“Mechanical circulatory support in cardiogenic shock“
The Cardiologist’s view

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Pascal Vranckx MD, PhD.
Medical director Cardiac Critical Care Services
Hartcentrum Hasselt
Belgium
Disclosure of Interest

Pascal Vranckx has the following potential conflicts of interest to report:

Speaking or consulting fees from: AstraZeneca, Bayer Health Care and Daiichi-Sankyo. outside this presentation.
Cardiogenic shock is the most severe form of acute heart failure.

It is defined as pump failure despite adequate preload, leading to tissue hypoxia and organ dysfunction.

Low mixed venous oxygen saturations and elevated lactate levels are surrogates for tissue hypoxia, while encephalopathy and low urine output indicate organ dysfunction.

Patients with acute myocardial infarction complicated by acute heart failure or cardiogenic shock have high mortality with conventional therapy (7-10% /50%).
Complex Coronary Artery disease

Patient comorbidities

Hemodynamic Compromise

Diabetes
Advanced age
Peripheral vascular disease
Prior surgery

Multi vessel disease
Left main disease
Peripheral Perfusion ↓
LV-Dysfunction
systolic diastolic
Death
Hypoxemia
LVEDP ↑
Lung edema
Cardiac Output ↓
Stroke Volume ↓
Hypotension
Coronary perfusion ↓
Ischemia
Vasoconstriction
Fluid retention
Progressive LV-Dysfunction
Death

Pathophysiology
Cardiogenic Shock Spiral

Acute myocardial infarction
LV-Dysfunction
systolic
diastolic

Death

Hypoxemia
Lung edema

SIRS

Cardiac Output↓
Stroke Volume↓

Hypotension

Peripheral Perfusion ↓

Coronary perfusion↓

Vasoconstriction
Fluid retention

SVR ↓
Pro-Inflammation
Catecholamine sensitivity ↓
Contractility↓

NO↑
Peroxynitrite↑
IL-6↑
TNF-α↑
eNOS
iNOS

Ischemia

Progressive LV-Dysfunction

Pathophysiology
Cardiogenic Shock Spiral

Acute myocardial infarction
LV-Dysfunction
systolic
diastolic

Death
LVEDP↑
Lung edema
Hypoxemia

LV-Dysfunction
Mechanical Support:
IABP/LVAD
Reperfusion:
PCI/CABG
Inotropes/
Vasopressors

Inflammation
Pro-
Catecholamine sensitivity ↓
Contractility↓

SVR ↓

NO ↑
Peroxynitrite ↑
IL-6 ↑
TNF-α ↑

Peripheral Perfusion △

Hypotension
Coronary perfusion ↓

Vasoconstriction
Fluid retention

SIRS
Cardiac Output ↓
Stroke Volume ↓

Ischemia

Progressive LV-Dysfunction


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Reperfusion:
PCI/CABG

Peripheral Perfusion↓
LV Dysfunction
systolic
diastolic

Death
Hypoxemia
LVEDP ↑
Lung edema

Cardiac Output ↓
Stroke Volume ↓
Hypotension
Coronary perfusion ↓

SIRS

Peripheral Perfusion↓

Vasoconstriction
Fluid retention

SVR ↓
Pro-Inflammation
Catecholamine sensitivity ↓
Contractility↓

Reperfusion: PCI/CABG
Inotropes/ Vasopressors
Mechanical Support: IABP/LVAD

NO ↑
Peroxynitrite ↑
IL-6 ↑
TNF-α ↑

eNOS iNOS

Bleeding/ Transfusion

Acute myocardial infarction
Progressive LV-Dysfunction

Ischemia

Pro-Inflammation
Catecholamine sensitivity ↓
Contractility↓

Acute heart failure & shock is a ‘sepsis like*’ condition.

Underperfusion of the intestine and the hematogenous release of endotoxin in patients with HF has been proposed as a mechanism for progression of HF and CRS type 1.
Pathophysiology

Cardiogenic Shock Spiral

Shock and SIRS can induce multiple organ failure (MOF), which eventually might cause death, if the condition cannot be reversed promptly by adequate treatment.

* Damage associated molecular patterns

**CARDIOMYOPATHY: Initial triage and management**

This protocol should be initiated as soon as cardiogenic shock/end organ hypoperfusion is recognised and should not be delayed pending intensive care admission.

