The Pathophysiology of Cardiogenic Shock and the Hemodynamic Effects of Different forms of Mechanical Circulatory Support

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Learning Objectives

At the conclusion of this talk, you should be able to:
1. Explain the impact of elevated CVP on mortality in patients with cardiogenic shock due to acute myocardial infarction and in cardiogenic shock due to decompensated chronic heart failure
2. Compare the primary hemodynamic and metabolic effects of a percutaneous left ventricular assist device and ECMO circuit in the setting of cardiogenic shock
3. Explain why the hemodynamic response to any form of mechanical circulatory support differs among patients
4. Explain why some patients require LV unloading during ECMO support and at least 8 ways this can be treated
Understanding Ventricular-Vascular Coupling through the Window of the Pressure-Volume Diagram:

Ventricular Pressure-Volume Loop
End-Systolic Pressure-Volume Relationship
End-Diastolic Pressure-Volume Relationship
Ventricular-Vascular Coupling: Overview

Pathophysiology of CS

- Primary insult of the myocardium
- Primary effects of ↓LV, ↓RV or ↓BiV contractility
- Results in:
  - ↓BP, ↓CO, ↑/↓↔ CVP and PCWP, acidemia
- Secondary, effects of baroceptor activation (rapid)
  - ↑HR,
  - ↑SVR,
  - Venoconstriction \(\rightarrow\) ↑stressed blood volume (SBV)
- Longer term:
  - Inflammation, MOF

Hochman 2003
Pressure-Volume Relations in Shock due to Isolated LV Failure

- Abrupt reduction of LV contractility
- Decreased BP and CO
- Baroceptor activation increases HR, SVR and stressed blood volume (SBV)
- PCWP increase
- Variable changes of CVP

Pressure-Volume Relations in Shock due to Isolated RV Failure

- Abrupt reduction of RV contractility
- LV underfilling leads to decreased CO and BP
- Baroceptor activation increases HR, SVR and SBV
- CVP increases
- Variable changes of PCWP
Pressure-Volume Relations in Shock due to Acute Biventricular Failure

- Reductions of both LV and RV contractilities
- Decreased BP and CO
- Baroceptor activation increases HR, SVR and stressed blood volume
- Variable changes of CVP and PCWP

Invasive Hemodynamic Assessment and Classification of In-Hospital Mortality Risk Among Patients With Cardiogenic Shock

Thayer, et al., Circ Heart Fail. 2020;13:e007099
Invasive Hemodynamic Assessment and Classification of In-Hospital Mortality Risk Among Patients With Cardiogenic Shock

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Therapeutic Options

- Pharmacology
  - Inotropic agents
  - Pressors

- Devices
  - IABP
  - RA→Ao (ECMO)
  - LA→Ao (Tandem)
  - LV→Ao (Impella)
  - ECMO + Impella
**KEY POINT**

Hemodynamic response to device and drug therapies variable among patients due to baseline characteristics and secondary effects:

- Degree of LV and/or RV compromise
- Short term recoverability of LV/RV function
- SVR and PVR
- Volume Status
- MR / TR
- Background medical therapy
- Other...

**Impact of Inotropes/Pressors on LV Mechanics and Energetics**

- Inotropes can:
  - Increase CO
  - Increase BP

- Inotropes:
  - Increase LV contractility
  - Increase Work (PVA)
  - Increase HR
  - Increase MVO2
Intraaortic Balloon Pump:
No significant effects on hemodynamics (CPO) or mortality

VA-ECMO
RA → FA
Peripheral Cannulation

Venoarterial Extracorporeal Membrane Oxygenation in Cardiogenic Shock.
Keebler ME, Lindenfeld J. JACC Heart Fail. 2018
Impact of RA→Ao MCS (ECMO) on Hemodynamics and Energetics

↑ Afterload
↑ Preload

↑ AoP
↑ LVP

Hala et al, Physiol Res 2016;65:S621-632

Regional Tissue Oximetry Reflects Changes in Arterial Flow in Porcine Chronic Heart Failure Treated With Venoarterial Extracorporeal Membrane Oxygenation

Hala et al, Physiol Res 2016;65:S621-632

LVV
AoP
CVP
SvO2
VA-ECMO in Profound Cardiogenic Shock

Møller-Helgestad et al. EuroIntervention 2019;14:e1585-e1592

Harlequin Syndrome / North-South Syndrome

Harlequin: a mute character in traditional pantomime, typically masked and dressed in a diamond-patterned costume
Harlequin Syndrome / North-South Syndrome

Harlequin Syndrome / North-South Syndrome
Harlequin Syndrome / North-South Syndrome

LV Distention and Pressure Overload during ECMO Support

- Loss of aortic valve opening
- Lung edema
- Bronchial bleeding
- LV thrombosis

Curtesy of Dr. Jiri Maly, IKEM, Prague
Left ventricular thrombus formation in patients undergoing femoral veno-arterial extracorporeal membrane oxygenation

Weber et al, Perfusion 2017
Impact of RA→Ao MCS (ECMO) on Hemodynamics and Energetics

- ↑ Afterload
- ↑ Preload
- ↑ PVA
- ↑ MVO2

KEY POINT

Hemodynamic response to device and drug therapies variable among patients due to baseline characteristics and secondary effects:

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- Background medical therapy
- Other...
Impact of RA→Ao ECMO in CGS with LV Contractile Reserve

Percutaneous Transvalvular Pumps

Impella Family of Devices
2.5/4.0/5.0/RP
Impact of LV→Ao MCS on Hemodynamics and Energetics

- ↓ Peak LVP
- ↓ Preload
- ↑ AoP
- ↓ LVP
- LV-Ao Uncoupling

HRPCI under IMPELLA support
Courtesy of William O’Neill

REAL PV Loops assume triangular shape during LVAD Support

Impella Removed from LV

PV Loops during Impella support and NTG injection
Impella CP or VA-ECMO in Profound Cardiogenic Shock

Møller-Helgestad et al.
EuroIntervention 2019;14:e1585-e1592

Impact of LV→Ao MCS on Hemodynamics and Energetics

↓ Peak LVP
↓ Preload

↓ PVA
↓ MVO2
Impact of LV→Ao in CGS with LV Contractile Reserve

LV Decompression during ECMO
Venoarterial Extracorporeal Membrane Oxygenation for Cardiogenic Shock and Cardiac Arrest
Cardinal Considerations for Initiation and Management

Rao, Khalpey, Smith, Burkhoff and Kociol
CirCHF 2018

1. Reduce ECMO speed
2. Inotropes
3. Afterload reduction (e.g., nitropruside)
4. IABP
5. Atrial Septostomy
6. LA→FA bypass (TandemHeart)
7. LV Vent
8. LV→Ao pump (e.g., Impella)

RA→Ao MCS + LV→Ao MCS

↑ Afterload
↑ Preload

AoP
LVP

MHIF Cardiovascular Grand Rounds | February 28, 2022
Rapid and Marked Reduction of PCWP with Impella added to ECMO

Schrage et al, JACC:HF, in press
Summary

1. Understanding cardiac physiology in the framework of the ventricular PV domain helps explain the hemodynamics of CGS and therapeutics
   a. ECMO
   b. Percutaneous LVAD
2. Responses to devices vary among patients
3. Percutaneous LVADs directly unload the LV while decreasing PCWP and increasing blood flow to the body
4. VA ECMO has the potential to increase the load on the LV and reduce AoV opening (LV and Ao root stasis)
5. At least 8 approaches to LV unloading
   a. Important to know advantages and limitations of each

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