Cardiogenic Shock and Acute Mechanical Circulatory Support

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Division of Cardiology
• I have no disclosures
Overview

• Cardiogenic shock (CS)
  – Definition
  – Etiology
  – Risk of mortality
  – Clinical, hemodynamic, & laboratory parameters
  – Classification scheme
  – General Management
Overview

• Acute Mechanical Circulatory Support
  – Rationale for use
  – Intra-aortic Balloon Pump
  – Impella (left, right, and biventricular)
  – TandemHeart
  – VA ECMO
  – Centrimag
Cardiogenic Shock

• State of end-organ hypoperfusion due to cardiac failure

• MI remains the most common cause of CS
  – Complicates 8.6% of STEMIs
  – Complicates 2.5% of NSTEMIs
  – 40,000-50,000 cases/yr in the US
  – 70-80% of pts develop CS in hospital as opposed to presenting to ER

Common Causes of Cardiogenic Shock

- Acute MI and mechanical complications
- Acute decompensated HF
- Myocarditis
- Postcardiotomy
- Postpartum Cardiomyopathy
- Valvular
- Cardiac Tamponade
- Arrhythmias

What is the approximate in-house mortality for cardiogenic shock?

A) 5%
B) 25%
C) 50%
D) 80%
Mortality in AMI and CS

AMIS Registry (All ACS)
1997-2006

Risk Factors for Mortality

• In-hospital mortality at 30 days in SHOCK trial was 57%
• Independent risk factors in this cohort
  – Age
  – Shock on admission
  – Clinical evidence of end-organ hypoperfusion
  – Anoxic brain injury
  – Systolic BP
  – Prior CABG
  – Non-inferior wall MI
  – Creatinine ≥1.9 mg/dL

Pathophysiology of shock is complex


Early recognition of cardiogenic shock is extremely important for patient outcomes
Clinical Parameters of Shock

- Tachycardia
- Cool Extremities
- Decreased urine output
- Pulmonary congestion
- Altered Mental Status
- Arrhythmias
## Classifying Shock

<table>
<thead>
<tr>
<th>Peripheral Circulation</th>
<th>Volume Status</th>
<th>Wet</th>
<th>Dry</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cold</td>
<td></td>
<td>Classic Cardiogenic Shock</td>
<td>Euvolemic Cardiogenic Shock</td>
</tr>
<tr>
<td></td>
<td></td>
<td>((\downarrow) CI; (\uparrow) SVRI; (\uparrow) PCWP)</td>
<td>((\downarrow) CI; (\uparrow) SVRI; (\leftrightarrow) PCWP)</td>
</tr>
<tr>
<td>Warm</td>
<td></td>
<td>Vasodilatory Cardiogenic Shock or Mixed Shock</td>
<td>Vasodilatory Shock (Not Cardiogenic Shock)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>((\downarrow) CI; (\downarrow)/(\leftrightarrow) SVRI; (\uparrow) PCWP)</td>
<td>((\uparrow) CI; (\downarrow) SVRI; (\downarrow) PCWP)</td>
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</tbody>
</table>

Hemodynamic Parameters

• Persistent hypotension
  – SBP <80-90 mmHg or MAP 30 mmHg lower than baseline

• Severe reduction in cardiac index
  – <1.8 L/min without support
  – <2.0-2.2 L/min with support

• Elevated filling pressure
  – LVEDP >18 mmHg OR
  – RVEDP >10-15 mmHg
Other Hemodynamic Parameters

- RA pressure
  - Reflects volume overload
  - Reflects RV function

- PA pressure
  - Degree of pulmonary hypertension
  - Mean PAP ≤25 mmHg can signify RV failure

- PA saturation
  - Reflection of cardiac output
Laboratory Parameters

- Lactic acidosis
- Acute renal failure
- Liver dysfunction
- Coagulopathy
### Clinical Spectrum of CS

<table>
<thead>
<tr>
<th>Level</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preshock</td>
<td>At significant risk for developing CS</td>
</tr>
<tr>
<td>Mild</td>
<td>Responsive to low-dose inotropes/vasopressors</td>
</tr>
<tr>
<td>Profound</td>
<td>Responsive to high-dose inotropes/vasopressors</td>
</tr>
<tr>
<td>Severe refractory</td>
<td>Unresponsive to high-dose inotropes/vasopressors and IABP</td>
</tr>
</tbody>
</table>
### Table 4. INTERMACS: Patient Selection

<table>
<thead>
<tr>
<th>Patient profile/status: INTERMACS levels</th>
<th>← Degrees of Class IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Critical cardiogenic shock</td>
<td></td>
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<tr>
<td>2. Progressive decline</td>
<td></td>
</tr>
<tr>
<td>3. Stable but inotrope dependent</td>
<td></td>
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<tr>
<td>4. Recurrent advanced HF</td>
<td></td>
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<tr>
<td>5. Exertion intolerant</td>
<td></td>
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<tr>
<td>6. Exertion limited–NYHA IIIb</td>
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<tr>
<td>7. Advanced NYHA III</td>
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</table>

