American College of Cardiology
Kentucky Chapter

18th Annual Meeting & Scientific Session

LIVE & IN-PERSON!

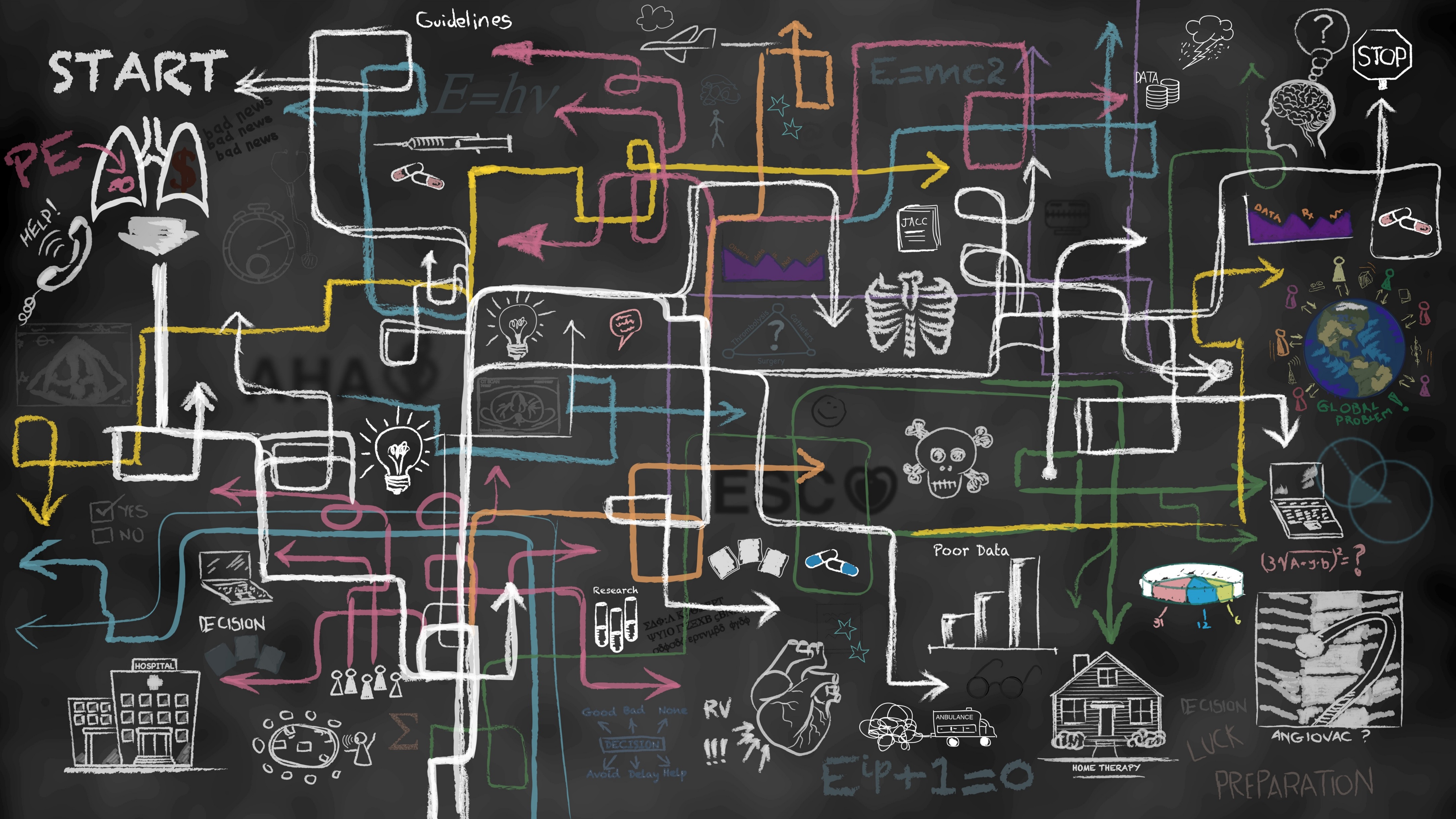
Louisville Marriott East • September 10, 2022

Percutaneous Mechanical Circulatory Support

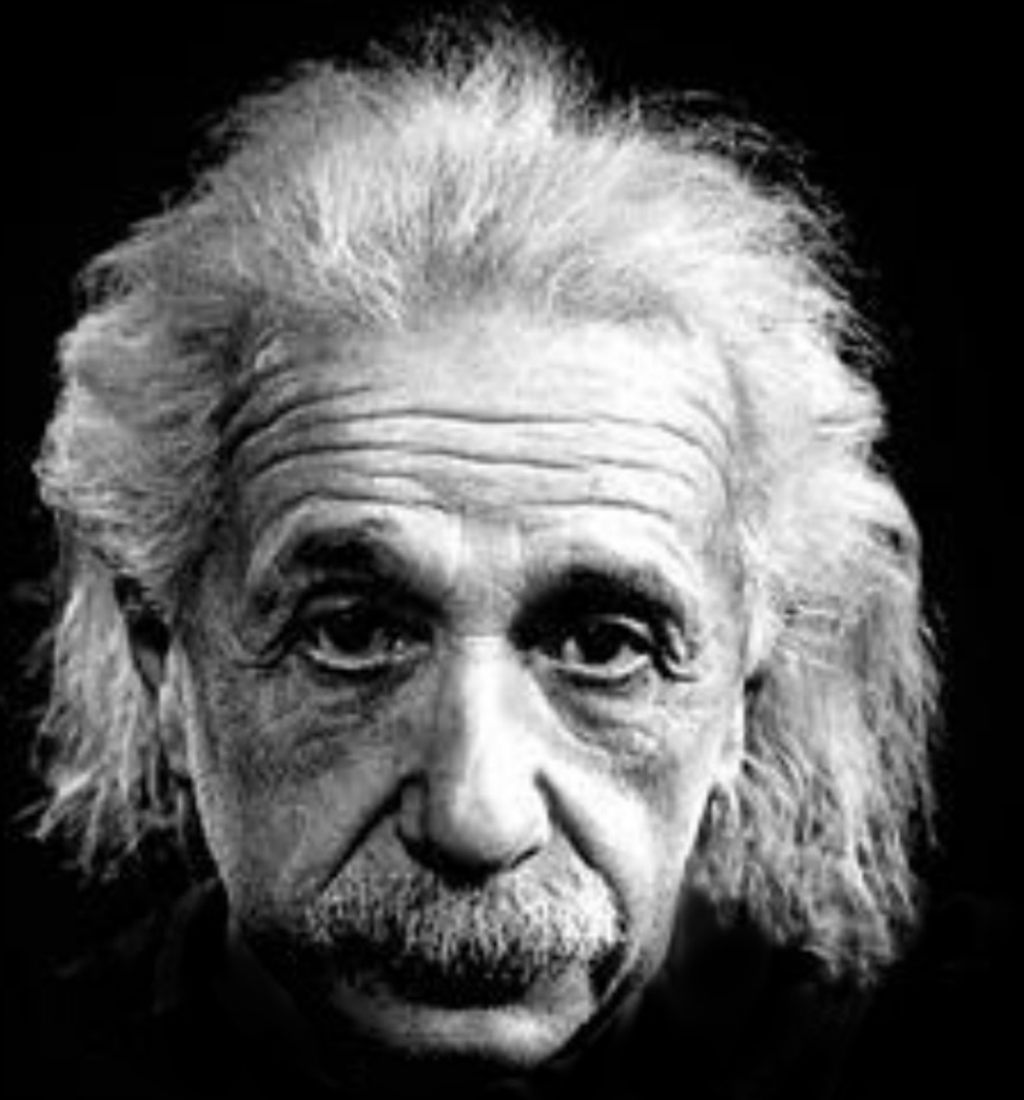
In Cardiogenic Shock

John C. Gurley, MD
University of Kentucky

A detailed algorithm for the deployment of resources?

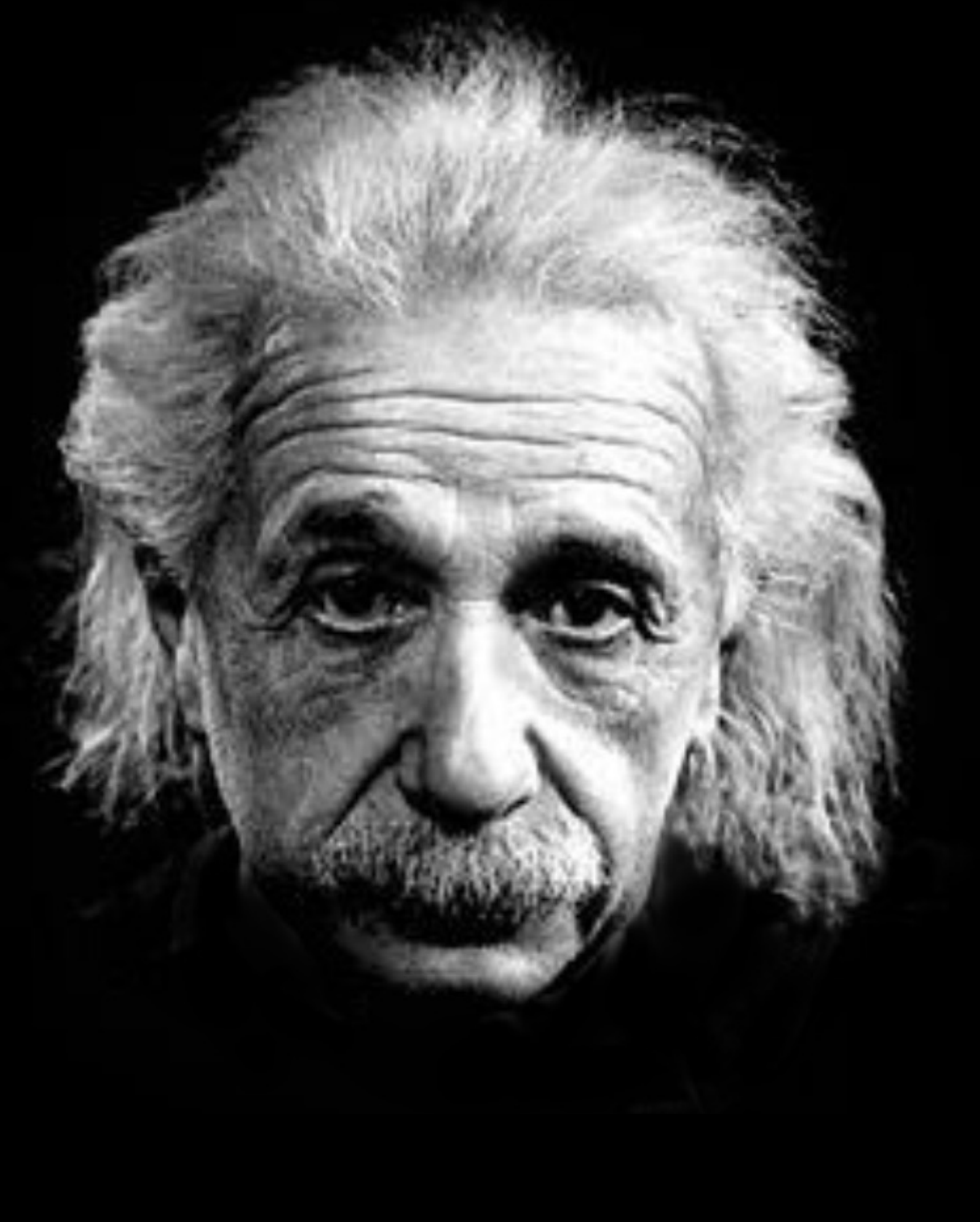


START
Guidelines
PE
HELP!
bad news
bad news
bad news
E=hv
E=mc2
DATA
STOP
JACC
DATA
Rx
GLOBAL PROBLEM
Thrombolysis
Catheters
Surgery
AHA
ESC
YES
NO
DECISION
HOSPITAL
Research
Poor Data
31
12
6
(3√A-y·b)²=?
RV
!!!
Good Bad None
DECISION
Avoid Delay Help
ANBULANCE
HOME THERAPY
DECISION
LUCK
PREPARATION
ANGIOVAC ?



“Make everything as simple as possible, but not simpler.”

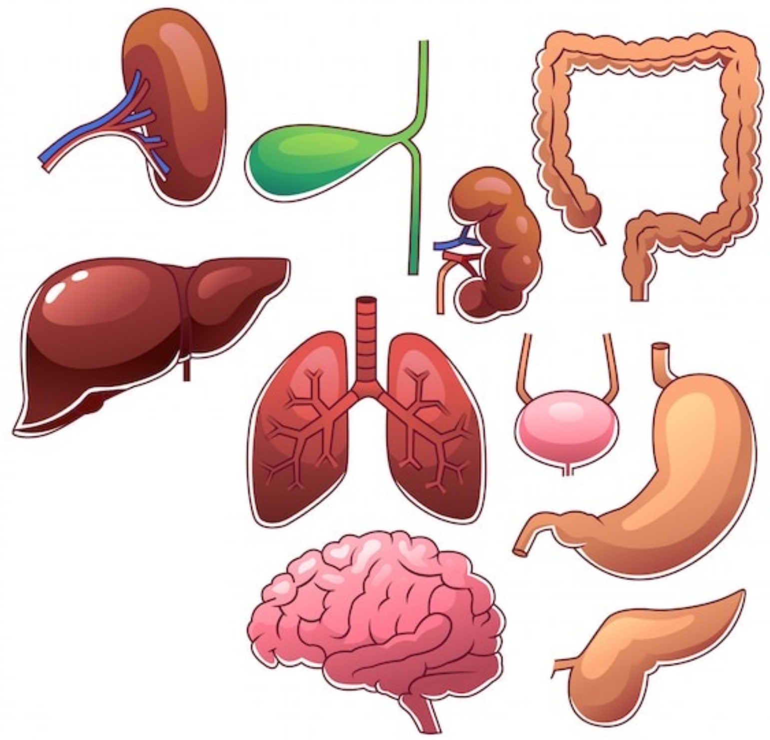
--Albert Einstein



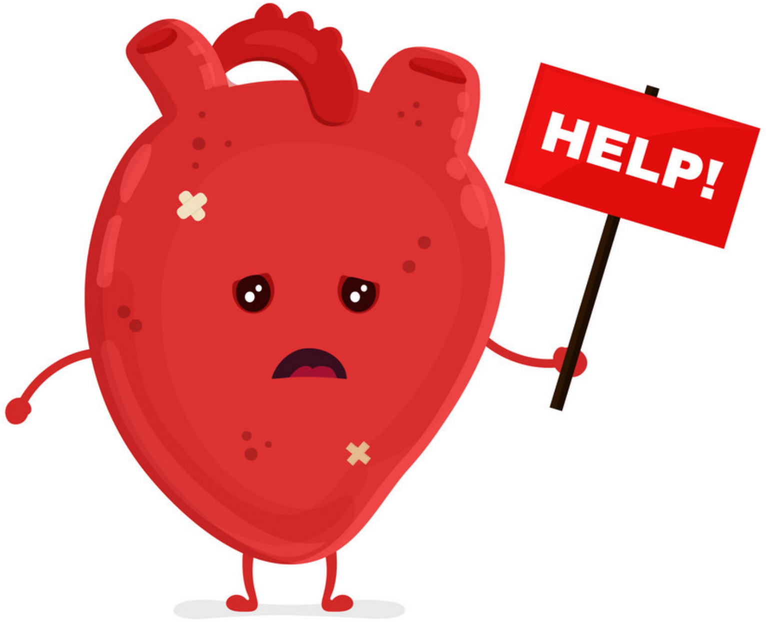
$$E = DO_2$$

The fundamental problem

“We want oxygen”

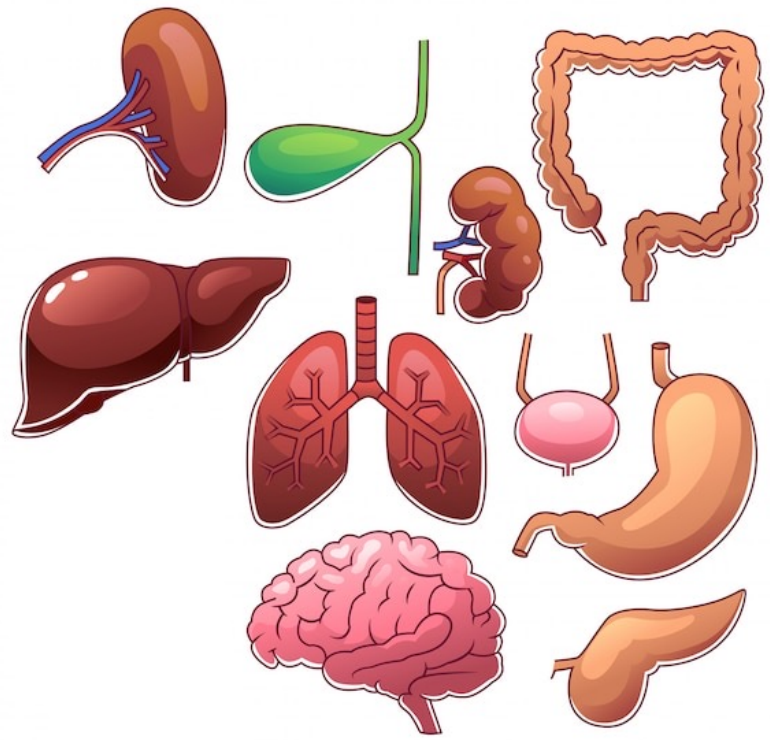


“But I need to rest”

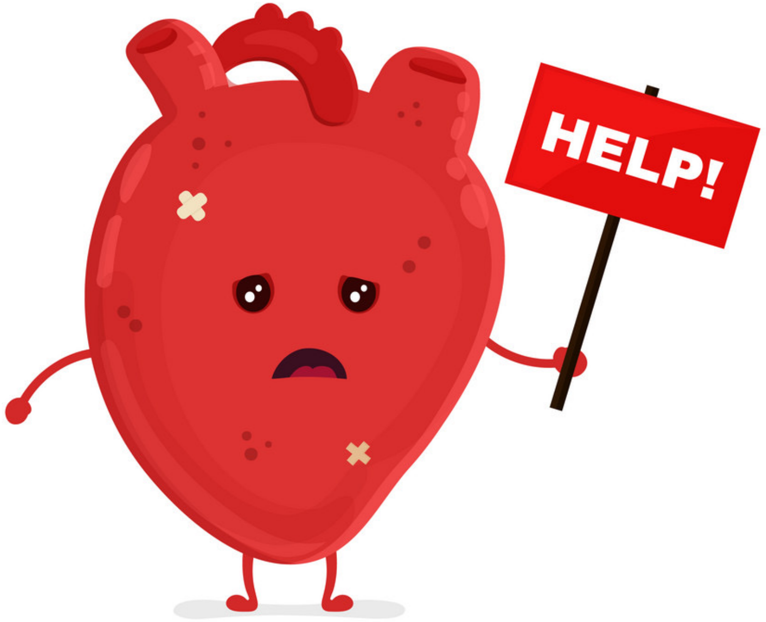


What we need

Oxygen delivery (DO_2)



