Ventricular Assist Devices

OBJECTIVES

- What is a VAD?
- Who can get one?
- Timing of implant
- Surgical procedure
- Patient management
- Complications

Definition

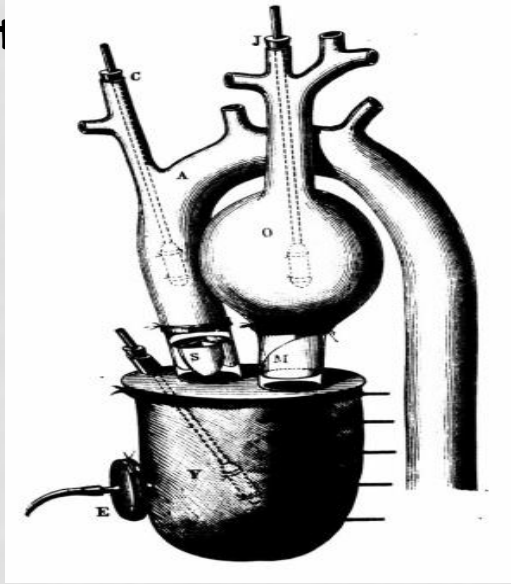
Ventricular Assist Devices

is a mechanical circulatory device that is used to partially or completely replace the function of a failing heart.

Conceptual eras of mechanical circulatory support..

Le Gallois "parts of the body may be preserved by external perfusion" 1812

Etienne-Jules Marey (Paris, 1881) – physician, invent



.. the 1st "artificial heart

1929

Guillotined head of a dog in perfusion experiments of Brukhonenko and Tchetchuline. This preparation relied on gas exchange from a second donor dog's lungs. Diaphragm-like pumps pumped blood into the recipient dog's carotid arteries. Dog heads perfused in this manner remained functional for a few hours. (Reprinted from Brukhonenko S, Tchetchuline S. Experiences avec la tete isolee du chien.1.Technique et conditions des experiences. *J Physiol Pathol Gen* 1929;27:42)

..a "biological oxygenator"

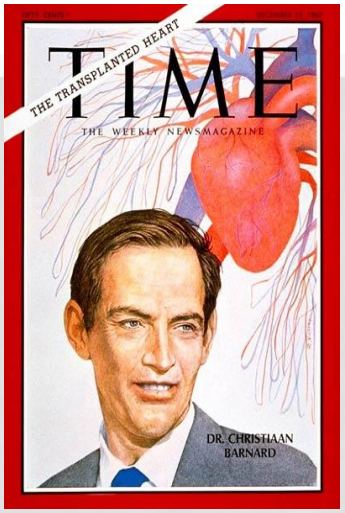
Evolution of Mechanical Circulatory Support…

