Mechanical Circulatory Support

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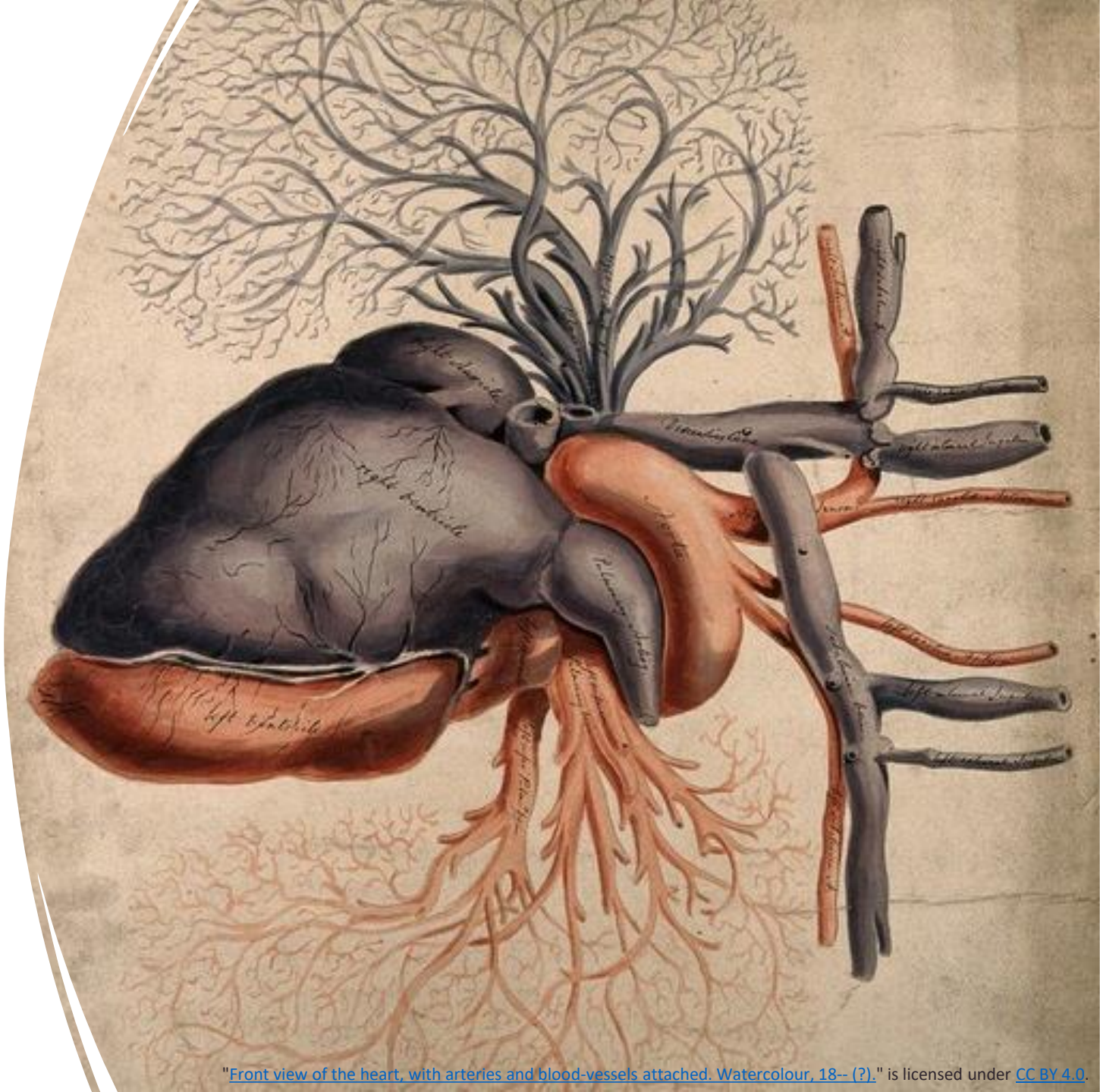


Objectives

- Basic Circulatory Pathway
- What is MCS?
- Biventricular Support (VA ECMO, TAH)
- Support for Left sided Heart (IABP, HM3, Impella)
- ECpella (VA ECMO + Impella)

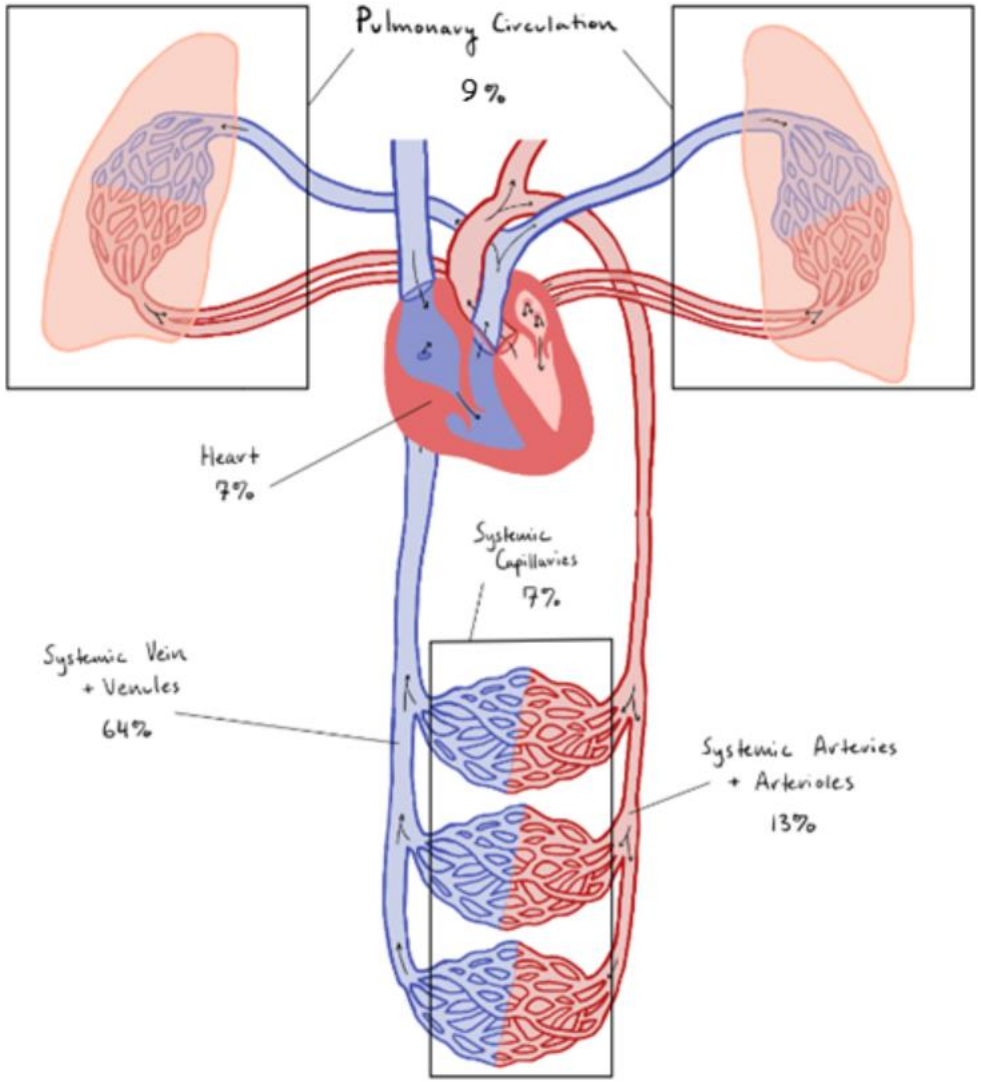
Circulatory Pathway

Right Ventricle – Pumps blood to lungs, eventually to left heart

Lungs – Gas exchange

Left Ventricle – Pumps blood to systemic organs

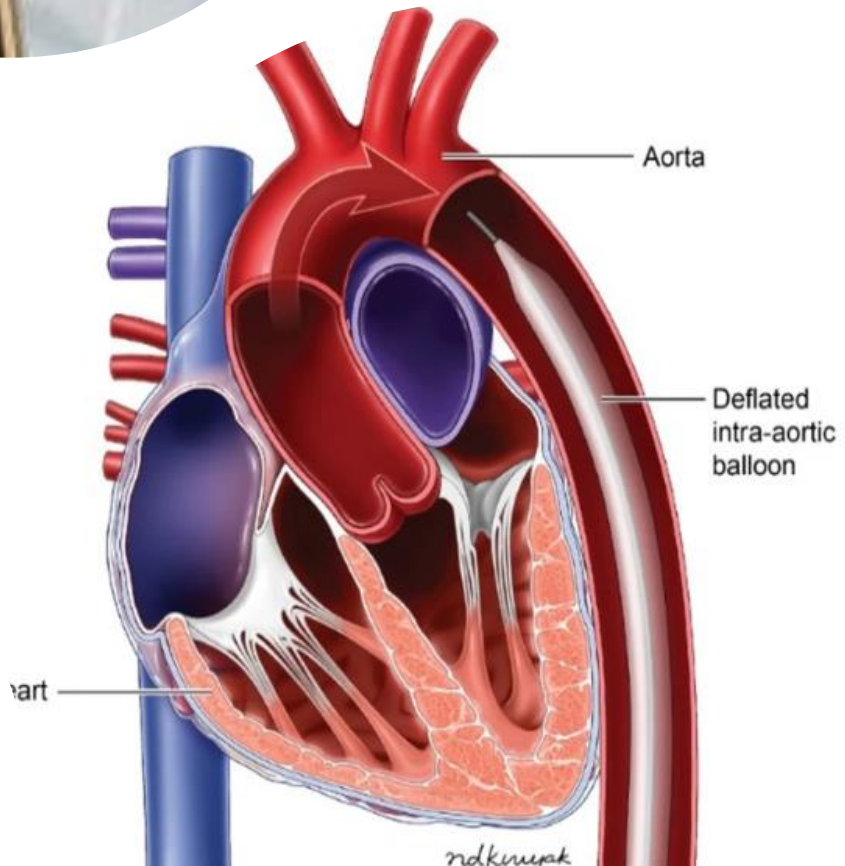
Oxygen delivery and organ perfusion is compromised if one fails



What is MCS?

Augments or replaces the work of RV/Lung/LV to maintain adequate perfusion and oxygen delivery

