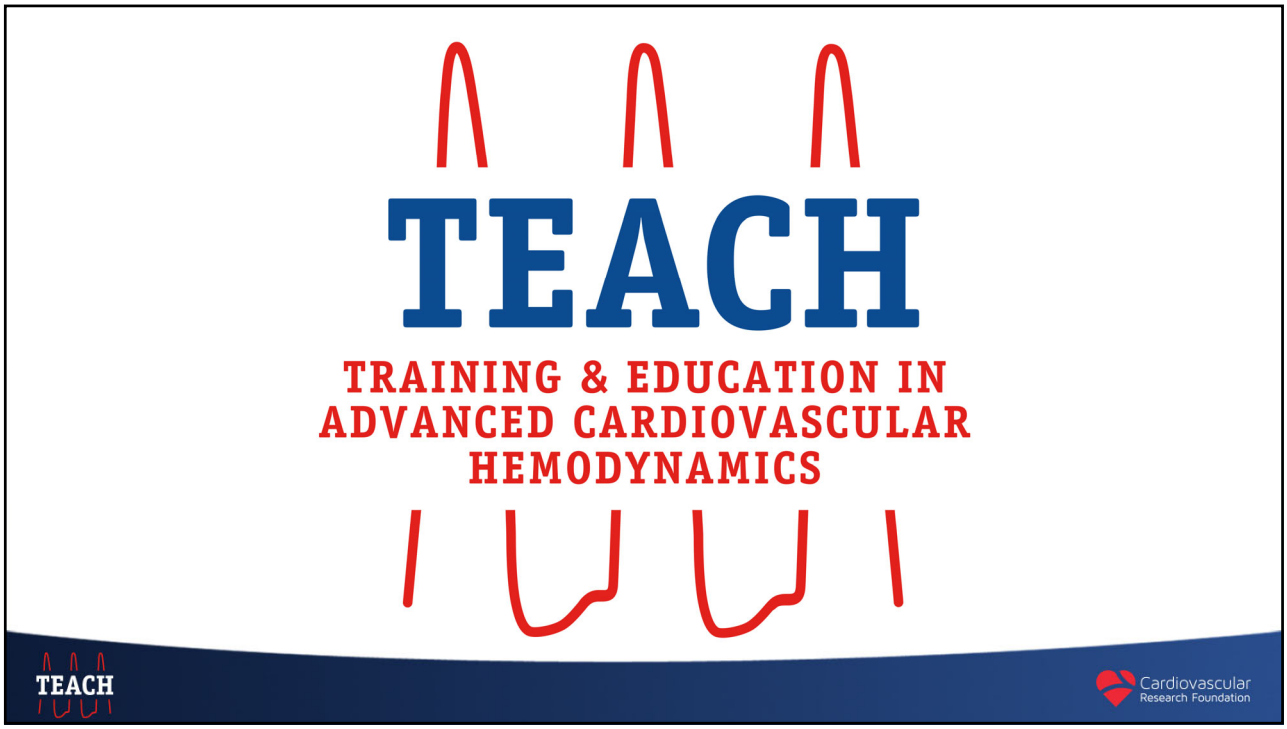

Minneapolis
Heart Institute
Foundation
GRAND ROUNDS



1

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

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Director
Heart Failure, Hemodynamics and Mechanical Circulatory Support Research
Cardiovascular Research Foundation
New York, NY

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Disclosures

- Unrestricted institutional educational grant from Abiomed
- Consultant to PVLoops LLC

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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

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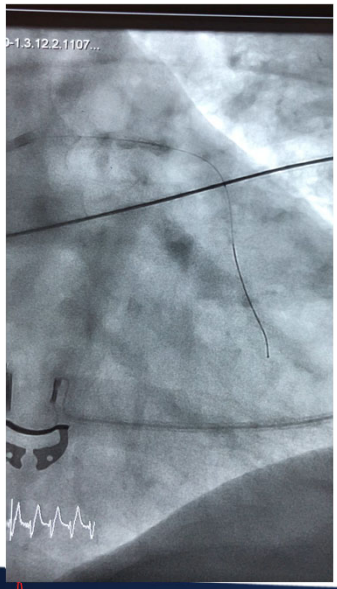
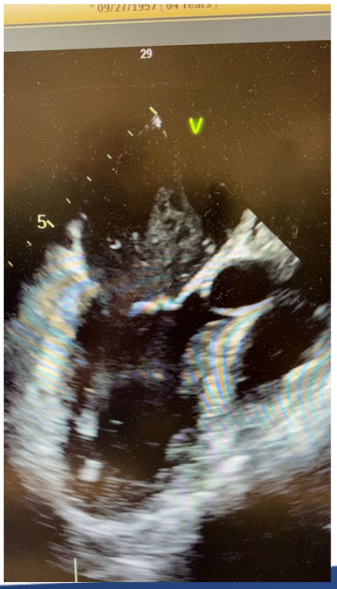
Courtesy of Dr. Manreet Kanwar. Allegheny General Hospital





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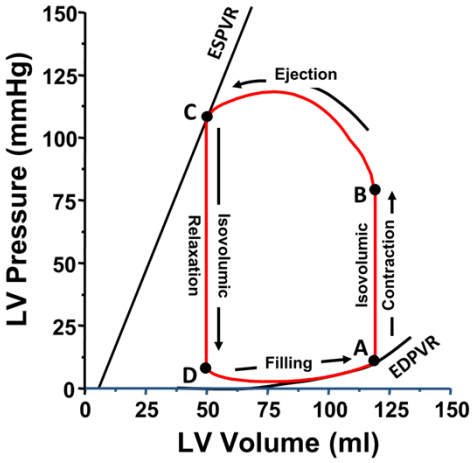
Understanding Ventricular-Vascular Coupling through the Window of the Pressure-Volume Diagram:

