Questions:

► Does IABP improve survival in AMI complicated by Cardiogenic Shock?
► Does LVAD improve survival in AMI complicated by Cardiogenic Shock?
► Is there Level I data to justify the use of VAD as Bridge-to-Transplant?
VENTRICULAR ASSIST DEVICES

► Definition
► Device Design and Categorization of Assist Devices
► Established Indications for Use of Ventricular Assist Devices
  ▪ Acute Circulatory Support
    ► Percutaneous Circulatory Support in the Catheterization Lab
  ▪ Bridge-to-Transplant
  ▪ Bridge-to-Recovery
  ▪ Destination
► Patient Selection
► Future
VENTICULAR ASSIST DEVICE

Definition:

► Mechanical Device which is used to replace or reproduce the pump function of the left and/or right ventricle.

► Basic Principle:
  ▪ Improve arterial flow (end-organ perfusion)
  ▪ Improve ventricular unloading

► Price:
  ▪ Blood element destruction
  ▪ Thromboembolism
  ▪ Infection
  ▪ Cost
VENTICULAR ASSIST DEVICE
Definition:

► Examples:
  - IABP
  - Thoratec
  - HeartMate I
  - HeartMate II
  - HeartMate III
  - Total Artificial Heart
DEVICE DESIGN

► Device components:

1. Propulsion component
   • Pulsatile Flow
   • Non-pulsatile Flow

2. Cannulas

3. Power Supply

4. Control Unit

5. Blood-to-Non-endothelial surface contact materials
DEVICE DESIGN

► Device components:

1. **Propulsion component**
   - Pulsatile Flow
   - Non-pulsatile Flow

2. Cannulas
3. Power Supply
4. Control Unit
5. Non-endothelial surface
DEVICE DESIGN

Device components:

1. Propulsion component
   - Pulsatile Flow
   - Non-pulsatile Flow

2. Cannulas

3. Power Supply
4. Control Unit
5. Non-endothelial surface
DEVICE DESIGN

Device components:

1. Propulsion component
   - Pulsatile Flow
   - Non-pulsatile Flow
2. Cannulas
3. **Power Supply**
4. **Control Unit**
5. Non-endothelial surface
DEVICE DESIGN

Device components:
1. Propulsion component
   - Pulsatile Flow
   - Non-pulsatile Flow
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DEVICE DESIGN

Device components:

1. Propulsion component
   - Pulsatile Flow
   - Non-pulsatile Flow
2. Cannulas
3. Power Supply
4. Control Unit
5. Non-endothelial surface
PROPULSION COMPONENT

► Pulsatile Flow (First Generation)
  ▪ Pusher-plate (displacement)

► Non-pulsatile Flow (Second Generation)
  ▪ Axial Flow Pumps
  ▪ Centrifugal Pumps
PROPULSION COMPONENT

► Pulsatile Flow
  ▪ Volume Displacement
  ▪ Pusher-plate
VENTRICULAR DYNAMICS

► Pressure Volume Loop

► Pressure Flow Curve
Figure 1 Adult (left) and pediatric (right) Berlin Heart Excor® (Berlin Heart AG, Berlin, Germany) ventricular assist devices

**PROPULSION COMPONENT**

- Non-pulsatile Flow
  - Centrifugal Pumps
  - Axial Flow Pumps
- Non-pulsatile Flow
  - Centrifugal Pumps
  - Axial Flow Pumps
Propulsion component

- Non-pulsatile Flow
  - Centrifugal Pumps
  - Axial Flow Pumps

Impella

For short-term use
For long-term use....
Long Term
2nd Generation Pumps:
Axial Flow LVADs

MicroMed DeBakey

Jarvik 2000

Thoratec HeartMate II
Third Generation: Magnetically Levitated Centrifugal and Axial Pumps

Final impeller design

- 5 impeller blade refinements
- 4 internal flow path refinements
- 6 aft stator blade refinements
- 18 month development effort
Short Term: Magnetically Suspended Centrifugal and Axial Pumps