We will be discussing the most widely used options



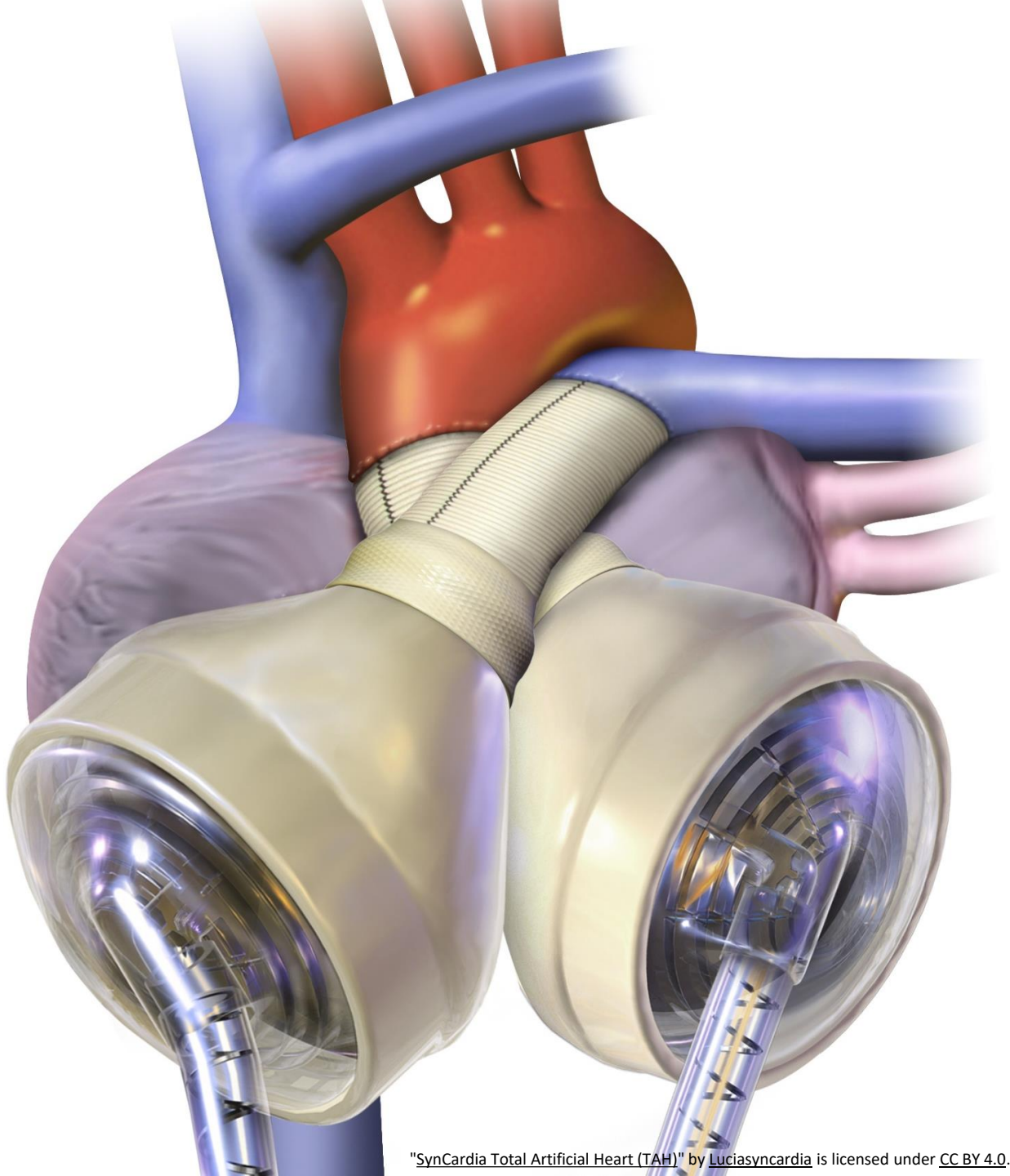
Biventricular Support

- Total Artificial Heart (TAH)
- Veno-Arterial Extracorporeal Membrane Oxygenation (VA ECMO)

Total Artificial Heart (TAH)

Total Artificial Heart

- First human implantation of Liotta TAH used as BTT in 1969.
- SynCardia TAH
- Indicated for Severe biventricular failure
- Originally Bridge to Transplantation, but can be used as destination
- Can provide long-term support, documented greater than 5 years as bridge device.



Total Artificial Heart

- Two models: Syncardia 50ml (BSA < 1.85) and 70ml (BSA > 1.85)
- Pneumatic diaphragm pump (pulsatile)
- Existing ventricles are completely excised
- Connected to the external driver and patients can be discharged home.
- Heart rate and drive pressure are regulated to maintain partial fill of each ventricle, thus reducing risk of thrombus formation.
- ASA and Warfarin

Total Artificial Heart

- Based on data provided by Interagency Registry for Mechanically Assisted Circulatory Support (INTERMACS)…
- 1 year after surgery, 53.3% received transplant, 32.3% died before transplant, 14.4% still alive with device at 12 months.
- 24% of the patients with TAH at 12 months were discharged from hospital.
- Most common cause of death was multi organ failure (36%), neurological dysfunction (17.9%), and withdrawal of support (11.7%).
- In the first 6 months, infection 70%, stroke, 22.7%, and GI hemorrhage 20%.

Extracorporeal Membrane Oxygenation (ECMO)

ExtraCorporeal Membrane Oxygenator (ECMO)

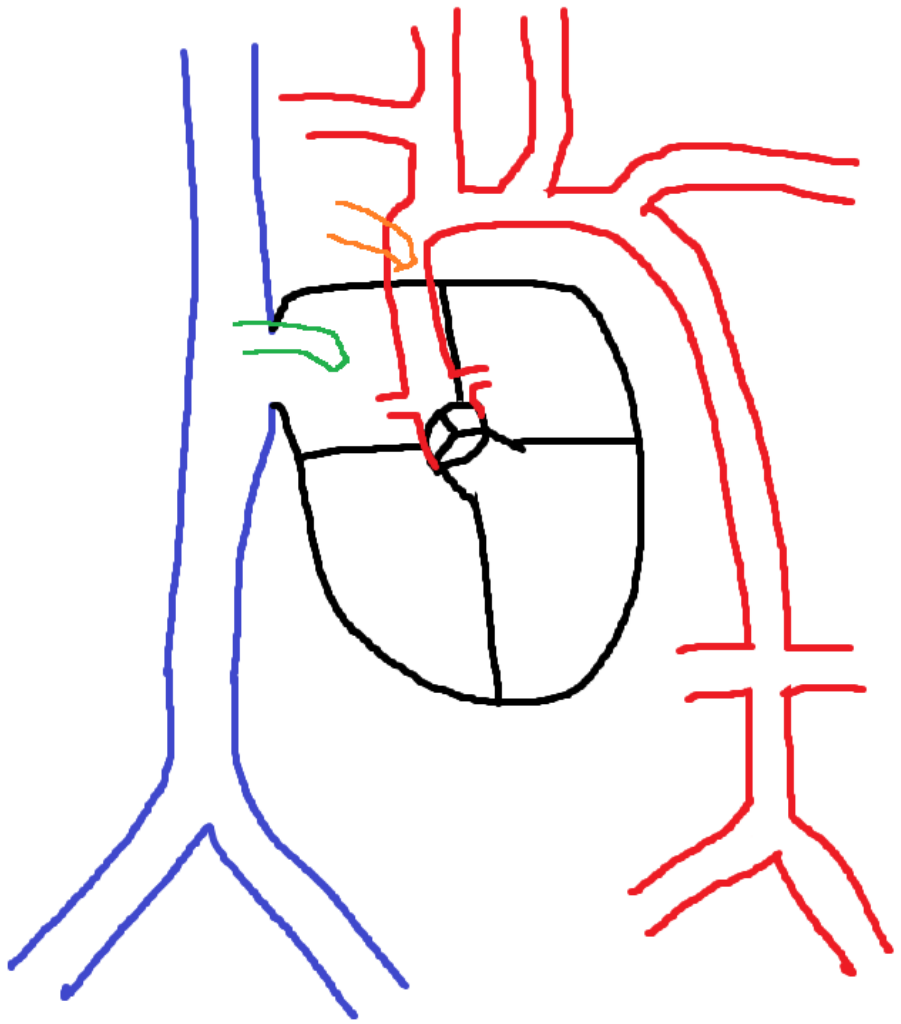
- ECMO pumps blood outside the body to oxygenate and remove CO2 from blood and pumps back into the circulation to replace the work of heart and/or lungs.
- ECMO circuit is smaller than the usual cardiopulmonary bypass. Portable.
- VA: Replaces the work of the Heart +/- lungs
- VV: Replaces the work of the lungs only
- VA ECMO Indications: Cardiogenic shock, Cardiac arrest with CPR in progress
- Bridge to decision, Bridge to recovery, Bridge to transplant, but donor availability limiting
- Relative contraindications: Irreversible organ dysfunction, decreasing quality of life (neurologic damage, malignancy, severe risk of anticoagulation), old age, aortic dissection, lack of exit strategy

VA ECMO cannulation

- Central
  - Aorta, Right atrium/SVC/IVC/Fem V
- Peripheral
  - Fem A, Fem V
  - Axillary A, Fem V

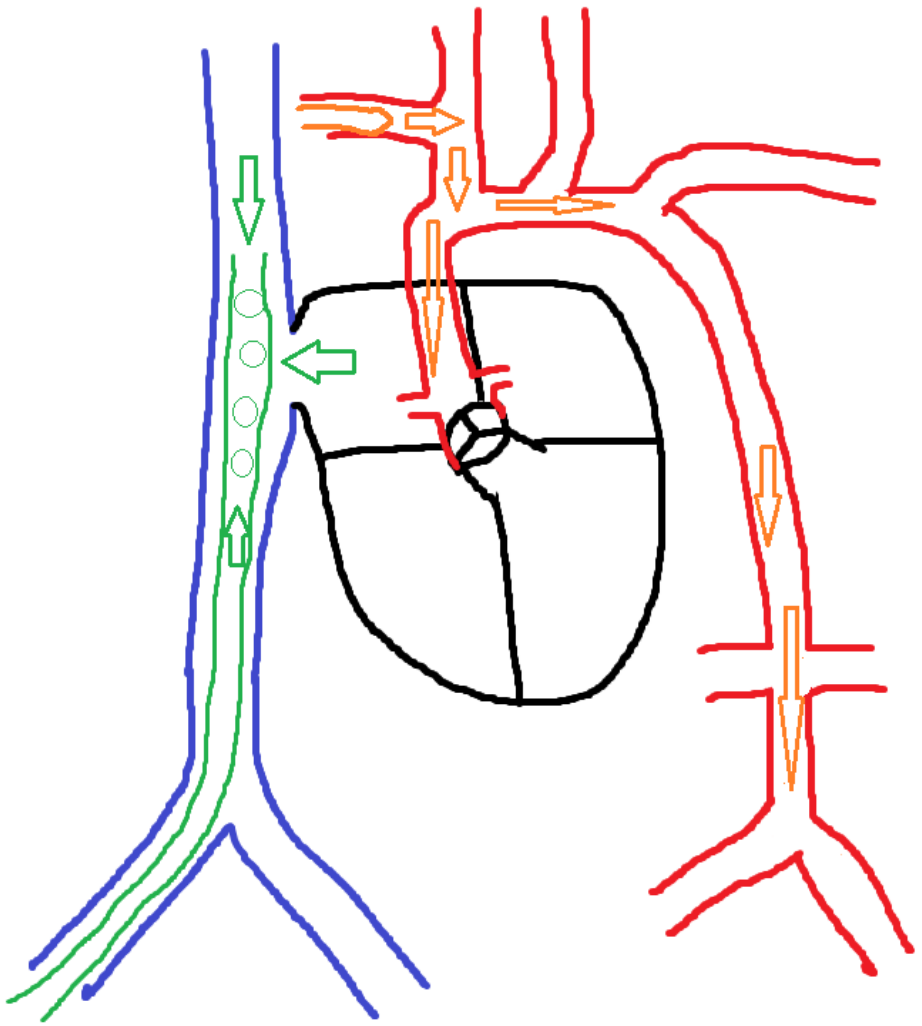
Central VA ECMO Cannulation

- Arterial
  - Aorta
- Venous
  - Right atrium
  - SVC + IVC
  - Femoral Vein



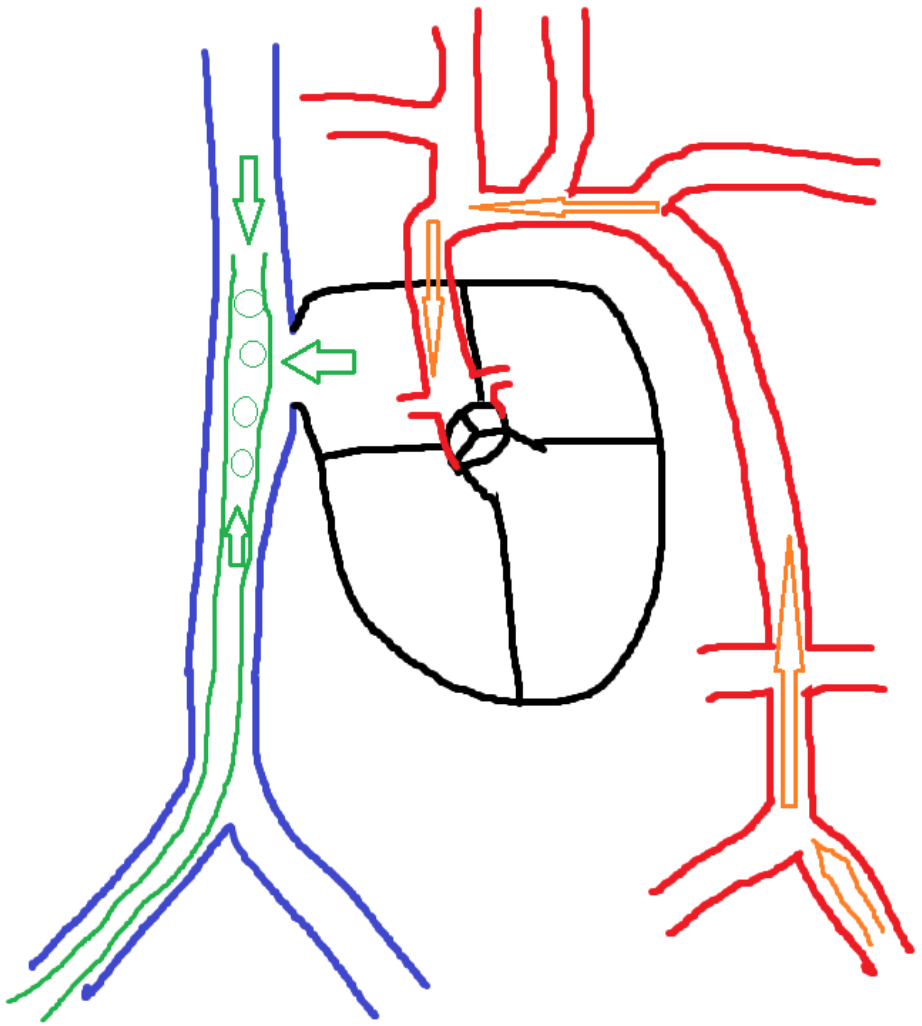
Peripheral VA ECMO Cannulation (Axillary)