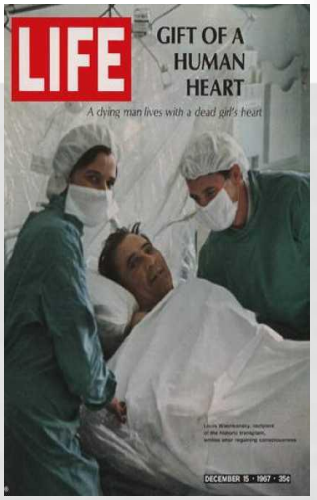
1936

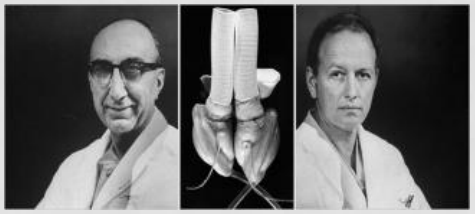
1965

1969

1968







As socio-political history…

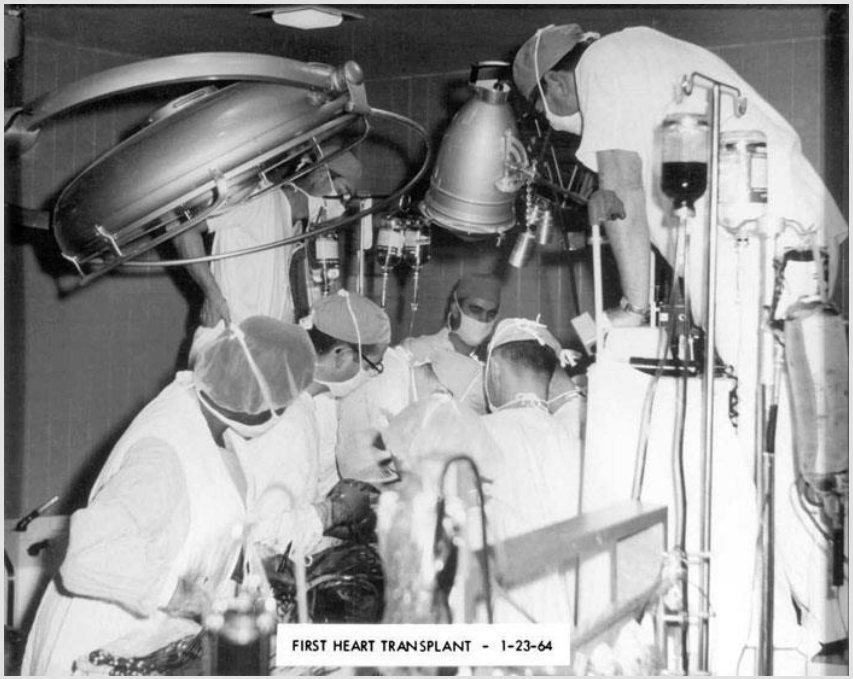
1981

1982

Intellectual origins of "mechanical assist" and "circulatory support"…

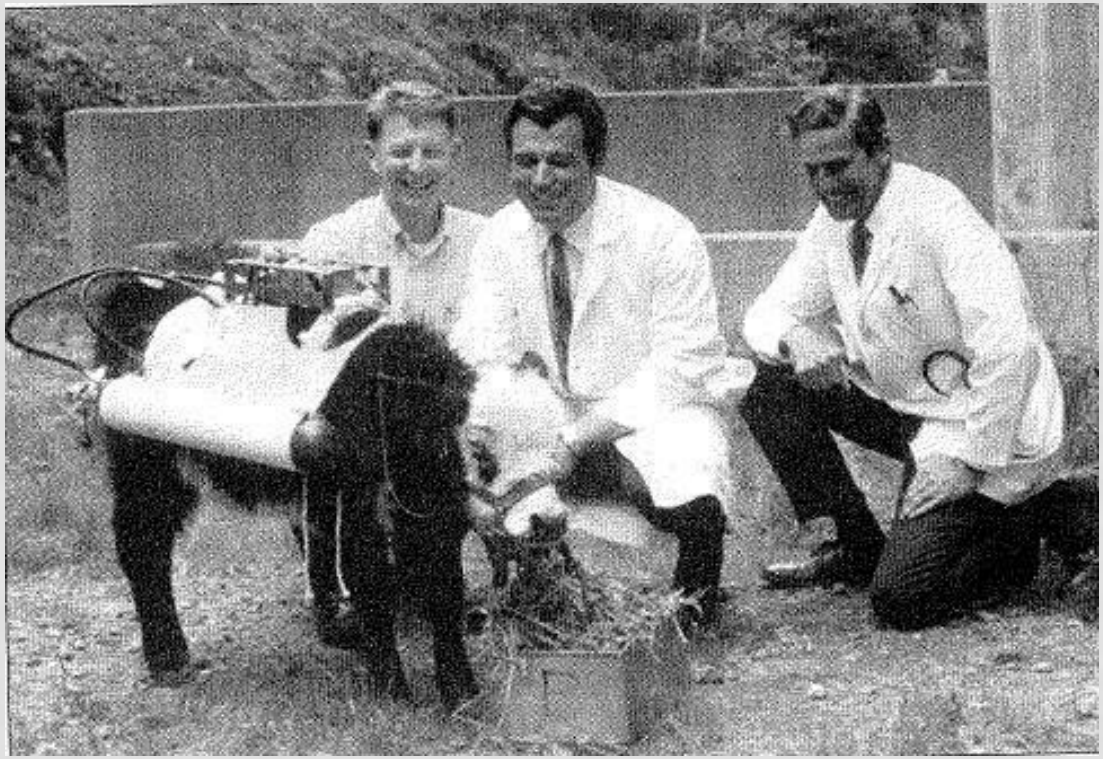
"Experimentally, it is possible to completely replace the heart with an artificial heart, and animals have been known to survive as long as 36 hours. This idea, I am sure, could be reached to full fruition if we had more funds to support more work, particularly in the bioengineering area"
DeBakey (1963) Senator Lister Hill's Subcommittee on Health

