Cath Lab Essentials: LV Assist Devices for Hemodynamic Support
(IABP, Impella, Tandem Heart, ECMO)

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Disclosures

- I have no financial or other conflicts of interest to report.
Cardiogenic Shock

Inadequate end organ perfusion due to a reduced cardiac output despite adequate circulatory volume
- AMS; Cold, clammy skin; Oliguria;
- Increased serum lactate

1. Cardiac Index (CI)
   - CI < 1.8 L/min/m\(^2\)
   - CI < 2.2 L/min/m\(^2\) with inotropic/pressor support

2. PCWP > 15 mmHg or LVEDP > 18

3. Systolic Blood Pressure (SBP)
   - SBP < 90 mmHg for at least 30 mins
   - SBP > 90 mmHg with inotropic/pressor support
Causes of Cardiogenic Shock

- Acute myocardial infarction: 38%
- Cardiomyopathy: 32%
- Mitral regurgitation: 12%
- Right ventricular infarction: 6%
- Myocarditis: 6%
- Tako-tsubo: 3%
- Aortic regurgitation: 3%
Physiology of Cardiogenic Shock: A Downward Spiral

Myocardial Infarction

Blood pressure [↓ BP]

Vasodilation [SVR ↓]

Cardiac output [↓ CO]

Damaged heart muscle

Inflammatory activation (TNF-α, IL-6)

Myocardial perfusion

Myocardial ischemia

Coronary artery perfusion

Reducing inflammatory response: ?

Hemodynamic support

Reperfusion: PCI or CABG

Death

NO synthesis

Venous return

CO

CO & BP
Emergency revascularisation - SHOCK Trial

85% of survivors NYHA Class I/II at 12 months after early revascularization or initial medical stabilization

Hochman JAMA 2000;285:190
Heart muscle can recover with support

High Potential of heart muscle recovery, Gain in Ejection Fraction

Low Potential of heart muscle recovery, Loss in Ejection Fraction

A. Ventricular remodeling after acute infarction

Initial infarct

Expansion of infarct (hours to days)

Global remodeling (days to months)

The primary goals of nondurable MCS devices are to acutely:
1. Increase vital organ perfusion
2. Augment coronary perfusion
3. Reduce ventricular volume and filling pressures, thereby reducing wall stress, stroke work, and myocardial oxygen consumption
Intra-Aortic Balloon Pump

- Introduced in 1968 (Kantrowitz)
- First “true percutaneous” support device
- Cheapest, most common (20% of all cardiogenic shock cases), CO 0.5L/min
- Stabilize pt, but not full support
- No outcome benefit

Hemodynamic Effects

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diastolic pressure</td>
<td>↑↑</td>
</tr>
<tr>
<td>CO/cardiac workload</td>
<td>↑</td>
</tr>
<tr>
<td>MAP</td>
<td>↑</td>
</tr>
<tr>
<td>LV Wall Tension</td>
<td>↓↓</td>
</tr>
<tr>
<td>PCWP</td>
<td>↓↓</td>
</tr>
<tr>
<td>Oxygen Demand</td>
<td>↓</td>
</tr>
<tr>
<td>LV Volume</td>
<td>↓</td>
</tr>
<tr>
<td>Coronary Blood Flow</td>
<td>↔️</td>
</tr>
</tbody>
</table>
Optimal IABP function is determined by four factors:

1. The magnitude of diastolic pressure augmentation
2. The magnitude of reduced systolic pressure
3. The magnitude of volume displacement
4. The timing of balloon inflation and deflation

Curr Cardiol Rep. 2015; 17:40
Figure 4. Pulmonary capillary wedge pressure (left) and pulmonary artery pressure (right) before (top) and after (bottom) insertion of the intra-aortic balloon pump.
IABP-Shock II Trial: Results Primary Study Endpoint:
30-day Mortality
(IABP in Cardiogenic Shock and Primary PCI)

P=0.92 by log-rank test

Thiele H et al. NEJM 2012;367:1287
Indications for IABP

- High Risk PCI
- Cardiogenic Shock
- Refractory Ischemia
  - Left Main
  - 3 Vessel CAD
  - VT/VFib
- MR or VSD after MI
- Severe CHF? Bridge to Transplant
- Pre-operative stabilization
Contraindication to IABP