- Arterial
  - Axillary Artery
- Venous
  - Femoral Vein



Peripheral VA ECMO Cannulation (Femoral)

- Arterial
  - Femoral Artery
- Venous
  - Femoral Vein



Physiologic effects of VA ECMO

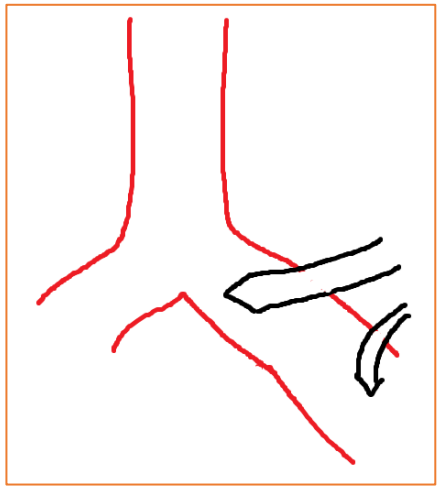
- Patients with heart failure already have high LVEDV and LVEDP
- When VA ECMO is started at this state the following happens:
  - MAP increases (from ECMO flow)
  - Stroke volume decreases (reduction of intracardiac blood flow & increased afterload)
  - Reduction in SV leads to increase in LVEDV, which leads to further increase in LVEDP
  - Although less blood is entering LA/LV, there still is blood entering via Right heart & lungs, thebesian veins, and Aortic regurgitation, if present
  - Leads to higher myocardial oxygen consumption
- Monitoring LV distension is important
- All this negative effect of VA ECMO is balanced by increase in coronary perfusion and increase in oxygen delivery

VA ECMO considerations

- Anticoagulation
  - Activated partial thromboplastin time between 50-60 seconds to prevent circuit thrombosis
- Ventilator
  - Mechanical ventilation is less critical since VA/VV ECMO provides full support, but is important to minimize injury
  - Ultra Lung Protective Ventilation
    - Low tidal volume (3-5ml/kg) with low airway pressure.
    - PEEP 10-15mmHg to maintain alveolar expansion.
    - FiO2 below 40%
- Transfusion
  - Hemoglobin goal of 10 mg/dl

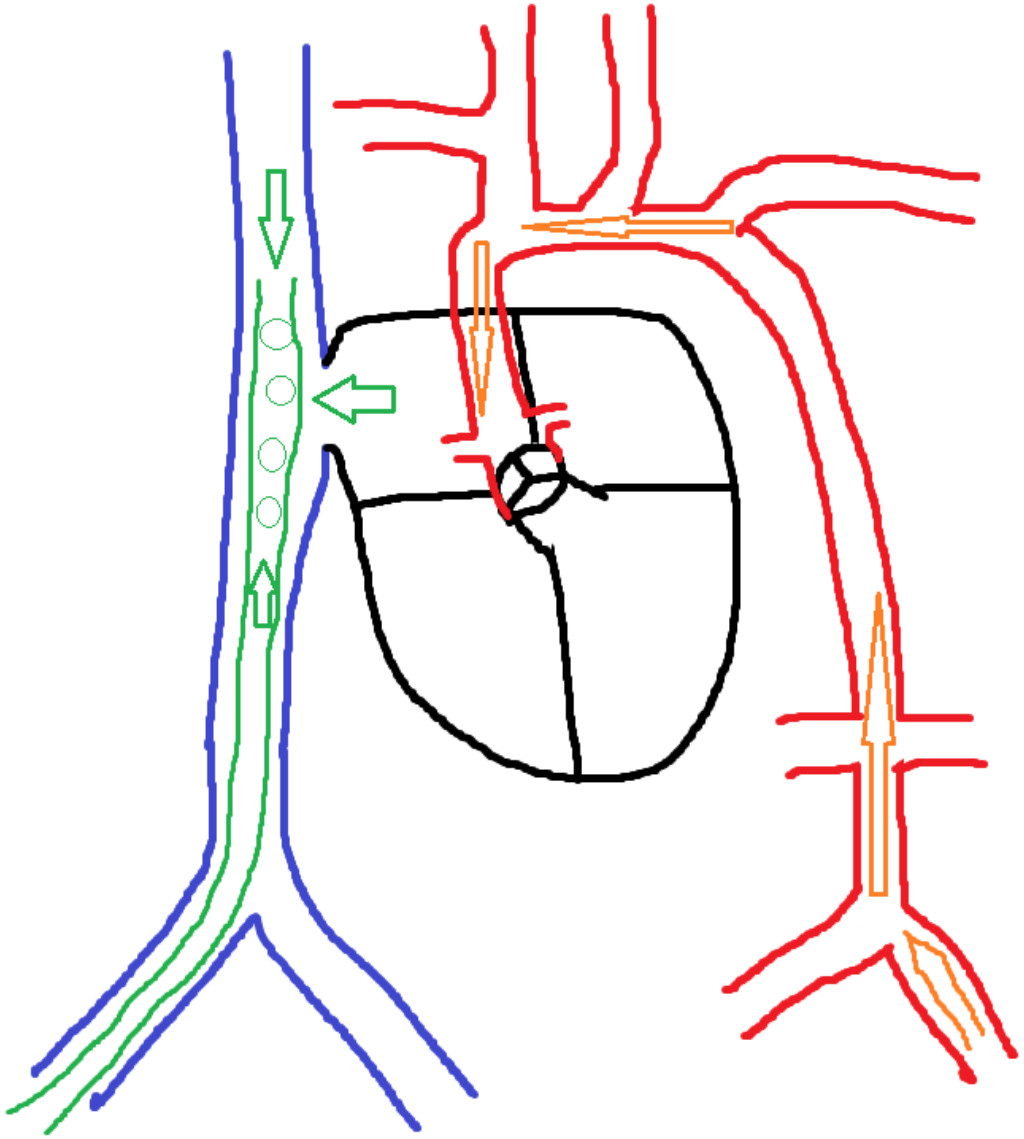
Complications of ECMO

- Bleeding
- Stroke (4%)
- Infection (50% -> mortality rate greater than 60%)
- Limb Ischemia (Femoral A) – Use of distal perfuser helpful
- LV thrombus
  - Very low stroke volume with minimal AV opening -> Stagnant blood in LV -> LV thrombus
  - Assess AV opening and pulse pressure using arterial line
- Pulmonary edema
  - Increased afterload -> Increased LVEDP -> Increased LAP -> Increased PCWP -> Pulmonary edema
  - Goal pulmonary artery diastolic pressure < 22 mmHg
  - LV Venting strategies (IABP, Impella, transseptal cannula)



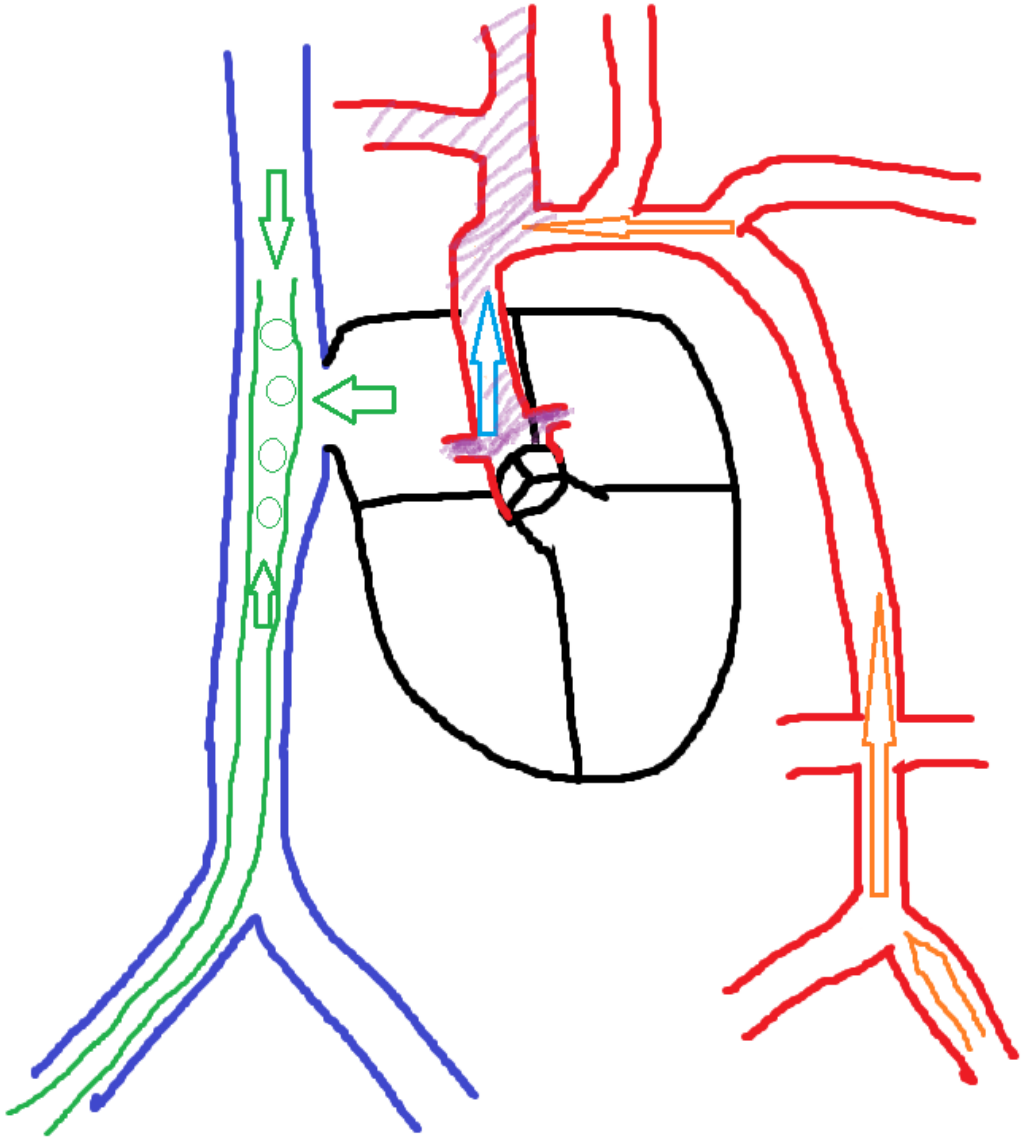
Harlequin Syndrome

- North-South Syndrome
- Peripheral VA ECMO
- Respiratory function is poor and deoxygenated blood from the left ventricle is pumped into the arterial circulation to proximal structures (Coronary arteries and carotid arteries)
- In severe cases, deterred myocardial recovery and cerebral ischemia