Unloading



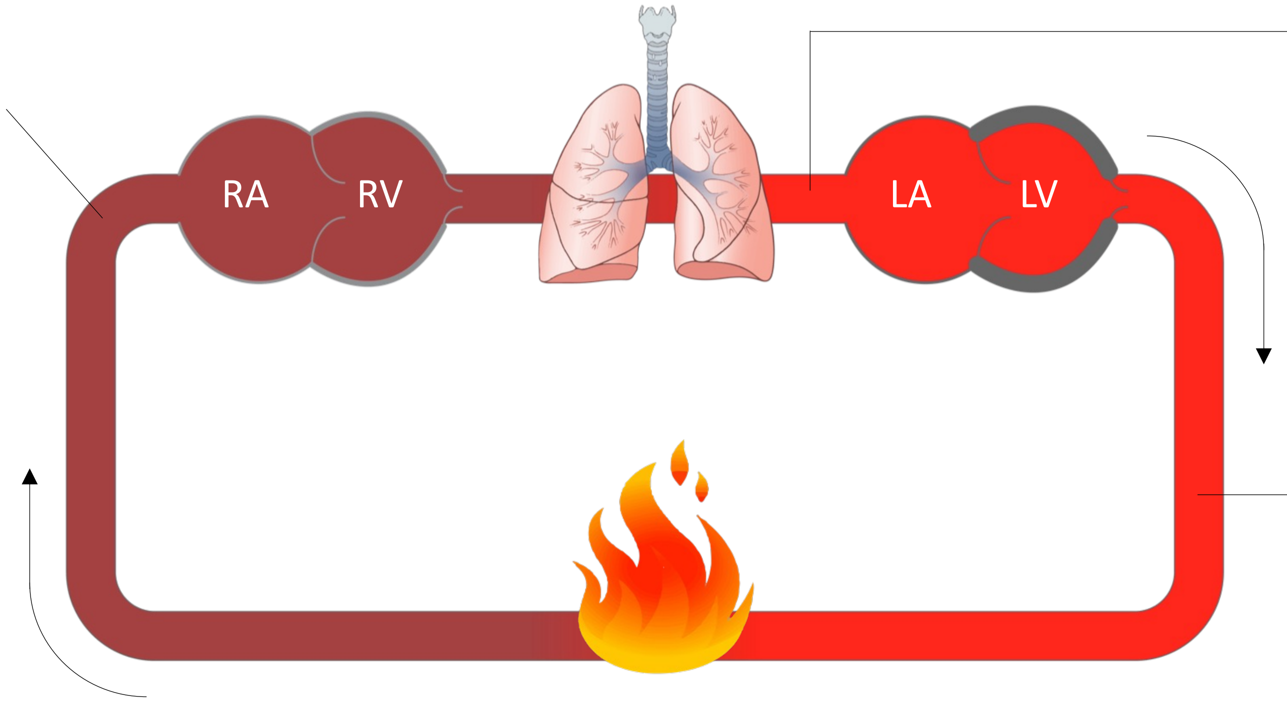
Normal Circulation

Oxygen uptake and consumption

O_2 Uptake
VO_2 = 120 ml/min/m^2

O_2Delivery > O_2 Consumption
Normal ratio VO_2/DO_2 = 1/5

Arterial O_2 Content
Determined by Hgb and PO_2
Normal Hgb 15, 100% O_2 sat
O_2 content = 20 ml/dl



Cardiac Output
Normal resting cardiac index is 3 L/min/m^2

Venous Return
Contains 80% of delivered O_2
Venous O_2 sat = 80%
Venous O_2 content = 16 ml/dl
AV O_2 cont. difference = 4 ml/dl

O_2 Delivery
Determined by arterial O_2 content times cardiac output.
DO_2 = (20 ml/dl) X (3 L/min/m^2)
= 600 ml/min/m^2

O_2 Consumption
Consumption = uptake = 120 ml/min/m^2
(1/5th of delivered)

Blood Oxygen Content

Measuring the gas content of a liquid

A liquid that contains gas

This 355 ml can of Coke contains 1,775 ml of dissolved CO_2 gas.

CO_2 content of Coke:

(1,775 ml CO_2) ÷ (335 ml Coke) = 5.3 ml/ml

or…

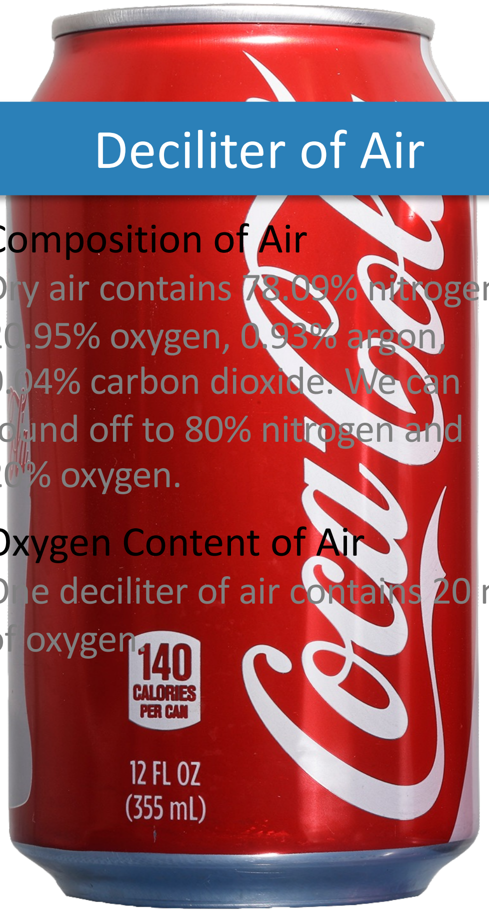
CO_2 $\text{Content}_{\text{Coke}}$ = 530 ml/100 ml

= 530 ml/deciliter

+ Mentos

Blood Oxygen Content

The deciliter (dl)



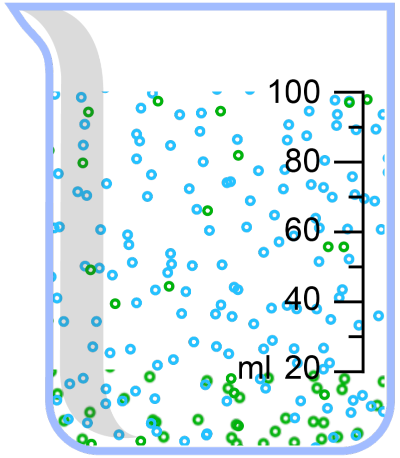
Deciliter of Air

Composition of Air

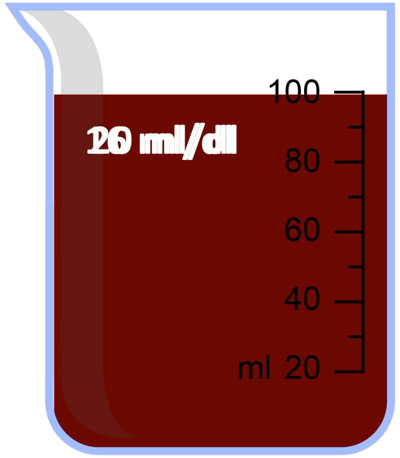
Dry air contains 78.09% nitrogen, 20.95% oxygen, 0.93% argon, 0.04% carbon dioxide. We can round off to 80% nitrogen and 20% oxygen.

Oxygen Content of Air

One deciliter of air contains 20 ml of oxygen.



One deciliter = 100 ml



One deciliter = 100 ml

Deciliter of Blood

Unique Ability to Bind Oxygen

Blood exists to transport oxygen.

Arterial Blood Oxygen Content

The oxygen content of normal arterial blood is 20 ml/dl.
C_aO_2 = 20 ml/dl

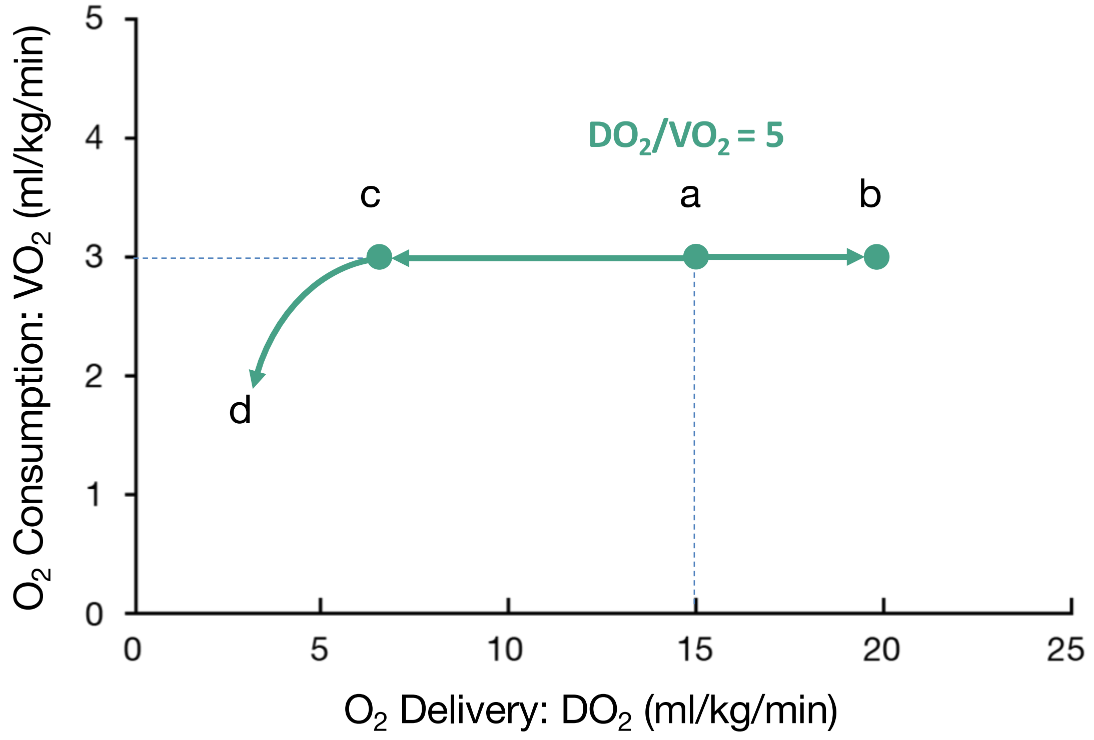
Venous Blood Oxygen Content

The oxygen content of normal venous blood is 16 ml/dl.
C_vO_2 = 16 ml/dl

Notice that venous blood still contains a lot of oxygen

Normal DO_2/VO_2 Homeostasis

Oxygen delivery exceeds consumption by 5:1

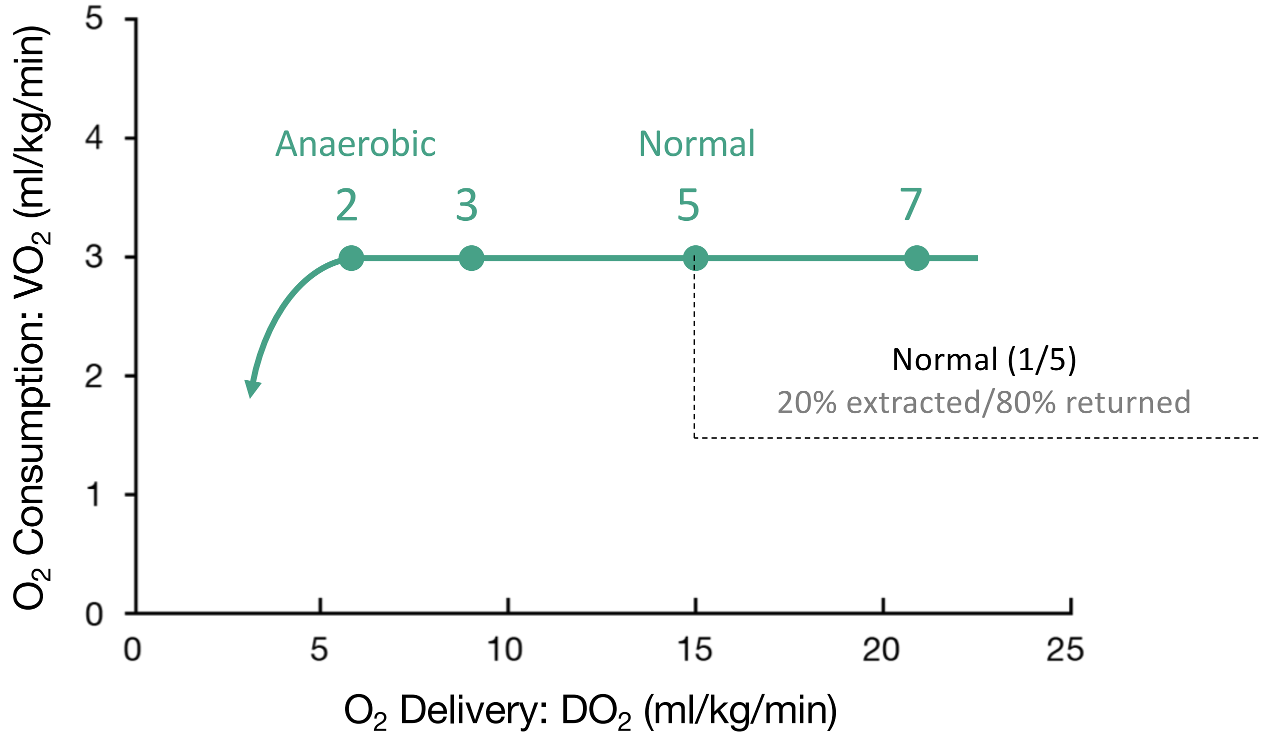


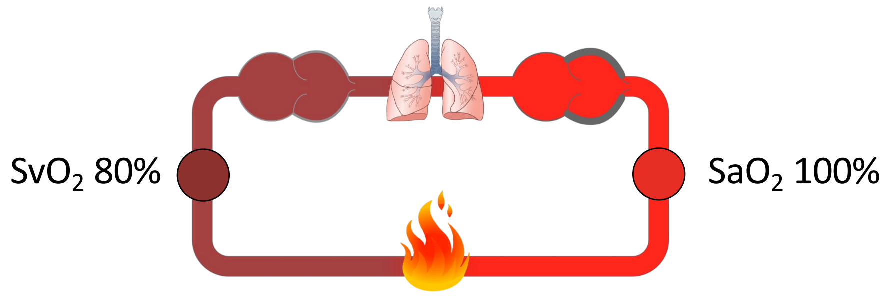
a) **Normal O_2 Delivery**
At rest, oxygen delivery exceeds consumption 5X.

1. Adaptation based on: Bartlett RH (2012). Physiology of Extracorporeal Life Support. In: Annich, Bartlett et al. (Eds).,ECMO Extracorporeal Life Support in Critical Care 4th Edition.

DO_2/VO_2 Ratio

At rest, normal oxygen delivery exceeds consumption by 5:1 ($DO_2/VO_2 = 5$)



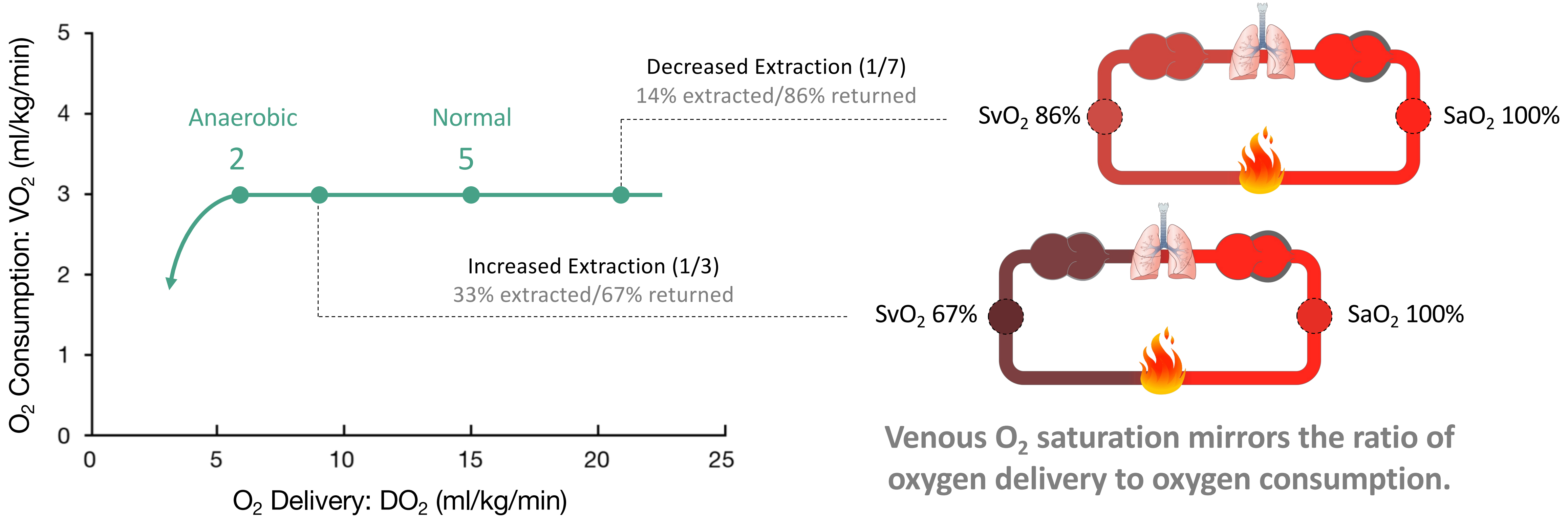


Venous O_2 saturation mirrors the ratio of oxygen delivery to oxygen consumption.