INTERMACS Levels

Figure 1 Clinical severity of end-stage heart failure defined by the Interagency Registry for Mechanically Assisted Circulatory Support (INTERMACS) levels

General Management of CS

- Adequate oxygenation
- Hemodynamic monitoring
  - Intra-arterial BP monitoring
  - PA catheter
    - Establish diagnosis
    - Guide changes in therapy
- Pharmacologic/inotropic support
  - Dopamine
  - Dobutamine
  - Milrinone
  - Norepinephrine
  - Epinephrine
Revascularization in ACS in setting of cardiogenic shock

- Timing is important
- Earlier is better
- Increased survival

Figure 1. Overall 30-Day Survival in the Study.
The 30-day survival rate was 53.3 percent for patients assigned to revascularization and 44.0 percent for those assigned to medical therapy.

Increased Inotrope Exposure is Associated with Mortality in AMI/CGS

Mortality and Number of Inotropes from cVAD Registry

$P < 0.001$ (N=287)

Rationale for Mechanical Circulatory Support

- Break downward spiral by restoring adequate systemic perfusion pressure
- Allow time to address underlying etiology of myocardial pump failure
- Allow for myocardial recovery
What form of mechanical circulatory support cannot be placed percutaneously?

A) Impella CP
B) ECMO
C) Centrimag Biventricular VAD
D) Impella RP
E) Intra-aortic balloon pump
### Acute Mechanical Circulatory Support Options for the LV

<table>
<thead>
<tr>
<th>Continuous Flow Pumps</th>
<th>Pulsatile</th>
<th>Axial-Flow</th>
<th>Centrifugal Flow</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>IABP</td>
<td>Impella CP</td>
<td>TandemHeart</td>
</tr>
<tr>
<td></td>
<td>Intracorporeal</td>
<td>PHP *</td>
<td>VA-ECMO</td>
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</tbody>
</table>

* Investigational

Intra-aortic balloon pumps have been shown to improve survival in cardiogenic shock?

A) True

B) False
Intra-aortic Balloon Pump

- Inflates during diastole
- Deflates during systole
- Improves coronary perfusion
- Decreases afterload
- Augments CO $\sim 0.5$ L/min
- Complications
  - Balloon migration
  - Bleeding
  - Leg ischemia
  - Thrombocytopenia

http://www.rocarendonapress.com/IABP/iabp-0.htm
Intra-aortic Balloon Pump

• ACC/AHA Class IB recommendation for CS in the setting of AMI
• Observational studies have shown mixed benefits in terms of mortality
• Improvements in hemodynamic profiles have been shown (CO, CI, PCWP)
• Recent randomized controlled trials have not shown 30-day mortality benefit

IABP-SHOCK II Trial

- Randomized, prospective, open-label trial
- AMI c/b CS
- 600 pts
- Early revasc strategy
- No sig diff in mortality or secondary endpoints

- 6 year f/u also no difference in mortality (66.3% vs 67.0%; RR 0.99; 95% CI, 0.88–1.11), recurrent MI, stroke, revasc, readmission

Impella CP

- Catheter-mounted microaxial rotary pump inserted into LV across AV via femoral artery access
- Can increases CO by 3.5 L/min
- Complications
  - Migration of device
  - Bleeding
  - Limb ischemia
  - Hemolysis
Impella CP
ISAR-SHOCK Trial

- Randomized trial of 26 pts with AMI c/b CS
- IABP vs Impella
- Sig improved hemodynamics in Impella group
- Median duration of support ~24 hrs
- No sig diff in survival
- 30 day mortality 46%
- Increased adverse events in Impella group

Comparison of IABP vs PVAD

- Meta-analysis
- Majority of pts had CS 2/2 AMI
- PVAD pts had higher CI and MAP and lower PCWP compared to IABP pts

Comparison of IABP vs PVAD

<table>
<thead>
<tr>
<th>Study</th>
<th>LVAD n/N</th>
<th>IABP n/N</th>
<th>30-day mortality relative risk</th>
<th>$P$(heterogeneity)</th>
<th>$I^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thiele et al.</td>
<td>9/21</td>
<td>9/20</td>
<td>0.95 (0.48 – 1.90)</td>
<td>0.83</td>
<td>0%</td>
</tr>
<tr>
<td>Burkhoff et al.</td>
<td>9/19</td>
<td>5/14</td>
<td>1.33 (0.57 – 3.10)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seyfarth et al.</td>
<td>6/13</td>
<td>6/13</td>
<td>1.00 (0.44 – 2.29)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pooled</td>
<td>24/53</td>
<td>20/47</td>
<td>1.06 (0.68 – 1.66)</td>
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</tr>
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</table>