Harlequin Syndrome

- Must have right radial arterial line for arterial blood gas (or pulse ox on right hand)
- Cerebral oximeter may be useful
- Treatment
  - Increase VA ECMO flow
  - Decrease inotropic medication
  - Beta blocker to decrease HR to decrease Left heart output
  - Re-configuration to central VA ECMO or VAV ECMO (Outflow to Fem A and SVC)

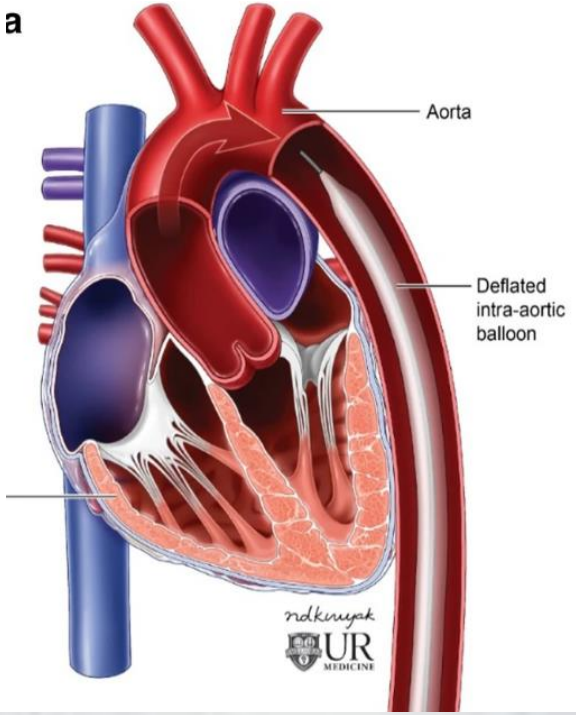


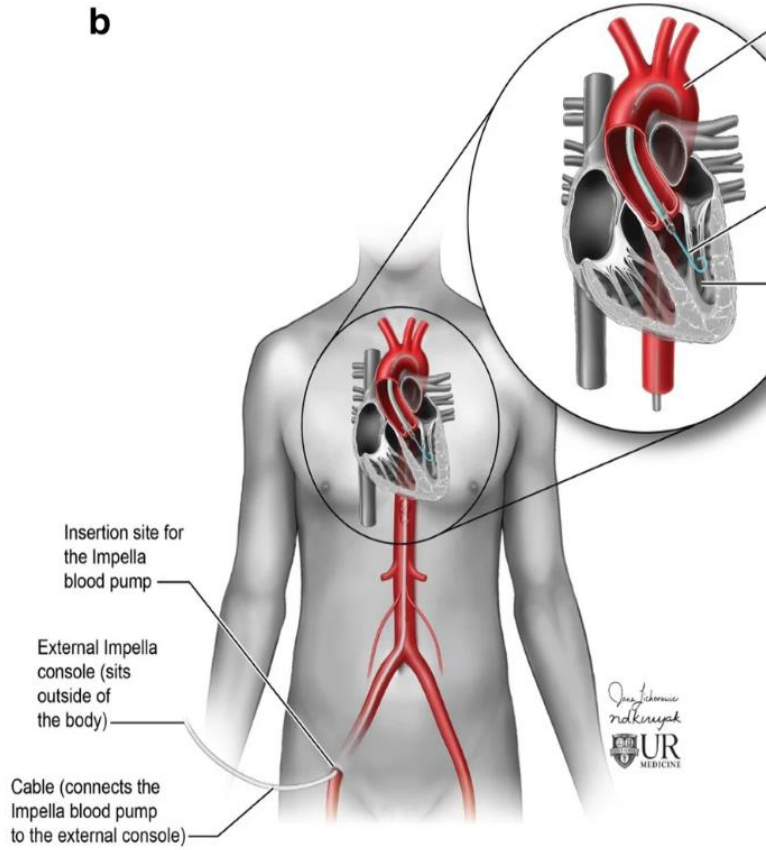
Clinical Pearls

- Confirming intubation – May have very low end tidal CO2
- Do not assume the ECMO flow is full flow
  - If low ECMO flow, patient relies heavily on native circulation, so must be ventilated appropriately
- Some medications are highly sequestered by ECMO circuit, so may require higher dose
  - Fentanyl, Propofol, Midazolam

Left Heart Support

- Intra-aortic balloon pump (IABP)
- Left Ventricular Assist Device (LVAD)
- Impella
- VA ECMO

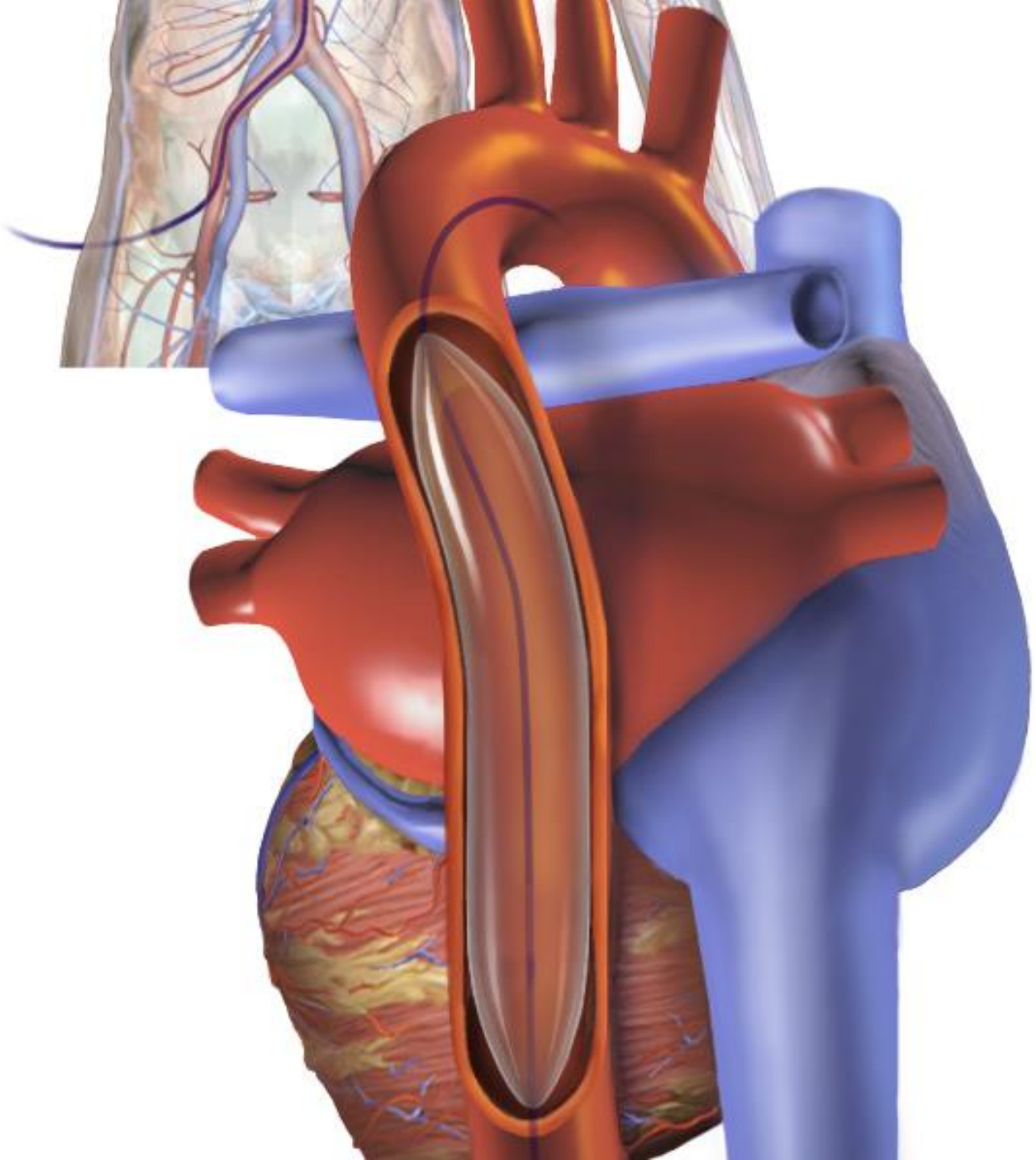




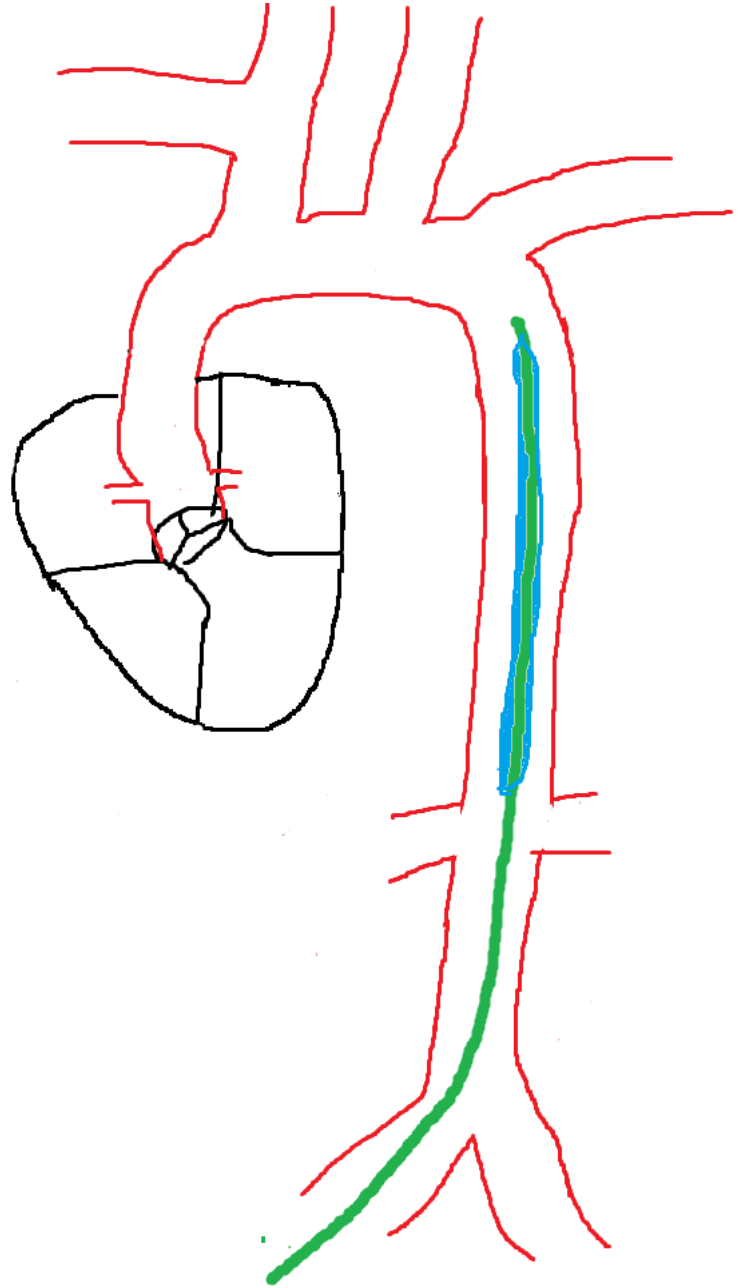
Intra-Aortic Balloon Pump (IABP)

Intra-aortic Balloon Pump

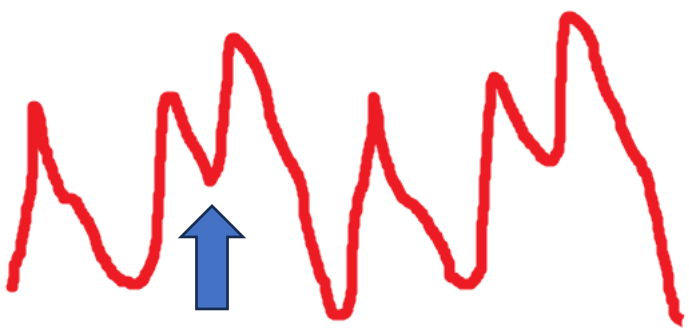
- 1st IABP placement in 1968 by Dr. Kantrowitz
- Percutaneous IABP introduced in 1979
- Counterpulsation
  - Inflation in diastole
    - Increased coronary perfusion
  - Deflation in early systole
    - Decreased LV afterload
    - Decreased Cardiac work
    - Decreased LVEDP
    - Decreased myocardial oxygen consumption
    - Increased cardiac output