1. Adaptation based on: Bartlett RH (2012). Physiology of Extracorporeal Life Support. In: Annich, Bartlett et al. (Eds).,ECMO Extracorporeal Life Support in Critical Care 4th Edition.

DO_2/VO_2 Ratio

Oxygen delivery exceeds consumption by 5:1 ($DO_2/VO_2 = 5$)



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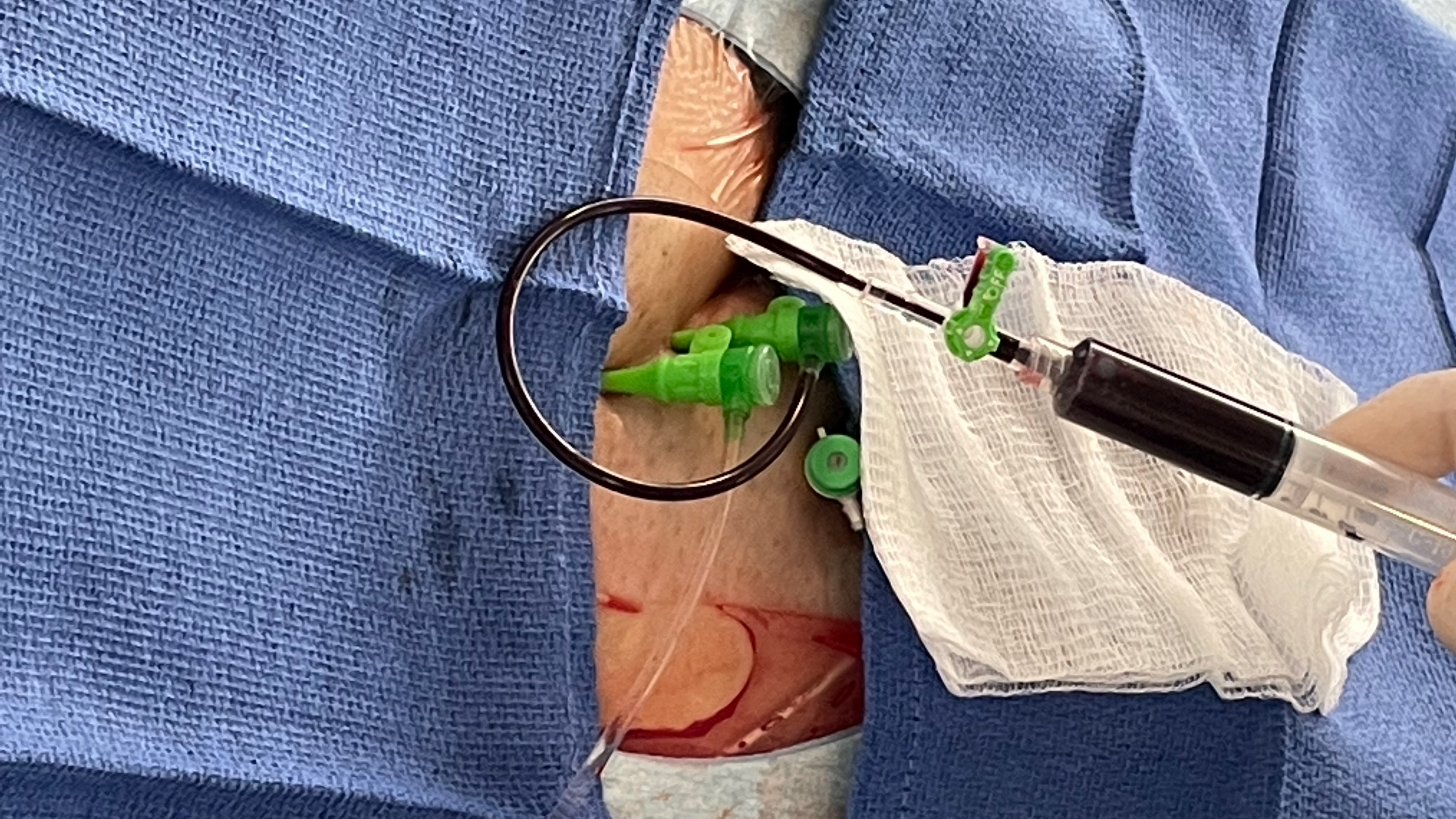
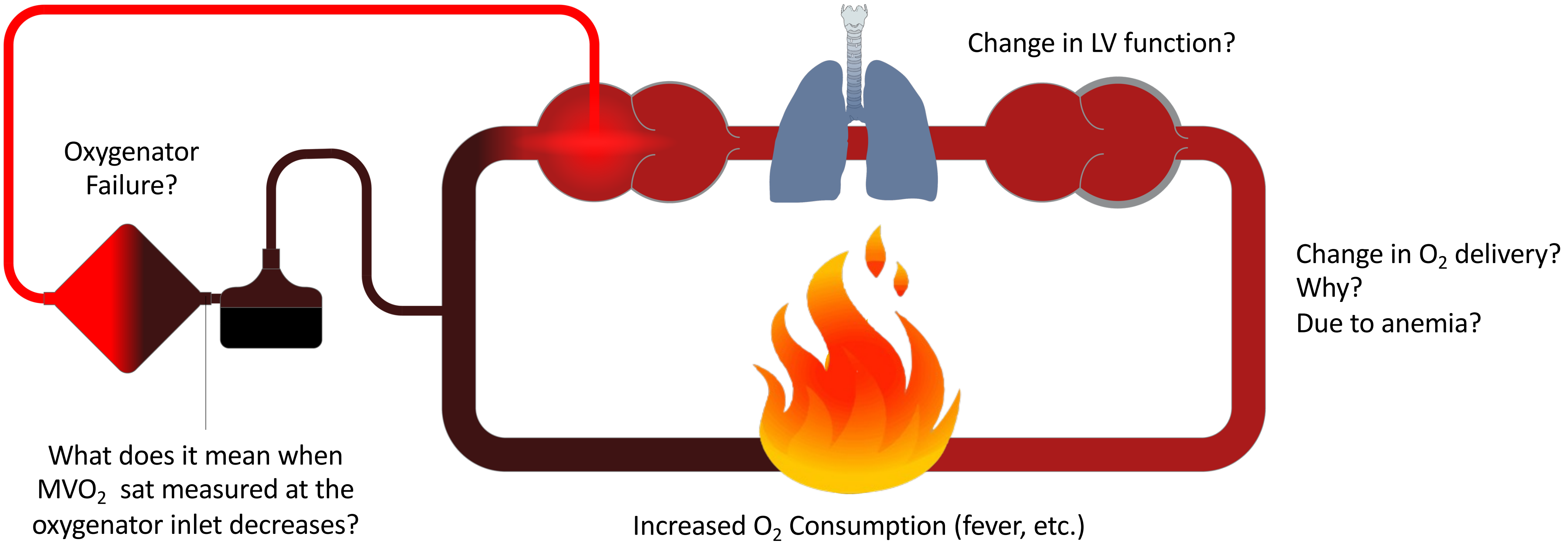


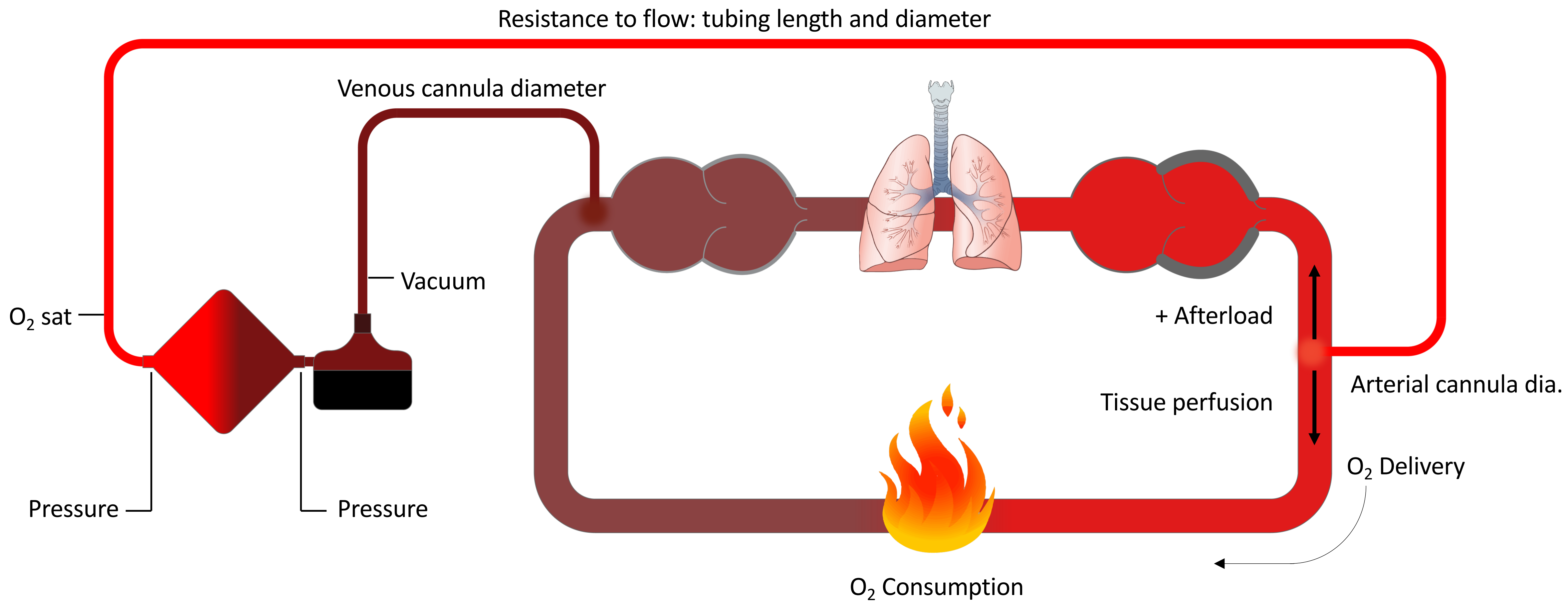
Intuitive Understanding

V-V ECMO circuit designed to minimize recirculation



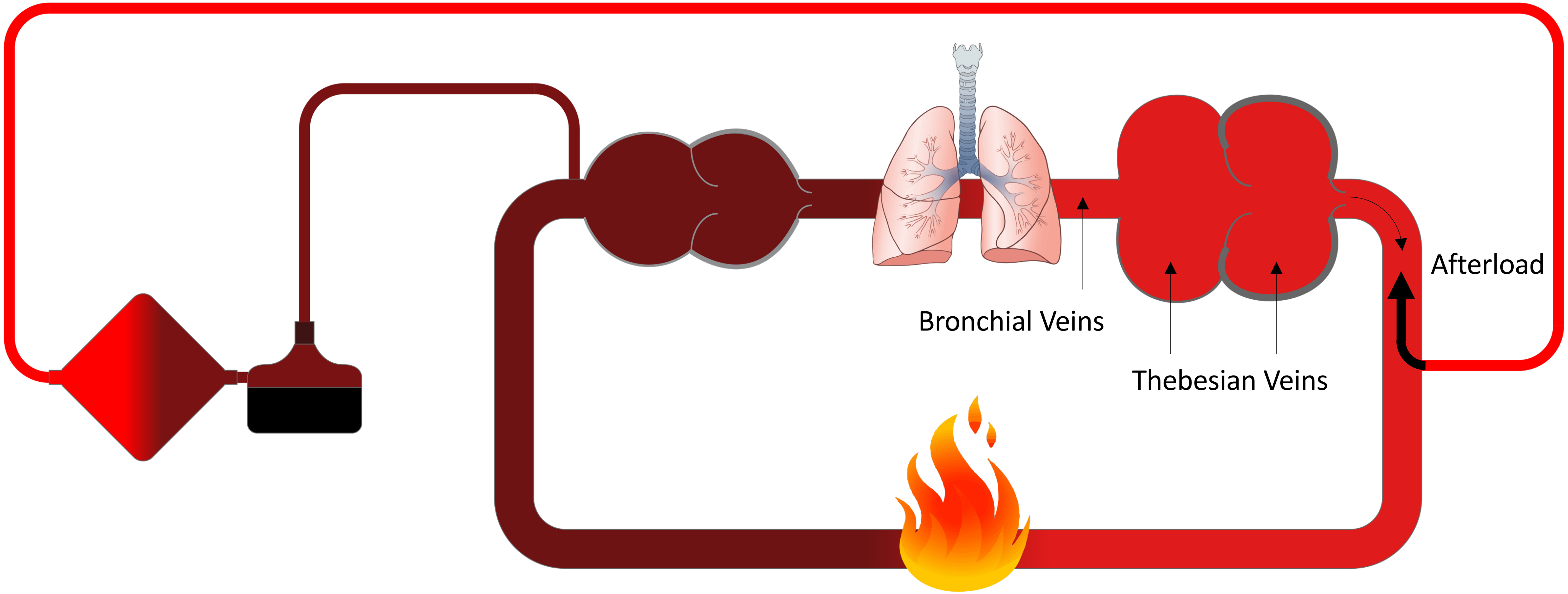
Physiology and Circuit Design

Typical V-A ECMO circuit considerations



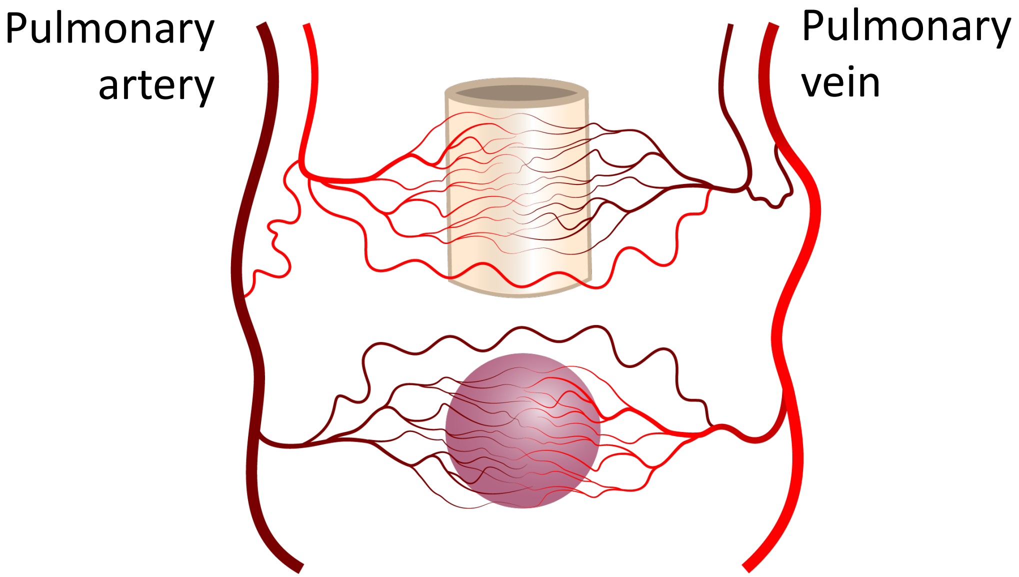
Physiology and Circuit Design

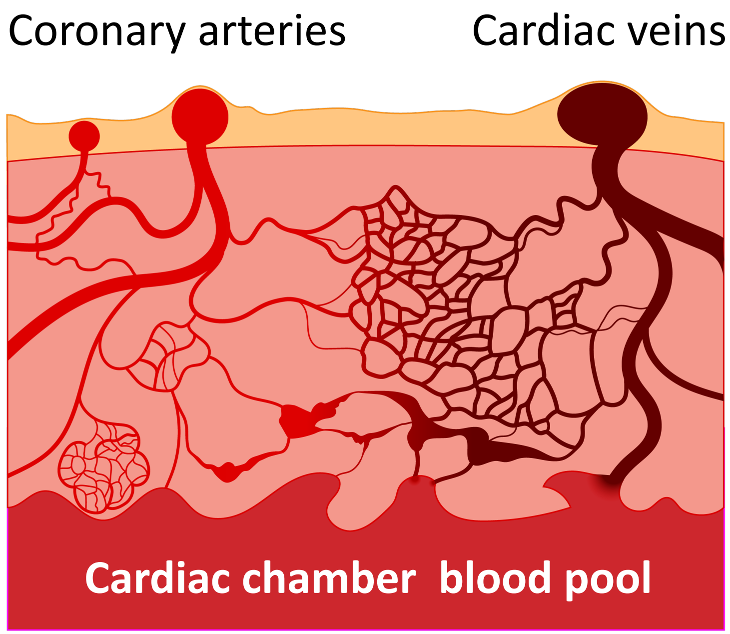
V-A ECMO in severe LV failure: organ perfusion at the expense of cardiac distention

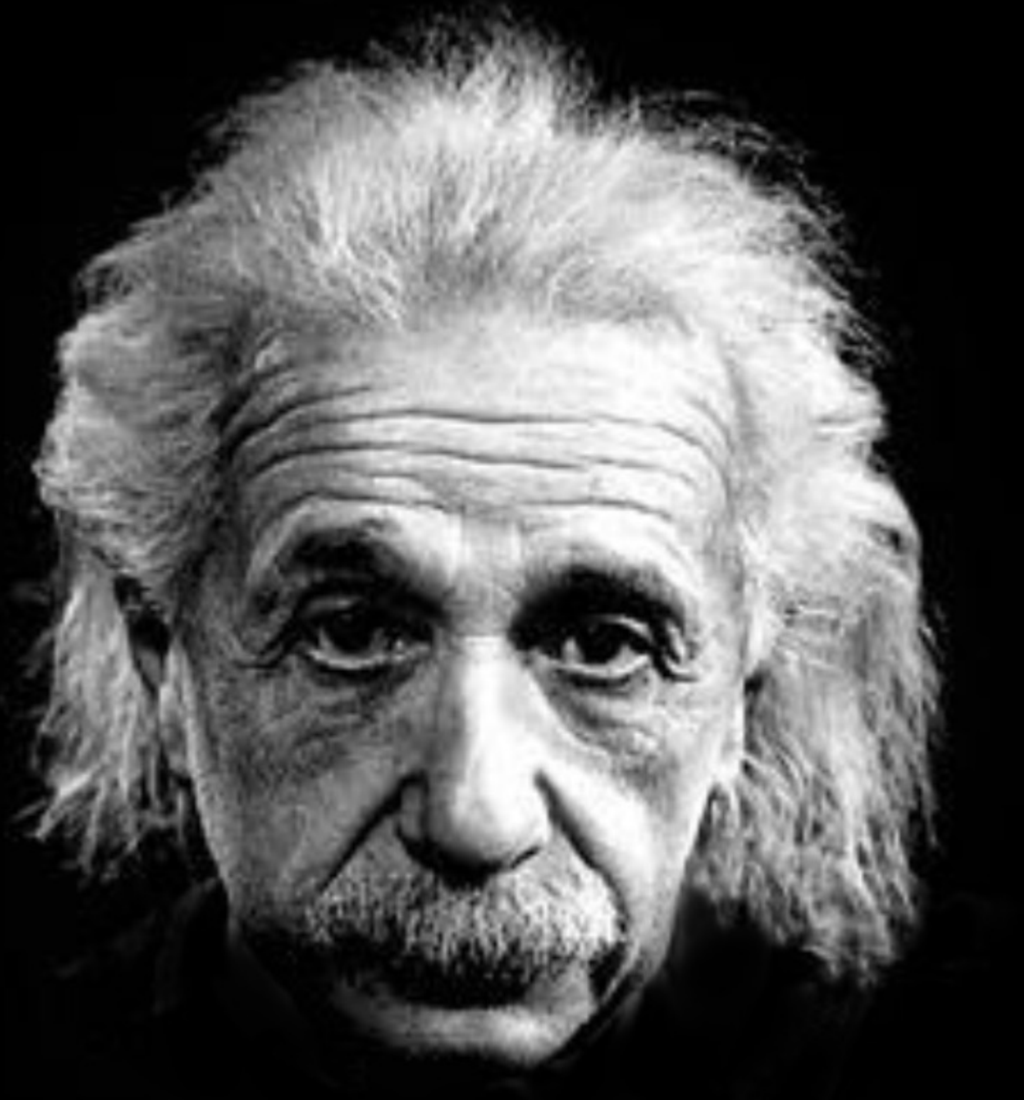


Thebesian and Bronchial Vessels

Return of systemic venous blood to the left heart causes distention







It’s simple…
choose the right tool.

