0 to 200
- **Ventricular end-diastolic volume (mL)**
  - X-axis: 0 to 400
Pathophysiology: P-V Loop

Ventricular Pressure-Volume Loop

- P: Pressure
- V: Volume
- Ees: End-systolic pressure
- ESPVR: End-systolic pressure-volume relationship (contractility)
- EDPVR: End-diastolic pressure-volume relationship (stiffness)
- preload
- afterload
- isovolumic contraction
- isovolumic relaxation
- filling
- end-diastole
- ejection
- systole
- end-systole
Effects of Different Interventions on PV Loops

A  (-) Inotropy

B  (+) Inotropy

C  (+) Inotropy/Lusitropy

D  (↑) Afterload

E  (↓) Afterload

F  (↑) Preload
Effects of Different Interventions on PV Loops

A. BB, CCB

B. Dobutamine

C. Epi, Isoproterenol

D. Phenylephrine

E. ACEi, Hydralazine

F. IV Fluids
Cardiac Effects of Mechanical Support

Illustrations of PV loops after activation of device therapy (gray loops). (A) Intra-aortic balloon pump (IABP) counterpulsation reduces both peak LV systolic and diastolic pressures and increases LV stroke volume. The net effect is a reduced slope of arterial elastance (Ea2). (B) Percutaneous LV assist devices (pLVAD: Impella and TandemHeart) significantly reduce LV pressures, LV volumes, and LV stroke volume. The net effect is a significant reduction in cardiac workload. (C) Veno-arterial extra-corporeal membrane oxygenation (VA-ECMO) without a LV venting strategy increases LV systolic and diastolic pressure, while reducing LV stroke volume. The net effect is an increase in arterial elastance (Ea).
Systemic tissue hypoperfusion secondary to inadequate cardiac output despite adequate circulatory volume and LV filling pressure.

**Diagnostic hemodynamic criteria include:**

- a. SBP < 90 mm Hg for >30 min
- b. A drop in MAP > 30 mm Hg below baseline
- c. With a cardiac index (CI) < 1.8 L/min/m² without hemodynamic support, or < 2.2 L/min/m² with support
- d. Pulmonary capillary wedge pressure (PCWP) >15 mmHg
“Device therapy” in the ICU/CCU

Mechanical Circulatory Support (MCS) Devices
2011 ACC/AHA/SCAI Guideline for Percutaneous Coronary Intervention:

1. As an adjunct to High Risk PCI (Class IIb)
2. For cardiogenic shock in patients presenting with ST-elevation myocardial infarction (Class Ib)
Expert Consensus Statement: J Am Coll Cardiol 2015; Apr 7.
Percutaneous MCS provides superior hemodynamic support compared to medical therapy.

“Percutaneous MCS is revolutionizing the treatment of high-risk cardiac patients. In certain patients, these devices can mean the difference between recovery and the need for heart transplant or death, and they may be used to maintain hemodynamic stability during interventional procedures and as a bridge to longer-term treatment”

(Charanjit S. Rihal, MD, FACC, chair of the Division of Cardiovascular Diseases at the Mayo Clinic)
Percutaneous hemodynamic support has historically been limited to the intra-aortic balloon pump (IABP) or extracorporeal bypass with membrane oxygenator (ECMO) ECMO can provide full hemodynamic support but is limited by complexity and need for perfusion expertise and is rarely used in the catheterization laboratory environment or in the ICU
(Relative) Indications for P-MCS

- High-risk PCI patients
- Certain patients with acute decompensated heart failure with worsening symptoms.
- Patients in cardiogenic shock (when initial interventions do not stabilize the patient).
- Patients who failed to wean off cardio-pulmonary bypass.
- Right-sided support for severe right heart failure
Benefits of P-MCS

1. Maintain vital organ perfusion, thereby preventing systemic shock syndrome
2. Reduce intracardiac filling pressures (and reducing congestion and/or pulmonary edema)
3. Reduce left ventricular volumes, wall stress, and myocardial oxygen consumption
4. Augment coronary perfusion
5. Support the circulation during complex interventional and electrophysiologic procedures
6. (Potentially) Limit infarct size
Types of percutaneous P-MCS Devices