Retrospective Data for Impella in CS

- Retrospective analysis of 47 patients with CS who received Impella 2.5 (20%) or 5.0 (80%)
- Indications: AMI/ADHF in 15 pts (32%) and postcardiotomy CS in 32 (68%)
- Complications occurred in 14 pts (30%): device malfunction, high purge pressures, tube fracture, and groin hematoma

Early Mechanical Support May Improve Outcomes in CS and AMI

USPella Registry
154 patients with CS complicating AMI who received Impella 2.5, comparison between Impella pre-PCI and Impella post-PCI

- Mortality: Pre-PCI (40.7%), Post-PCI (65.1%)
- Door to Balloon Time: Pre-PCI (112 mins), Post-PCI (52 mins)
- Pre-PCI Group with more lesions and vessels treated

What device does not provide mechanical right ventricular support?

A) ECMO

B) Impella CP

C) Impella RP

D) Protek Duo
Impella RP

- Catheter-mounted microaxial rotary pump inserted via the femoral vein, into the RA, across the tricuspid and pulmonic valves, and into the PA
- Inlet sits in the IVC and the outlet is in the PA
- Approved for acute right heart failure/decompensation following LVAD implantation, MI, heart transplant, or cardiac surgery
Impella RP

Outlet into main PA

Inlet at the IVC/Right atrial junction

PROTECT RIGHT Study

- 30 patients with RVF refractory to medical treatment received Impella RP
- Cohort A: 18 patients with RVF after LVAD
- Cohort B: 12 patients with RVF after cardiotomy or myocardial infarction
- Primary end point: survival to 30 days or hospital discharge
- Secondary end points: safety and efficacy

### PROTECT RIGHT Study

<table>
<thead>
<tr>
<th>Event</th>
<th>All patients</th>
<th>Cohort A</th>
<th>Cohort B</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alive at</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30 Days</td>
<td>73.3 (22)</td>
<td>83.3 (15)</td>
<td>58.3 (7)</td>
<td>0.129</td>
</tr>
<tr>
<td>Discharge</td>
<td>70.0 (21)</td>
<td>77.8 (14)</td>
<td>58.3 (7)</td>
<td>0.255</td>
</tr>
<tr>
<td>180 days</td>
<td>70.0 (21)</td>
<td>77.8 (14)</td>
<td>58.3 (7)</td>
<td>0.255</td>
</tr>
</tbody>
</table>


![Graph showing Cardiac Index and Central Venous Pressure](image)
• Dual lumen cannula (29F or 31F) inserted percutaneously via IJ venous access connected to a para-corporeal pump
• Oxygenator can also be introduced into the circuit if needed
Combined use of Impella CP/5.0 with Impella RP for biventricular support
BiPella Support

Impella CP activated
• RA pressure rising
• PA pressure slowly declining

Impella RP activated in addition to Impella CP
• RA pressure decreasing
• PA pressure increasing

• 21F venous cannula inserted percutaneously into the left atrium by transseptal puncture
• Blood returned by a para-corporeal pump to the iliac artery through an arterial cannula
• Circuit can be connected to an oxygenator if needed
Does pulmonary artery catheter monitor help in the management of cardiogenic shock?

A) Yes

B) No
Practices Associated with Improved Survival in AMI and CS

- 15,259 patients with AMI and CS treated with Impella CP between 2009-2016
  - Impella PrePCI
  - Use of Hemodynamic Monitoring
  - Use of Impella CP

Mean Survival
(N= # of Patients)
(\(p<0.001\))

<table>
<thead>
<tr>
<th>Tercile</th>
<th>Survival Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tercile 1</td>
<td>23.8%</td>
</tr>
<tr>
<td>Tercile 2</td>
<td>52.3%</td>
</tr>
<tr>
<td>Tercile 3</td>
<td>78.4%</td>
</tr>
</tbody>
</table>

N=1069  N=10808  N=2107

Survival to Explant
Centers supporting > 4 pts

Impella Pre-PCI associated with Improved Survival in AMI/CGS

IQ Database

- IABP and/or Inotropes Pre-PCI: 54% (P<0.001)
- Impella Pre-PCI: 60%

CVAD Registry

- IABP and/or Inotropes Pre-PCI: 41% (P<0.003)
- Impella Pre-PCI: 65%

References:
Hemodynamic Monitoring associated with Improved Survival in AMI/CGS

**IQ Database**
- No Hemodynamic Monitoring: 50% (N=10876)
- Hemodynamic Monitoring: 62% (N=8018)
  \[ P < 0.0001 \]

**cVAD Registry**
- No Hemodynamic Monitoring: 68% (N=634)
- Hemodynamic Monitoring: 76% (N=516)
  \[ P = 0.002 \]

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2. cVAD survival to explant 2009–2016
Solving the Hemodynamic Support Equation in CS