Ventricular Pressure-Volume Loop
End-Systolic Pressure-Volume Relationship
End-Diastolic Pressure-Volume Relationship



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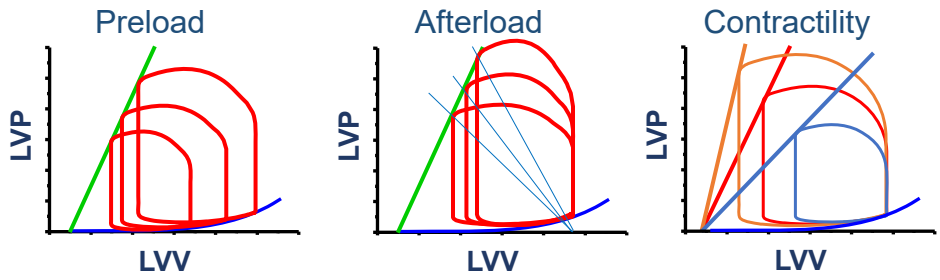
Ventricular-Vascular Coupling: Overview



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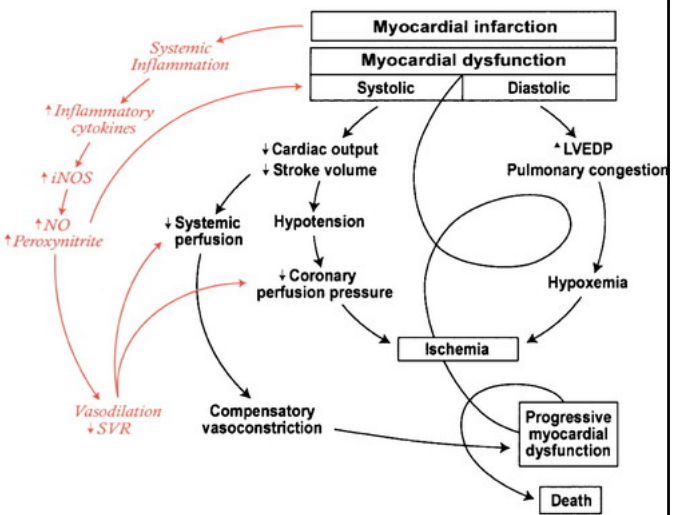
Pathophysiology of CS

- 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 → ↑stressed blood volume (SBV)
- Longer term:
  - Inflammation, MOF



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Hochman 2003

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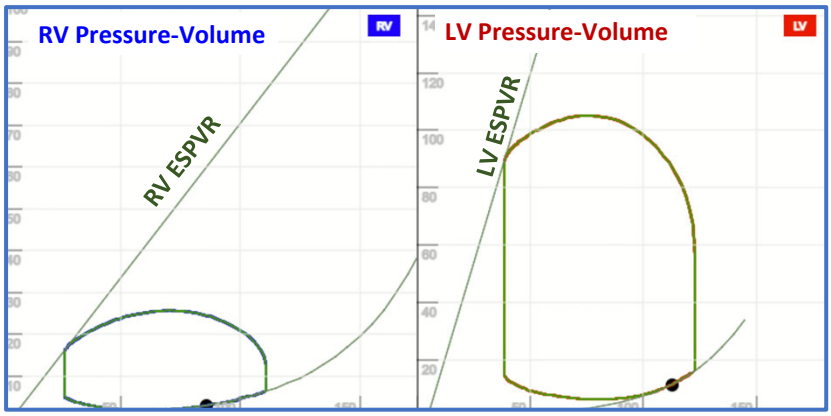
Pressure-Volume Relations in Shock due to Isolated LV Failure



- 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

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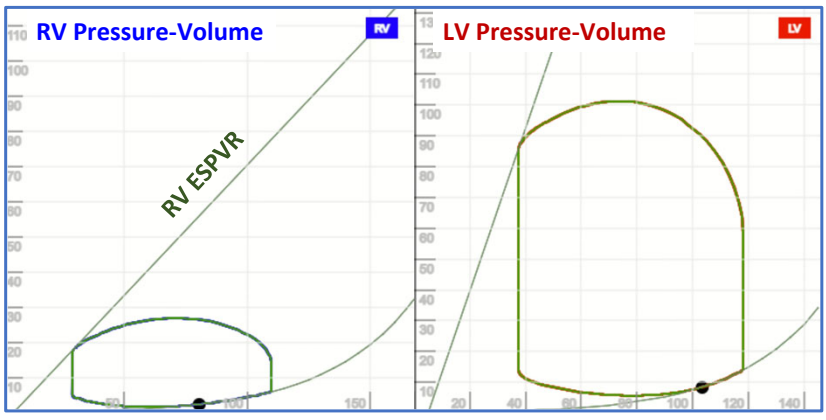
Pressure-Volume Relations in Shock due to Isolated RV Failure