1. Intra-aortic balloon pump (IABP)
2. Left Atrial to Aortic Devices (eg: TandemHeart)
3. LV to Aortic Assist Devices (eg: Impella)
4. ECMO
Introduced in the late 1960’s.
Most commonly used form of circulatory support.
  - Largely due to ease of insertion and wide availability
Two major components:
  - Balloon catheter
  - Pump console to control the balloon.
The catheter itself is a double-lumen 7.5–8.0 Fr catheter with a polyethylene balloon attached at its distal end.
One lumen is attached to the pump and is used to inflate the balloon with gas.
  - Helium is used because its low viscosity facilitates rapid transfer in and out of the balloon, and because it absorbs very rapidly in blood in the case of balloon rupture.
IABP

- The second lumen of the IABP is used for guidewire insertion and to transduce aortic pressure.
- Timing of balloon inflation and deflation is based on electrocardiogram (ECG) or pressure triggers.
- The balloon inflates with the onset of diastole, which corresponds with repolarization or the middle of the T-wave on the surface ECG.
- Following diastole, the balloon rapidly deflates at the onset of LV systole, which is timed to the peak of the R-wave on the surface ECG.
IABP Hemodynamic Effects

1. ↑ Diastolic blood pressure
2. ↓ Afterload
3. ↓ Myocardial oxygen consumption
4. ↑ Coronary artery perfusion
5. ↑ Cardiac output (modest ↑ of approx 0.5 L/min)
IABP Hemodynamic Effects

- Provides modest ventricular unloading but does increase mean arterial pressure and coronary blood flow (in non-obstructive CAD).
- Patients must have some level of left ventricular function and electrical stability for an IABP to be effective.
- Optimal hemodynamic effect from the IABP is dependent on several factors, including:
  1. Balloon's position in the aorta
  2. Blood displacement volume (size of the balloon)
  3. Balloon diameter in relation to aortic diameter
  4. Timing of balloon inflation in diastole and deflation in systole
  5. HR
  6. BP
  7. Vascular resistance
IABP

Balloon Catheter

Console
IABP
IABP Waveform

- Unassisted Systole
- Unassisted Aortic End-Diastolic Pressure
- Balloon Aortic End-Diastolic Pressure
- Assisted Systole
- Diastolic Augmentation
  - Coronary Perfusion
- Balloon Inflation
Cardiac Effects of Mechanical Support: Illustrations of PV loops after activation of device therapy (gray loops).

(A) Intra-aortic balloon pump (IABP) counterpulsation reduces both peak LV systolic and diastolic pressures and increases LV stroke volume. The net effect is a reduced slope of arterial elastance (Ea2)
IABP Contraindications & Complications

- Aortic valve regurgitation (Moderate or Severe) is a contraindication since diastolic balloon inflation increases the degree of regurgitation.
- Vascular complications - including stroke, limb ischemia, or vascular trauma.
  - Trauma to the aorta or ostia of visceral arteries which can result in severe life-threatening complications such as bowel ischemia, atheroembolism, and acute kidney injury
- Thrombocytopenia:
  - Due to platelet deposition on the IABP membrane, or related to use of heparin
- Infection
- Complications of immobility
Currently, only one left atrial-aorta assist device is commercially available, the TandemHeart. This is a percutaneously inserted circulatory assist device that pumps blood extracorporeally from the left atrium (LA) to the iliofemoral arterial system via a trans-septally placed left atrial cannula, thereby bypassing the LV.

The TandemHeart has four components:
1. 21-F transseptal cannula
2. Centrifugal pump
3. Femoral arterial cannula
4. Control console
Left Atrial to Aorta Assist Devices

- Regulatory status includes U.S. Food and Drug Administration (FDA) approval to provide extracorporeal circulatory support for up to 6 hours and CE mark for use up to 30 days.
- It also has FDA approval to add an oxygenator to the circuit allowing for concomitant LV unloading and oxygenation.
The transseptal cannula is made of wire-reinforced polyurethane with a large end-hole and 14-side holes that allow for aspiration of left atrial blood.

The arterial perfusion cannula is available in sizes ranging from 15- to 19-F and is the main determinant of flow.

The centrifugal blood pump contains a hydrodynamic bearing that supports a spinning impeller. The pump has a motor chamber and a blood chamber that are separated by a polymeric membrane.

The impeller is powered by a brushless DC electromagnetic motor, rotating between 3,000 and 7,500 rpm.

The external console controls the pump and provides battery backup in case of power failure.