Case 1 Presentation

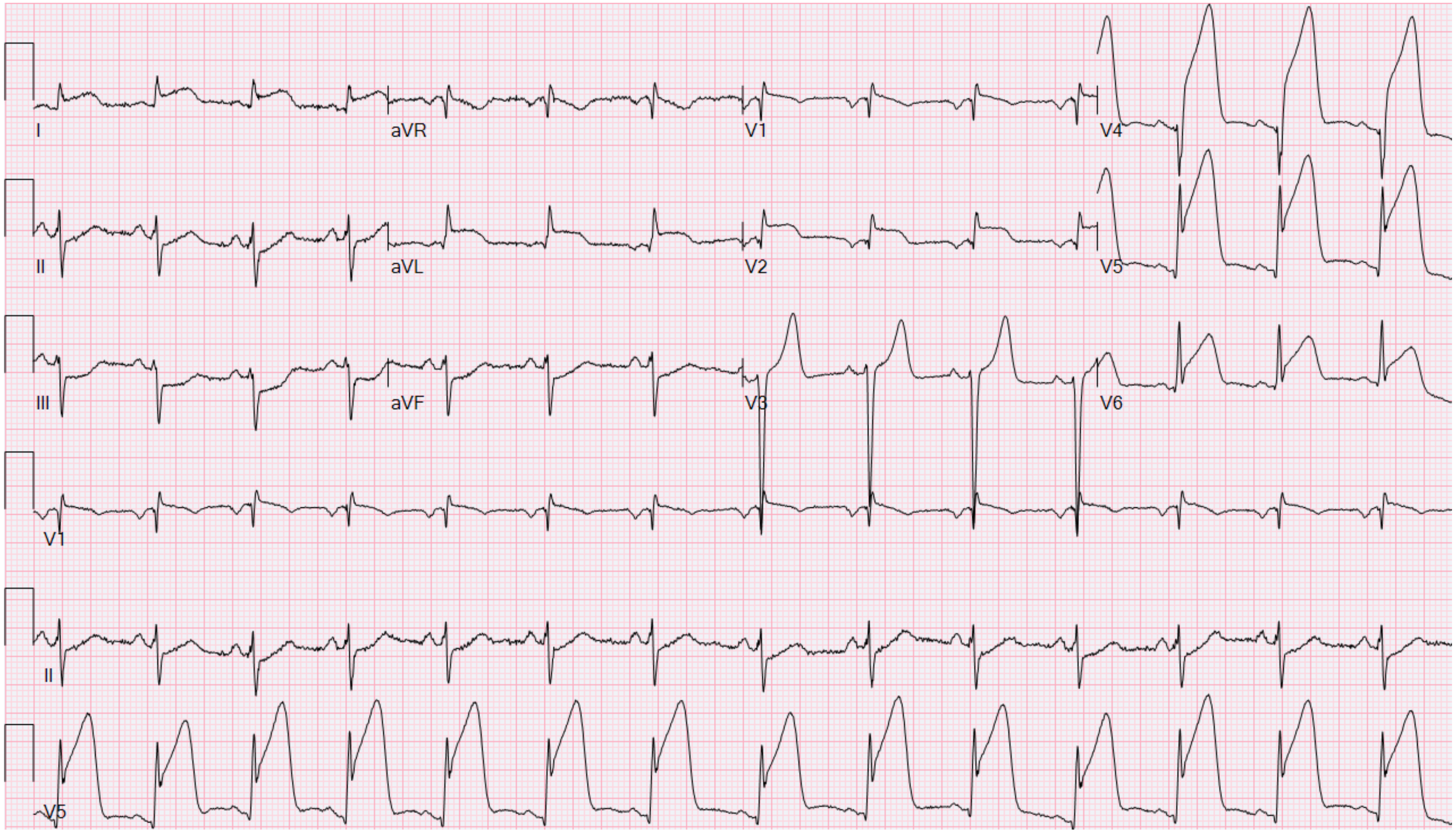
STEMI ACTIVATION

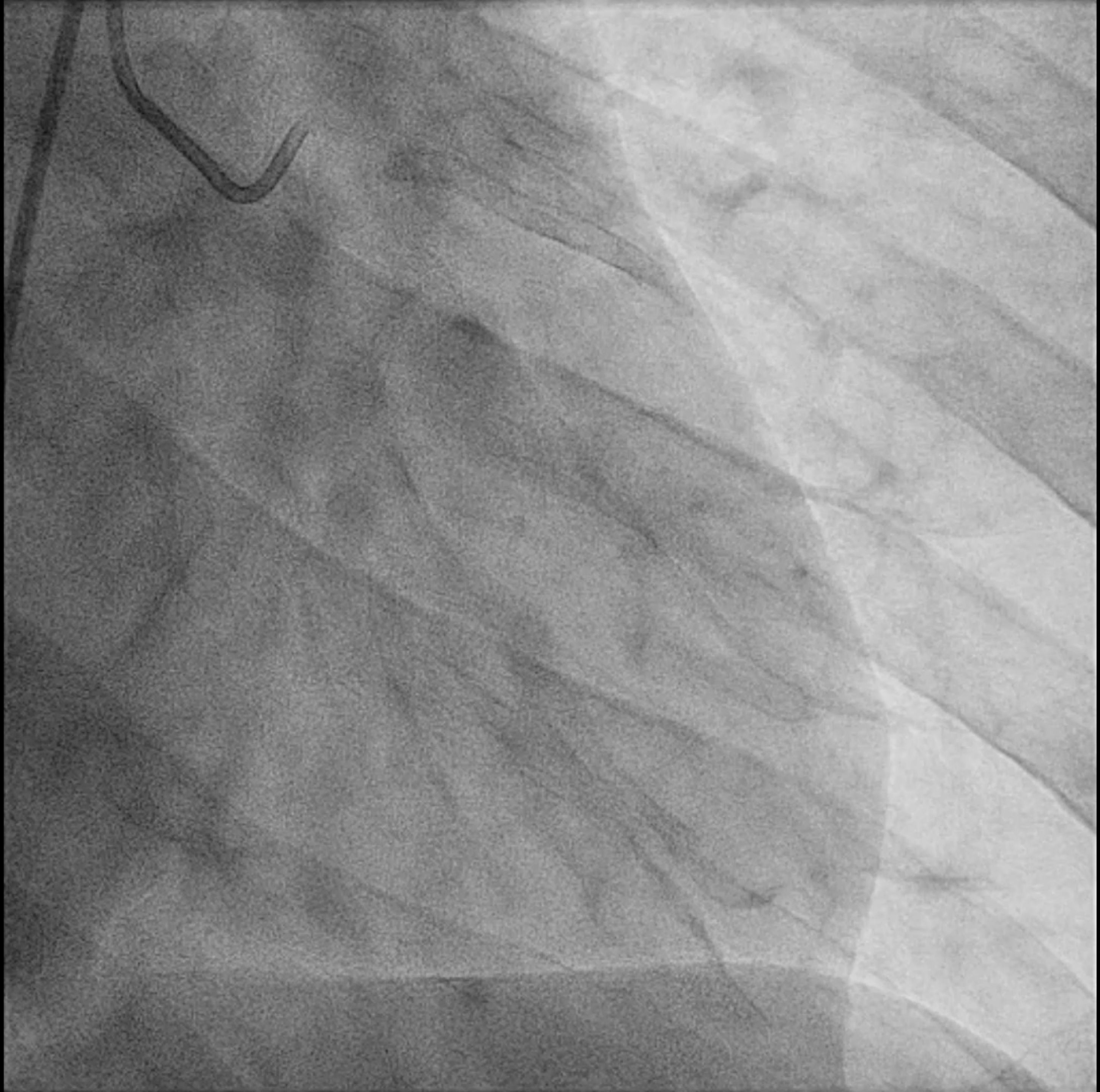
57-year-old male directly to Cath Lab per STEMI protocol

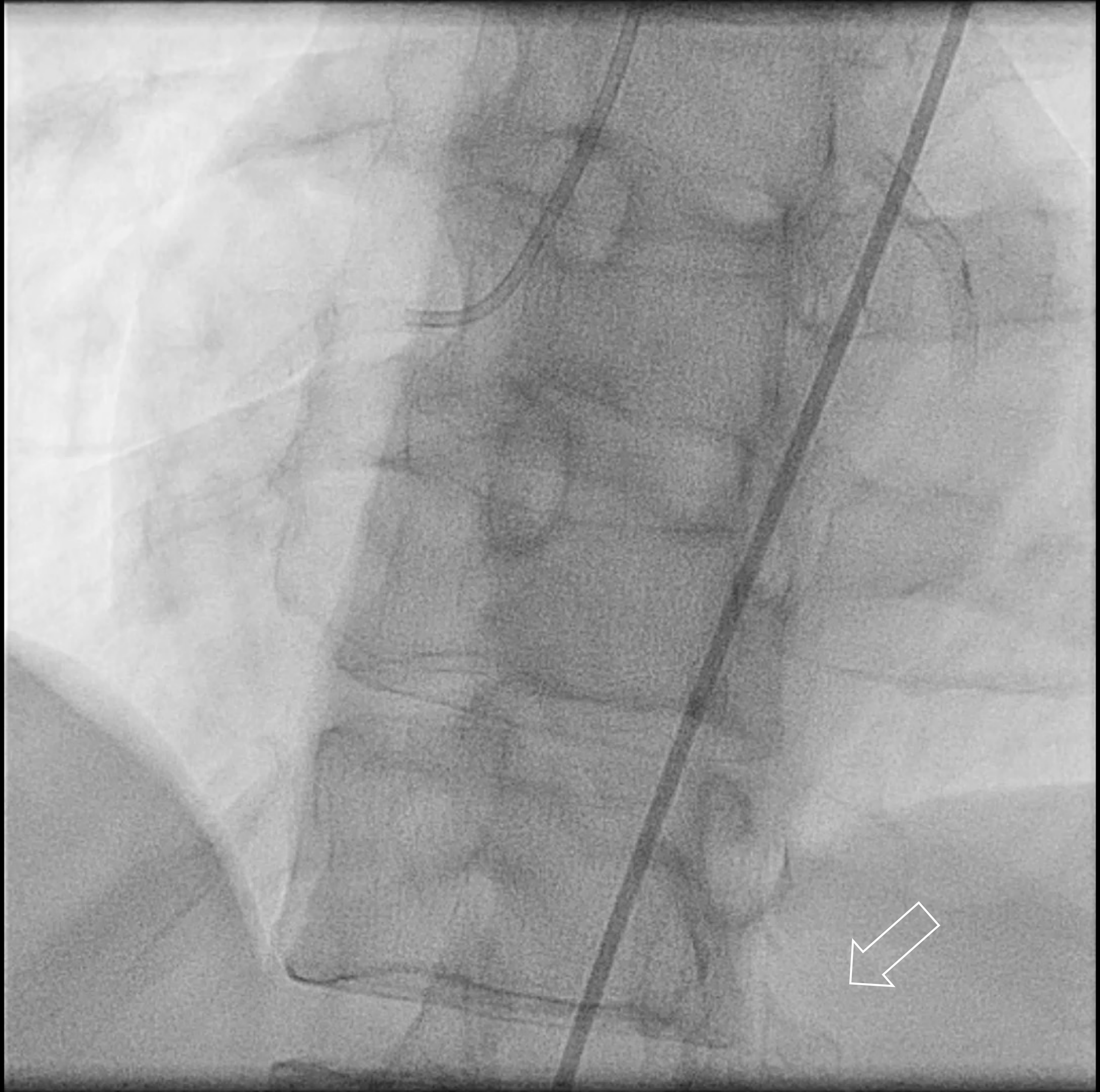
- Awake
- Chest pain
- Diaphoresis
- Dyspnea
- SBP 90 mmHg
- Norepinephrine drip
- Early pulmonary edema

Case 1 Presentation

Acute MI with cardiogenic shock—initial ECG







Case 1 Presentation

Acute MI with cardiogenic shock

APPROACH

Rapid reperfusion with minimum door-to-balloon time (time is muscle)

STRATEGY

- RCA first
- Simple intervention
- Stent placement within minutes
- Restore hemodynamic stability
- Avoid the delay and risks of MCS

