Acute Mechanical Circulatory Support
Left Ventricular Support Devices

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The Acute MCS Working Group
ACC/SCAI Interventional Cardiology Overview and Board Preparatory Course
## The Spectrum of Acute MCS Devices in 2017

### Concept 1: Acute MCS Devices are Not VADs

<table>
<thead>
<tr>
<th></th>
<th>Durable MCS</th>
<th>Acute MCS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Primary Objectives</strong></td>
<td>Outpatient Discharge</td>
<td>Inpatient Stabilization</td>
</tr>
<tr>
<td><strong>Clinical Scenarios</strong></td>
<td>Stable, but sick</td>
<td>Sick and unstable</td>
</tr>
<tr>
<td><strong>Technical Implant Features</strong></td>
<td>Cardiotomy</td>
<td>Vascular Puncture</td>
</tr>
<tr>
<td><strong>Post-procedural Management</strong></td>
<td>Surgical</td>
<td>Medical</td>
</tr>
<tr>
<td><strong>Outcomes/Metrics of Success</strong></td>
<td>OHTx or DT-VAD</td>
<td>Recovery, Durable MCS, OHTx</td>
</tr>
<tr>
<td><strong>Withdrawal of Care</strong></td>
<td>Failure</td>
<td>Success in select cases</td>
</tr>
</tbody>
</table>

### Left Ventricle

**Pulsatile**

- Impella RP

### Continuous Flow Pumps

- **Axial-Flow**
  - VA-ECMO

- **Centrifugal Flow**
  - Tandem pRVAD
  - Protek Oxy-RVAD
Left Ventricular Unloading
A Fundamental Target of Therapy for Acute MCS

A

PVA = SW + PE

LV Pressure (mmHg)

0 50 100 150
0 50 100 150

LV Volume (ml)

B

Oxygen for:
- Mechanical Work
- Calcium Cycling
- Basal Metabolism

MVO2 (mI/O2/beat)

0.05 0.10 0.15 0.20
0 5000 10000 15000

PVA (mmHg.ml)

Reduced Myocardial O2 Demand

LV Pressure

LV Volume

Pressure

Volume
The Theory of Counter-pulsation

Diastole: IABP Inflated
Systole: IABP Deflated

Windkessel Effect:
Volume displacement creates a negative pressure sink in the aorta

\[ \downarrow E_a = \frac{\downarrow LVSP}{\uparrow SV} \]

Figure: J Inv Card 1999

Kapur & Steinberg SCAI Board Review 2015
Augmented Diastolic Pressure: 122 mmHg
Assisted Systolic Pressure: 75 mmHg

MEGA-IABP Hemodynamic Effect:
Systolic Unloading: 98 → 75 mmHg
Diastolic Augmentation: 58 → 122 mmHg

LV Unloading Mechanics: IABP
Diastolic Augmentation vs Systolic Unloading

Unassisted Systolic Pressure: 98 mmHg
Unassisted Diastolic Pressure: 58 mmHg
The Fundamentals of Counter-pulsation
Turning Pulsatility Upside-Down

Augmented Aortic Diastolic Pressure
Reduced LV Systolic Pressure
Increased Myocardial Supply: Demand Ratio

SPTI = Myocardial O$_2$ Demand
DPTI = Myocardial O$_2$ Supply

Majithia & Kapur et al J Inv Card 2015
Annamalai & Kapur et al Under Review
Recent IABP Trials Fail to Show Clinical Benefit

1. No assessment of IABP effect
2. No trials examining IABP in advanced HF
3. No trials incorporating larger capacity IABPs

Diastolic Augmentation does not equal increased cardiac output

Arjun Majithia (PGY3) and Kapur et al J Inv Card 2014
Cardiac Index Increased > 20% in IABP Responders

Responder Characteristics:
Lower Cardiac Filling Pressures and Higher SVR

LV End-Diastolic Pressure
- Non-Responder
- Responder
- p<0.05

Systemic Vascular Resistance
- Non-Responder
- Responder
- p<0.05

Right Atrial Pressure
- Non-Responder
- Responder
- p<0.05

Pulmonary Artery Pulastility Index
- Non-Responder
- Responder
- p<0.05

RA:PCWP Ratio
- Non-Responder
- Responder
- p<0.05

Annamalai and Kapur et al. Under Review 2017
The Hemodynamic Principle of IABPs

Counterpulsation Requires Native LV Pulsation

The more dysfunctional the ventricle, the less functional an IABP becomes.
Hemodynamic Principles of Rotary Flow Pumps
Higher Flow with Lower Transvalvular Pressure Gradient

The more dysfunctional the ventricle, the more functional a CF-AMCS device becomes.