A continuous infusion of heparinized saline flows into the lower chamber of the pump, which provides lubrication and cooling, and prevents thrombus formation.
Left Atrial to Aorta Assist Devices
TandemHeart Hemodynamic Effects

- During MCS with TandemHeart, both the LV and the pump contribute flow to the aorta simultaneously (thereby working in parallel, or tandem, rather than in series).
- The redirection of blood from the LA reduces LV preload, LV workload, filling pressures, wall stress, and myocardial oxygen demand.
- The increase in arterial blood pressure and cardiac output supports systemic perfusion.
- The 19-F arterial cannula allows up to 5 L/min of flow whereas the 15-F cannula will allow up to 3.5 L/min.
- These values are additive to left ventricular output through the aortic valve, although the contribution of the heart is typically reduced as MCS support is increased due to changes in LV loading conditions (i.e., decrease in preload and increase in afterload).
Cardiac Effects of Mechanical Support: Illustrations of PV loops after activation of device therapy (gray loops).

(B) Percutaneous LV assist devices (pLVAD: Impella and TandemHeart) significantly reduce LV pressures, LV volumes, and LV stroke volume. The net effect is a significant reduction in cardiac workload.
Left Atrial to Aorta Assist Devices

TandemHeart
Contraindications/Complications

Relative Contraindications:
1. RV failure
2. VSD
3. Severe aortic regurgitation
4. Severe PAD

Contraindications:
1. Profound coagulopathies and bleeding diatheses such as heparin induced thrombocytopenia (HIT/HITT) or disseminated intravascular coagulation (DIC).
2. Presence of a right or left atrial thrombus.
Vascular trauma and limb ischemia.

Complications unique to transseptal puncture, such as cardiac tamponade can occur; and these risks are increased among anticoagulated patients.

Thrombo-embolism or air-embolism

Hemolysis.

Care must be taken to prevent dislodgement of the left atrial cannula, particularly during patient transport, or if the patient moves their leg

- Dislodgement into the right atrium will result in massive right to left shunt and severe systemic desaturation.
- The cannula may also migrate into a pulmonary vein leading to device malfunction.
Expertise with trans-septal puncture is required, especially given the caliber of the venous cannula.

The relatively low numbers of interventional cardiologists regularly performing trans-septal puncture in their practice is an important barrier to clinical application in many labs.
The Impella is a non-pulsatile axial flow Archimedes-screw pump designed to propel blood from the LV into the ascending aorta, in series with the LV.

Three versions are now available.

1. **12-F (Impella 2.5)** - maximal flow rate 2.5 L/min
2. **14-F (Impella CP)** - maximal flow rate 3.0 to 4.0 L/min.
3. **21-F (Impella 5.0)** - maximal flow rate 5.0 L/min

These devices are designed to be placed via the femoral artery, either percutaneously (2.5 and CP) or with a surgical cutdown (5.0).
Unlike the IABP, and comparable to the TandemHeart, the Impella does not require timing, nor is a trigger from an electrocardiographic rhythm or arterial pressure needed.

Similar to the TandemHeart, the device allows for stability despite transient arrhythmias, but asystole and ventricular fibrillation are poorly tolerated.

The device has received FDA approval for providing up to 6 h of partial circulatory support whereas in Europe, the Impella 2.5 is approved for use of up to 5 days.
Impella

Figure 1. The Impella 2.5, a minimally invasive, catheter-based cardiac assist device (Abiomed, Danvers, MA).
Impella: Design and Hemodynamic Effects

Inflow (ventricle) to Outflow (aortic root)

- EDV, EDP: Decrease
- Flow: Increase
- AOP: Increase
- O₂ Demand: Decrease
- O₂ Supply: Increase
- Cardiac Power Output: Increase

Myocardial Protection
Systemic Hemodynamic Support
LV to Aorta-Assist Devices- Hemodynamic Effects

- Unloads the LV and increases forward flow.
- Reduces myocardial oxygen consumption
- Improves MAP
- Reduces PCWP
- The Impella 2.5 provides a greater increase in C.O. than the IABP but less than the TandemHeart device.
- The more powerful Impella CP and 5.0 devices are comparable to the TandemHeart device in terms of support
- Similar to the TandemHeart, adequate RV function or concomitant RVAD is necessary to maintain LV preload and hemodynamic support during biventricular failure or unstable ventricular arrhythmias.
**Cardiac Effects of Mechanical Support:** Illustrations of PV loops after activation of device therapy (gray loops).