Case 1 Presentation

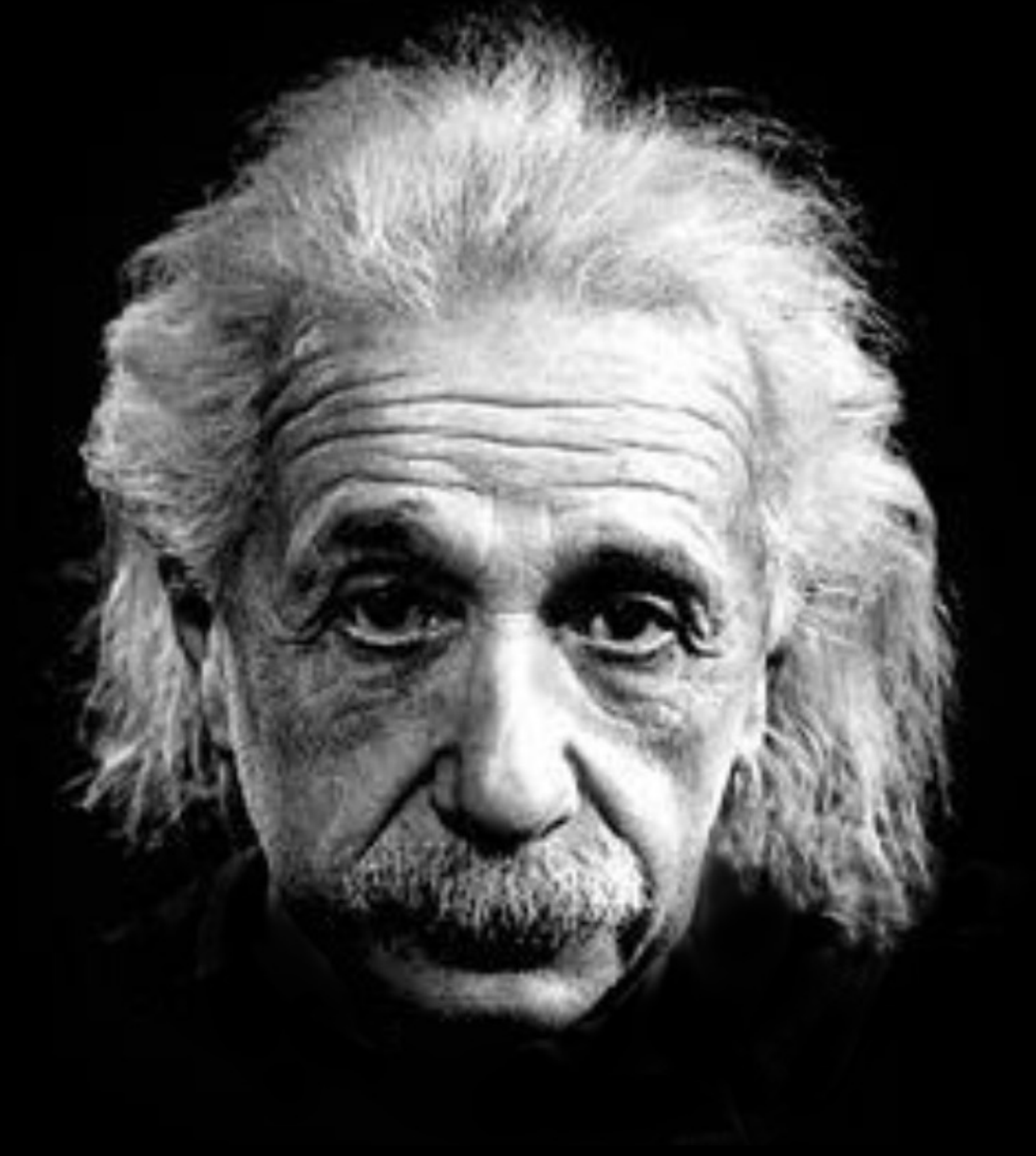
Acute MI with cardiogenic shock

5 MINUTES LATER…

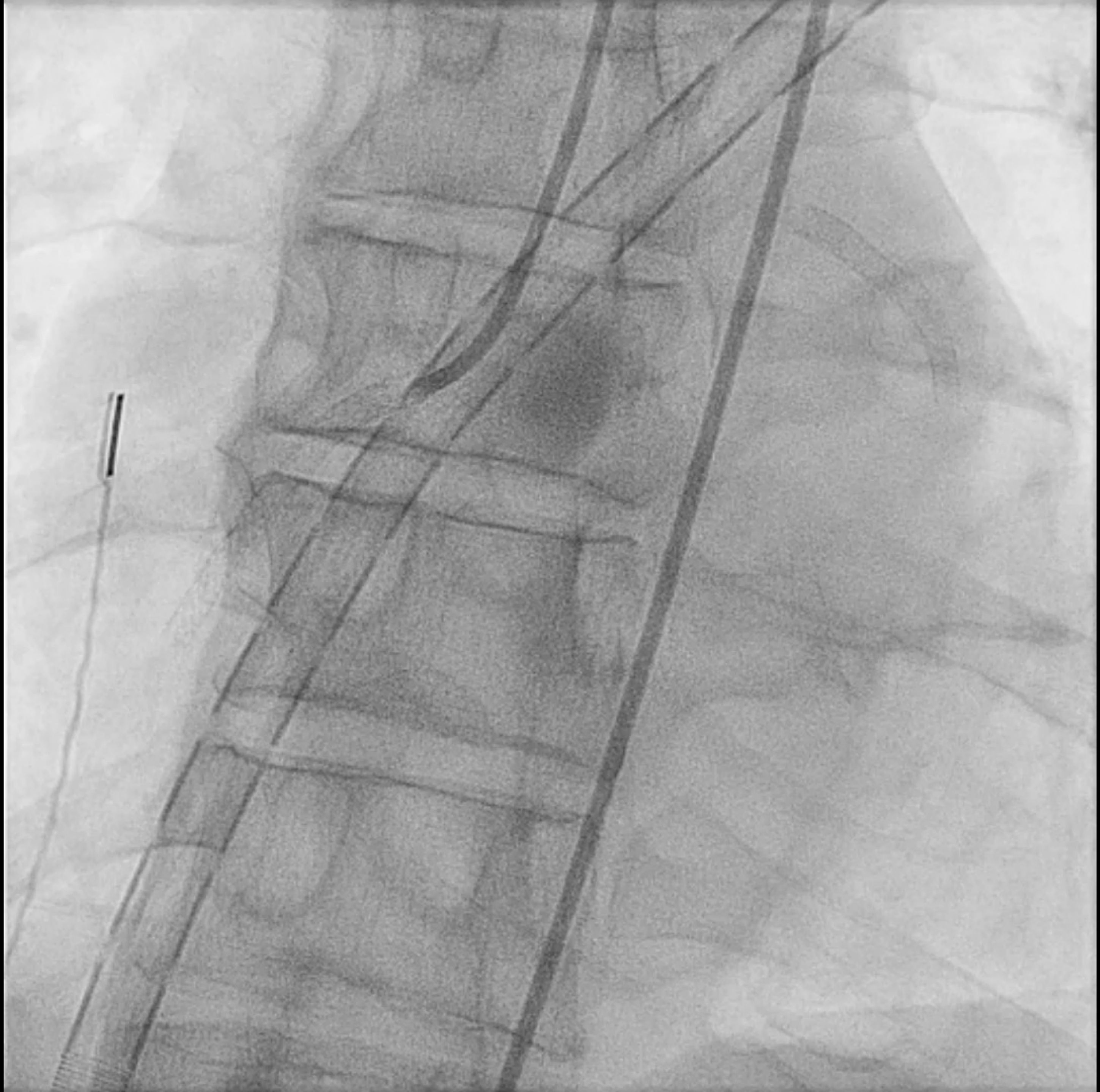
RCA stent placed easily

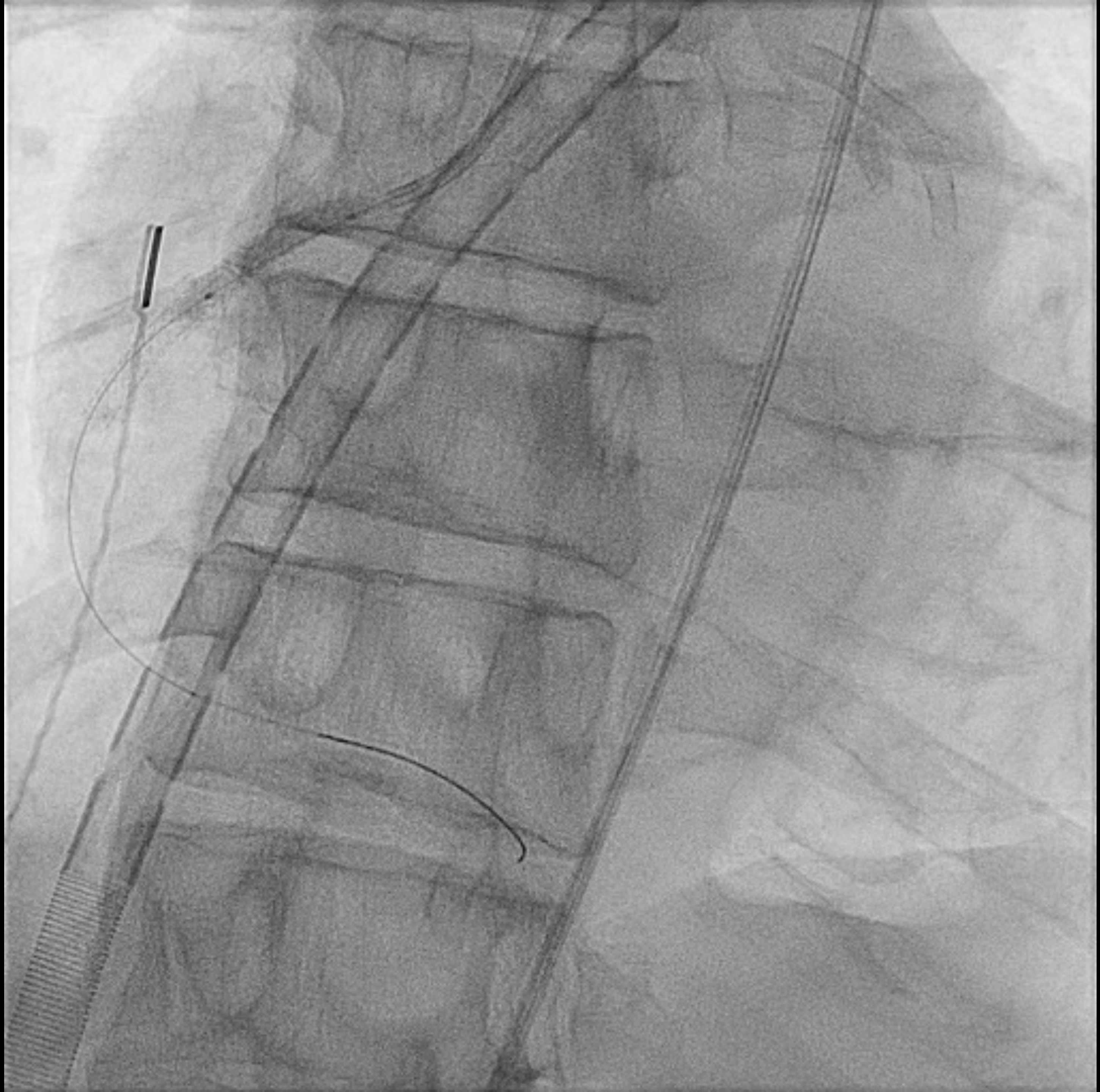
RESULT

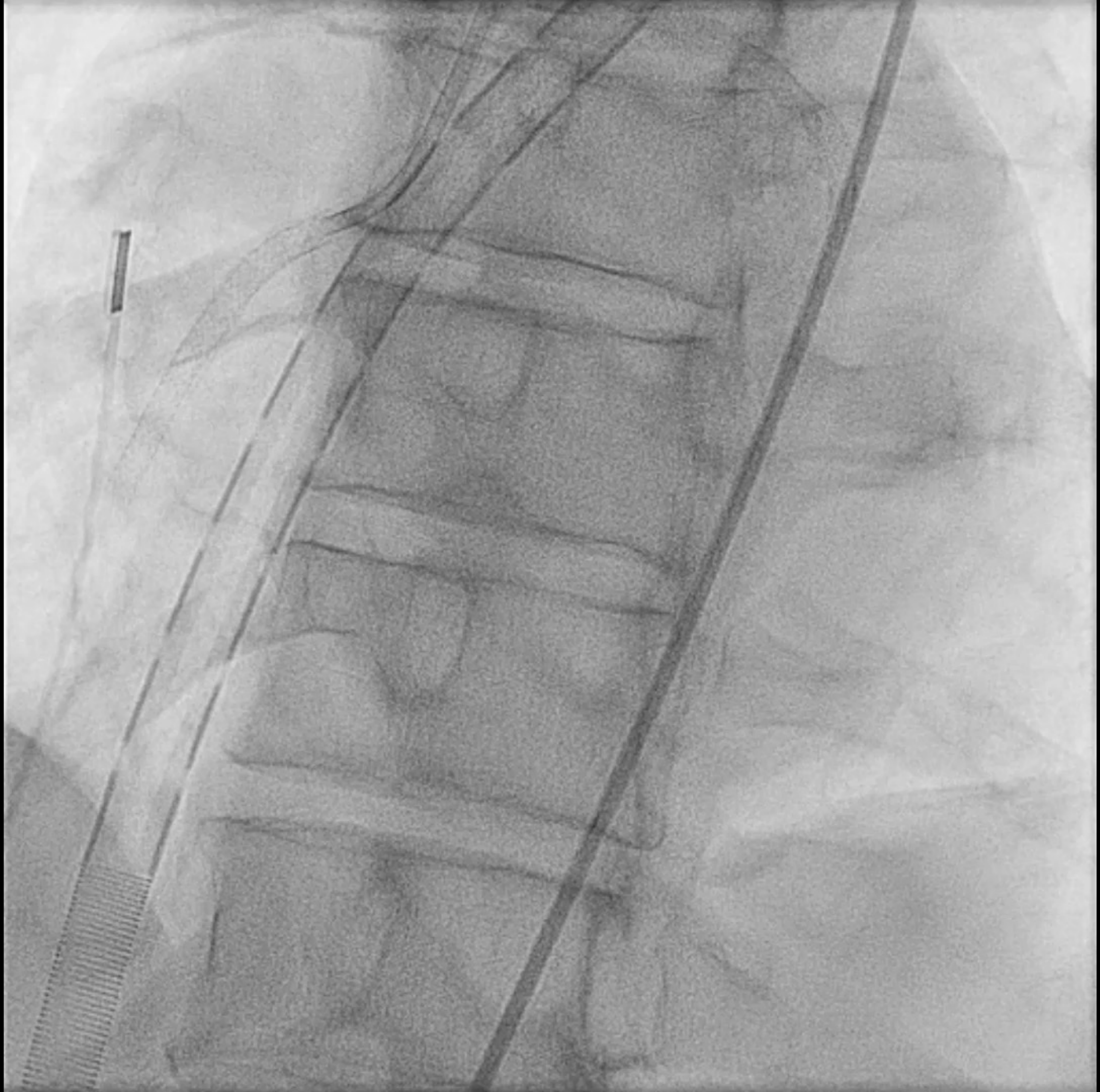
- Rapid hemodynamic deterioration
- SBP 40 mmHg despite bolus doses of epinephrine
- Intubation
- CPR
- Emergency ECMO with LA drain

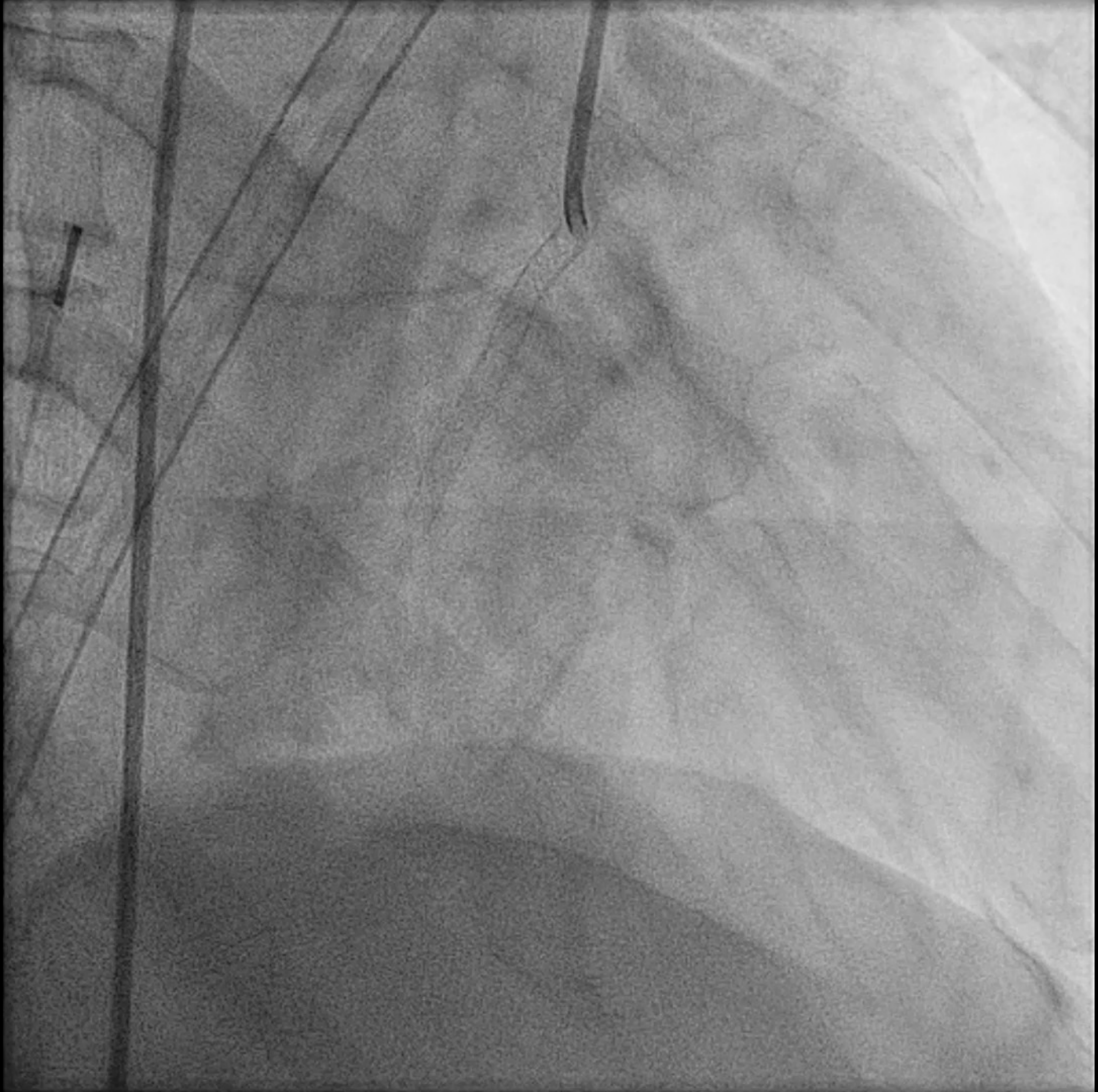


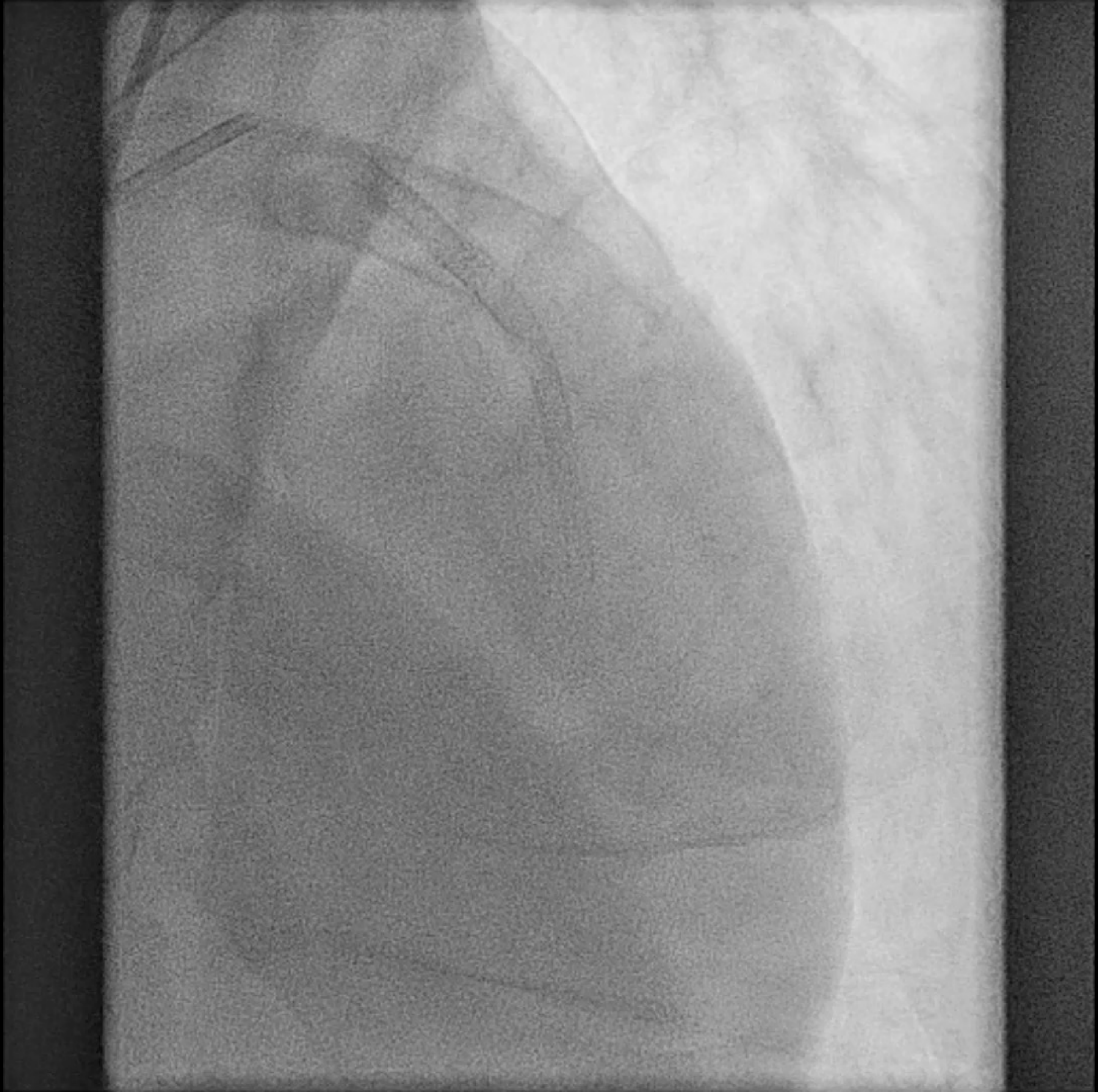
That was not the right tool.