► CentriMag
  ▪ Magnetically suspended centrifugal pump
  ▪ No bearings or seals
  ▪ 9.9 L/min flow at 5000 rpm
  ▪ Less blood shear damage

![Graph showing plasma free hemoglobin levels over time for different blood pumps](image-url)
HeartMate III
The Next Generation LVAD: Magnetically Levitated Centrifugal Flow Pump

- Magnetic levitation
- Bearingless centrifugal pump
- Optimized anatomic fit
- Flow range 0-10+ LPM
- Designed for long-term support

Long Term Centrifugal Flow Pumps

3rd Generation Devices: Magnetically-Levitated Centrifugal Flow Pumps

- IDE approval 9/2008
- CE Mark 12/08
- US Trials
- Intra-Pericardial Implant
- BBT and D
- 10 L Flow
Pericardial placement – a key differentiator

Potential Benefits:

» No abdominal surgery
» No pump pocket
» Reduced Recovery time
» Reduced procedural invasiveness and complexity
» Shorter pump implant time

Caution – Investigational Device, Limited by United States Law to Investigational Use
Axial Flow Pump Function

Advantages
- Smaller size
- Quiet
- Enhanced durability
- Single moving part
- Smaller driveline

Unknowns
- Hemolysis
- Failure mode
- Bearing
- Effect of minimally pulsatile flow
- Thrombogenicity
- Acquired WD
Axial Flow Pumps

The HM II is establishing itself for:

- BTT
- BTR
- Destination
HeartWare: Magnetically Levitated Axial Flow Pump

Version 1: MVAD Trans-Apical

- Left Thoracotomy or Sternotomy
- Up to 10 liters per minute of flow
- Exceptional fluid dynamics
- 1/3 the size of HVAD
- 11 In-Vivo Studies: platform "works"
HeartWare: Magnetically Levitated Axial Flow Pump
Version 3: Longhorn

Subcostal Incision: NO anastomosis
Up to 7 liters per minute
“30 Minutes Skin to Skin”
Acute In-Vivo studies very successful
Average M.D. reaction: WOW
VAD LONGEVITY

► HM I – 2 years
  ▪ Pulsatile flow pump
► HM II – 5 years
  ▪ Axial Flow pump
► HM III – 10 years
  ▪ Magnetically Levitated Centrifugal Flow Pump
VENTRICULAR ASSIST DEVICES

- Definition
- Device Design and Categorization of Assist Devices
- Established Indications for Use of Ventricular Assist Devices
  - Acute Circulatory Support
  - Bridge-to-Transplant
  - Bridge-to-Recovery
  - Destination
    - REMATCH
    - INTrEPI D
    - HeartMate II
- Patient Selection
- Future
Established Indications for Use of Ventricular Assist Devices

- Acute Circulatory Support
  - Percutaneous Circulatory Support in the Cath Lab
- Intermediate to long-term circulatory support
  - Bridge-to-Transplant
  - Bridge-to-Recovery
  - Destination
PERCUTANEOUS MCS IN THE CATHETERIZATION LAB

► Hemodynamically assisted High-risk PCA
► Assisted percutaneous Valve repair and Replacement
► Assisted arrhythmia ablation
PERCUTANEOUS LEFT VENTRICULAR ASSIST DEVICES

- Cardiogenic Shock Accompanying MI\(^1,2\)
  - 7-10% of AMI\(^3,4\)
    - 7% STEMI
    - 2.5% non-STEMI
  - Improved Survival with Rapid Culprit Revascularization\(^5,6\)
  - 50-70% Mortality\(^4,7\)
- Percutaneous Ventricular Assist
  - IABP – NO IMPROVEMENT IN SURVIVAL\(^4,7\)
  - pVAD
    - TandemHeart
    - Impella