- 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

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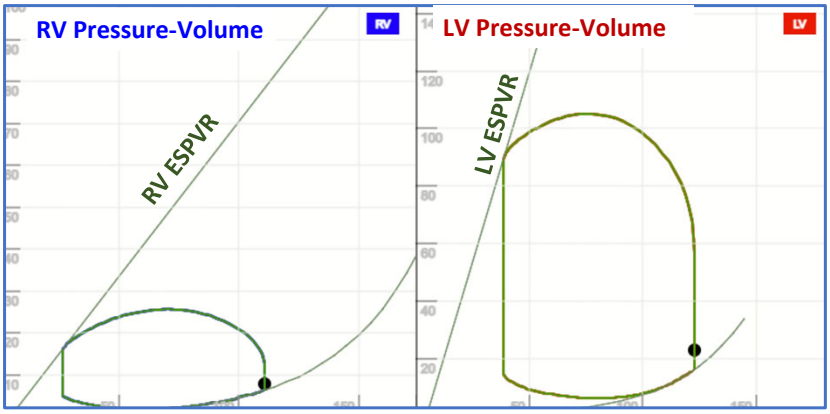
Pressure-Volume Relations in Shock due to Acute Biventricular Failure



- 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

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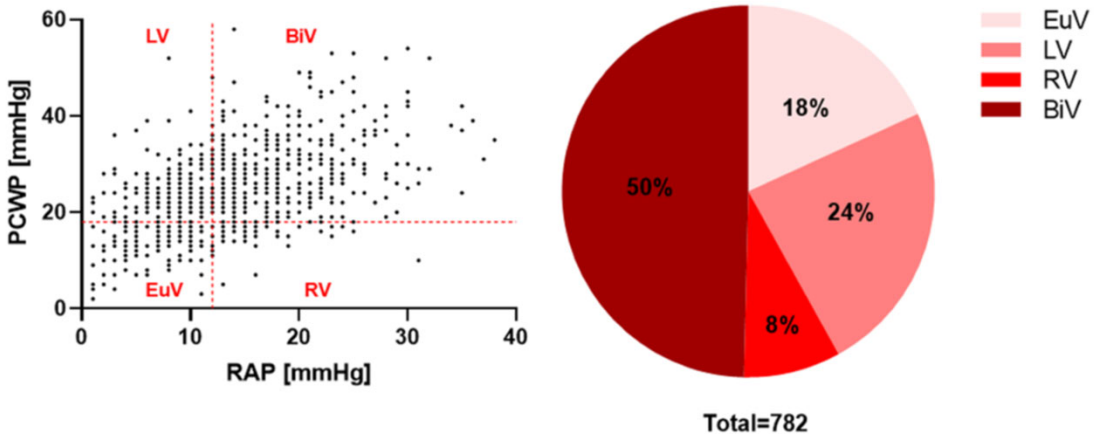
Invasive Hemodynamic Assessment and Classification of In-Hospital Mortality Risk Among Patients With Cardiogenic Shock



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Thayer, et al., Circ Heart Fail. 2020;13:e007099

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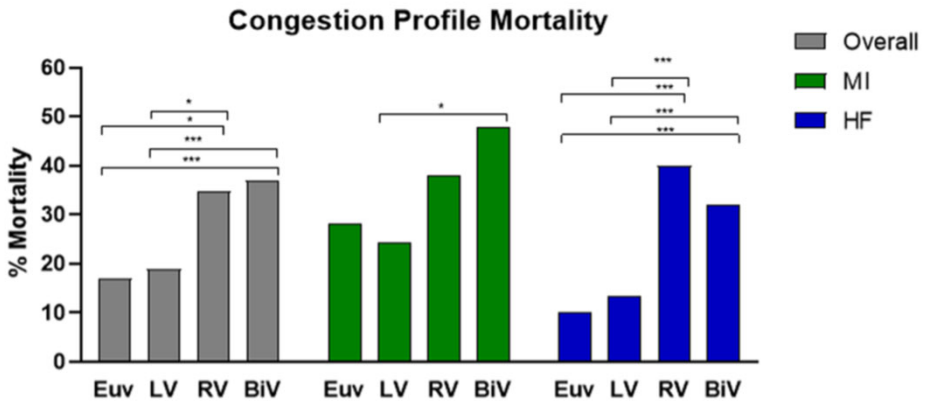
Invasive Hemodynamic Assessment and Classification of In-Hospital Mortality Risk Among Patients With Cardiogenic Shock



Thayer, et al., Circ Heart Fail. 2020;13:e007099

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Therapeutic Options

- Pharmacology
  - Inotropic agents
  - Pressors
- Devices
  - IABP
  - RA→Ao (ECMO)
  - LA→Ao (Tandem)
  - LV→Ao (Impella)
  - ECMO + Impella

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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…

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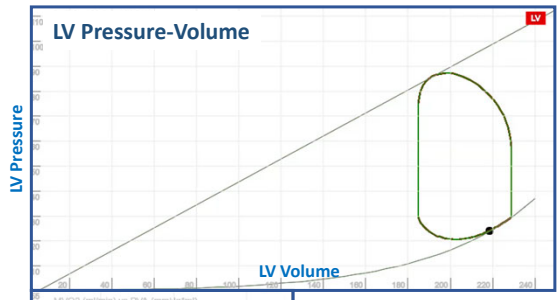
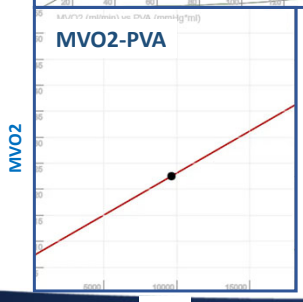
Impact of Inotropes/Pressors on LV Mechanics and Energetics



Inotropes can:
- Increase CO
- Increase BP



Inotropes:
- Increase LV contractility
- Increase Work (PVA)
- Increase HR
- Increase MVO2