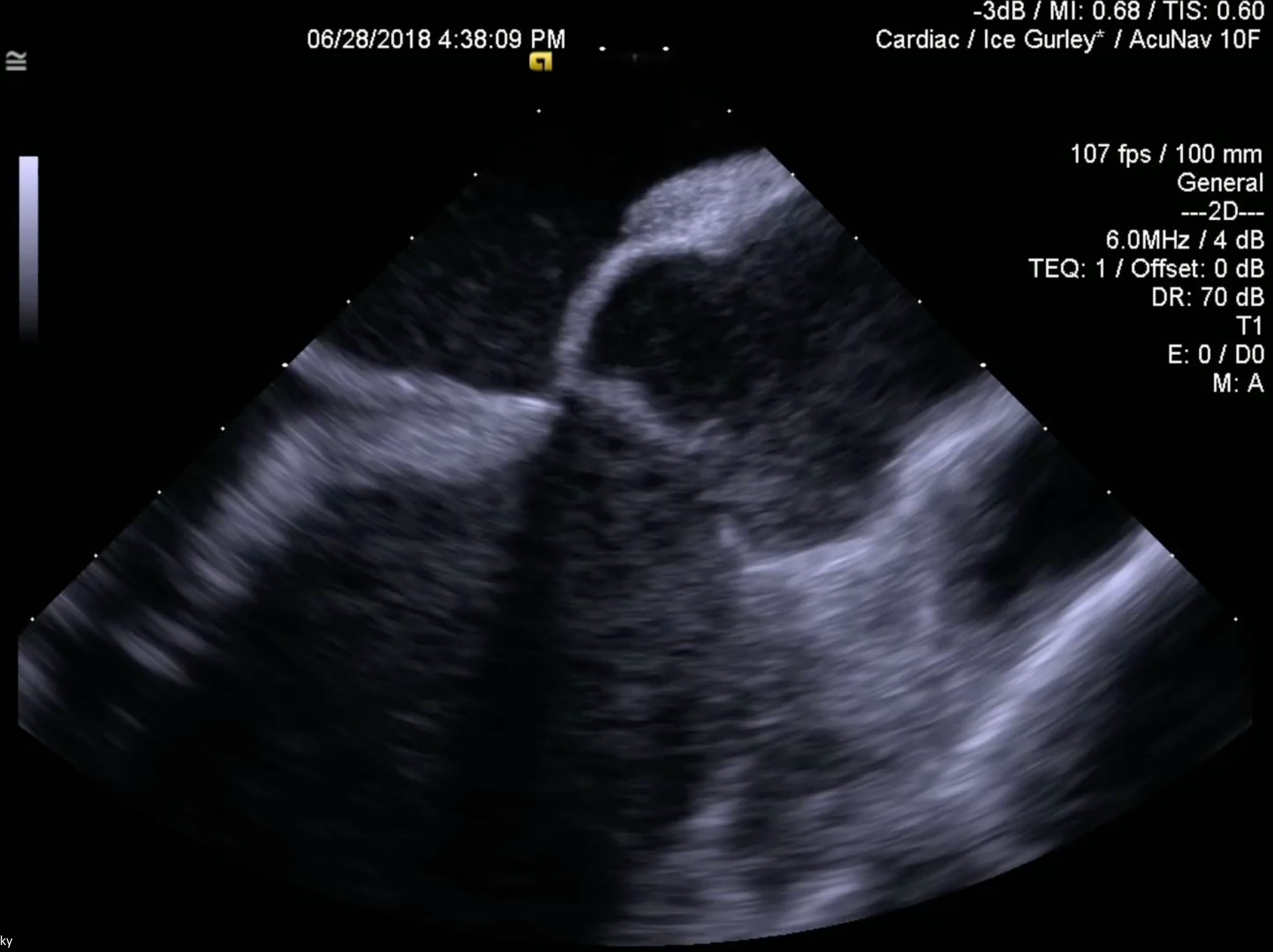


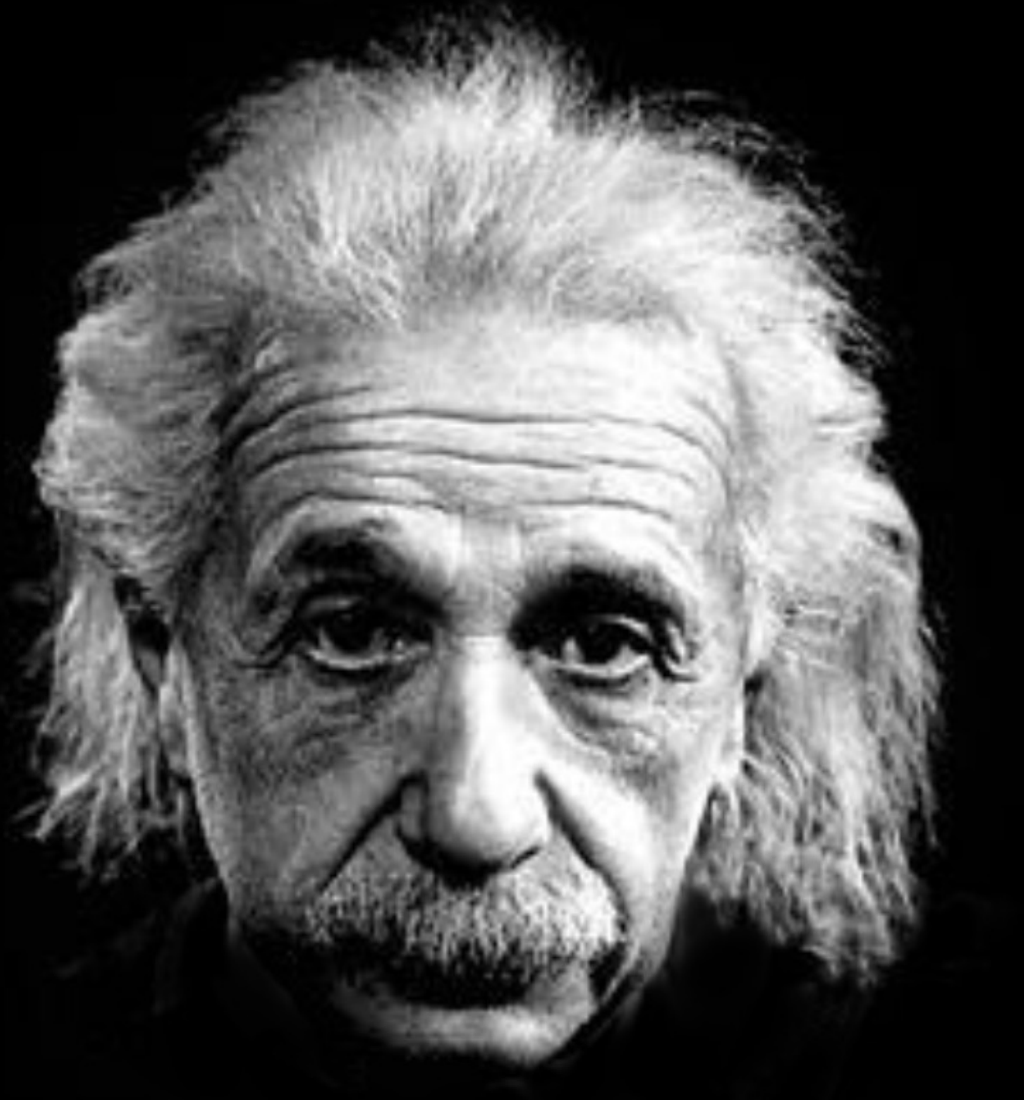








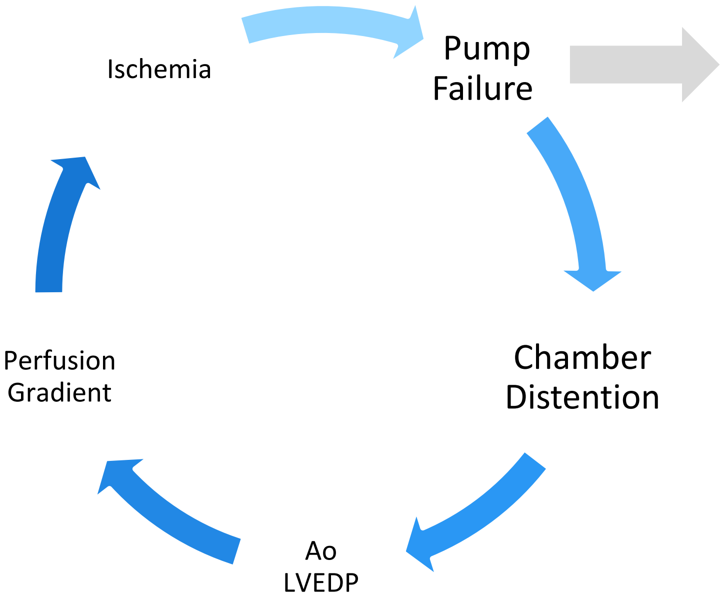

-3dB / MI: 0.68 / TIS: 0.60
06/28/2018 4:38:09 PM
Cardiac / Ice Gurley* / AcuNav 10F
107 fps / 100 mm
General
---2D---
6.0MHz / 4 dB
TEQ: 1 / Offset: 0 dB
DR: 70 dB
T1
E: 0 / D0
M: A



And don’t spend too much time thinking.

Cardiogenic Shock in AMI: Two Cascades

Myocardial ischemia initiates a cascade of events leading to progressive cardiac and metabolic dysfunction[1]



Cardiac

- LOW CARDIAC OUTPUT
- RETAINED LV VOLUME
- CHAMBER DISTENTION
- LV WALL STRESS
- LV STROKE WORK
- OXYGEN DEMAND
- MYOCARDIAL ISCHEMIA
- INCREASED LVEDP
- PULMONARY EDEMA
- ARTERIAL HYPOXEMIA

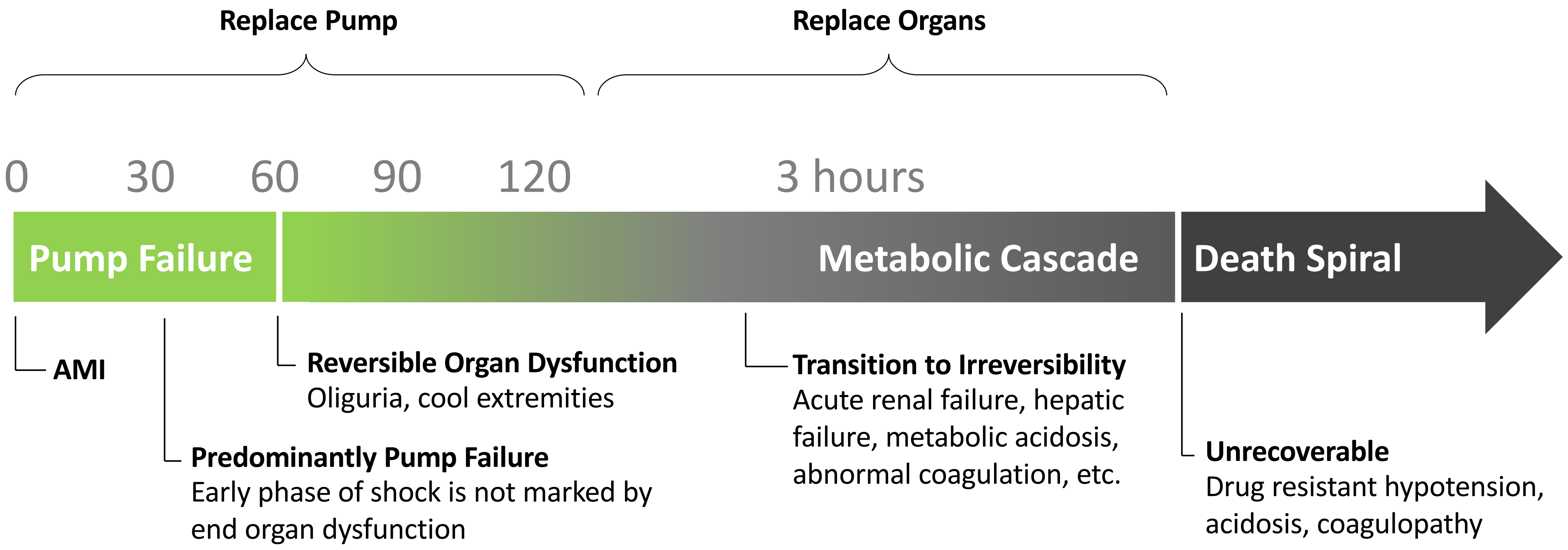
Metabolic

- O_2 DELIVERY
- TISSUE ISCHEMIA
- ACIDOSIS
- VASOPLEGIA
- HYPOTENSION
- RENAL FAILURE
- VOLUME OVERLOAD
- SHOCK LIVER
- COAGULOPATHY
- IRREVERSIBILITY

1. Reynolds HR, Hochman JS: Cardiogenic shock: current concepts and improving outcomes. Circulation.2008;117(5):686–97.

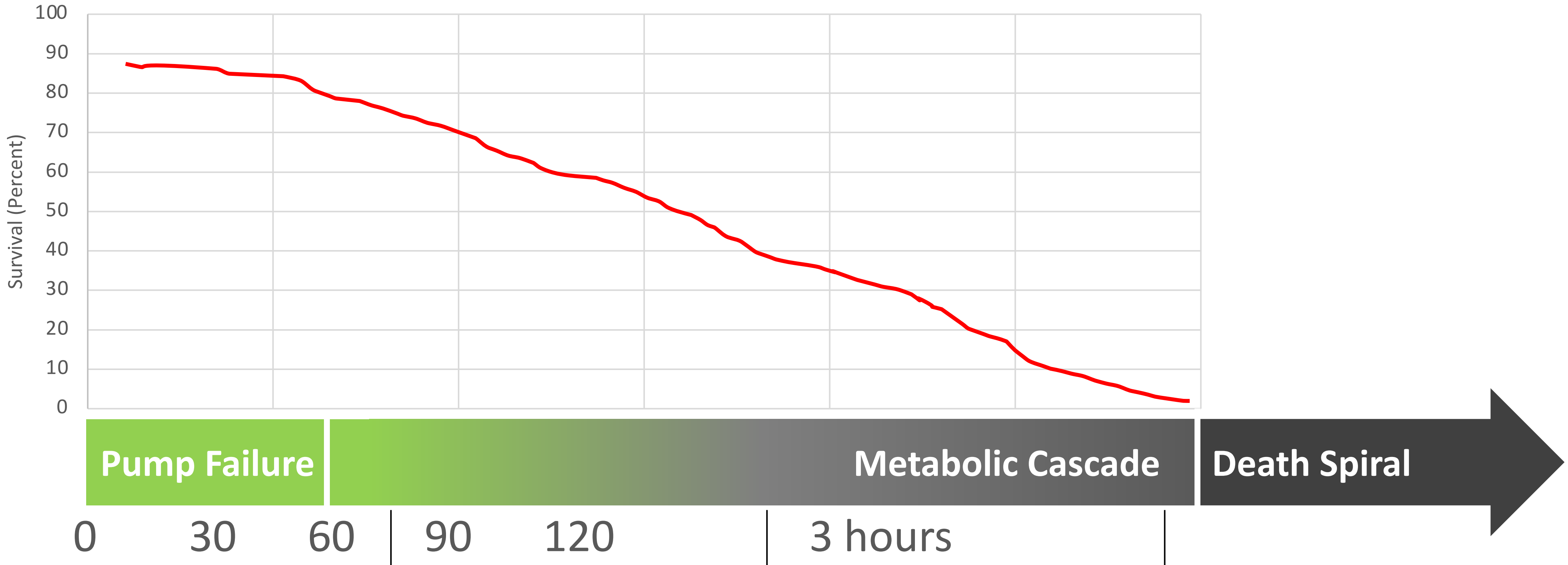
Organ Perfusion in Cardiogenic Shock

Transition from predominantly pump failure to predominantly multiple organ failure



Avoiding the Metabolic Cascade

The importance of early intervention in Acute MI with Cardiogenic Shock

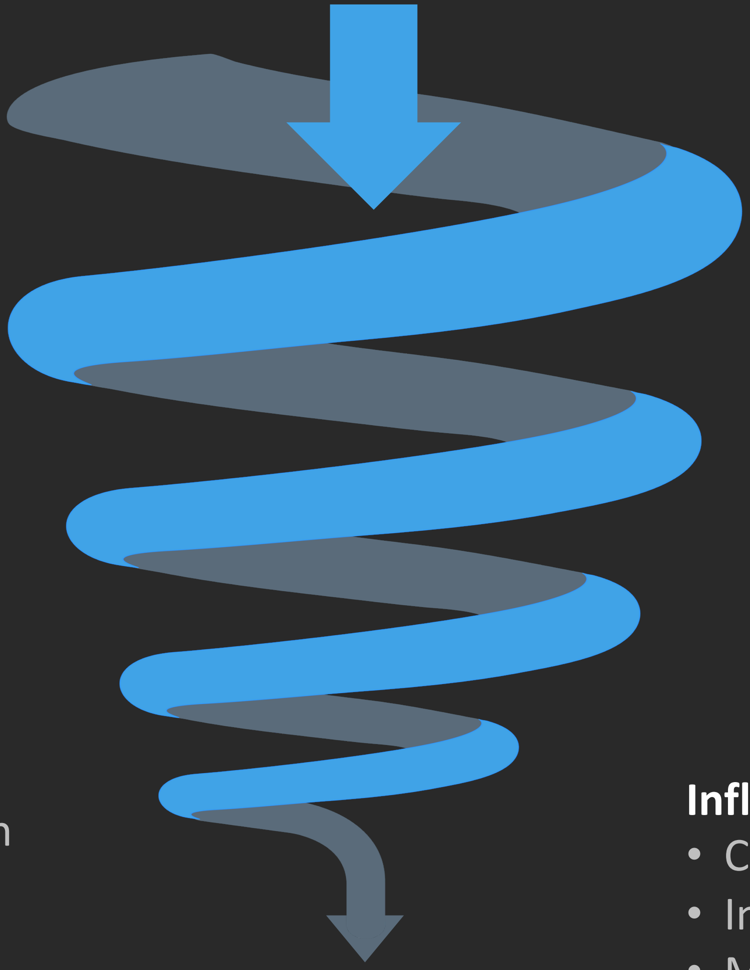


Effective
Early and aggressive deployment of resources

Questionable
Decision rules needed for appropriate use of MCS

Futile
Do not expend MCS resources

Acute RV Afterload



RV Failure Cascade
- ↑ RV myocardial wall stress
- ↑ RV myocardial O_2 demand
- ↑ RV Ischemic injury
- ↓ RV contractility