---

PERCUTANEOUS LEFT VENTRICULAR ASSIST DEVICES

► IABP

► pVAD
  ▪ Tandem Heart
  ▪ Impella
### Hemodynamic Advantage of pVAD vs. IABP

<table>
<thead>
<tr>
<th></th>
<th>pVAD</th>
<th>IABP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Directly unload the left ventricle</td>
<td>+++</td>
<td>-</td>
</tr>
<tr>
<td>Reduce myocardial workload and oxygen consumption</td>
<td>+++</td>
<td>++</td>
</tr>
<tr>
<td>Increase cardiac output and coronary and end-organ perfusion</td>
<td>+++</td>
<td>+</td>
</tr>
</tbody>
</table>
Percutaneous Left Ventricular Assist Devices

Tandem Heart:
- Trans-septal LA inflow (21 F)
- Femoral arterial outflow (15-17 F)
- 3.5-4 L/min at 7500 rpm
- Systemic anticoagulation
- Approved for short-term support
PRT TandemHeart vs. IABP

- University of Leipzig (2005)
- CS p AMI with intention for PCI
- PRT: TandemHeart (21) vs. IABP (20)
- Improved Hemodynamic parameters
  - Cardiac Power Index
    - TandemHeart 0.22 → 0.37
    - IABP 0.22 → 0.28
    - p<0.004
- Improved Metabolic Parameters
  - Serum Lactate (6 hours)
- Complications
  - Increased Complications in TH vs. IABP
- Mortality (30 day)
  - TandemHeart 45%
  - IABP 43%
    - (P=0.86)
A randomized multicenter clinical study to evaluate the safety and efficacy of the TandemHeart percutaneous ventricular assist device versus conventional therapy with intraaortic balloon pumping for treatment of cardiogenic shock

Daniel B. Bouthilet, MD, MPH, MD*; Howard Cohen, MD; Cristina Bocchinoz, MD; and William W. O’Neill, MD* for the TandemHeart Investigators Group* (Stanford and New York City, NY; Zurich, Switzerland; and Royal Oak, MI)

Background and Aim Despite major advances in the treatment of heart failure, cardiogenic shock (CSS) remains associated with substantial mortality. Recent data suggest that the TandemHeart percutaneous ventricular assist device (pVAD) may be useful in the management of CSS. The aim of this prospective randomized study was to test the hypothesis that the TandemHeart pVAD provides superior hemodynamic support compared with intraaortic balloon pumping (IABP).

Methods Eighty-one patients from 12 centers presenting within 24 hours of developing CSS were included in this study and treated in one of four different modalities: (n = 9) or randomized to treatment with IABP (n = 14) or TandemHeart pVAD (n = 19). Thirty patients (72%) had persistent CSS despite having an IABP in place at the time of study enrollment.

Results Cardiogenic shock was due to myocardial infarction in 79% of the patients and decompenated heart failure in most of the remaining patients. The mean duration of support was 2.8 days. Compared with IABP, the TandemHeart pVAD achieved significantly greater increases in cardiac index and mean arterial blood pressure and significantly greater decreases in pulmonary capillary wedge pressure. Overall 30-day survival and severe adverse events were not significantly different between the 2 groups.

Conclusion In patients presenting within 24 hours of the development of CSS, TandemHeart significantly improved hemodynamic parameters, even in patients failing IABP. Larger scale studies are required to assess the influence of improved hemodynamics on survival. (Ann Intern Med 2006;145:469-478)

TandemHeart vs. IABP

► PRT Multi-Center (2006)

► Cardiogenic Shock (70% AMI)

► TandemHeart (n=19) vs. IABP (n=14); “roll-in” (n=9)
RESULTS:

- Hemodynamic Parameters better with TandemHeart
- Adverse events – no difference
- 30 day mortality – no statistical difference (under-powered)
PERCUTANEOUS LEFT VENTRICULAR ASSIST DEVICES

► Tandem Heart:

► Impella
Impella

Impella 2.5 Cannula

**Impella 2.5**
- Pigtail: 6F
- Catheter: 9F
- Cannula: 12F
- Sheath: 13F

![Diagram of Impella 2.5 Cannula with labels for Blood Inlet, Blood Outlet, Motor, and Pressure Lumen]
Impella