- Severe Peripheral vascular disease
- Aortic regurgitation
- Aortic Dissection
- PDA
- HOCM
- Heparin intolerance
- Bleeding Diathesis
- Sepsis
Complications of IABP

- Vascular access bleeding/complications
- Limb ischemia
- Infection
- Thrombocytopenia
- Migration and aortic arch trauma
- Other non-vascular (CVA, embolization of cholesterol, balloon rupture)
- Air embolism risk (reduced by using helium gas)
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>
Impella

- Continuous axial flow pump
- Simple insertion
- Increases cardiac output & unloads LV
- LP 2.5 – CO 2.5 L/min
- CP 4.0 L/min
  - 14 F percutaneous
- LP 5.0
  - 21 F surgical cutdown; Maximum 5L flow
Impella Insertion

Impella®
World’s Smallest Heart Pump
Impella 2.5/Rota
Principles of Impella Design

*Mimic Heart’s Natural Function*

**Inflow (ventricle)**
- EDV, EDP

**Outflow (aortic root)**
- AOP
- Flow

- O$_2$ Demand
- O$_2$ Supply
- Cardiac Power Output

*Myocardial Protection*

*Systemic Hemodynamic Support*

Naidu S S Circulation 2011;123:533-543
IMPELLA Unloads Actively the Ventricle, Reduces Work Loads and Increases Cardiac Output

End-Diastolic LV Pressure

\[ \begin{align*}
\text{Pump Off} & : 18 \text{ mmHg} \\
\text{Pump On} & : 11 \text{ mmHg}
\end{align*} \]

End-Diastolic Stroke Volume

\[ \begin{align*}
\text{Pump Off} & : 94 \text{ mL} \\
\text{Pump On} & : 76 \text{ mL}
\end{align*} \]

Total Cardiac Output

\[ \begin{align*}
\text{Pump Off} & : 6.0 \text{ L/min} \\
\text{Pump On} & : 7.4 \text{ L/min}
\end{align*} \]

M. Valgimigli et al., Catheterization & Cardiovascular Interventions 65:263–267 (2005)
ISAR Shock: A Randomized Clinical Trial to Evaluate the Safety and Efficacy of a Percutaneous LV Assist Device Versus IABP in Cardiogenic Shock

Overall 30 day mortality was 46% in both groups
Complications

- Hemolysis
  - May respond to repositioning the device
- Persistent hemolysis associated with acute kidney injury
- Bleeding
- Limb ischemia/vascular injury
- Stroke

Contraindications

- Mural thrombus in the LV
- Presence of a mechanical aortic valve
- Aortic valve stenosis (AVA ≤ 0.6cm²)
- Moderate to severe aortic insufficiency
- Severe PAD
- VSD
<table>
<thead>
<tr>
<th>Performance Level</th>
<th><em>Flow Rate (L/min)</em></th>
<th>Revolutions Per Minute (rpm)</th>
</tr>
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<tbody>
<tr>
<td>P0</td>
<td>0.0 – 0.0</td>
<td>0</td>
</tr>
<tr>
<td>P1</td>
<td>0.0 – 0.5</td>
<td>25,000</td>
</tr>
<tr>
<td>P2</td>
<td>0.4 – 1.0</td>
<td>35,000</td>
</tr>
<tr>
<td>P3</td>
<td>0.7 – 1.3</td>
<td>38,000</td>
</tr>
<tr>
<td>P4</td>
<td>0.9 – 1.5</td>
<td>40,000</td>
</tr>
<tr>
<td>P5</td>
<td>1.2 – 1.8</td>
<td>43,000</td>
</tr>
<tr>
<td>P6</td>
<td>1.4 – 2.0</td>
<td>45,000</td>
</tr>
<tr>
<td>P7</td>
<td>1.6 – 2.2</td>
<td>47,000</td>
</tr>
<tr>
<td>P8</td>
<td>1.9 – 2.5</td>
<td>50,000</td>
</tr>
<tr>
<td>P9</td>
<td>2.1 – 2.6</td>
<td>51,000</td>
</tr>
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- **Performance Level P0:** Impella® Catheter motor is stopped
- **Performance Level P1:** Flow rate increases as the performance level increases
- **Performance Level P2:**
- **Performance Level P3:**
- **Performance Level P4:**
- **Performance Level P5:**
- **Performance Level P6:**
- **Performance Level P7:**
- **Performance Level P8:** Recommended maximum performance level for continuous use
- **Performance Level P9:** Used to confirm stable position after placement; can be used to provide maximum flow for up to 5 minutes. After 5 minutes, the Automated Impella® Controller will automatically default to P8.
Case