LV Performance Cascade
- ↓ RV output
- ↓ LV preload
- ↓ Global CO

Shock Cascade
- Hypotension
- Organ hypoperfusion
- Metabolic acidosis
- Obstructive shock

Hypoxemia Cascade
- Intrapulmonary shunting
- Myocardial ischemia
- ↓ O_2 delivery

Neuro-hormonal Cascade
- ↑ Catecholamines
- ↑ RV O_2 demand
- RV myocardial ischemia
- Myocardial inflammation
- Ischemic RV injury

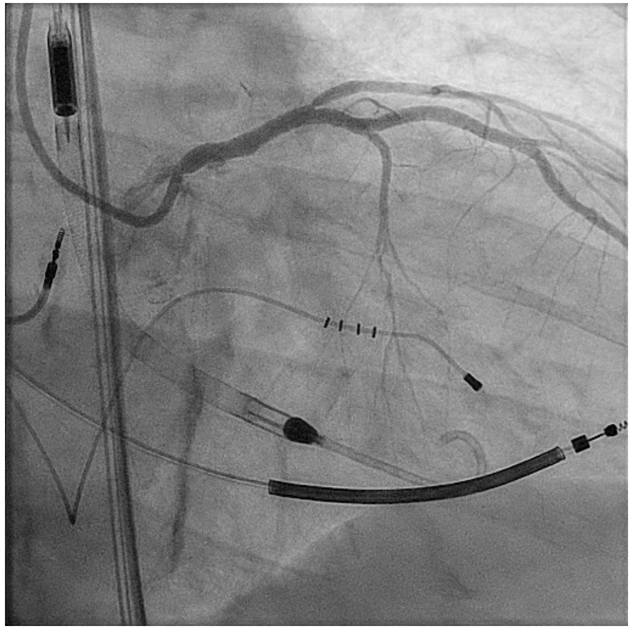
Inflammation Cascade
- Catecholamines + ischemia
- Inflammatory infiltrates
- Myocardial cell death

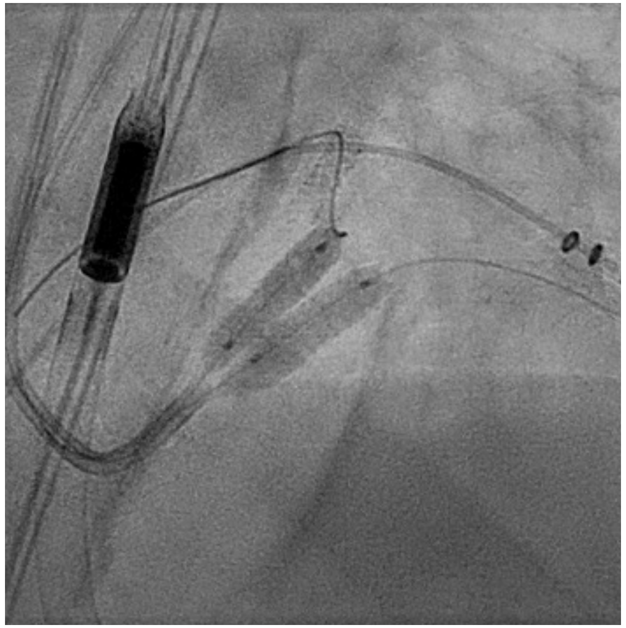
Death

1. Cohen AT, et al; VTE Impact Assessment Group in Europe (VITAE). Venous thromboembolism (VTE) in Europe. The number of VTE events and associated morbidity and mortality. Thromb Haemost 2007;98:756764.

Impella Support: High-risk PCI

Impella CP can provide nearly full hemodynamic support on a short-term basis

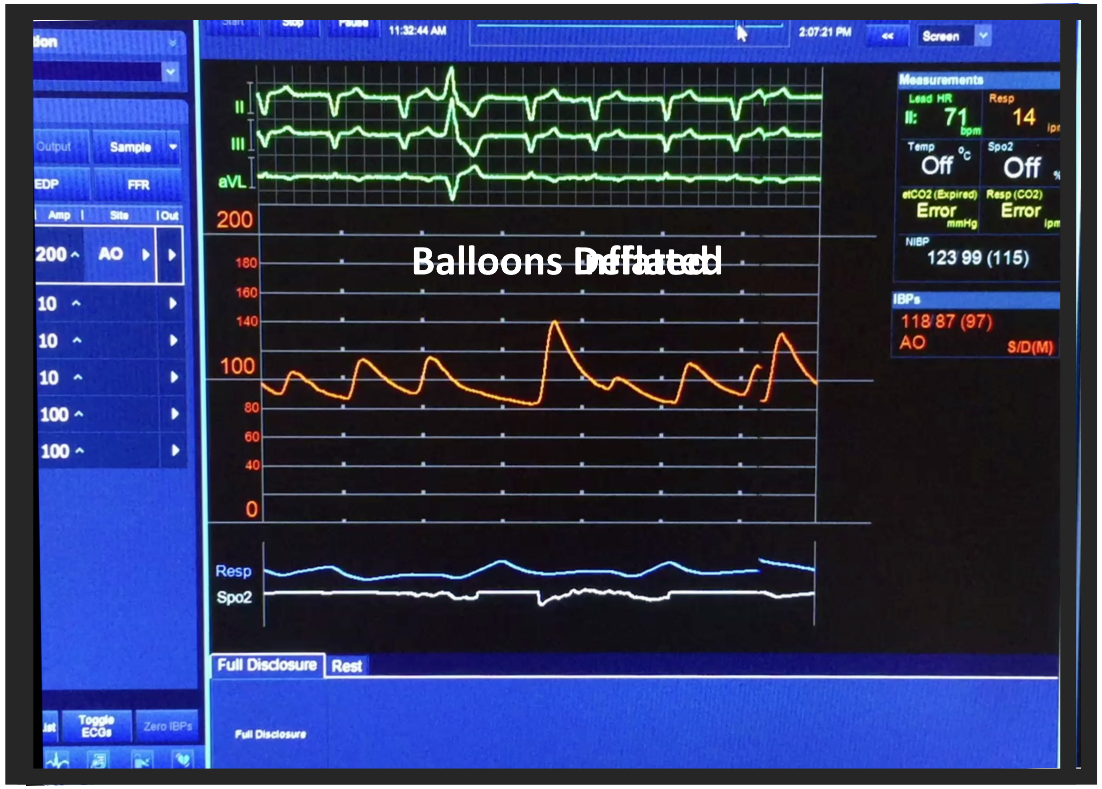




Temporary interruption of all coronary flow

- Last remaining vessel: ostial LAD + Cx oclusion
- Chronic LVEF 20% despite cardiac resynchronization therapy
- Unstable angina
- Surgical revascularization declined due to risk

Effective hemodynamic support



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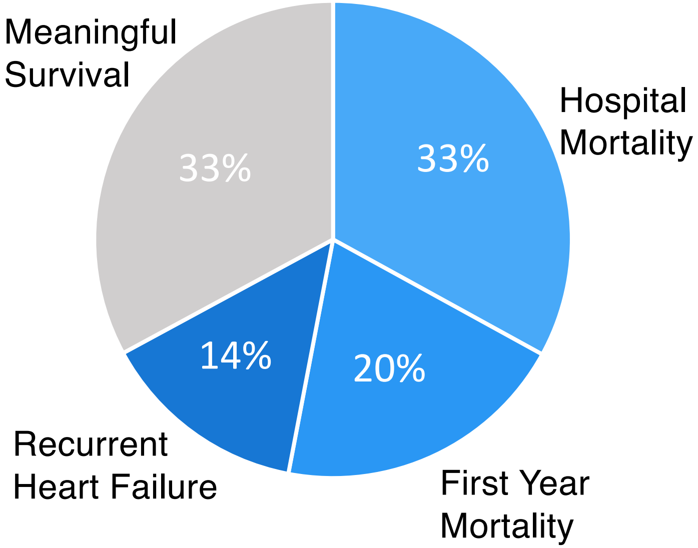
AMI with Shock: Morbidity and Mortality

Cardiogenic shock is a growing cause of early and late mortality following acute myocardial infarction (AMI)[1,2]

OUTCOMES OF AMI WITH SHOCK

Early Mortality
33%
Die in-hospital



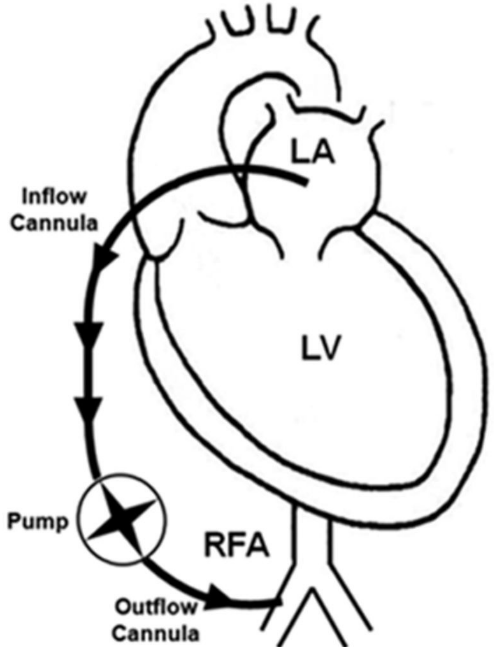
Despite the widespread availability of STEMI networks and protocols for early PCI, outcomes are often disappointing.[3-5]

1. Menees DS, Peterson ED, et al. Door-to-balloon time and mortality among patients undergoing primary PCI. N Engl J Med. 2013;369(10):901–9.
2. McNamara RL, et al. Predicting In-hospital mortality in patients with acute myocardial infarction. J Am Coll Cardiol. 2016;68(6):626–35.
3. Wayangankar SA, et al. Temporal trends and outcomes [PCI for Cardiogenic Shock]... JACC Cardiovasc Interv. 2016;9(4):341–51.
4. Shah RU, et al. Post-hospital outcomes of patients with AMI with cardiogenic shock: NCDR. J Am Coll Cardiol. 2016;67(7):739–47.
5. Ezekowitz JA, et al. Declining in-hospital mortality and increasing heart failure incidence in elderly patients with first MI. J Am Coll Cardiol. 2009;53(1):13–20.

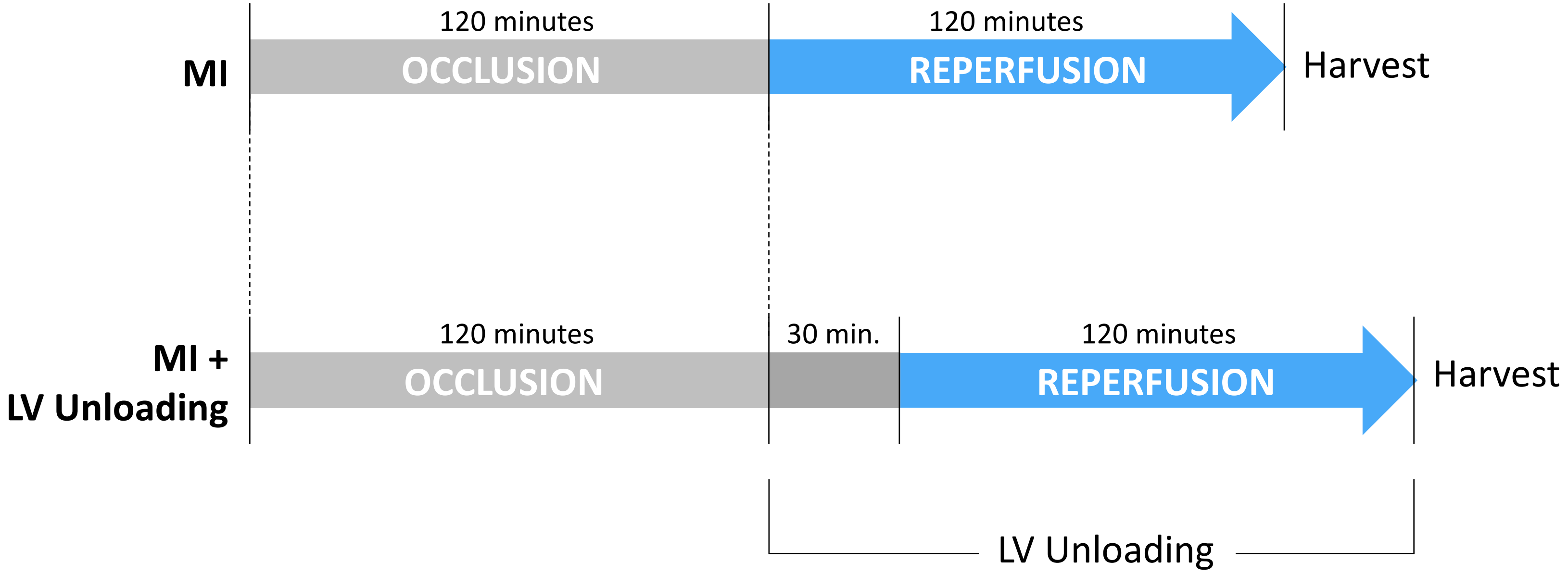
Hypothesis: LV Unloading Before Reperfusion

Does mechanical unloading of the LV before coronary reperfusion reduce infarct size?

EXPERIMENTAL MODEL (Kapur 2013)



TandemHeart

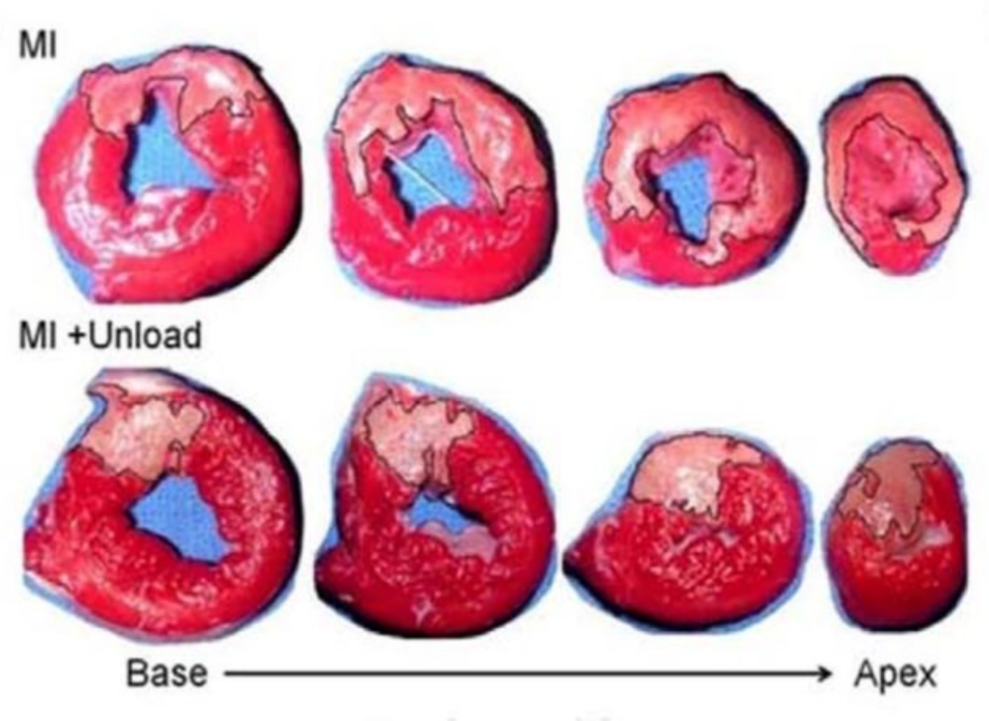


1. Kapur NK, Paruchuri V, et al. Mechanically unloading the left ventricle before coronary reperfusion reduces left ventricular wall stress and myocardial infarct size. Circulation. 2013 Jul 23;128(4):328-36.

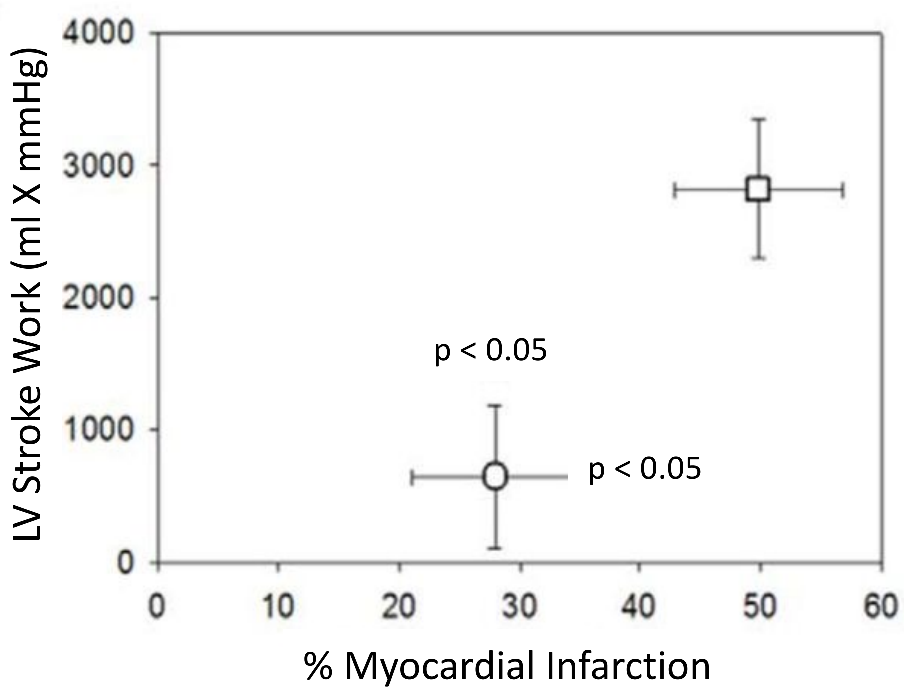
Results: LV Unloading Before Reperfusion

Does mechanical unloading of the LV before coronary reperfusion reduce infarct size?