(B) Percutaneous LV assist devices (pLVAD: Impella and TandemHeart) significantly reduce LV pressures, LV volumes, and LV stroke volume. The net effect is a significant reduction in cardiac workload.
Contraindications/Complications-Impella

- Patients with Mechanical aortic valve or LV thrombus.
- Aortic stenosis and regurgitation are relative contraindications although reports of use in critical aortic stenosis for hemodynamic rescue or to facilitate valvuloplasty exist.
- Severe PAD or those who cannot tolerate systemic anticoagulation.
- The most commonly reported complications of Impella placement are limb ischemia, vascular injury (eg: hematoma, pseudoaneurysm, and A-V fistula, and retroperitoneal hemorrhage), and bleeding requiring blood transfusion.
- Hemolysis due to mechanical erythrocyte shearing has been reported within the first 24 h of use in 5% to 10% of patients, and may respond to repositioning the device.
  - Persistent hemolysis associated with acute kidney injury is an indication for device removal.
Interference with device operation

**Inflow Obstruction**

- If inflow windows get obstructed by ventricular structures, and pump remains at same flow rate, blood will travel faster to enter through unobstructed windows
- Higher speed against cannula wall and other structures causes higher shear, pulling blood cells apart and causing hemolysis

**Obstruction within Cannula**

- Obstruction within pump (clot, fiber, etc) creates narrowing of cannula and small passages for blood to pass through, creating high shear and hemolysis

**Outflow Obstruction**

- At outflow the blood is ejected into the Aorta
- If outflow windows are obstructed by aortic valve or wall of the aorta, blood will exit pump at higher speeds from unobstructed windows and will make violent contact with obstructing structures causing hemolysis
Impella Positioning-Normal Position
Extracorporeal Membrane Oxygenation (ECMO)

- ECMO provides cardiopulmonary support for patients whose heart and lungs can no longer provide adequate physiologic support.
- ECMO can be either veno-veno (V-V) for oxygenation only or veno-arterial (V-A) for oxygenation and circulatory support.
- In cases of biventricular failure, V-A ECMO is the MCS of choice for patients in cardiogenic shock and impaired oxygenation, as it provides full cardiopulmonary support.
- ECMO may be placed at the bedside without fluoroscopic guidance.
Similar to a cardiopulmonary bypass circuit used in cardiac surgery, V-A ECMO involves a circuit composed of a centrifugal, nonpulsatile pump for blood propulsion, and a membrane oxygenator for gas exchange.

- A venous cannula drains deoxygenated blood into a membrane oxygenator for gas exchange, and oxygenated blood is subsequently infused into the patient via an arterial cannula.
- Venous and arterial cannulae can vary in size but typically will be similar to TandemHeart (20-F venous, 17-F arterial).
- An experienced cardiac perfusionist is required for management of the ECMO system.
ECMO
ECMO

[Femoroaortal] outflow

[Femoroaortal] inflow

CARDIOHELP
ECMO Hemodynamic Effects

- V-V ECMO offers gas exchange without hemodynamic support and is useful for conditions associated with severe impairment of gas exchange with stable hemodynamics such as ARDS, or rarely, pulmonary embolism.
- V-A ECMO provides systemic circulatory support with flows sometimes exceeding 6 L/min depending on cannula sizes.
  - However, due to high myocardial oxygen demand (secondary to high filling pressures and volume) V-A ECMO alone may not significantly reduce ventricular wall stress.
  - This has theoretic negative consequences on myocardial protection unless the LV is vented or unloaded by concomitant IABP or Impella.
- Metabolic derangement and deleterious systemic effects of cardiogenic shock can often be corrected within hours of initiation of ECMO
Cardiac Effects of Mechanical Support: Illustrations of PV loops after activation of device therapy (gray loops).