- 52 year old female lap cholecystectomy complicated by injury to the common bile duct and sepsis.
- Patient become acutely tachycardic to 160s and hypoxic.
TandemHeart

- Left atrial-to-femoral arterial LVAD
- 21F venous transseptal cannula
- 17F arterial cannula
- Maximum flow 4L/min

Hemodynamic Effects

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Transseptal puncture

21 F cannula in LA
TandemHeart Cannula

Venous cannula

arterial return cannula
TandemHeart Shock Study

**Cardiac Index**

- **Pre**
  - IABP: 1.5 (n=20)
  - PerVAD: 1.7 (n=21)
- **Post**
  - IABP: 2.3
  - PerVAD: 2.3

**30-day Mortality**

- IABP: 45% (9/20)
- PerVAD: 43% (9/21)

**Transfusion**

- IABP: 40% (8/20)
- PerVAD: 90% (19/21)

**Limb Ischemia**

- IABP: 0% (0/20)
- PerVAD: 33% (7/21)

Extracorporeal Membrane Oxygenation (ECMO)
Cannulation

- Femoral vein cannulated with 21-25Fr catheter tip in the right atrium.
- Femoral artery cannula 17-21 Fr inserted to the taper with the tip at the common iliac artery or lower aorta.
- Distal antegrade perfusion cannula inserted into common femoral artery to prevent distal limb ischemia. Usual size 5-9 Fr
Peripheral Cannulation

- Retrograde peripheral flow leads to admixing in the arch.
- If there is respiratory insufficiency, the heart will pump poorly oxygenated blood to the coronaries and proximal arch vessels while ECMO supplies oxygenated blood to the rest of the body.
Advantages and Disadvantages

- Relatively Inexpensive (as compared to Impella/TandemHeart)
  - Double the cost of conventionally treated patients ($65K)
  - Favorable lifetime predicted cost-utility
- Minimally invasive (peripheral cannulation)
- Bedside deployment
- Biventricular support
- Pulmonary support
- Labor intensive (ACT monitoring, bedside monitoring, management)
- Patient is immobilized
- LV distention
- High complication risk (57%)
Bridge to Nowhere

- **Absolute**
  - Unrecoverable heart and not a candidate for transplant or VAD
  - Presence of severe chronic organ failure
  - Severe brain injury OR Prolonged CPR
  - Severe peripheral vascular disease
  - Severe aortic insufficiency

- **Relative**
  - Obesity
  - Malignancy
  - Contraindication to anticoagulation
  - Advanced age >75
  - Compliance (financial, cognitive, psychiatric, or social limitations)
71 yo M 4h intermittent chest pain, light headedness, pallor, sweating. Inferior STEMI. Left Coronary System has mild CAD. RCA is 100%. JVD 12cm. Fluids, Dopamine given. BP 72/55, HR 68bpm. What now? IABP? LVAD?
Percutaneous Biventricular Acute MCS Support Configuration
Mechanical circulatory support for RV failure

Approach to Cardiogenic Shock

- Consider IABP in:
  - Cardiogenic shock (mild)
- Moderate to severe cardiogenic shock, on inotropes and vasopressors:
  - Consider Impella (CP, 5.0L), TandemHeart, ECMO
- Biventricular cardiogenic shock:
  - Consider ECMO or combined percutaneous LVAD/RVAD
Optimal Timing (early, late, futility)

Optimal Support Device

Optimal Therapy

Optimal management of device (avoiding complications)
Thank You