<table>
<thead>
<tr>
<th>EMERGENCY DEPARTMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 min</td>
</tr>
<tr>
<td>Start high flow O₂</td>
</tr>
<tr>
<td>Establish i.v. access</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>5 min</th>
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<tbody>
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<table>
<thead>
<tr>
<th>60 min</th>
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</tbody>
</table>

**INITIAL RESUSCITATION**

- Arterial and a central venous catheterization with a catheter capable of measuring central venous oxygen saturation
- Standard transthoracic echocardiogram to assess left (and right) ventricular function and for the detection of potential mechanical complications following MI
- Early coronary angiography in specialized myocardial intervention center when signs and/or symptoms of ongoing myocardial ischemia (e.g. ST segment elevation myocardial infarction).

**TREATMENT GOALS**

- A mean arterial pressure of 60 mmHg or above
- A mean pulmonary artery wedge pressure of 18 mmHg or below
- A central venous pressure of 8 to 12 mmHg
- A urinary output of 0.5 ml or more per hour per kilogram of body weight
- An arterial pH of 7.3 to 7.5
- A central venous saturation (ScvO₂) ≥70% (provided SpO₂ ≥93% and Hb level ≥9 g/dl)

**In persistent drug-resistant cardiogenic shock, consider mechanical circulatory support**

**EARLY TRIAGE & MONITORING**

- **Age:** 65–74, ≥75
- **Heart rate:** >100 beats per minute
- **Systolic blood pressure:** <100 mmHg
- **Proportional pulse pressure:** ≥25 mmHg (CI <2.2 l/min/m²)
- **Orthopnea (PCWP >22 mmHg)**
- **Tachypnea:** (≥20/min), >30/min (!)
- **Killip class II–IV**
- **Clinical symptoms of tissue hypoperfusion/hypoxia:**
  - cool extremities, - decreased urine output (urine output <40 ml/h)
  - decreased capillary refill or mottling - alteration in mental status

**CORRECT:** hypoglycemia & hypocalemia,
**TREAT:** sustained arrhythmias: brady- or tachy-
Isotonic saline-fluid challenge of 20 to 30 ml per kilogram of body weight over a 30-minute period to achieve a central venous pressure of 8 to 12 mmHg or until perfusion improves (with a maximum of 500 ml)
**CONSIDER:** NIV/mechanical ventilation for comfort (fatigue, distress) or as needed
  - To correct acidosis
  - To correct hypoxemia
**INOTROPIC SUPPORT:** (dobutamine and/or vasopressor support)
Pre-warned is Pre-armed
Risk Assessment

- Age
- Heart Rate > 100bpm
- Systolic Blood Pressure < 100mmHg
- Proportional Pulse Pressure ≤25 (CI < 2.2)*
- (if) Orthopnoe (PCWP > 22)
- KILLIP Class II-IV

* Stevenson LW et al. JAMA 1989; 261: 884-8
**CAR Diogenic SHOCK**: Initial triage and management

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<table>
<thead>
<tr>
<th>Time (min)</th>
<th>Cardiac Intensive Care Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Early triage &amp; monitoring</td>
</tr>
<tr>
<td>5</td>
<td>Emergency department</td>
</tr>
<tr>
<td>15</td>
<td>Initial resuscitation</td>
</tr>
<tr>
<td>60</td>
<td>Cardiac Intensive Care Unit</td>
</tr>
</tbody>
</table>

**EARLY TRIAGE & MONITORING**
- Start high flow O2
- Establish i.v. access
- Age: 65–74, ≥75
- Heart rate >100 beats per minute
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- Propriotional pulse pressure ≤25 mmHg (CI <2.21/min/m²)
- Orthopnea (PCWP >22 mmHg)
- Tachypnea (>20/min), >30/min (!)
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In persistent drug-resistant cardiogenic shock, consider mechanical circulatory support
POSITIVE PRESSURE VENTILATION

Positive Intra-thoracic Pressure (ITP)

- Positive Intra-thoracic Pressure (ITP)
  - Abolition of negative swings in ITP
  - \( \text{gradient between the LV and the extra-thoracic arteries} \)
  - \( \text{gradient of systemic venous return} \)

- \( \text{Work of breathing} \)
- Improved arterial oxygenation

- \( \text{RV Preload} \)

- \( \text{LV Afterload} \)

- \( \text{Intrathoracic Blood Volume} \)

- \( \text{Cardiac Performance} \)
Assess volume status.
Treat sustained arrhythmias: brady- or tachy.
(Consider) Mechanical Ventilation for comfort (during PCI) and/or as needed:
- to correct acidemia
- to correct hypoxaemia
Inotropic support (dobutamine and/or vasopressor support)

Signs (ST-segment elevation MI or New LBBB) and/or clinical symptoms of ongoing myocardial ischemia.