"..surgeons at Baylor hailed the Jackson transplant. The Baylor surgeons say there are two solutions for support of the failing heart..transplants from humans or animals and artificial hearts. The Baylor group is concentrating its efforts on developing *an artificial heart.*"
Associated Press, 25 Jan 1964



In Jan of 1964 James Hardy consented the sister of Boyd Rush – a 68 yo comatose deaf mute with ischemic heart failure and lower extremity gangrene – for "the insertion of a suitable heart transplant if such should be available. Rush decompensated and was placed on cardiopulmonary bypass. In the absence of a viable donor Hardy transplanted the heart of a 45 kg chimpanzee. The heart provided hemodynamic support for 90 minutes…

Ben Roe and the UCSF "artificial heart" circa 1970



BioE 298-26
ANTI-MEDICAL SCHOOL

Mechanical Hearts and Mechanical Lungs: Why Simple Ideas are Rarely Simple

Charles Hoopes, MD
Associate Professor of Surgery
290 Hearst Mining Memorial Bldg, UCB
Wednesday 10/20, 4pm-6pm

ucb·ucsc·ucsf

WHAT IS A VAD

- Tremendous progress in the last 20-25yrs
- Several generations developed over time
- Thousands of patients worldwide have undergone cardiac transplantation with long term MCS devices
- Hundreds of centres implanting devices
- Requires infrastructure within the program to obtain good clinical outcomes

WHO CAN GET ONE?

- **Bridge to Transplant (BTT)**

  Must be suitable for transplant
  Available in QLD
  Imminent risk of dying
  Long term placement

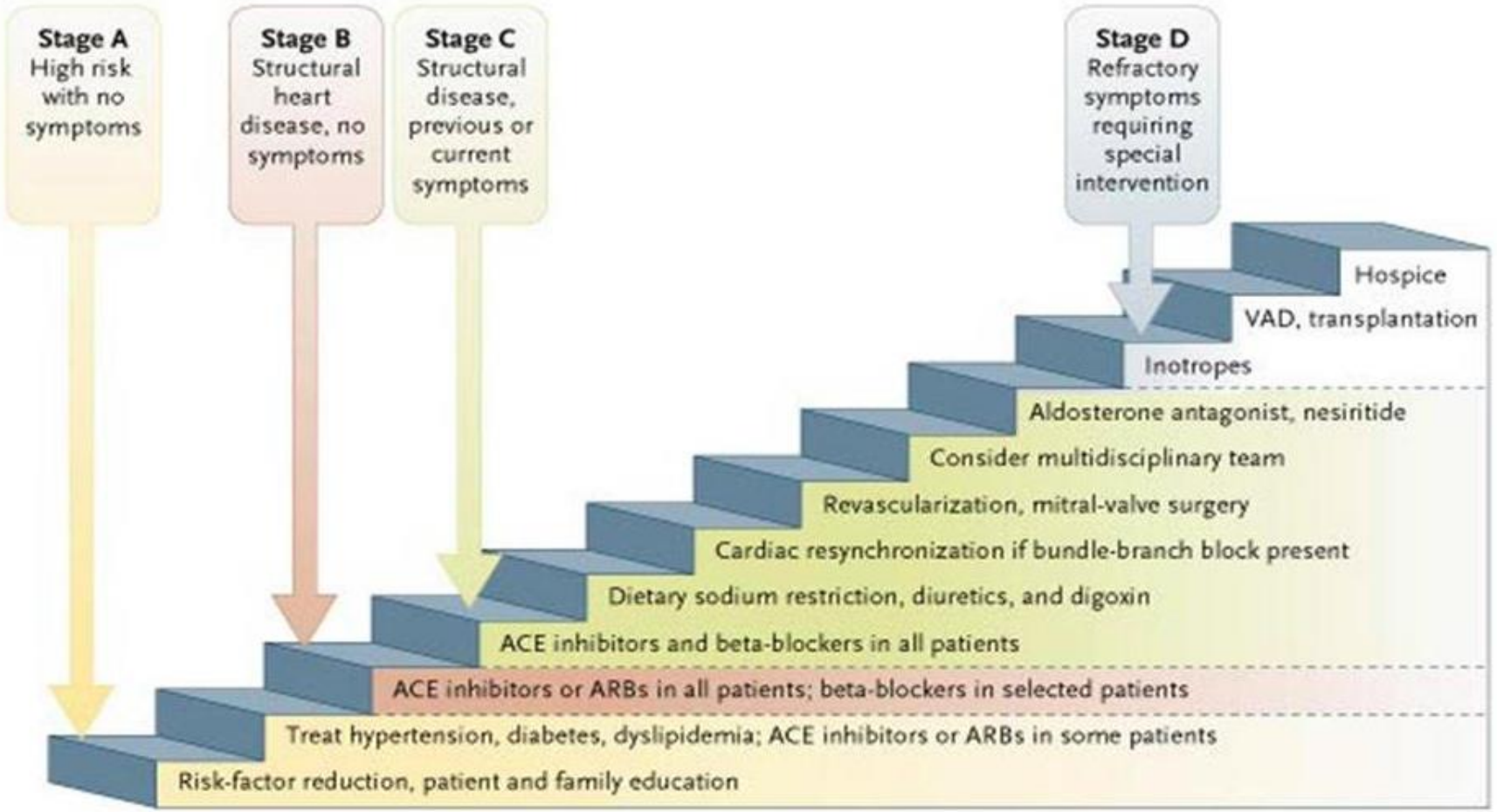
- **Contraindications for transplant include;**