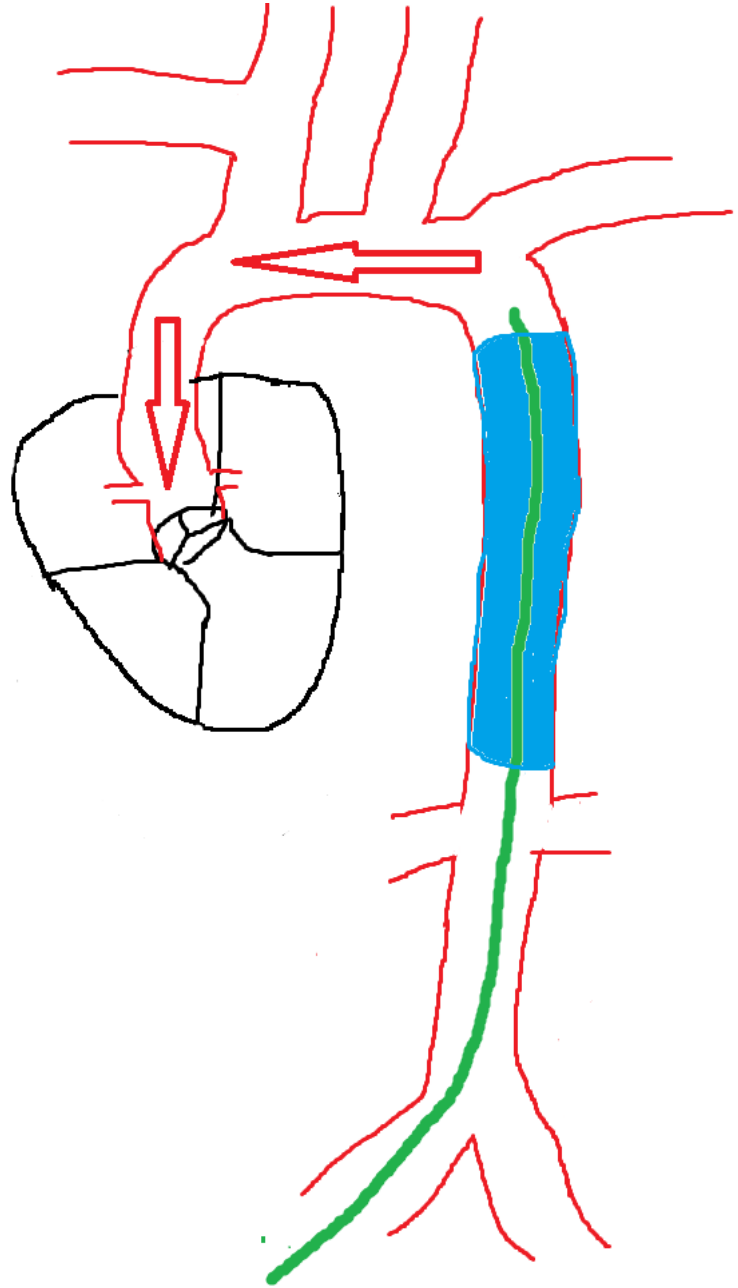


IABP

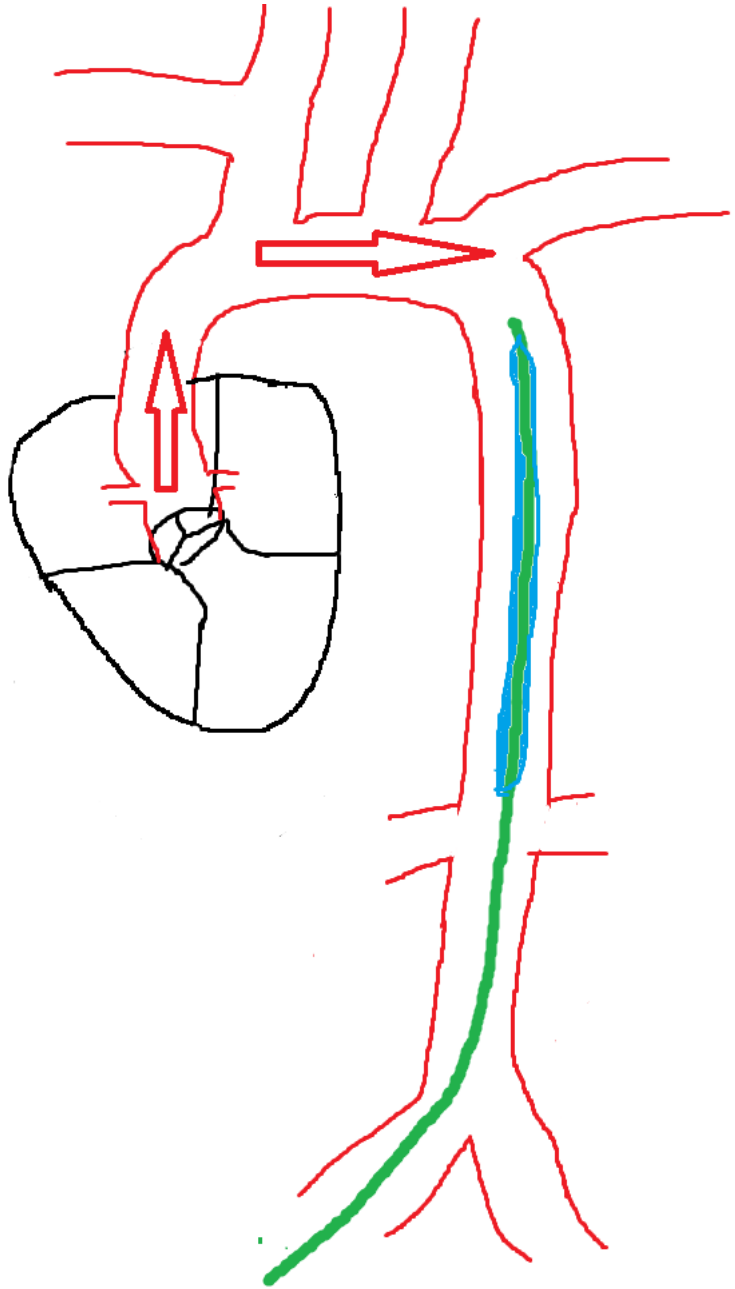


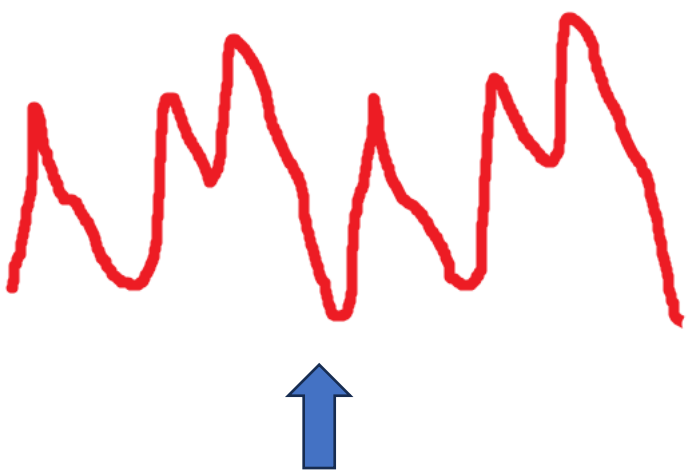
IABP





IABP





Indications/Contraindications of IABP

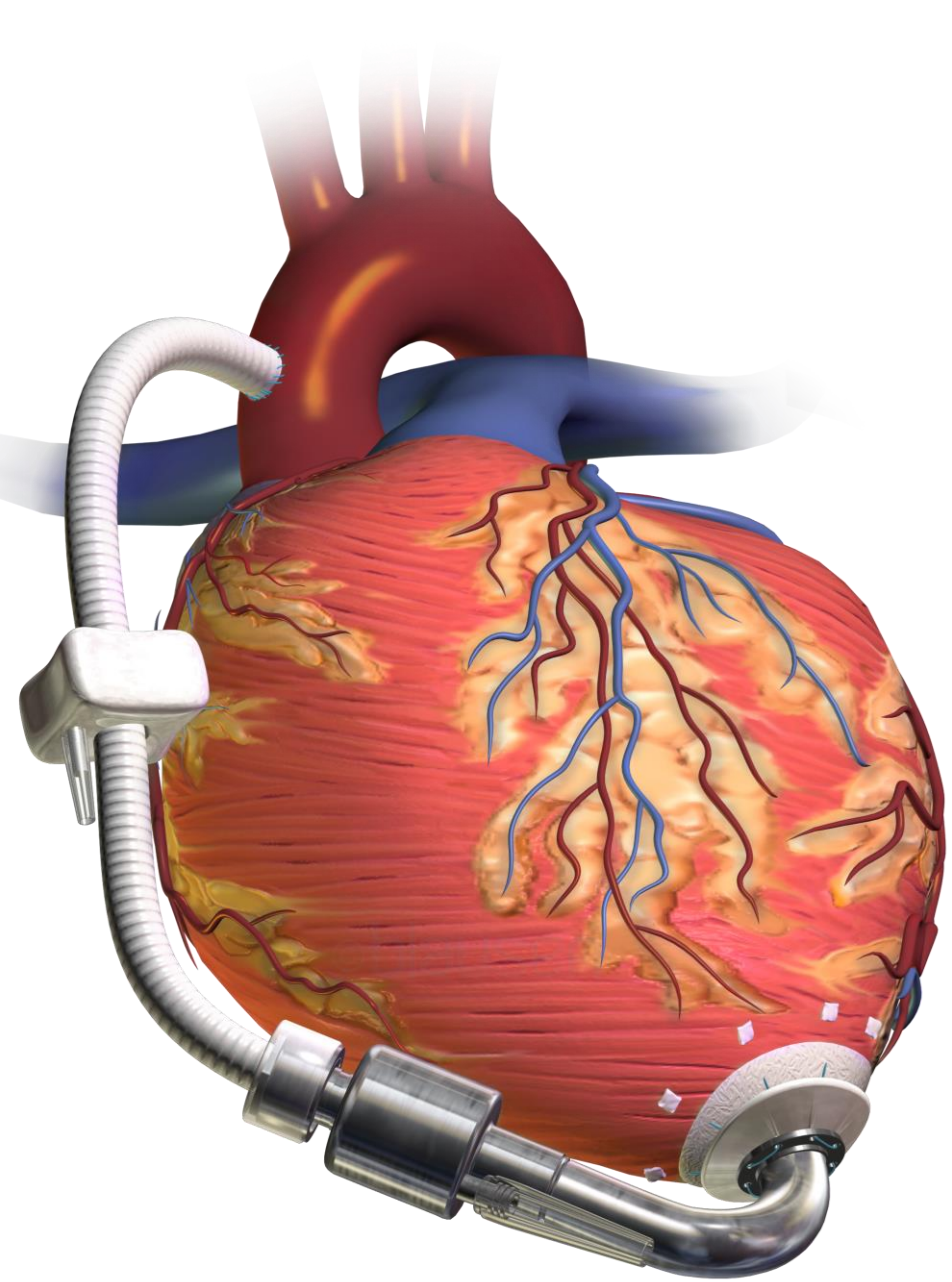
- Indications
  - Acute myocardial infarction (unstable angina, ruptured papillary muscle, until definitive therapy)
  - Cardiogenic shock
  - Prior to high-risk CABG or PCI
  - Inability to separate from CPB
  - Bridge to transplant/decision

- Contraindications
  - Absolute
    - Aortic regurgitation
    - Aortic dissection
    - No exit strategy
    - Aortic stents
  - Relative
    - Sepsis
    - Abdominal aortic aneurysm
    - Severe peripheral vascular disease

Complications of IABP

- Limb ischemia
- Local vascular injury
- Thromboembolism
- Aortic dissection
- Balloon rupture leading to helium embolization
- Thrombocytopenia & hemolysis
- Mesentery ischemia
- Malperfusion of organs secondary to malpositioning