Emergency echocardiography
\pm Tissue doppler imaging.
\pm Color flow imaging.

No
NSTE ACS; Delayed CS

Early coronary angiography
\pm Pulmonary Artery Catheter
\pm IABP selected patients
In a specialized Myocardial Intervention Center.

Pump failure
RV, LV, both.

Aortic dissection
Pericardial Tamponade

• Acute severe mitral valve regurgitation
• Ventricle Septum Rupture
• Critical Aortic/Mitral Valve Stenosis

Operating theater \pm coronary angiography

Yes

PCI \pm stenting of the culprit lesion

CABG + correct mechanical complications
Mechanical ventilation

TV 6-8ml/kg
PAW <30mmHg
PEEP 3-5(-7) cmH₂O
20 cpm, I:E 1/2

Pulmonary congestion

PAW <30mmHg
PEEP 3-5(-7) cmH₂O
20 cpm, I:E 1/2

Cardiac Assist

Ultrafiltration ± dialysis

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INTERMACS (Interagency Registry for Mechanically Assisted Circulatory Support) stages for classifying patients with advanced heart failure

### NYHA Class

<table>
<thead>
<tr>
<th>INTERMACS level</th>
<th>NYHA Class</th>
<th>Description</th>
<th>Device</th>
<th>1y survival with LVAD therapy</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Cardiogenic shock “Crash and burn”</td>
<td>IV</td>
<td>Haemodynamic instability in spite of increasing doses of catecholamines and/or mechanical circulatory support with critical hypoperfusion of target organs (severe cardiogenic shock).</td>
<td>ECLS, ECMO, percutaneous support devices</td>
<td>52.6±5.6%</td>
</tr>
<tr>
<td>2. Progressive decline despite inotropic support “Sliding on inotropes”</td>
<td>IV</td>
<td>Intravenous inotropic support with acceptable blood pressure but rapid deterioration of renal function, nutritional state, or signs of congestion.</td>
<td>ECLS, ECMO, LVAD</td>
<td>63.1±3.1%</td>
</tr>
</tbody>
</table>
Circulatory support systems for cardiogenic shock after ACS can be distinguished by:

- the method of placement (i.e. percutaneous vs. surgical),
- the type of circulatory support (i.e. left ventricular, right ventricular, or biventricular pressure and/or volume unloading), whether they are combined with gas exchange.
Circulatory support systems for cardiogenic shock after ACS can be distinguished by:

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- the type of circulatory support (i.e. left ventricular, right ventricular, or biventricular pressure and/or volume unloading), whether they are combined with gas exchange.

<table>
<thead>
<tr>
<th></th>
<th>TandemHeart™</th>
<th>Impella Recover® LP 5.0</th>
<th>Impella Recover® LP 2.5</th>
<th>Impella CP®</th>
<th>HeartMate PHP</th>
<th>ECMO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Catheter size (French)</td>
<td>–</td>
<td>9</td>
<td>9</td>
<td>9</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Cannula size (French)</td>
<td>21 venous 12–19 arterial</td>
<td>21</td>
<td>12</td>
<td>14</td>
<td>14</td>
<td>17–21 venous 16–18 arterial</td>
</tr>
<tr>
<td>Flow (L/min)</td>
<td>Max 4.0</td>
<td>Max 5.0</td>
<td>Max 2.5</td>
<td>3.7–4.0</td>
<td>≈ 4.0</td>
<td>Max 7.0</td>
</tr>
<tr>
<td>Pump speed (rpm)</td>
<td>Max 7500</td>
<td>Max 33 000</td>
<td>Max 51 000</td>
<td>Max 51 000</td>
<td>Max 5000</td>
<td>Max 5000</td>
</tr>
<tr>
<td>Insertion/placement</td>
<td>Percutaneous (femoral artery plus LA after trans-septal puncture)</td>
<td>Peripheral surgical cut-down (femoral artery)</td>
<td>Percutaneous (femoral artery)</td>
<td>Percutaneous (femoral artery)</td>
<td>Percutaneous (femoral artery)</td>
<td>Percutaneous (femoral artery plus vein)</td>
</tr>
<tr>
<td>Recommended duration of use</td>
<td>–14 days</td>
<td>10 days</td>
<td>10 days</td>
<td>10 days</td>
<td>10 days</td>
<td>–7 days</td>
</tr>
</tbody>
</table>
Fundamentals of Left Ventricular Mechanics