  -Irreversible end organ damage
  -Neurological defects
  -Malignancy
  - sepsis
  -alcohol, smoking or drug dependency

WHO CAN GET ONE?

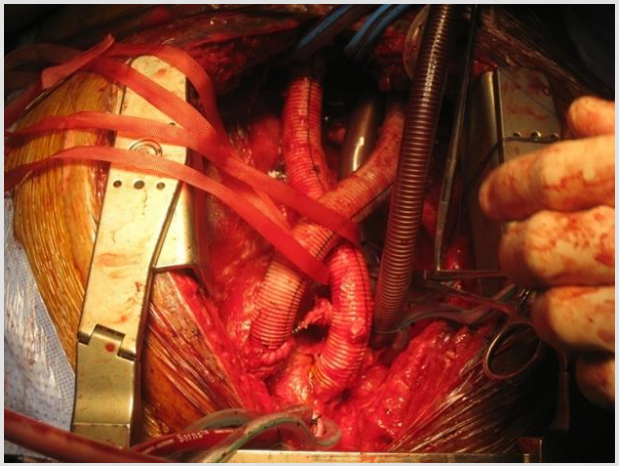
- **Bridge to recovery (BTR)**
  - Short term device placement(ECMO)
  - Unknown time to explant
- **Destination therapy**
  - Not yet available in QLD
  - Require infrastructure
  - Funding/Reimbursement requirements
- **Bridge to candidacy**
  - Unknown diagnosis, patient & eligibility for transplant
  - Buys time
  - **Candidacy can change if their clinical condition changes**

HEART FAILURE TRAJECTORY



TIMING OF IMPLANT

- When all pharmacological & non pharmacological means have been explored
- Before end organ damage ensues
- Often a small window of opportunity
- Intermacs patient profile 2 and 3
- Transplant assessment complete



INTERMACS PATIENT PROFILE

1 "Crash and burn"

- Persistent hypotension despite rapidly
- escalating inotropic support and eventually IABP, and critical organ hypoperfusion.

2 "Sliding on inotropes"

- Intravenous inotropic support with acceptable values of blood pressure and continuing
- deterioration in nutrition, renal function, or fluid retention.

3 "Dependent stability"

- Stability reached with mild to moderate doses of inotropes but demonstrating failure to
- wean from them due to hypotension, worsening symptoms, or progressive renal dysfunction.

4 "Frequent flyer"

- Possible weaning of inotropes but experiencing recurrent relapses, usually fluid retention.

5 "Housebound"

- Severe limited tolerance for activity: comfortable at rest with some volume overload and often with some renal dysfunction.