Left Ventricular Assist Device (LVAD)



Left Ventricular Assist Device

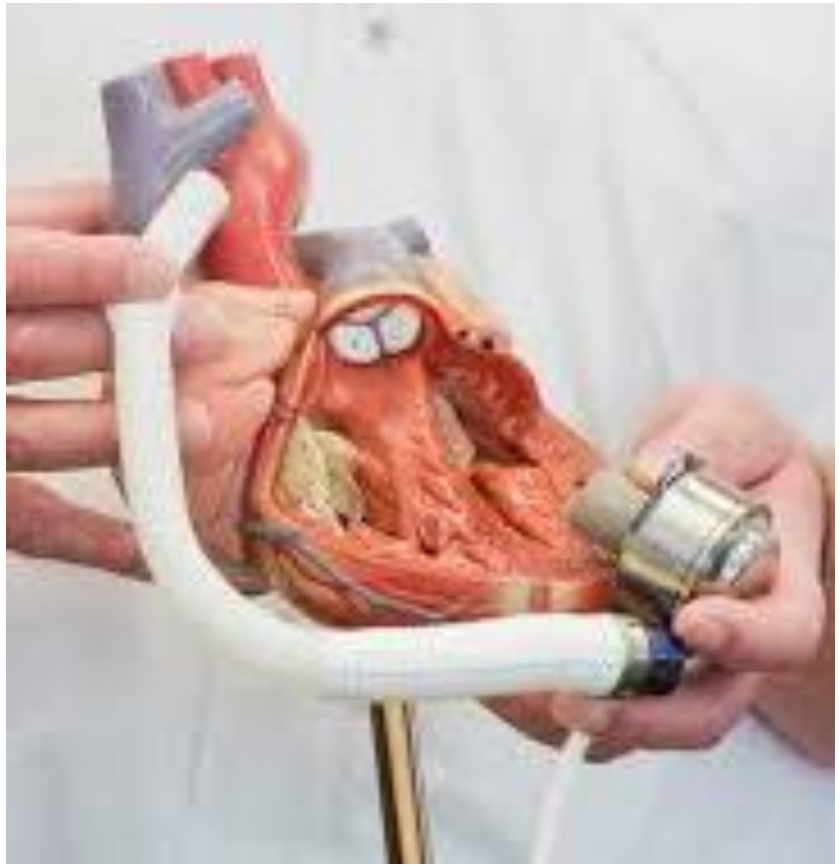
- Replaces/Assists the work of left ventricle
- Removes blood from LV and pumps the blood into the aorta
- Only supports the left ventricle
- Modern day LVADs are portable

LVAD history

- 1953 – 1st open-heart surgery using cardiopulmonary bypass (for ASD repair) by Dr. Gibbon
- 1963 – 1st artificial ventricle in patient with cardiogenic shock s/p AVR (intrathoracic pump implanted in left chest that connected LA to thoracic aorta. Patient died 4 days later.)
- 1966 – 1st pneumatic powered, paracorporeal left ventricular assist device (LVAD). Flow rate of 1200mL/min. DC 10 days later. Patient survived. Dr. DeBakey
- 1967 – 1st heart transplant (Since then, no longer bridge to recovery. Now bridge to transplant)
- 1984 – 1st electric pulsatile Novacor LVAD introduced. (Pulsatile pump designed to mimic the function of the heart)
- 2001 – REMATCH Trial. LVAD vs maximal medical therapy. 1st year survival 52% vs 25%. LVAD now approved for Destination Therapy.
- 2008 – HM II approved by the FDA (Axial pump)
- 2017 – HM III approved by the FDA (Centrifugal pump)

HeartMate 3

- Approved in 2017 by the FDA
- Most commonly implanted LVAD (20,000 implanted worldwide)
- Indications
  - Destination Therapy
  - Bridge to Transplant
  - Bridge to Candidacy
- Magnetic levitation technology that minimizes the shear stress and stasis
- Centrifugal pumps (HM3) vs axial pump (HM2)
  - Reduced hemolysis and platelet activation.
- Expected lifespan of 5-10 years



LVAD Key Trials

- MOMENTUM 3 (HM3 vs HM2)
  - 2 year event free survival 74.7% vs 60.6%
  - 5 year survival rate 58% vs 44% (2019)
  - Statistically significant reduction in stroke, suspected pump thrombosis, pump replacement, & GI bleeding at 2 years and 5 years
  - HM3 was declared “superior” to the HM2
  - Led to removal of HM2 from the US market

- ELEVATE Registry
  - Follows HM3 patients in Europe, Australia, and the Middle East
  - 5 year survival rate 63% (published Nov 2023)

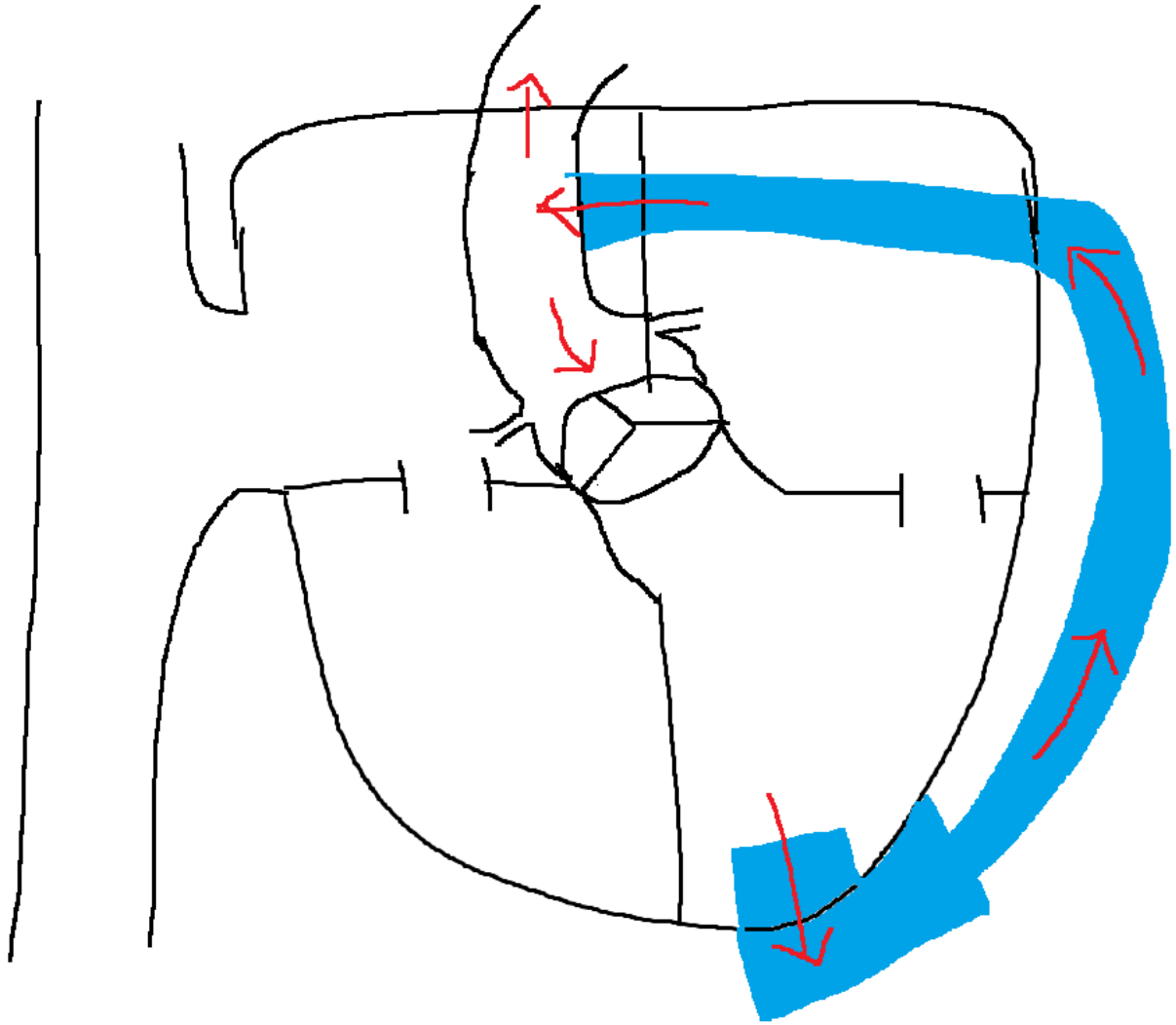
LVAD Intraoperative consideration

Pre-Procedure

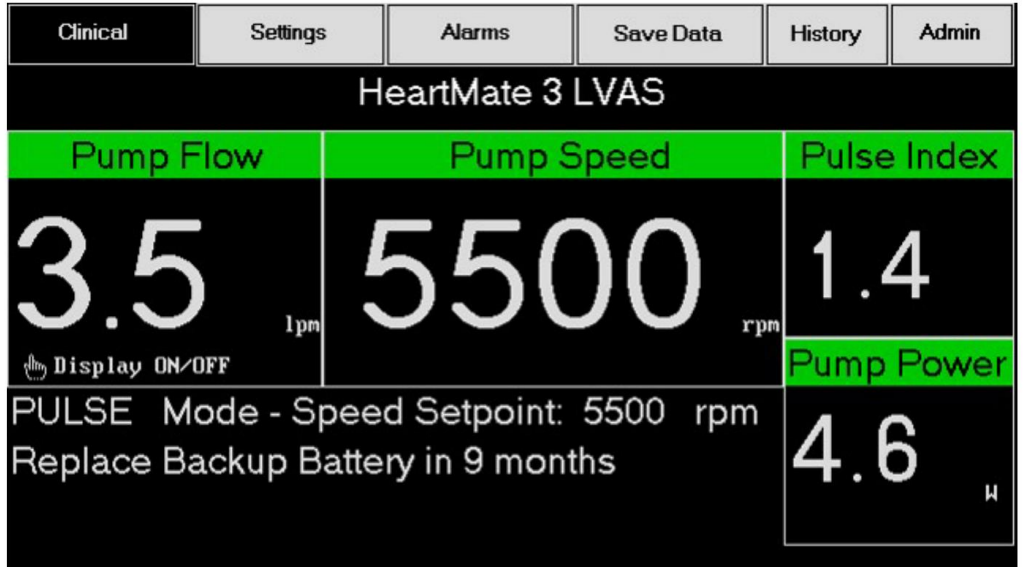
- **S**hunt
  - Patent foramen ovale
  - Atrial septal defect
  - Ventricular septal defect
- **T**hrombus
  - Left atrial appendage thrombus
  - Left ventricular apical thrombus
- **A**ortic Regurgitation
- **R**V dysfunction
- Mitral Stenosis

Post-Procedure

- **STAR**
- Ventricular septum position
- Velocity through inflow and outflow cannula



LVAD Dashboard



- Speed (RPM): Fixed range of 3,000 – 9,000
  - Higher the speed, higher the flow
- Flow (L/min): Estimate that is derived from a calculation of fixed speed, power, and patient's hematocrit value
  - Increased BP will DECREASE flow through the pump
- Power (watt): Direct measurement of pump motor voltage and current.
  - Increased power could indicate thrombus or AI
  - Gradual power decrease may indicate obstruction of flow
- Pulsatility Index (unitless): Flow pulses averaged over 15-second intervals
  - During systole, LV contracts, increasing ventricular pressure that causes increase in pump flow (Pump pulse)
  - Decrease in PI may indicate a decrease in circulating blood volume

P160054 Device@FDA. https://www.accessdata.fda.gov/scripts/cdrh/devicesatfda/index.cfm

Common LVAD Alarms

- High Flow
  - Likely 2/2 vasodilatory state
  - Diagnose and treat. Possible Sepsis. Consider vasopressor
- Low Flow
  - Suction event: Hypovolemia
  - Fluid bolus, transfusion, treat arrhythmia, decrease RPM transiently
- High Power
  - Pump thrombosis
  - Anticoagulation, pump exchange
- Low Power
  - Pump failure/disconnection
  - Check connections
- Low Pulse Index
  - Suction event: Hypovolemia
  - Fluid bolus, transfusion, treat arrhythmia