- Circulatory Support
  - Increased Mean Arterial Pressure
  - Increased Urine Output
  - Decreased Serum Lactate

- Ventricular Support
  - Reduced LV Pressure & Volume
  - Reduced Pulmonary Capillary Wedge Pressure

- Coronary Perfusion
  - Increased Trans-myocardial Perfusion
  - Resolution of ST-changes
  - Reduced CK-MB Levels

Kapur NK, Esposito M. J Am Coll Cardiol 2016.
Extracorporeal Membrane Oxygenation (ECMO)

- Variation of cardiopulmonary bypass
- Circuit of a centrifugal blood pump, membrane oxygenator and heparin-coated tubing
- Can provide ≥ 4.5 L/min of support
ECMO

• Two possible configurations
  – Veno-venous for pulmonary support
  – Veno-arterial for cardiac and pulmonary support
• Can be placed at the bedside
• Indications
  – Hypoxemic respiratory failure
  – Refractory cardiogenic shock
  – Failure to wean from cardiopulmonary bypass
  – Cardiac arrest (adjunct to CPR)
VV ECMO Configurations

VA ECMO Configurations

Peripheral veno-arterial ECMO cannulation approach

A

B

C

Relative Contraindications to ECMO

- Contraindication to anticoagulation
- Advanced age
- Morbid obesity
- Poor neurologic prognosis
- Terminal malignancy
- Prolonged cardiac arrest
- Irreversible cardiac failure
- Not candidate for durable MCS or OHT
ECMO Complications

- Bleeding
- Infection
- Hemolysis
- Limb Ischemia
- Stroke
ECMO Outcomes

• Retrospective review of 131 ECMO pts 1995-2005 at single center
  – ECMO used for CS of various etiologies
  – Mean support 2.9 days
  – Mean f/u 39 months
  – 50% long-term survivors
  – 46 pts weaned, 5 pts transplanted, 28 pts implanted with durable VAD

ECMO Outcomes by Age

National Inpatient Sample 2004-2016

Surgically Implanted MCS

• Short-term
  – Centrimag: external centrifugal blood pump with intrathoracic canulation
  – Can be used as LVAD, RVAD or BiVAD

• Long-term
  – Abbott Heartmate II: continuous flow LVAD
  – Abbott Heartmate 3: continuous flow LVAD
  – Heartware VAD: continuous flow LVAD

• Can provide up to 10 L/min of support
Centrimag
Temporary Continuous Flow

LVAD configuration: Inflow canula in LV, Outflow canula in Ao
RVAD configuration: Inflow canula in RA, Outflow canula in PA
Centrimag

Pump  Motor  Console
BiVAD Centrimag Configuration
Centrimag Outcomes

- Retrospective study pts implanted with Centrimag at CUMC 1/2007-8/2009
- 27 pts with acute refractory CS
  - 17 ICM, 7 DCM, 3 other
  - Mean age 47.1 yrs
  - 85% with IABP, 70% on vasopressors, 44% on more than 1 inotrope
- 24 of 27 survived to explant
- 20 of 27 survived to discharge
- 1-year survival 68%
- 10 pts with thromboembolic complications

Koji VAD

Courtesy of Koji Takeda, MD, PhD
Patient Selection

- Refractory cardiogenic shock
- Use when it will improve survival instead of prolonging the dying process
- Should be withheld if no foreseeable exit strategy for removal
  - Bridge to revascularization
  - Bridge to surgically-implanted MCS
  - Bridge to transplantation
  - Bridge to decision


Device Selection

- Degree of mechanical support needed to adequately restore circulation and provide adequate oxygenation
- Presence of RV dysfunction
- Severity of end-organ dysfunction
- Presence of PAD
  - Femoral arterial access and sheath/cannula size
Timing of Implantation

• Vasopressor/inotropitic support increases oxygen demand and myocardial ATP consumption

• Narrow window of opportunity

• Strongly consider MCS when there is continued escalation of medical therapy due to worsening hemodynamic and laboratory parameters
Multi-disciplinary Team at NYPH/Cornell

• Cardiology
  – Dr. Evelyn Horn, Dr. Irina Sobol, Dr. Maria Karas, Dr. Udhay Krishnan, Dr. Parag Goyal
  – NPs/RN: Neshama Avrahami, Rosemarie Gadioma, Cecilie Gjerde, Meghan Ward, Abby Donde

• CT Surgery
  – Dr. Arash Salemi

• Social Work, Psychiatry, Nutrition, Physical Therapy, Occupational Therapy
Take Home Points

• Importance of early recognition of refractory cardiogenic shock

• Determine patient eligibility for mechanical circulatory support

• Understand different options for hemodynamic support

• Involve multi-disciplinary team early for evaluation and intervention