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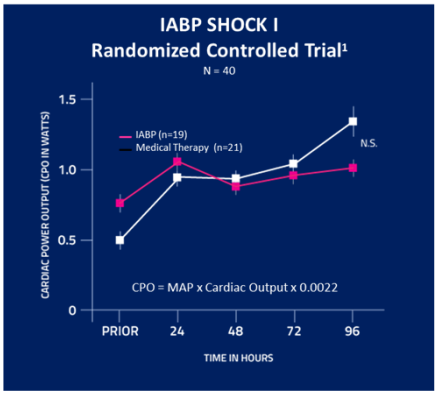
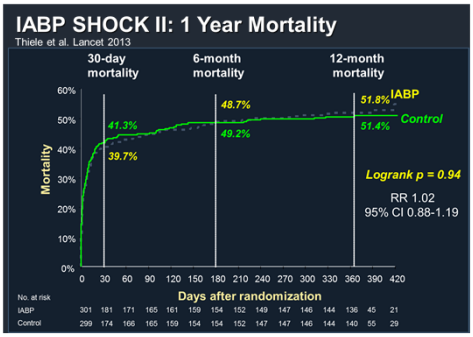
Intraaortic Balloon Pump:

No significant effects on hemodynamics (CPO) or mortality





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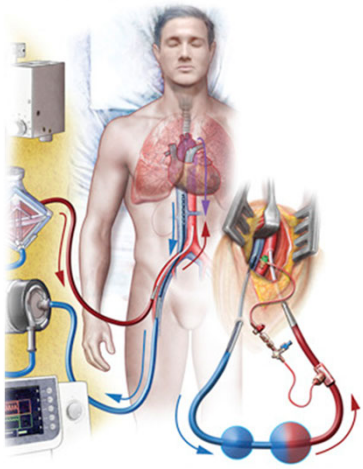
VA-ECMO

RA→FA

Peripheral Cannulation



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Venoarterial Extracorporeal Membrane Oxygenation in Cardiogenic Shock.
Keebler ME … Lindenfeld J. JACC Heart Fail. 2018

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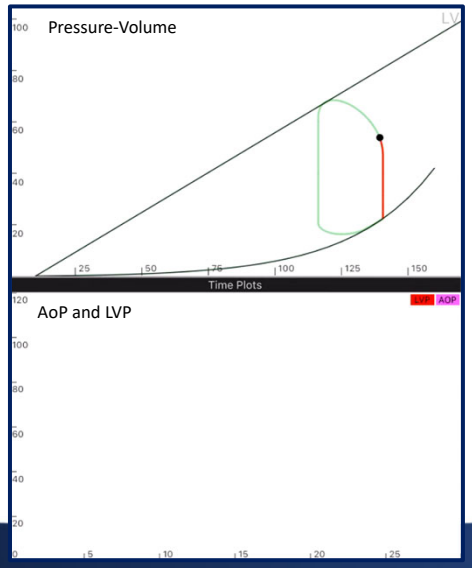
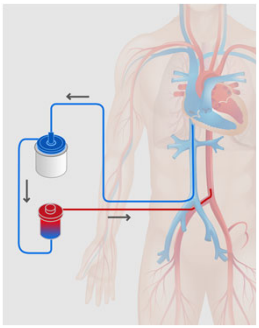
Impact of RA→Ao MCS (ECMO) on Hemodynamics and Energetics

↑ Afterload
↑ Preload



↑ AoP
↑ LVP



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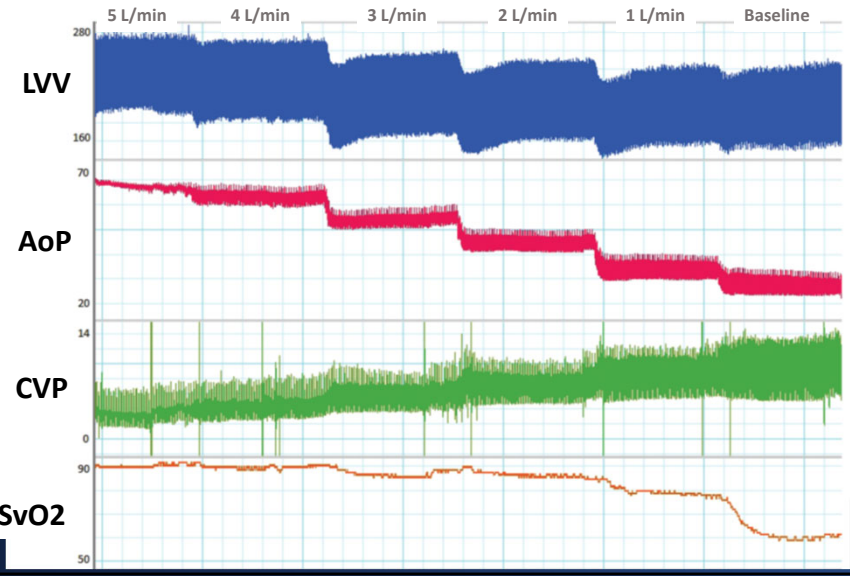
Regional Tissue Oximetry Reflects Changes in Arterial Flow in Porcine Chronic Heart Failure Treated With Venoarterial Extracorporeal Membrane Oxygenation

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



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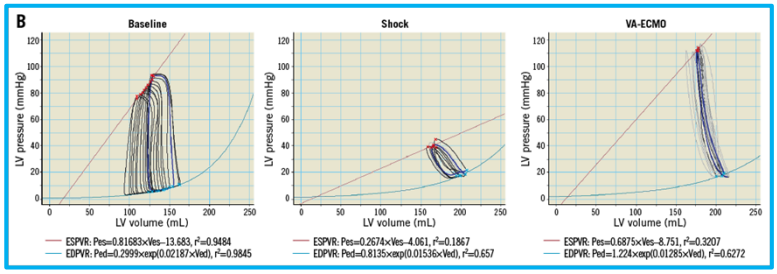
VA-ECMO in Profound Cardiogenic Shock