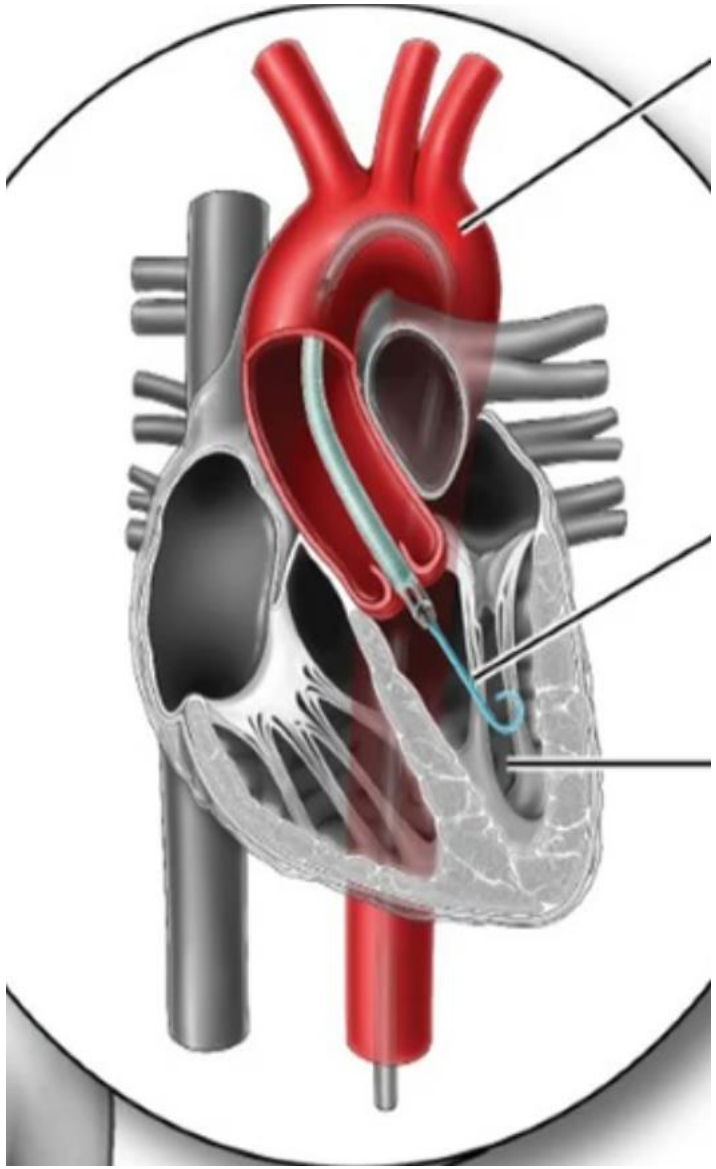
LVAD Complications

- Gastrointestinal Bleeding (9-24%)
  - Non-pulsatile flow increases the risk of GI AVM formation
  - Acquired vWS due to increased destruction of high-molecular weight von Willebrand monomers
  - Patients are on anticoagulation
- Pump Thrombosis
  - 10-13% on HM2, 1.5% on HM3
- Stroke (10%)
  - MAP > 90mmHg linked to hemorrhagic stroke
  - Ischemic stroke may result from emboli formed in the LA, LV, or pump thrombosis
- RV Failure (15-34%)
- Infection (25-58%)

Impella

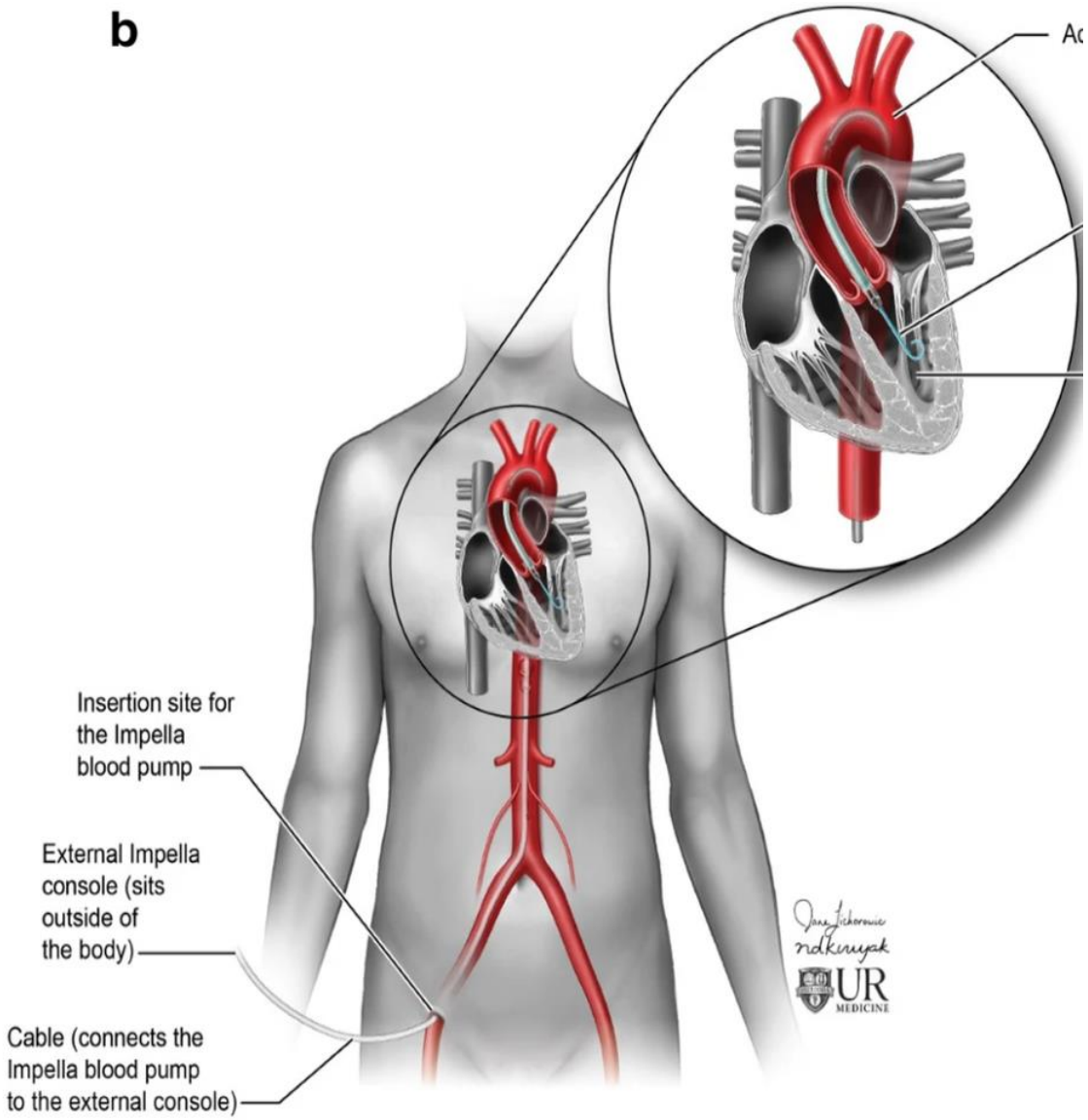
Impella

- LV assist device that continuously pumps blood from LV into the aorta.
- Replaces/supplements the work of LV
- Reduces LVEDV and LVEDP
- Introduced in 2002. First FDA approval in 2008 (Impella 2.5)
- Most recent model is Impella 5.5 (approved in 2019)
- Placed into femoral or axillary artery



Impella

- Indications
  - High-Risk Non-emergent PCI
  - Hemodynamic support during VT ablation
  - Bridge to permanent LVAD placement
- Contraindications
  - LV Thrombus
  - Mod to Severe AI
  - Severe peripheral vascular disease (placement)
- Complications
  - Vascular injury
  - Limb ischemia
  - Stroke
  - Myocardial infarction



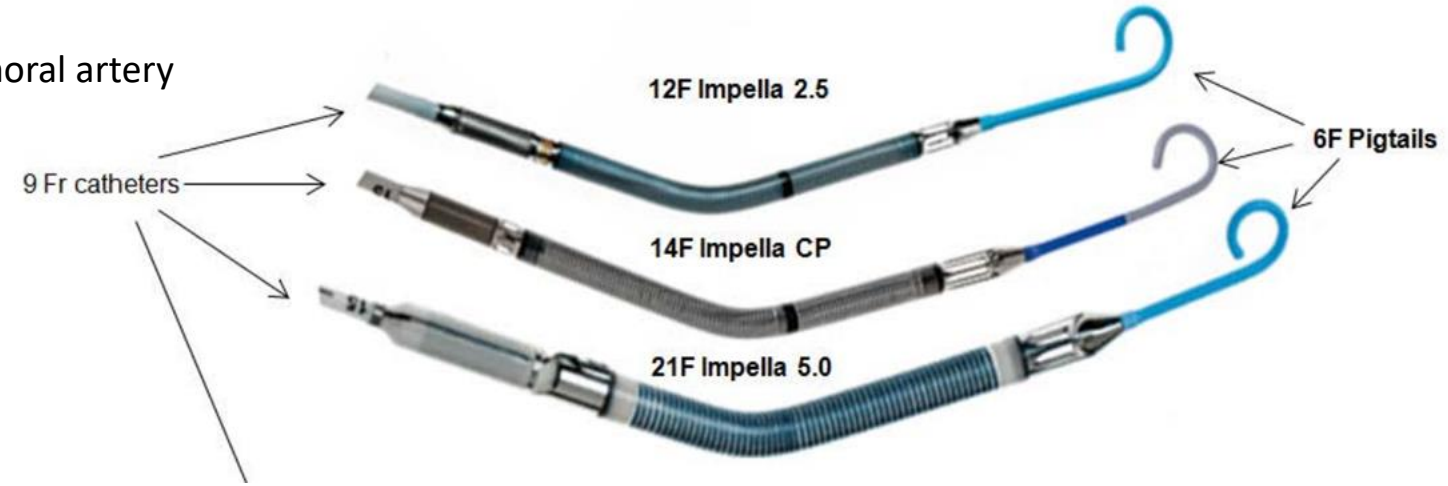
Impella Models

Impella 2.5
- Maximum flow rate 2.5L/min
- Percutaneous 12-Fr sheath in Femoral artery
- FDA approval up to 5 days

Impella CP
- up to 4.3 L/min
- Percutaneous insertion of 14-Fr sheath in the femoral artery
- FDA approval up to 5 days

Impella 5.0
- 5.0 L/min
- Surgical cut-down insertion of 21-Fr sheath.
- Axillary artery preferred to allow for ambulation
- FDA approval up to 10 days

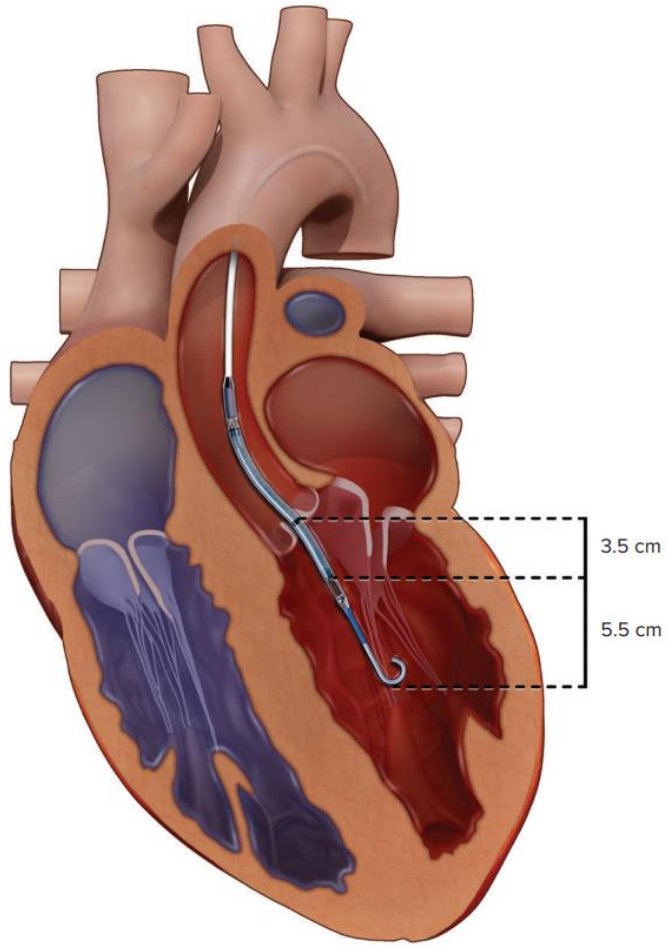
Impella 5.5
- up to 6.0L/min
- Surgical cut-down insertion with a 21-Fr sheath
- Axillary artery or directly to the ascending aorta
- FDA approval up to 30 days