Smaller Infarct Size by Histology



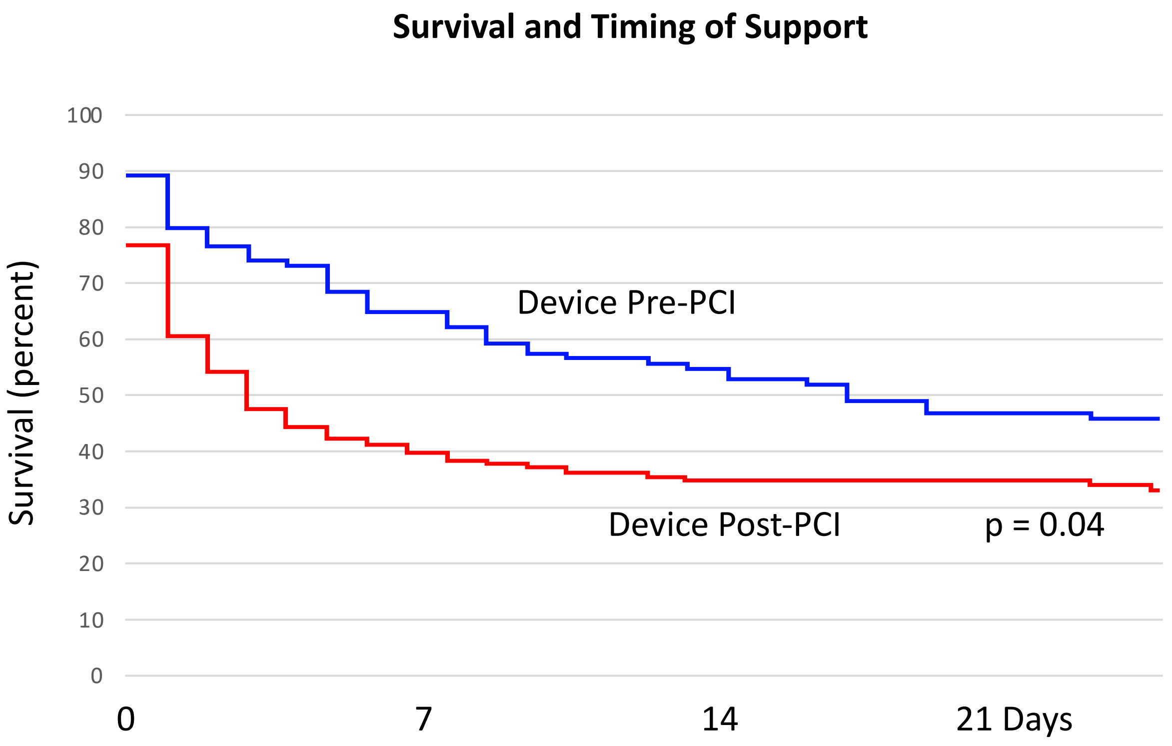
Smaller Infarct (% of LV Area and SW)



1. Kapur NK, Paruchuri V, et al. Mechanically unloading the left ventricle before coronary reperfusion reduces left ventricular wall stress and myocardial infarct size. Circulation. 2013 Jul 23;128(4):328-36.

Impella in AMICS: cVAD Registry (2017)

Based on retrospective analysis of cVAD, a commercial, voluntary Impella registry (U.S. and Canada)[1]



EVIDENCE OF BETTER SURVIVAL WITH MCS INITIATION BEFORE PCI

Notes:

OBSERVATIONAL STUDY

- Association not causality
- Potential selection bias
- Potential treatment bias (timing of Impella insertion and extent of revascularization at operator discretion)

1. Basir MB, Schreiber TL, Grines CL, et al. : Effect of Early Initiation of Mechanical Circulatory Support on Survival in Cardiogenic Shock. Am J Cardiol. 2017;119(6):845–51.

UK HealthCare GILL HEART & VASCULAR INSTITUTE

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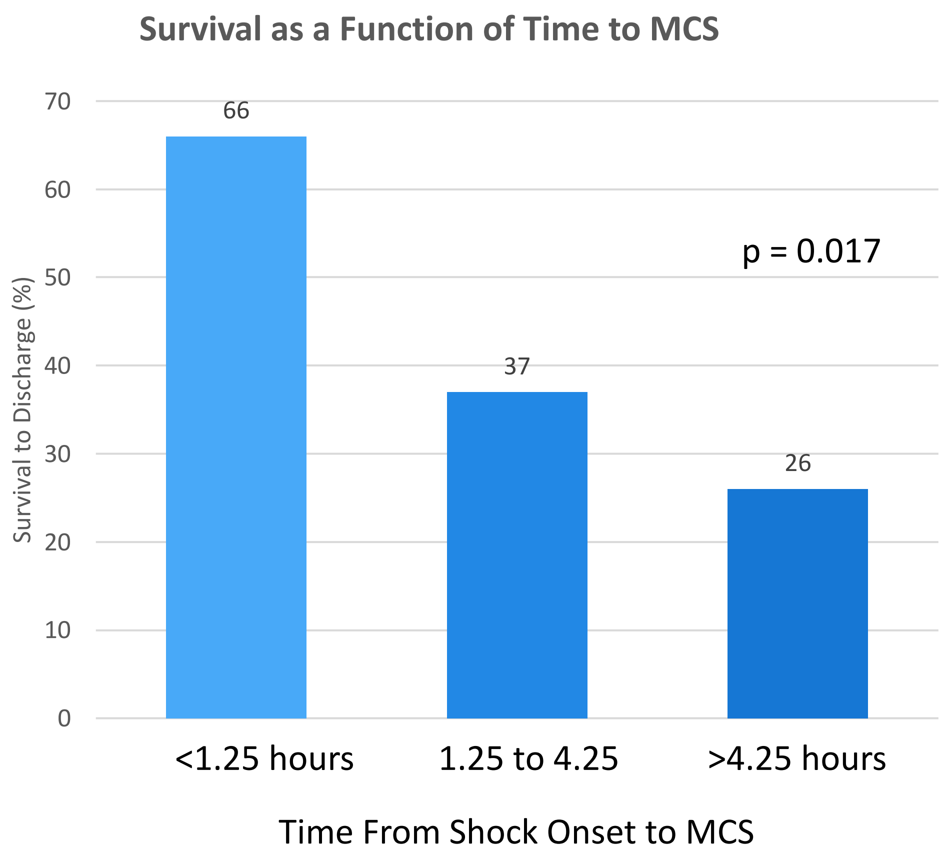

EARLY INITIATION ASSOCIATED WITH BETTER SURVIVAL

Notes:

OBSERVATIONAL STUDY

- Association not causality
- Potential selection bias
- Delay may select population with salvage indications and lower expectation of survival

1. Basir MB, Schreiber TL, Grines CL, et al. : Effect of Early Initiation of Mechanical Circulatory Support on Survival in Cardiogenic Shock. Am J Cardiol. 2017;119(6):845–51.

Fluids (Volume Infusion)

Volume infusion often necessary to maintain CO and function of MCS devices

CARDIAC PRESERVATION: NET HARM

Effect	Parameter	Net Benefit
↑↑↑↑	LVEDP	✗✗✗✗
↑	Ao diastolic pressure	✓
↓↓↓	Coronary perfusion gradient	✗✗✗
→	Heart rate	
→	Contractility	
↑	Afterload	✗✗
↑↑	Myocardial O_2 demand	✗✗
↑↑↑	Reperfusion injury	✗✗✗

ORGAN PRESERVATION: NET HARM

Effect	Parameter	Net Benefit
↑	MAP	✓
↑↑↑↑	Venous pressures	✗✗
↓	Tissue perfusion gradient	✗
→	Arterial O_2 content	
→	Tissue O_2 delivery	
→	Metabolic demand	
→	O_2 supply/demand ratio	
→	Tissue preservation	

Note: LAVA requires skilled implanter and off-label hardware modifications.

Catecholamines

Net effect of vasopressors and inotropes on heart and organs

CARDIAC PRESERVATION: NET HARM

Effect	Parameter	Net Benefit
↑↑↑	LVEDP	✗✗
↑↑↑	Ao diastolic pressure	✓✓
→	Coronary perfusion gradient	✓
↑↑↑↑	Heart rate	✗✗✗✗
↑↑↑↑	Contractility	✗✗✗✗
↑↑↑	Afterload	✗✗✗✗
↑↑↑↑	Myocardial O_2 demand	✗✗✗✗
↑↑↑↑	Reperfusion injury	✗✗✗✗

ORGAN PRESERVATION: MINIMAL BENEFIT

Effect	Parameter	Net Benefit
↑↑↑	MAP	✓
↑↑↑	Venous pressures	✗
↑	Tissue perfusion gradient	✓
→	Arterial O_2 content	
→	Tissue O_2 delivery	
→	Metabolic demand	
→	O_2 supply/demand ratio	
→	Tissue preservation	

Note: Vasopressors and inotropes are generally detrimental to the failing myocardium

IABP

Net effect of vasopressors and inotropes on heart and organs

CARDIAC PRESERVATION: SMALL BENEFIT

Effect	Parameter	Net Benefit
↓	LVEDP	✓
↑↑	Ao diastolic pressure	✓✓
↑↑	Coronary perfusion gradient	✓
→	Heart rate	
→	Contractility	
↓	Afterload	✓
→	Myocardial O_2 demand	
?	Reperfusion injury	

ORGAN PRESERVATION: MINIMAL BENEFIT

Effect	Parameter	Net Benefit
↑	MAP	✓
→	Venous pressures	
→↑	Tissue perfusion gradient	✓
→	Arterial O_2 content	
→	Tissue O_2 delivery	
→	Metabolic demand	
→	O_2 supply/demand ratio	
→	Tissue preservation	

Note: IABP has limited ability to augment cardiac output in severe LV pump failure.

Axial Flow: Impella CP

Axial flow devices combine LV unloading with improved peripheral perfusion

CARDIAC PRESERVATION: BENEFIT

Effect	Parameter	Net Benefit
↓↓↓	LVEDP	✓✓✓
↑↑↑	Ao diastolic pressure	✓✓✓
↑↑	Coronary perfusion gradient	✓✓✓
→	Heart rate	
→	Contractility	
→	Afterload	
↓↓	Myocardial O_2 demand	✓✓✓
↓↓	Reperfusion injury	✓✓✓

ORGAN PRESERVATION: BENEFIT

Effect	Parameter	Net Benefit
↑↑	MAP	✓
→	Venous pressures	
→	Tissue perfusion gradient	✓
→	Arterial O_2 content	
→	Tissue O_2 delivery	✓✓
→	Metabolic demand	
→	O_2 supply/demand ratio	✓✓
→	Tissue preservation	✓✓

Note: Magnitude of benefit depends on type of device (Impella 2.5, CP or 5) and patient variables (stability, LV thrombus, hemolysis). These devices may not meet full-flow demands on a sustained basis.

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Centrifugal: VA ECMO

Improved peripheral oxygen delivery without LV unloading

CARDIAC PRESERVATION: MAJOR HARM

Effect	Parameter	Net Benefit
↑↑↑	LVEDP	✗✗✗✗
↑↑↑	Ao diastolic pressure	✗✗✗✗
→	Coronary perfusion gradient	
→	Heart rate	
→	Contractility	
↑↑↑↑	Afterload	
↑↑↑	Myocardial O_2 demand	✗✗✗
↑↑↑	Reperfusion injury	✗✗✗

ORGAN PRESERVATION: MAJOR BENEFIT

Effect	Parameter	Net Benefit
↑↑↑↑	MAP	✓✓✓
→	Venous pressures	
↑↑	Tissue perfusion gradient	✓✓✓
↑↑↑↑	Arterial O_2 content	✓✓✓✓
↑↑↑↑	Tissue O_2 delivery	✓✓✓✓
→	Metabolic demand	
↑↑↑↑	O_2 supply/demand ratio	✓✓✓✓
↑↑↑↑	Tissue preservation	✓✓✓✓

Note: VA ECMO saves organs at the risk of pulmonary edema, LV distention, non-ejection and chamber thrombosis

Centrifugal: TandemHeart

LV unloading with improved peripheral oxygen delivery

CARDIAC PRESERVATION: MAJOR BENEFIT

Effect	Parameter	Net Benefit
↓↓↓	LVEDP	✓✓✓
↑↑↑	Ao diastolic pressure	✓✓✓
→	Coronary perfusion gradient	✓✓
→	Heart rate	
→	Contractility	
↑↑↑↑	Afterload	
→	Myocardial O_2 demand	✓
↓↓	Reperfusion injury	✓✓

ORGAN PRESERVATION: MAJOR BENEFIT

Effect	Parameter	Net Benefit
↑↑↑	MAP	✓✓✓
→	Venous pressures	
↑↑	Tissue perfusion gradient	✓✓✓
↑↑↑↑	Arterial O_2 content	✓✓✓
↑↑↑↑	Tissue O_2 delivery	✓✓✓
→	Metabolic demand	
↑↑↑↑	O_2 supply/demand ratio	✓✓✓
↑↑↑↑	Tissue preservation	✓✓✓

Note: TandemHeart requires skilled implanter and does not decompress the right side of the heart.

Centrifugal: LAVA ECMO

Simultaneous left and right side unloading with oxygenation and full systemic flow capability

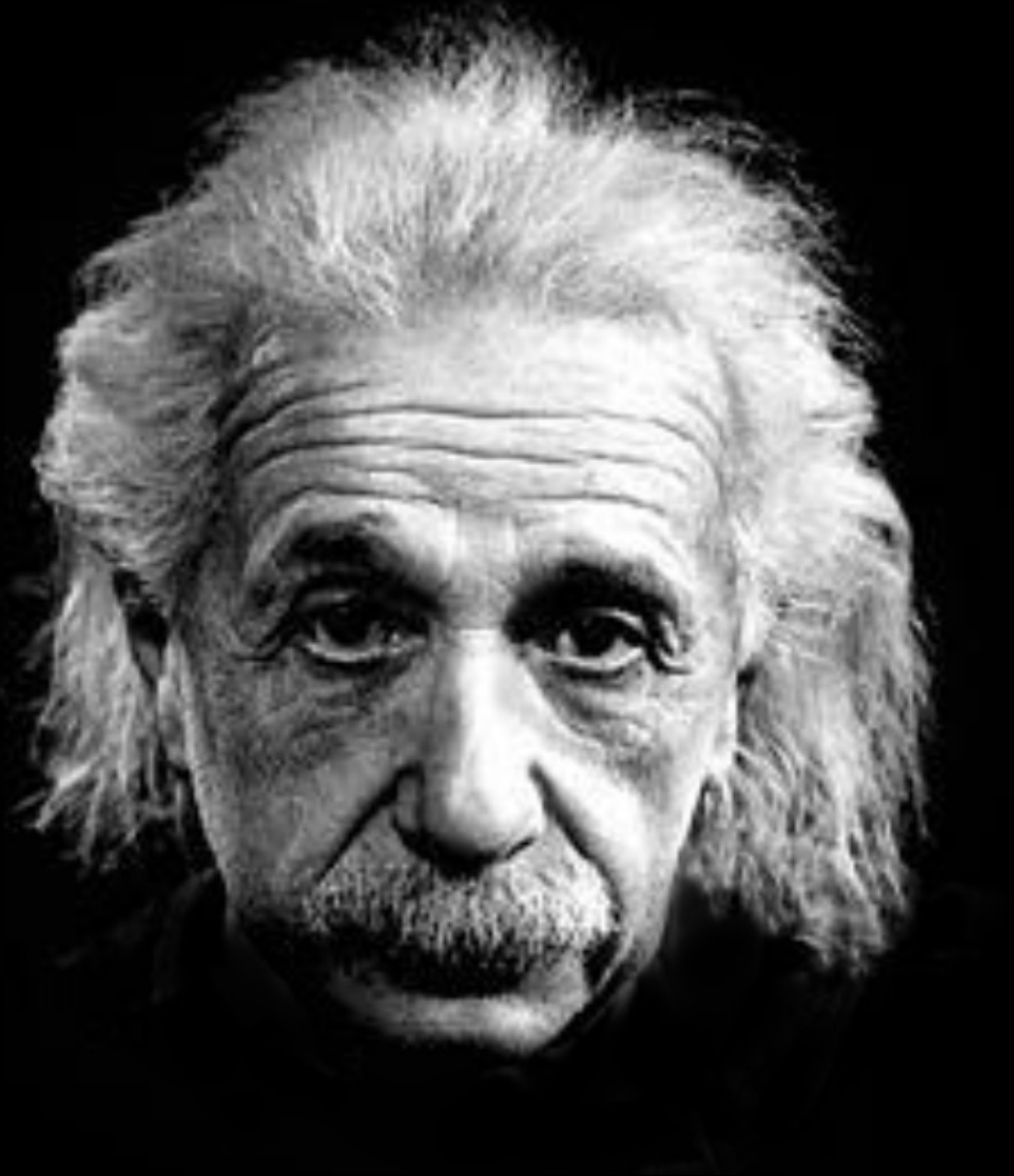
CARDIAC PRESERVATION: MAJOR BENEFIT

Effect	Parameter	Net Benefit
↓↓↓	LVEDP	✓✓✓
↑↑↑	Ao diastolic pressure	✓✓✓
→	Coronary perfusion gradient	✓✓
→	Heart rate	
→	Contractility	
↑↑↑↑	Afterload	
→	Myocardial O_2 demand	✓
↓↓	Reperfusion injury	✓✓

ORGAN PRESERVATION: MAJOR BENEFIT

Effect	Parameter	Net Benefit
↑↑↑	MAP	✓✓✓
→	Venous pressures	
↑↑	Tissue perfusion gradient	✓✓✓
↑↑↑↑	Arterial O_2 content	✓✓✓
↑↑↑↑	Tissue O_2 delivery	✓✓✓
→	Metabolic demand	
↑↑↑↑	O_2 supply/demand ratio	✓✓✓
↑↑↑↑	Tissue preservation	✓✓✓

Note: LAVA requires skilled implanter and off-label hardware modifications.



$$E=DO_2$$