Kapur NK. CathSAP V. 2016
Hemodynamic Principles of Rotary Flow Pumps
Reduced Flow with Higher Afterload

Percutaneous LA $\rightarrow$ FA Bypass (TandemHeart): Unloading Characteristics

pLA-FA Bypass

Circ Arrhythm Electrophysiol. 2012 Dec;5(6):1202-6
Percutaneous LA → FA Bypass (TandemHeart): Unloading Characteristics

1) Increased $E_a$
2) Reduced Wall Stress (Afterload)

pLA-FA Bypass

Annals of Thorac Surg 1994
Kapur et al. ASAIO 2015
TandemHeart: Troubleshooting Tip
Left Atrial Cannula Suction & Migration

Avoid LA Suction and Migration:
1. Restrict patient movement
2. Look for Venous Pulsing in Arterial Cannula
3. Maintain adequate device preload (PCWP 10-15)
<table>
<thead>
<tr>
<th>Adverse Event</th>
<th>Frequency</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Groin hematoma</td>
<td>6/117</td>
<td>5.12</td>
</tr>
<tr>
<td>Limb ischemia</td>
<td>4/117</td>
<td>3.41</td>
</tr>
<tr>
<td>Bleeding around cannula site</td>
<td>34/117</td>
<td>29.05</td>
</tr>
<tr>
<td>Femoral artery dissection</td>
<td>1/117</td>
<td>0.85</td>
</tr>
<tr>
<td>Atrial perforation</td>
<td>1/117</td>
<td>0.85</td>
</tr>
<tr>
<td>Sepsis</td>
<td>35/117</td>
<td>29.90</td>
</tr>
<tr>
<td>Coagulopathy</td>
<td>13/117</td>
<td>11.00</td>
</tr>
<tr>
<td>Stroke</td>
<td>8/117</td>
<td>6.83</td>
</tr>
<tr>
<td>Blood transfusions</td>
<td>70/117</td>
<td>59.80</td>
</tr>
<tr>
<td>Gastrointestinal bleed</td>
<td>23/117</td>
<td>19.65</td>
</tr>
</tbody>
</table>
Trans-valvular AMCS Devices
Axial Flow Pump: Impella “LV-Direct” Cannulation

Impella 2.5 = Perc. (13 Fr Sheath)
Impella CP = Perc. (14Fr Sheath)
Impella 5.0 = Surgical Access (21 Fr)
Axial Flow Catheter (Impella): Unloading Characteristics

1) Increased Ea
2) Reduced Wall Stress (Afterload)

Impella 2.5
Impella CP
Impella 5.0
Axial Flow Catheter (Impella):
Unloading Characteristics

[Diagram showing the Axial Flow Catheter (Impella) with labels for 40mm Pigtail, 20mm Reinforced, 15mm Inflow Cage, and longer Cannula.]

Graphs showing TV-Pump OFF and TV-Pump ON conditions with pressure measurements and annotations for Aortic Valve Opening and Closed states.

Kapur Lab
Next Generation Axial Flow Catheter:
Heartmate PHP (St. Jude/Thoratec)
14Fr Sheath → 24Fr Impeller

SHIELD-I : High Risk PCI Trial TCT 2015
SHIELD-II : High Risk PCI Trial in USA
Randomized 2:1 (HeartMate PHP vs. Impella 2.5)
Peripheral Cannulation VA-ECMO
(RA→FA Bypass)
VA-ECCMO: LV Loading

Morine and Kapur et al Curr Treatment Cardiov 2015
Veno-Arterial ECMO

1) Increased Ea
2) Increased Wall Stress (Afterload)
VA-ECMO + IABP Venting

Morine and Kapur et al Curr Treatment Cardiov 2015
Rationale for Venting the LV with VA-ECMO

1) Unchanged Ea
2) Reduced Wall Stress (Afterload)
Monitor for North-South Syndrome

1. Right radial arterial line
2. Optimize ventilator
3. Consider VAV-ECMO
4. Consider VVA-ECMO

Pavlushkov et al. Ann Transl Med 2017
Distinct Hemodynamic Profiles of Acute MCS

IABP (↓ Pressure + Δ Volume)