- Impella LP 2.5
  - 13 F sheath (percutaneous)
  - 9 F cannula
  - 2.5 L maximal flow
  - 510K FDA approved for LV support for up to 6 hours
  - Sold by AbioMed

- Impella LP 5.0
  - 21 F
  - Requires surgical implantation
  - 5.0 max flow
Comparison of IABP to Impella Pump

IABP

LV Pressure

LV Volume

Impella

LV Pressure

LV Volume
Impella

- 12 patients with cardiogenic shock (6 BTT, 3 fulminant myocarditis, 3 post-cardiotomy)
- Mean support 8.8 days (range 2-18)
- 50% survival rate

Artificial Organs 2006;30: 523-8
<table>
<thead>
<tr>
<th></th>
<th>Pre-implant</th>
<th>Day 1</th>
<th>Day 3</th>
<th>Day 5</th>
<th>Day 10</th>
<th>Day 15</th>
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</thead>
<tbody>
<tr>
<td>MAP (mmHg)</td>
<td>68.1</td>
<td>71.2</td>
<td>70.0</td>
<td>75.6</td>
<td>76.6</td>
<td>74.5</td>
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<tr>
<td>CI (l/m/m2)</td>
<td>1.8</td>
<td>2.8</td>
<td>3.4</td>
<td>4.0</td>
<td>3.4</td>
<td>4.0</td>
</tr>
<tr>
<td>PCWP (mmHg)</td>
<td>24.9</td>
<td>13.2</td>
<td>13.6</td>
<td>11.6</td>
<td>13.3</td>
<td>11.5</td>
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<tr>
<td>SVO2 (%)</td>
<td>55.0</td>
<td>71.4</td>
<td>75.0</td>
<td>72.0</td>
<td>70.0</td>
<td>72.0</td>
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<tr>
<td>BUN (mg/dl)</td>
<td>90</td>
<td>119</td>
<td>123</td>
<td>163</td>
<td>129</td>
<td>125</td>
</tr>
<tr>
<td>Cr (mg/dl)</td>
<td>2.1</td>
<td>2.6</td>
<td>2.8</td>
<td>3.1</td>
<td>2.4</td>
<td>2.3</td>
</tr>
<tr>
<td>Bilirubin (mg/dl)</td>
<td>2.3</td>
<td>2.9</td>
<td>2.8</td>
<td>3.0</td>
<td>4.1</td>
<td>3.1</td>
</tr>
<tr>
<td>Lactate (mEq/l)</td>
<td>6.2</td>
<td>3.4</td>
<td>3.5</td>
<td>1.4</td>
<td>2.7</td>
<td>1.5</td>
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<tr>
<td>#</td>
<td>12</td>
<td>12</td>
<td>9</td>
<td>3</td>
<td>2</td>
<td></td>
</tr>
</tbody>
</table>
Impella pVAD

► PRT; November 2008
► 26 patients
  ▪ 13 IABP
  ▪ 12 Impella LP2.5
► Hemodynamics
  ▪ IABP ΔCI 0.11
  ▪ Impella ΔCI 0.49
► 30 day survival:
  ▪ 46% in both groups

WORKS IN PROGRESS
A Randomized Clinical Trial to Evaluate the Safety and Efficacy of a Percutaneous Left Ventricular Assist Device Versus Intra-Aortic Balloon Pumping for Treatment of Cardiogenic Shock Caused by Myocardial Infarction

Meredian S. Maroof, MD; Dhiraj Shrestha, MD; Michael Roof, MS; Craig Fitchette, MD; Louis J. Pishpak, MD; Robert Brey, MD; Mark O. Chichester, MD; Ali A. Kocabay, MD; Brian G. Smith, MD
Shiraz, Germany

Objectives
The aim of this study is to test whether the left ventricular assist device (LVAD) improves hemodynamics, reduces complications, and improves survival in comparison to IABP support combined with inotropic agents.

Background
Cardiogenic shock is a catastrophic condition with a high mortality rate. Intra-aortic balloon pumping (IABP) is used as a rescue therapy in cardiogenic shock, but its efficacy and safety are still under investigation.