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

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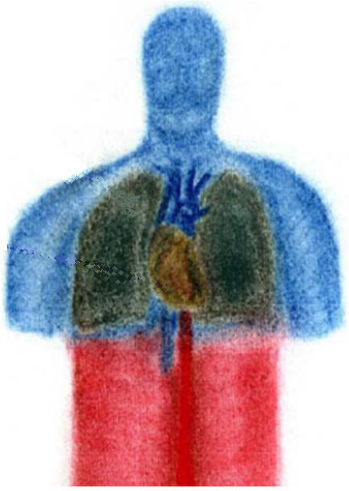
Harlequin Syndrome / North-South Syndrome



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

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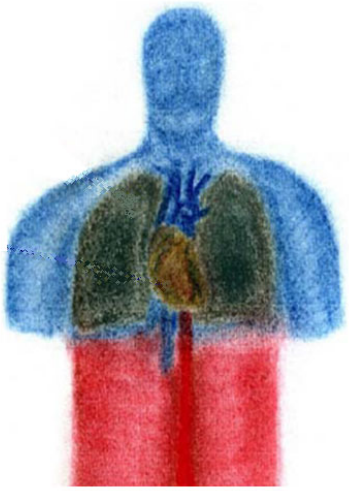
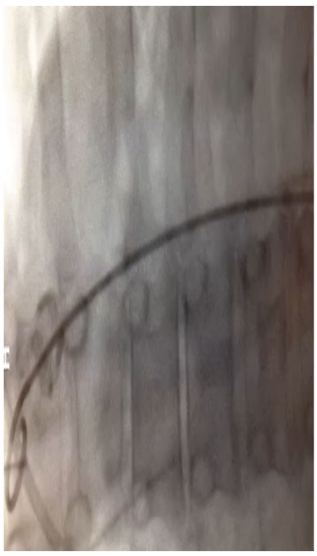
Harlequin Syndrome / North-South Syndrome





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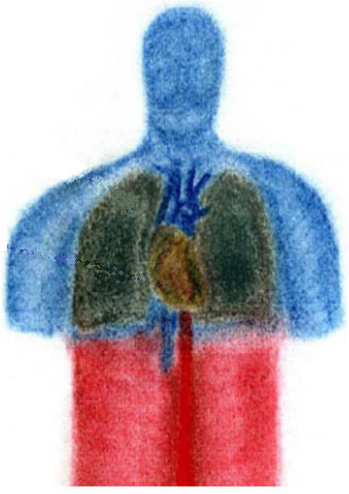
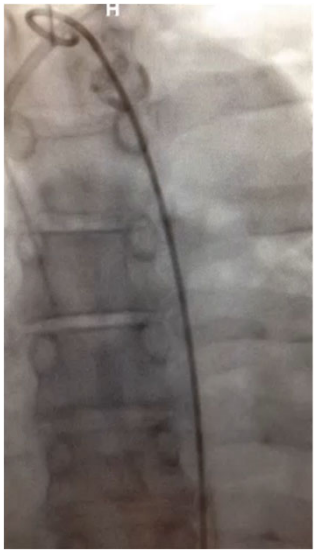
Harlequin Syndrome / North-South Syndrome





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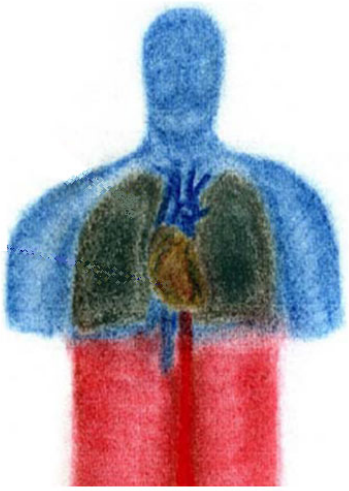
Harlequin Syndrome / North-South Syndrome



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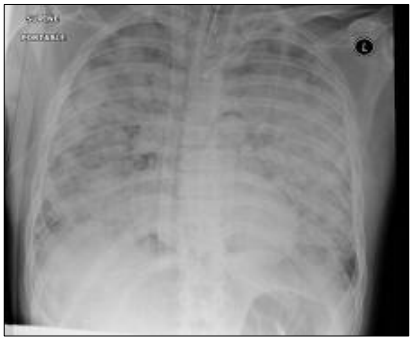
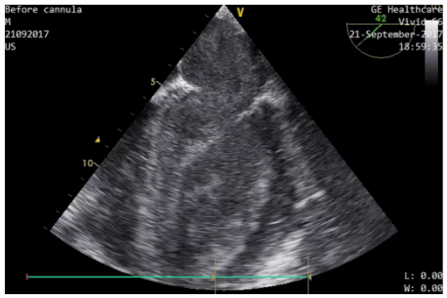
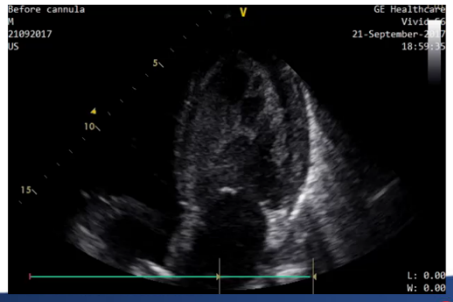
LV Distention and Pressure Overload during ECMO Support