VA-ECMO (↑ Pressure + Δ Volume)

Tandem (Δ Pressure + ↓↓ Volume)

Impella (↓ Pressure + ↓ Volume)

Annalalai et al JHLT 2016
Esposito et al ASAIO 2016
Kapur et al. ASAIO 2016
**The Hemodynamic Support Equation for Acute MCS**

From Arithmetic to Calculus

**Circulatory Support**
- Systemic Perfusion
  - Mean Arterial Pressure
  - Lactate
  - Creatinine

**Ventricular Support**
- LV/RV Unloading
  - LV-ESP & EDP
  - Aortic Pulse Pressure
  - Vent Tachycardia
  - BNP

**Coronary Perfusion**
- MAP - LVEDP
- ST-Changes
- Troponin/CK-Mb

**Renal & Hepatic Unloading**
- RA-PA Hemodynamics
- Creatinine, LFTs, Coagulopathy

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**Hemodynamic Problem**
- Recovery
- Time in Cardiogenic Shock
- Death

**Hemo-Metabolic Problem**

**Bridge to Recovery**
- Detroit Cardiogenic Shock Initiative

**It’s Too Late for AMCS Impress Trial**

Kapur and Esposito Curr Cardio Risk 2016 & F1000 2017
Solving the Hemodynamic Support Equation For Patients Referred for HR-PCI or Shock

- Circulatory Support Systemic Perfusion
  - Mean Arterial Pressure
- Ventricular Support LV/RV Unloading
  - LV-ESP & EDP Ao Pulse Pressure
- Coronary Perfusion
  - MAP - LVEDP

<table>
<thead>
<tr>
<th>Device</th>
<th>Circulatory Support</th>
<th>Ventricular Support</th>
<th>Coronary Perfusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>IABP</td>
<td>✓</td>
<td>×</td>
<td>✓</td>
</tr>
<tr>
<td>VA-ECMO</td>
<td>✓</td>
<td>×</td>
<td>×</td>
</tr>
<tr>
<td>TandemHeart</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Impella</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
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Optimal Patient Selection for AMCS Pumps

- **IABP**
  - Preserved LVEF, MV-CAD, Aortic Stenosis, Mitral Regurgitation

- **VA-ECMO**
  - Profound hypoxemia, cardiac arrest, sepsis, multi-organ failure

- **TandemHeart**
  - Aortic Regurgitation, profound hypoxemia, severe MR

- **Impella**
  - Cardiogenic shock, AMI/Shock, High Risk PCI with Low EF
Matching Patients and AMCS Pumps
The Tufts Cardiogenic Shock Algorithm

AMI and Cardiogenic Shock Refractory to 1 inotrope/vasopressor

Echocardiogram

Pericardial Disease Tamponade

No Pericardial Disease No Tamponade

Cardiac Index > 2.2 Consider non-cardiac origin or intra-cardiac shunt

PA Catheter

+ Severe Aortic Insufficiency

TH-LVAD

RA<15 PCWP<18 Hypovolemia

Volume Resuscitation

RA<15 PCWP≥18 LV-Dominant

Acute LV AMCS (Impella CP) (Impella 5.0) (TH-LVAD)

RA≥15 PCWP<18 RV-Dominant

PAPi > 1.0

PAPi < 1.0

PAPi > 1.0

PAPi < 1.0

Inotropes Vasodilators Diuresis

Acute RV AMCS (Impella RP) (TH-RVAD)

Acute RV AMCS (Impella CP) (Impella 5.0) (TH-LVAD)

Acute LV AMCS (Impella CP) (Impella 5.0) (TH-LVAD)

Acute BiV AMCS (BiPella) (VA-ECMO + LV Vent) (TH-BiVAD)

+ Hypoxemia or + Persistent VT/VF

VA-ECMO + LV Vent

Thank you

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To Learn More about Acute MCS & Hemodynamics

The Acute MCS Working Group

TEACH TRAINING & EDUCATION IN ADVANCED CARDIOVASCULAR HEMODYNAMICS

CHIP: Hemodynamic Support and Complex PCI

Tufts Medical Center

The CardioVascular Center

Interventional Heart Failure

ACURE

Device Therapies for Heart Failure
December 15-16 2017
Berlin, Germany

August 24-25, 2017: Barcelona, Spain