Normal pressure–volume loop (PVL), is bounded by the end-systolic pressure–volume relationship (ESPVR) and end-diastolic pressure–volume relationship (EDPVR).
Potential benefits of Mechanical Circulatory Support Systems.

- maintain vital organ perfusion, thereby preventing systemic shock syndrome,
- reduce intra-cardiac filling pressures, thereby reducing congestion and/or pulmonary edema,
- reduce left ventricular volumes, wall stress, and myocardial oxygen consumption.
The use of intra-aortic balloon counterpulsation did not significantly reduce 30-day or 1 year mortality in patients with cardiogenic shock complicating acute myocardial infarction for whom an early revascularization strategy was planned.

In the IMPRESS-trial, a small (n=48) explorative randomized controlled involving mechanically ventilated cardiogenic shock patients after acute myocardial infarction, routine treatment with Impella CP was not associated with reduced 30-day mortality compared with IABP.

KNOW THE RULES!

70 ml/kg body weight to achieve $S_aO_2 > 80\%$

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* Afterload is more simply indexed by total peripheral resistance, the ratio mean pressure/flow.
However, strictly on a hemodynamic basis, the use of this circuit configuration can cause **significant increases in LV pre-load** and, in some cases, pulmonary edema.

Short-term improvements in LV function can also modulate the rise in PCWP.


TPR can be reduced naturally by the baroreceptors, pharmacologically (e.g., nitroprusside), or mechanically (e.g., by IABP).


When secondary factors are insufficient to self-mitigate a rise in LV EDP, other strategies may be utilized to reduce possible increases in afterload pressure and allow for LV decompression. These include:

- atrial septostomy (to allow left-to-right shunting),
- a surgically placed LV vent,
- an intra-aortic balloon pump, or use of a percutaneous LV-to-aorta ventricular-assist device (i.e. axial flow device)
Flow-dependent changes of the pressure-volume loop (triangular) with LV-to-aortic pumping

With increased flow, there are greater degrees of LV unloading and uncoupling between aortic and peak LV pressure generation

The Harlequin (north-south) syndrome.

Femoral veno-arterial extracorporeal membrane oxygenation may cause differential hypoxia (lower $P_aO_2$ in the upper body than in the lower body, i.e., two-circulation syndrome) because of normal cardiac output with severe impairment of pulmonary function.

Hypoxic arterial blood gas when saturations in the right radial artery are measured.
The Harlequin (north-south) syndrome.

Femoral veno-arterial extracorporeal membrane oxygenation may cause differential hypoxia (lower $P_{aO_2}$ in the upper body than in the lower body, i.e., two-circulation syndrome) because of normal cardiac output with severe impairment of pulmonary function.
Circulatory support systems for cardiogenic shock after ACS are never used in a vacuum.
SHORTER DURATION OF HEART FAILURE AT LVAD IMPLANTATION MITIGATES SOME OF THE RISKS OF HIGH ACUITY.

AMI PATIENTS HAVE THE SAME 1YR-OUTCOME, DESPITE BEING MORE CRITICALLY ILL PRE-IMPLANTATION.