6 "Walking wounded"

- Less severe limited tolerance for activity and lack of volume overload. Fatigue easily.

7 "Placeholder"

- Patient without current or recent unstable fluid balance. NYHA class II or III.

WHEN TO REFER PATIENTS FOR ADVANCED HEART FAILURE ASSESSMENT

REMEMBER THIS ACRONYM TO ASSIST IN DECISION MAKING FOR REFERRAL TO ADVANCED HEART FAILURE SPECIALIST[1,2]

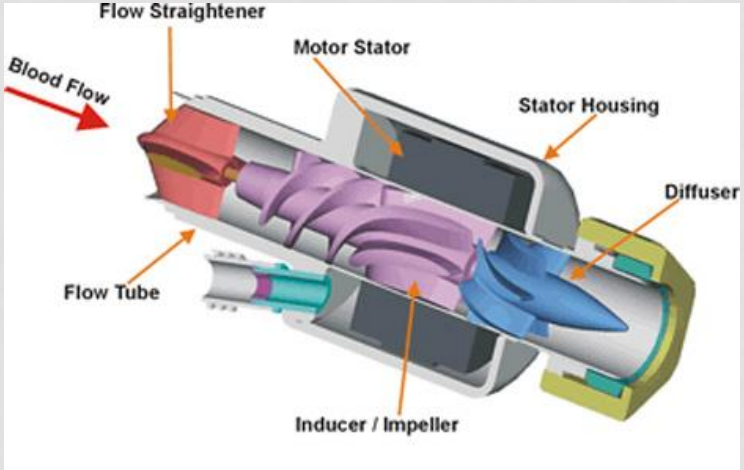
I	IV Inotropes
N	NYHA IIIB/IV or persistently elevated natriuretic peptides
E	End-organ dysfunction
E	Ejection Fraction < 35%
D	Defibrillator shocks
H	Hospitalizations > 1
E	Edema Despite escalating diuretics
L	Low Blood Pressure – High Heart Rate
P	Prognostic medication – progressive intolerance or down-titration of GDMT

I.
N. E. E. D.
H. E. L. P[1].

(1) Baumwol J. "I Need Help"—a mnemonic to aid timely referral in advanced heart failure. J Heart Lung Transplant. 2017;36:593–4.s
(2) The Journal of American College of Cardiology; Pathways for Optimization of Heart Failure Treatment; Vol. 71, No. 2, 2018:201-302017

PULSATILE VS. NON-PULSATILE

- Pulsatile
  - Older first generation models
- Non-Pulsatile
  - Second / Third Generation Models (Most Common)



VAD'S

- Ventricular Assist Devices
  - LVAD
  - RVAD
  - Bi-Vad

Heartware (impellar)

Left ventricular assist vs.
biventricular replacement…

Durable vs non-durable applications

Syncardia TAH

Heartmate II (axial flow)