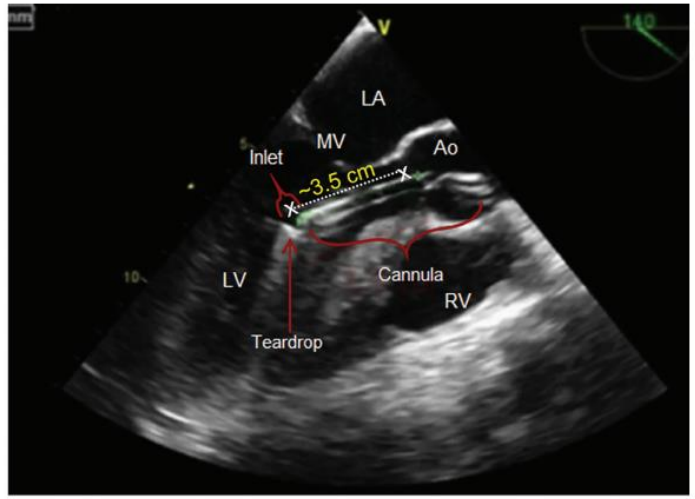


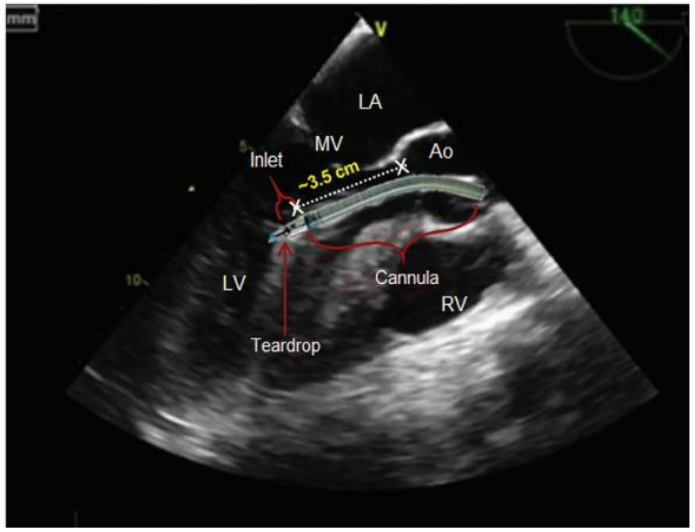
P140003 Device@FDA. https://www.accessdata.fda.gov/scripts/cdrh/devicesatfda/index.cfm

Impella positioning

- Positioning on TEE
- 2.5/CP
  - 3.5cm to inlet
  - 5.5cm to pigtail
- Impella 5.5
  - 5cm to inlet

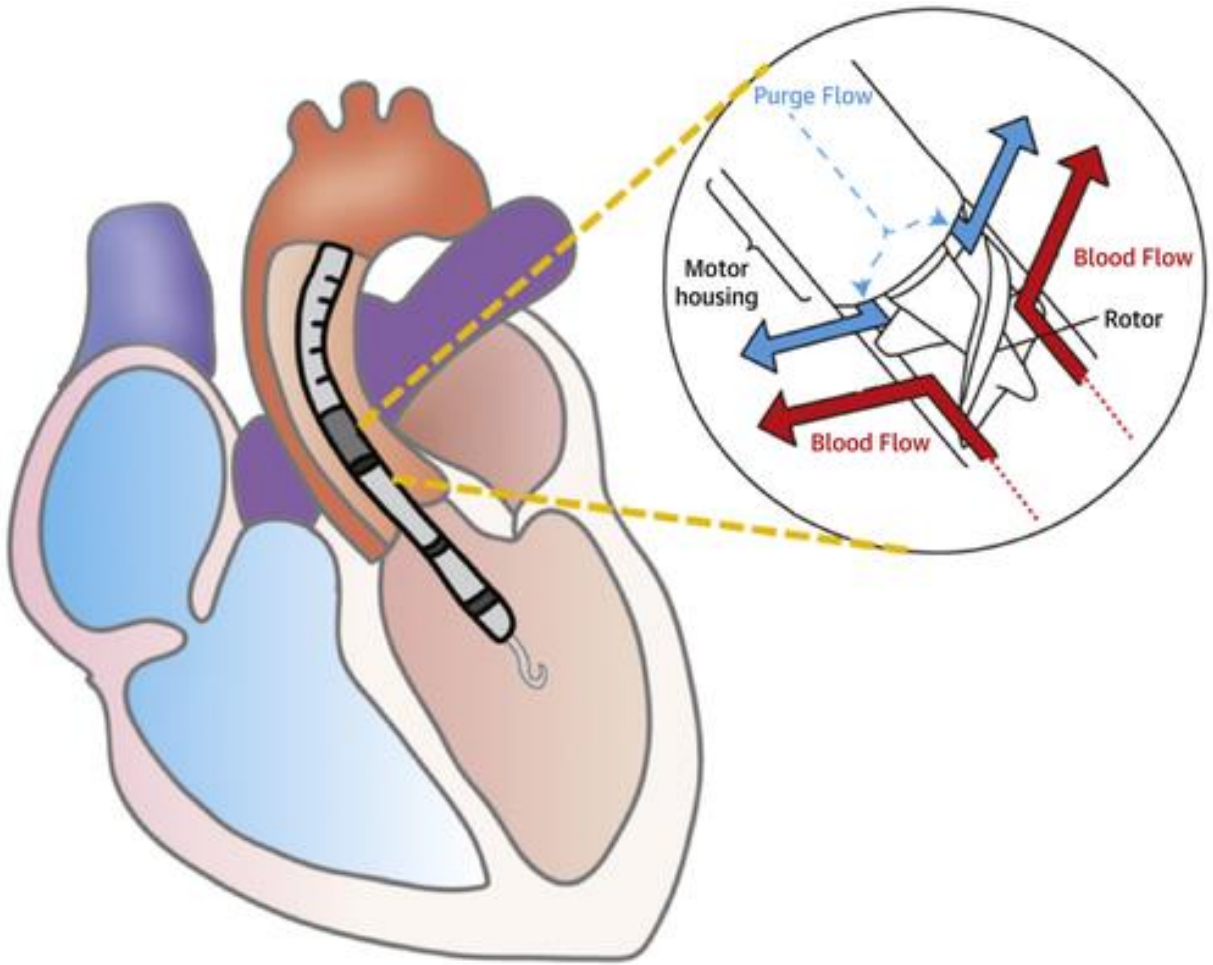






Impella

- Anticoagulation
  - Purge solution contains heparin
  - Purge enhances device protection against deposition of coagulated blood
  - Systemic heparin is usually necessary
- P-level
  - Determines the flow
  - P-1 to P-9 (Impella 5.5)
  - In cardiac arrest, reduce to P-2 to prevent suction event

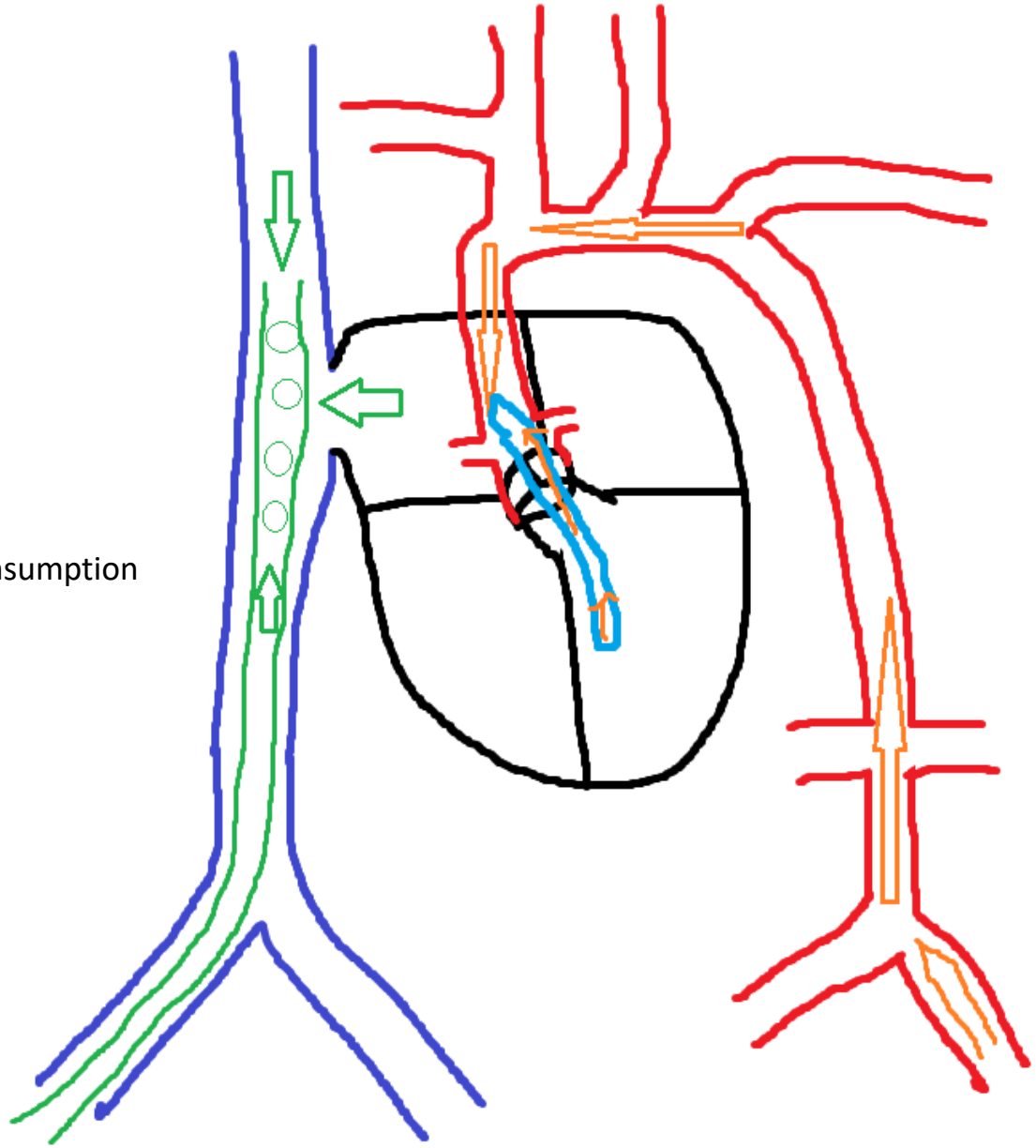


Vandenbriele, C, Arachchillage, D, Frederiks, P. et al. Anticoagulation for Percutaneous Ventricular Assist Device-Supported Cardiogenic Shock: JACC Review Topic of the Week. J Am Coll Cardiol. 2022 May, 79 (19) 1949–1962.
https://doi.org/10.1016/j.jacc.2022.02.052. Open Access Article under the CC BY-NC-ND License.

ECpella

ECpella

- VA ECMO + Impella
- Problem with VA ECMO
  - With retrograde flow, AI gets worse and LV is distended
  - Commonly used in the past if AI was severe with VA ECMO
  - Even with no significant AI
    - Higher LVEDP & LV Distension lead to higher oxygen consumption
    - Impella would allow for decompression of LV
- Desired effect
  - Decompression of LV
    - Decreases oxygen consumption
  - Decreased LV afterload
    - Decreases oxygen consumption
  - Coronary perfusion with decreased oxygen consumption
    - leads to LV recovery over time
- Easier transition to wean from Ecpella to Impella



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