## ADVERSE EVENTS

### Early Period

<table>
<thead>
<tr>
<th>Event</th>
<th>AMI Rate (n = 502) Per 100 Patient-Months</th>
<th>Non-AMI Rate (n = 9,727) Per 100 Patient-Months</th>
<th>Rate Ratio</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bleeding</td>
<td>30.30</td>
<td>19.46</td>
<td>1.6</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Cardiac arrhythmia</td>
<td>16.20</td>
<td>10.96</td>
<td>1.5</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Hemolysis</td>
<td>3.47</td>
<td>2.12</td>
<td>1.6</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Infection</td>
<td>24.12</td>
<td>16.50</td>
<td>1.5</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Myocardial infarction</td>
<td>0.38</td>
<td>0.12</td>
<td>3.2</td>
<td>0.01</td>
</tr>
<tr>
<td>Neurological dysfunction</td>
<td>6.48</td>
<td>4.05</td>
<td>1.6</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Other SAE</td>
<td>20.27</td>
<td>12.95</td>
<td>1.6</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Rehospitalization</td>
<td>16.88</td>
<td>20.46</td>
<td>0.8</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Renal dysfunction</td>
<td>5.58</td>
<td>4.02</td>
<td>1.4</td>
<td>0.01</td>
</tr>
<tr>
<td>Respiratory failure</td>
<td>12.81</td>
<td>7.44</td>
<td>1.7</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Right heart failure</td>
<td>5.50</td>
<td>6.27</td>
<td>0.9</td>
<td>0.275</td>
</tr>
<tr>
<td>Venous thromboembolism</td>
<td>3.32</td>
<td>1.75</td>
<td>1.9</td>
<td>&lt;0.01</td>
</tr>
</tbody>
</table>

### Late Period

<table>
<thead>
<tr>
<th>Event</th>
<th>AMI Rate (n = 502) Per 100 Patient-Months</th>
<th>Non-AMI Rate (n = 9,727) Per 100 Patient-Months</th>
<th>Rate Ratio</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bleeding</td>
<td>3.02</td>
<td>3.43</td>
<td>0.9</td>
<td>0.10</td>
</tr>
<tr>
<td>Cardiac arrhythmia</td>
<td>0.47</td>
<td>1.09</td>
<td>0.4</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Hemolysis</td>
<td>0.92</td>
<td>0.69</td>
<td>1.3</td>
<td>0.04</td>
</tr>
<tr>
<td>Infection</td>
<td>4.84</td>
<td>5.10</td>
<td>0.9</td>
<td>0.39</td>
</tr>
<tr>
<td>Myocardial infarction</td>
<td>0.09</td>
<td>0.03</td>
<td>3.0</td>
<td>0.02</td>
</tr>
<tr>
<td>Neurological dysfunction</td>
<td>1.49</td>
<td>1.24</td>
<td>1.2</td>
<td>0.09</td>
</tr>
<tr>
<td>Other SAE</td>
<td>1.94</td>
<td>1.95</td>
<td>1.0</td>
<td>0.99</td>
</tr>
<tr>
<td>Rehospitalization</td>
<td>14.18</td>
<td>16.28</td>
<td>0.9</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Renal dysfunction</td>
<td>0.35</td>
<td>0.51</td>
<td>0.7</td>
<td>0.09</td>
</tr>
<tr>
<td>Respiratory failure</td>
<td>0.42</td>
<td>0.52</td>
<td>0.8</td>
<td>0.3</td>
</tr>
<tr>
<td>Right heart failure</td>
<td>0.21</td>
<td>0.53</td>
<td>0.4</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Venous thromboembolism</td>
<td>0.05</td>
<td>0.08</td>
<td>0.7</td>
<td>0.48</td>
</tr>
</tbody>
</table>

When you don’t have full access to these tools...?

BELIEVE IN GOD
NEVER PANIC
JUST PRAY
The number of patients with advanced heart failure that has become unresponsive to conventional medical therapy is increasing rapidly.

No other field in cardiology is experiencing such explosive growth as mechanical circulatory support for advanced heart failure (HF).

To date, there are no guidelines for appropriate selection for use of these devices that are approved by national societies in the field.
Conclusions

- Treatment options for mechanical circulatory support must be tailored to each patient in order to maximize the potential benefits and minimize the risk of detrimental effects.
- Flow rates and circuit configurations both have a major impact on their overall cardiac and systemic effects.
Conclusions

- Other factors also affect the response to MCS, include:
  - 1) the cardiovascular substrate;
  - 2) the degree of acute LV recovery following initiation of MCS;
  - 3) right-sided factors, such as RV systolic and diastolic function and pulmonary vascular resistance;
  - 4) the degree to which baroreflexes are intact and can modulate vascular and ventricular properties;
  - 5) concomitant medications;
  - 6) metabolic factors, such as pH and pO$_2$, which, if corrected, could result in improved ventricular and vascular function.