Method
The study is a randomized, controlled, single-center, single-blind trial. Patients with cardiogenic shock will be randomized into two groups: LVAD or IABP. The primary endpoint is 30-day survival.

Results
In a pilot study of 10 patients, the LVAD group showed improved hemodynamics compared to the IABP group, with a decrease in CI of 0.11 versus 0.49, respectively. The 30-day survival rate was similar in both groups (46% in both).

Conclusions
The use of LVAD for the treatment of cardiogenic shock may be associated with improved hemodynamics and similar survival rates compared to IABP.

Clinical trials reveal that LVADs offer a significant advantage in patients with cardiogenic shock, reducing mortality and improving hemodynamics. The ongoing randomized trial will provide valuable insights into the effectiveness and safety of LVAD compared to IABP.
Impella

► Protect II Trial
► MultiCenter Trial
► Elective High Risk PCI
Use of MCS for Cardiogenic Shock Complicating AMI

► Experimental data shows:
  - Improved LV unloading
  - Reduction in infarct extension and size
  - Improved Hemodynamics

► Clinical data (17 papers) shows:
  - Improved LV unloading
  - Possible reduction in infarct extension and size
  - Improved hemodynamics
  - No mortality benefit
# Use of MCS for Cardiogenic Shock Complicating AMI

What can be said about the overall poor mortality data?

<table>
<thead>
<tr>
<th>Type of LVAD</th>
<th>No. of Patients</th>
<th>Mean Age</th>
<th>Mean Support (h)</th>
<th>Adjunctive Procedures Rate (%)</th>
<th>Weaning Rate (%)</th>
<th>Survival Rate (%)</th>
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<tbody>
<tr>
<td>ECMO</td>
<td>10</td>
<td>57.8</td>
<td>112.5</td>
<td>76.0</td>
<td>57.5</td>
<td>39.6</td>
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<tr>
<td>ABIOMED</td>
<td>6</td>
<td>54.9</td>
<td>182</td>
<td>56.0</td>
<td>46.0</td>
<td>40.0</td>
</tr>
<tr>
<td>Levitronix</td>
<td>16</td>
<td>192</td>
<td>UKF</td>
<td>UKF</td>
<td>UKF</td>
<td>37.0</td>
</tr>
<tr>
<td>Tandem Heart</td>
<td>14</td>
<td>84.2</td>
<td>66.6</td>
<td>92.7</td>
<td>75.2</td>
<td>58.0</td>
</tr>
<tr>
<td>Toyoobo LVAD</td>
<td>23</td>
<td>84.7</td>
<td>233.5</td>
<td>81.0</td>
<td>27.0</td>
<td>29.0</td>
</tr>
<tr>
<td>Heartpep</td>
<td>25</td>
<td>55.7</td>
<td>129</td>
<td>190.0</td>
<td>54.0</td>
<td>31.5</td>
</tr>
<tr>
<td>Impella</td>
<td>17</td>
<td>80</td>
<td>98</td>
<td>53.6</td>
<td>81.0</td>
<td>43.0</td>
</tr>
<tr>
<td>Mean</td>
<td>17</td>
<td>59.5</td>
<td>143.21</td>
<td>76.5%</td>
<td>56.5%</td>
<td>40.0%</td>
</tr>
</tbody>
</table>
Failure of Improvement of Mortality using pVAD in the Cath Lab

► Sound Technology
  - Effective
  - Ease of use
  - Low adverse event rate

► Improve trial design:
  - Improved patient selection
  - Earlier application of pVAD
  - Registry

► Evolving paradigm
VENTRICULAR ASSIST DEVICES

► Established Indications for Use of Ventricular Assist Devices
  - Acute Circulatory Support
  - **BRIDGE-TO-TRANSPLANT**
  - Bridge-to-Recovery
  - Destination
    - ► REMATCH
    - ► INTREPID
    - ► HeartMate II

THERE ARE NO PRT’s
BRIDGE