(C) Veno-arterial extra-corporeal membrane oxygenation (VA-ECMO) without a LV venting strategy increases LV systolic and diastolic pressure, while reducing LV stroke volume. The net effect is an increase in arterial elastance (Ea).
ECMO Complications/Contraindications

- Significant aortic insufficiency may worsen with ECMO and promote increased ventricular wall stress without a venting strategy.
- Patients with severe PAD should not undergo peripheral cannulation and central cannulation should be considered.
- Complications of ECMO relate to bleeding and thromboembolic events, as well as hemolysis.
- Thromboembolic events may occur both in the circuit or the patient if adequate anticoagulation is not achieved.
- Cannulation complications, common to all large cannulae, may include venous thrombosis or distal arterial ischemia.
  - Similar to TandemHeart, a second, antegrade, arterial sheath inserted into the superficial femoral artery can provide antegrade limb perfusion when needed.
- Stroke, either embolic or hemorrhagic, can occur and care must be taken to assure adequate but not excessive anticoagulation.
Patients with right ventricular (RV) failure are at considerably higher risk for morbidity and mortality when presenting with AMI, ADHF, or CS.

Use of MCS for RV or biventricular support has been reported, and represents an important new use for this technology.

Although not yet available in the United States, a dedicated RV support device is under clinical evaluation.
Example of R-sided MCS

- **01/2015**: FDA approved a humanitarian device exemption for its Impella RP heart pump.
Surgically implanted left ventricular assist devices (LVADs) are used as a bridge to recovery, bridge to transplant, bridge to decision, or for use as permanent (destination) therapy.

Biventricular assist devices and the total artificial heart are also available as a bridge to transplant for patients with biventricular heart failure.
Example of Surgical LVAD - HeartMate II
Components of the Continuous-Flow Left Ventricular Assist Device

- External battery pack
- Skin entry site
- Aorta
- Left ventricle
- System controller
- Percutaneous lead
- Continuous-flow LVAD
- To aorta
- Outlet stator and diffuser
- Motor
- Pump housing
- Percutaneous lead
- Blood flow
- From left ventricle
- Rotor
- Inlet stator and blood-flow straightener
### Who gets LVADs?

Interagency Registry for Mechanically Assisted Circulatory Support Level at Implant for 1,092 Primary Left Ventricular Assist Device (June 2006-March 2009)

<table>
<thead>
<tr>
<th>INTERMACS level (pre-implant)</th>
<th>Primary LVAD ($N = 1092$)</th>
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<tbody>
<tr>
<td></td>
<td>No.</td>
</tr>
<tr>
<td>1. Critical cardiogenic shock</td>
<td>328</td>
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<tr>
<td>2. Progressive decline</td>
<td>437</td>
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<tr>
<td>3. Stable but inotrope dependent</td>
<td>168</td>
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<td>4. Recurrent advanced HF</td>
<td>106</td>
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<td>5. Exertion intolerant</td>
<td>21</td>
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<td>6. Exertion limited</td>
<td>12</td>
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<tr>
<td>7. Advanced NYHA III</td>
<td>20</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1092</strong></td>
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LVAD Complications

- Thrombus formation in the device and subsequent risk for thromboembolic complications.
- High risk of mortality due to Stroke (14.1%), Bleeding (6.7%), and Infection (15%)
- Hemolysis
- Infectious: high risk for *Staphylococcus* and *Pseudomonas* infections
Heart transplantation is the treatment of choice for end-stage HF, but remains limited by donor organs and comorbidities in potential candidates.

Survival following heart transplantation is > 85% at 1 year, 70% at 5 years, and 50% at 10 years.

Complications following transplantation include rejection, infection, renal insufficiency, malignancy, and cardiac allograft vasculopathy (CAV).
Patients with acute decompensated heart failure may benefit from early use of percutaneous MCS devices when they continue to deteriorate despite initial interventions.

MCS devices may be considered if patients are candidates for surgically implanted ventricular assist devices (VADs), if rapid recovery is expected (e.g., fulminant myocarditis or stress-induced cardiomyopathy), or as a “bridge-to-decision”.
Severe biventricular failure may require use of both right- and left-sided percutaneous MCS or venoarterial ECMO.

Certain patients may respond to left ventricular assist device (LVAD) implantation with inotropes and/or pulmonary vasodilators to support the right heart.

MCS devices may also be considered for isolated acute right ventricular failure complicated by cardiogenic shock.
The end

Any Questions?
Sources

- American College of Cardiology Self Assessment Program 8- Chapter 11: Heart Failure module
- Counterpulsation: historical background, technical improvements, hemodynamic and metabolic effects," Volume 84 (1994). Cardiology (pp. 156-167)