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

Curtesy of Dr. Jiri Maly, IKEM, Prague







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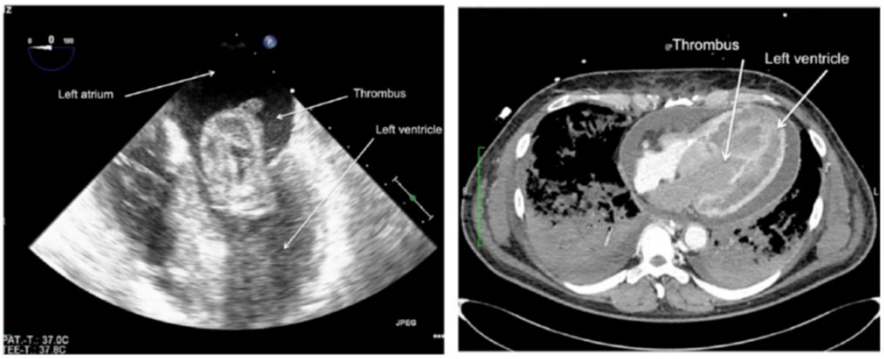
Left ventricular thrombus formation in patients undergoing femoral veno-arterial extracorporeal membrane oxygenation

Weber et al, Perfusion 2017



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Patient on ECMO
Courtesy of Dr Sal Monnino

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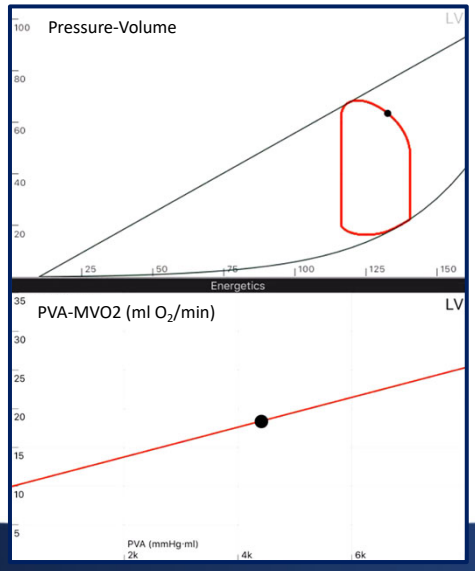
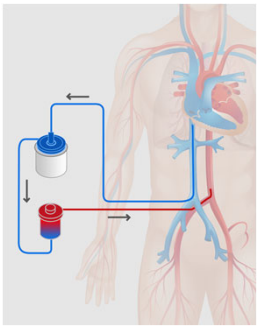
Impact of RA→Ao MCS (ECMO) on Hemodynamics and Energetics

↑ Afterload
↑ Preload



↑ PVA
↑ MVO2



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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…

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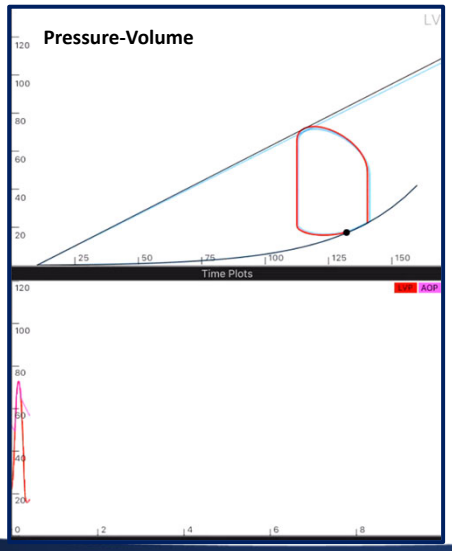
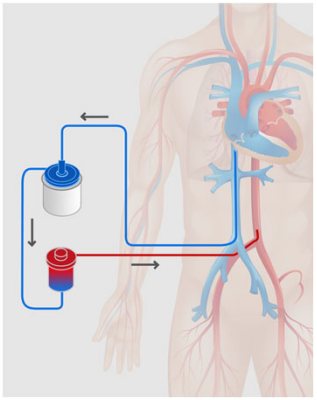
Impact of RA→Ao ECMO in CGS with LV Contractile Reserve





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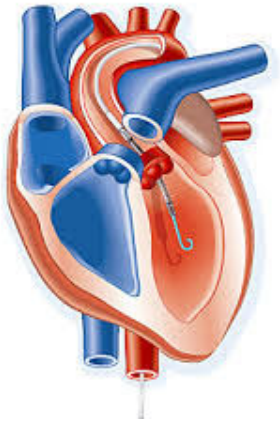
Percutaneous Transvalvular Pumps



Impella Family of Devices
2.5/4.0/5.0/RP

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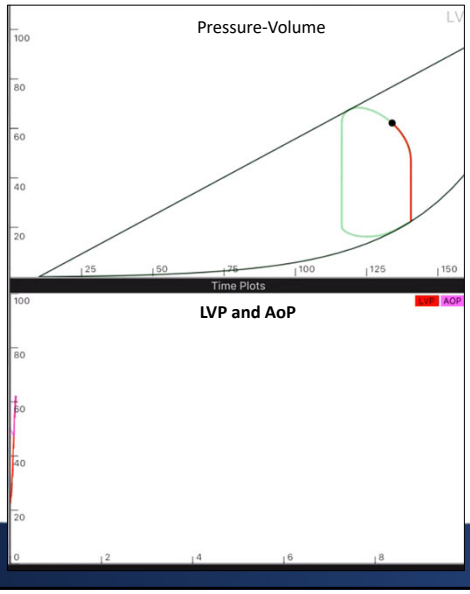
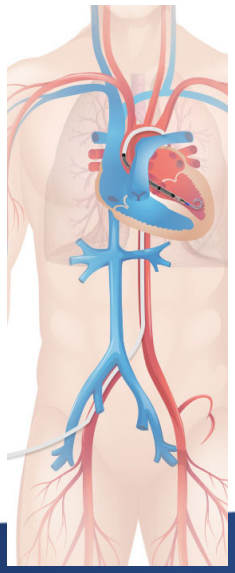
Impact of LV→Ao MCS on Hemodynamics and Energetics