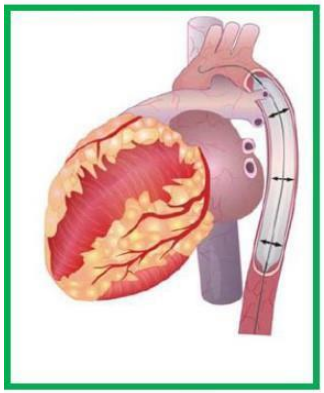
AbioCor TAH

THE SPECTRUM OF ACUTE MCS DEVICES IN 2017

Left Ventricle

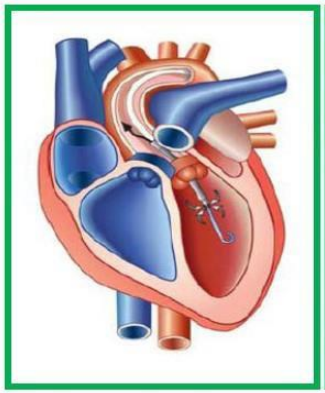
Continuous Flow Pumps

Pulsatile

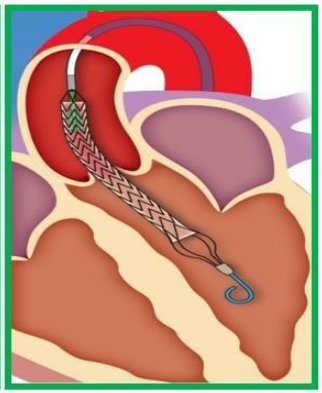


IABP

Axial-Flow



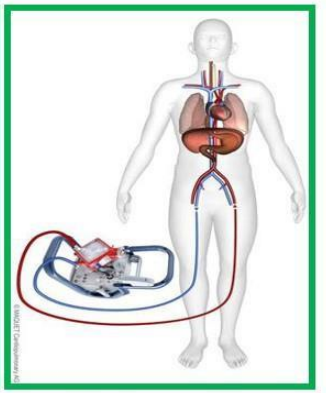
Impella CP



PHP *

Centrifugal Flow

TandemHeart



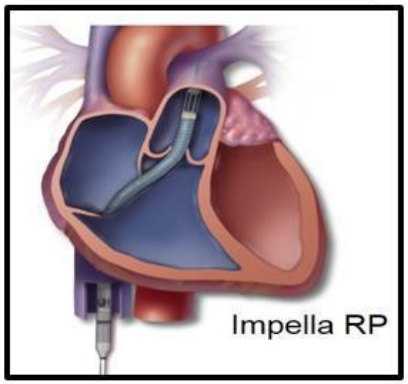
VA-ECMO

Intracorporeal

Extracorporeal

Right Ventricle

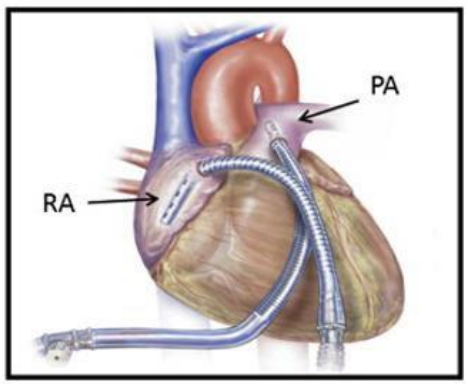
Axial Flow



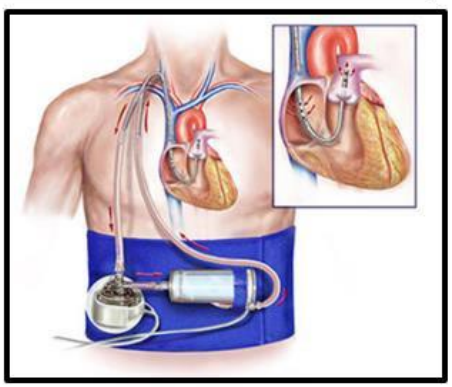
Impella RP

Centrifugal Flow

VA-ECMO

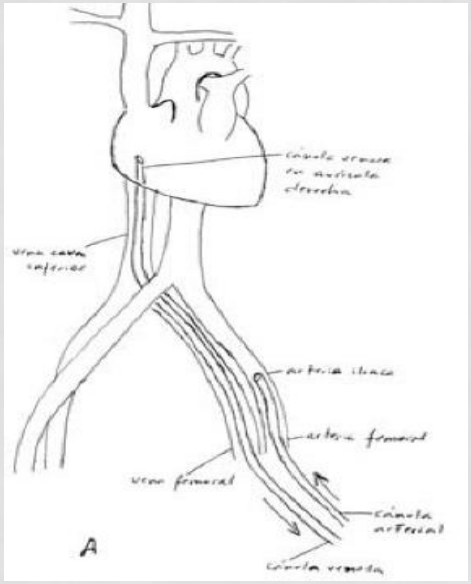


Tandem pRVAD



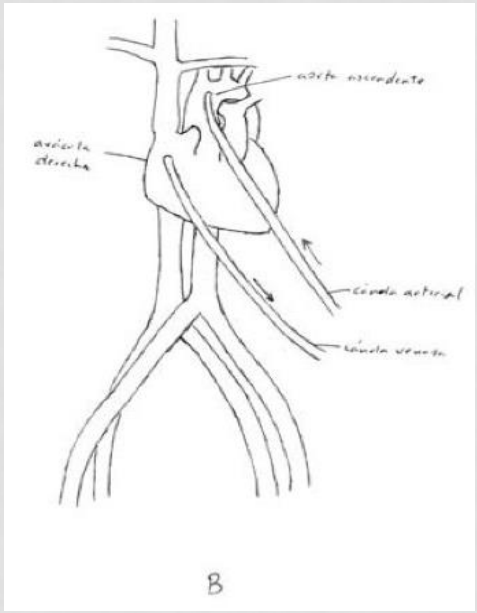
Protek Oxy-RVAD

ECMO: extracorporeal membrane oxygenation.



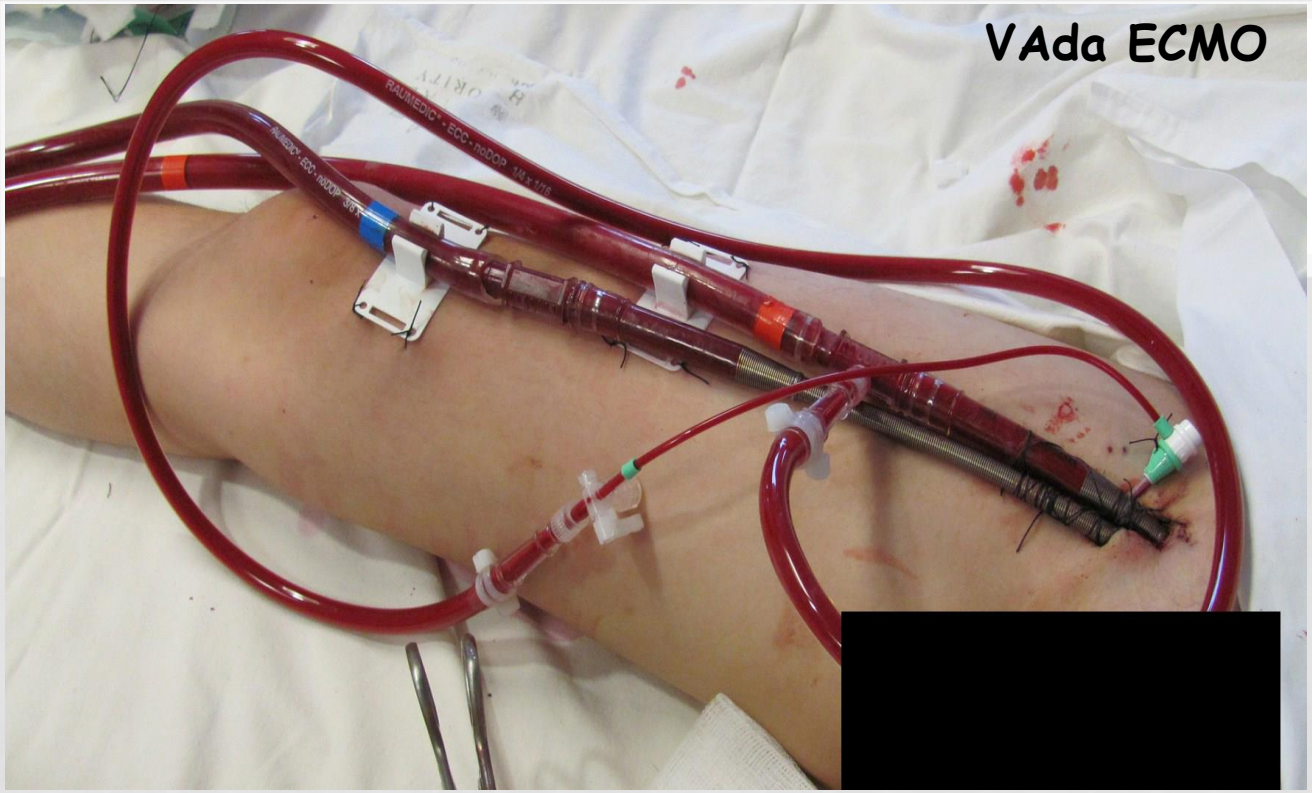
Peripheral veno-arterial ECLS

RA/femoral vein…retrograde femoral a. (ECMO)
RA…antegrade right subclavian a. (8mm Dacron graft/ECMO)
LA/femoral trans-septal …retrograde femoral a.