↓ Peak LVP
↓ Preload





↑ AoP
↓ LVP
LV-Ao Uncoupling

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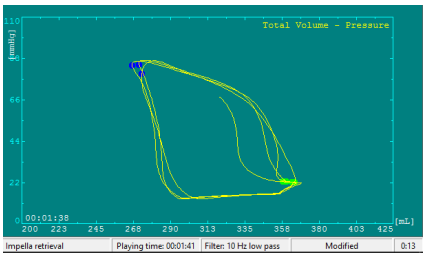
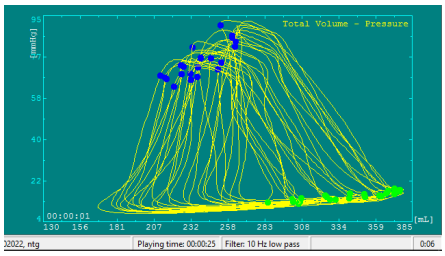
HRPCI under IMPELLA support
Courtesy of William O'Neill

REAL PV Loops assume triangular shape during LVAD Support

Impella Removed from LV



PV Loops during Impella support and NTG injection



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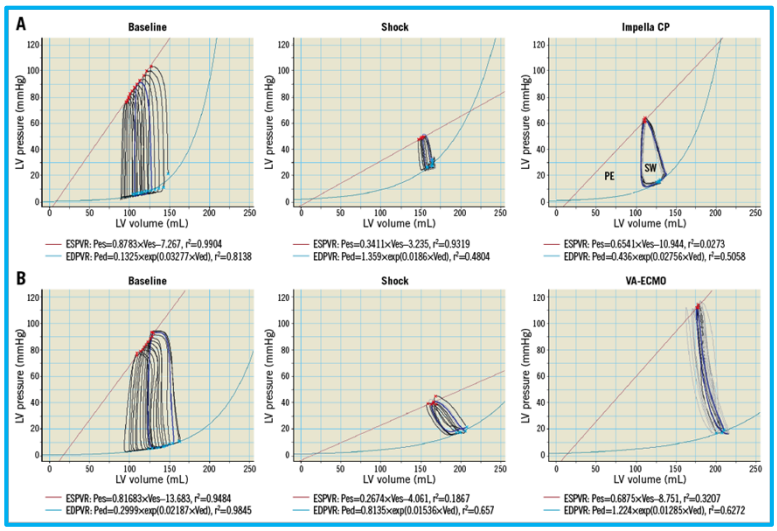
Impella CP or VA-ECMO in Profound Cardiogenic Shock



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

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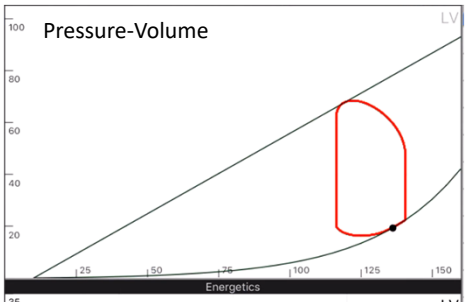
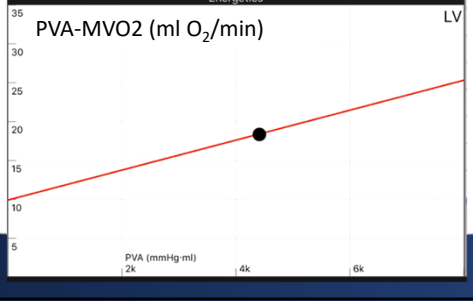
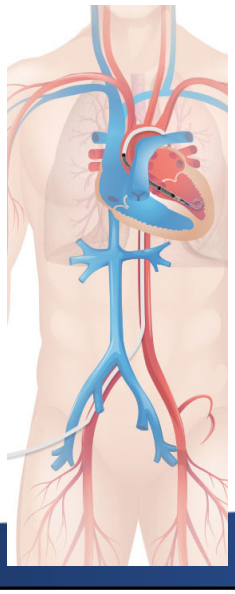
Impact of LV→Ao MCS on Hemodynamics and Energetics

↓ Peak LVP
↓ Preload





↓ PVA
↓ MVO2



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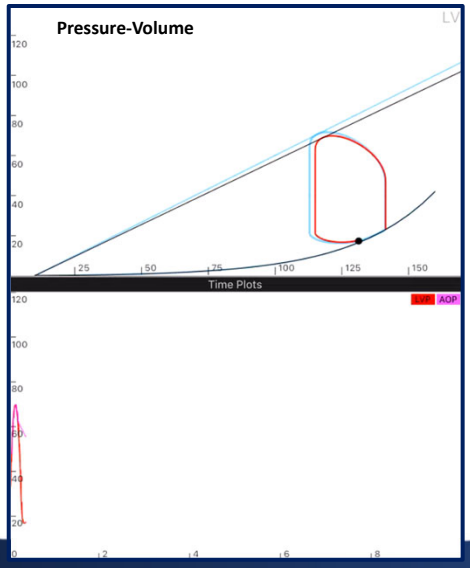
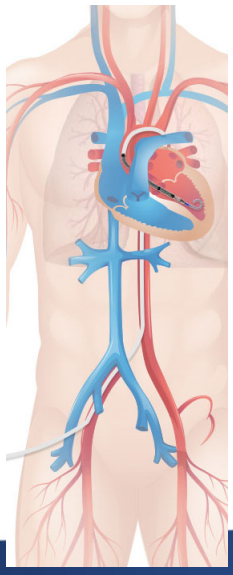
Impact of LV→Ao in CGS with LV Contractile Reserve





AoP
LVP

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LV Decompression during ECMO

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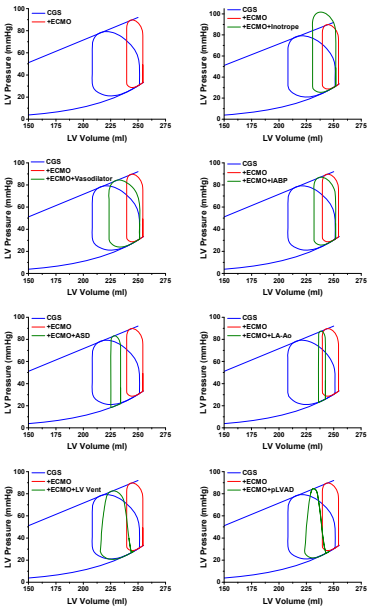
Venoarterial Extracorporeal Membrane Oxygenation for Cardiogenic Shock and Cardiac Arrest

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)



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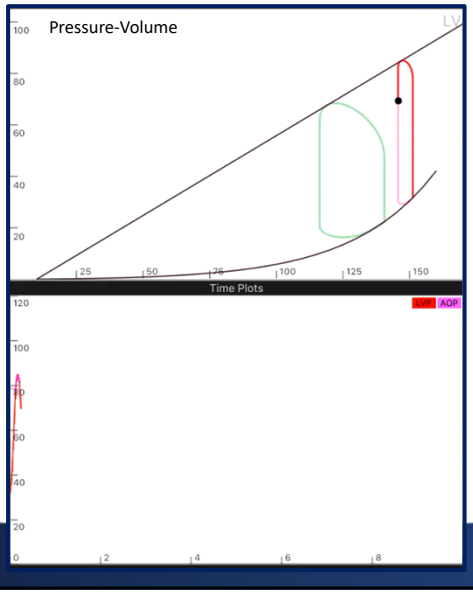
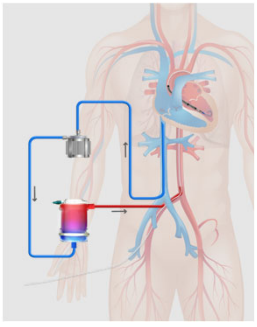
RA→Ao MCS + LV→Ao MCS

↑ Afterload
↑ Preload

AoP
LVP





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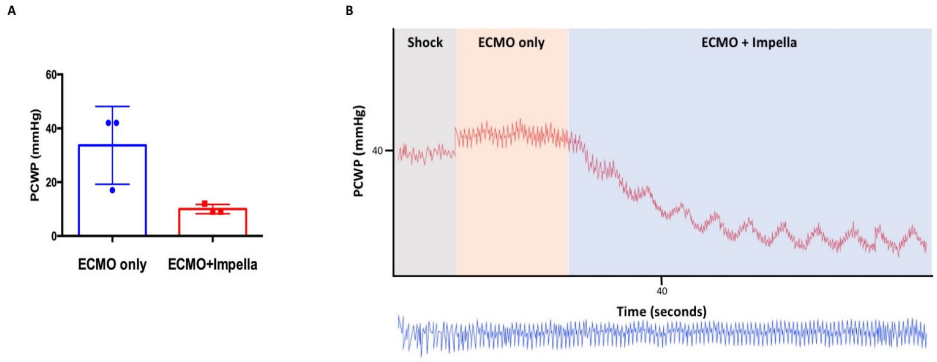
Rapid and Marked Reduction of PCWP with Impella added to ECMO



Schrage et al, JACC:HF, in press

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The Effect of Impella CP on Cardiopulmonary Physiology During Venoarterial Extracorporeal Membrane Oxygenation Support

HS Lim, Artificial Organs, 2017; 41:1109

TABLE 2. *Hemodynamic changes pre- and post-Impella on VA-ECMO support*

	VA-ECMO	VA-ECMO + Impella	*P*
Inotrope score	25.3 ± 3.9	24.8 ± 3.5	0.811
HR (min^{-1})	122 ± 7	111 ± 6	0.015
MAP (mm Hg)	60 ± 5	63 ± 3	0.109
SV (mL)	17.0 ± 1.9	31.8 ± 4.3	<0.001
PASP (mm Hg)	44.7 ± 4.3	36.0 ± 5.2	0.011
PADP (mm Hg)	29.8 ± 6.0	20.8 ± 5.2	0.015
Mean PA (mm Hg)	35.2 ± 5.8	27.6 ± 5.7	0.046
PAWP (mm Hg)	26.5 ± 6.7	17.5 ± 4.3	0.020
PCap (mL/mm Hg)	1.16 ± 0.10	2.15 ± 0.61	0.002
PVR (mm Hg/mL/s)	0.25 ± 0.03	0.17 ± 0.04	0.001
RC (s)	0.289 ± 0.026	0.360 ± 0.036	0.002

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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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