Central veno-arterial ECLS

RA to pulmonary a. (right heart)
LA to aorta (VAD)
RA to aorta (ECMO)



Veno**A**rterial (**d**istal **a**rtery) ECMO

Non physiologic and inherently unstable

Efficacy proportional to LVEF

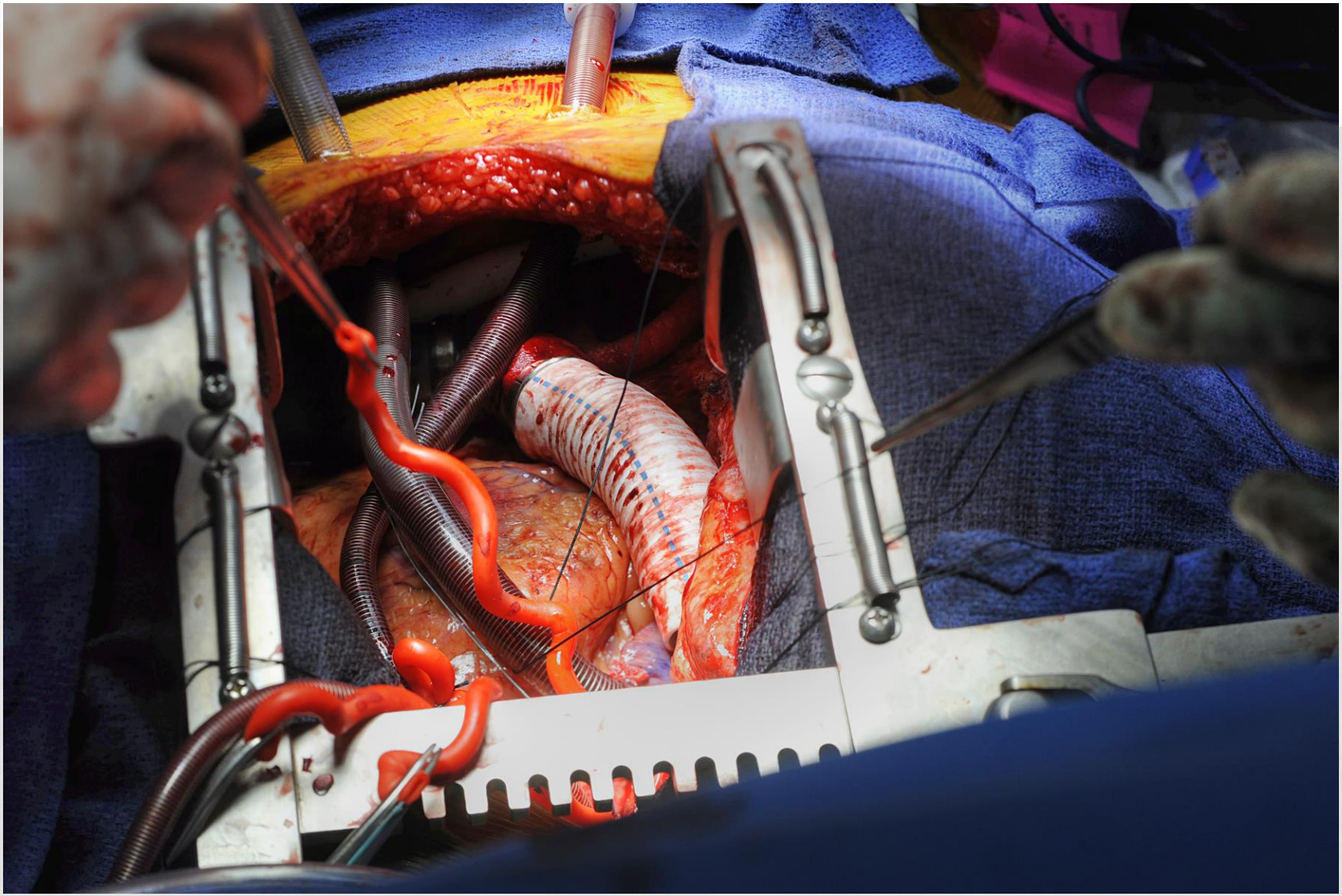
Retrograde arterial flow … LVEF and cerebral perfusion, LVEDP !

Distal malperfusion …

The patient … sedate and non-ambulatory

Blood path and directional flow …

Central cannulation …

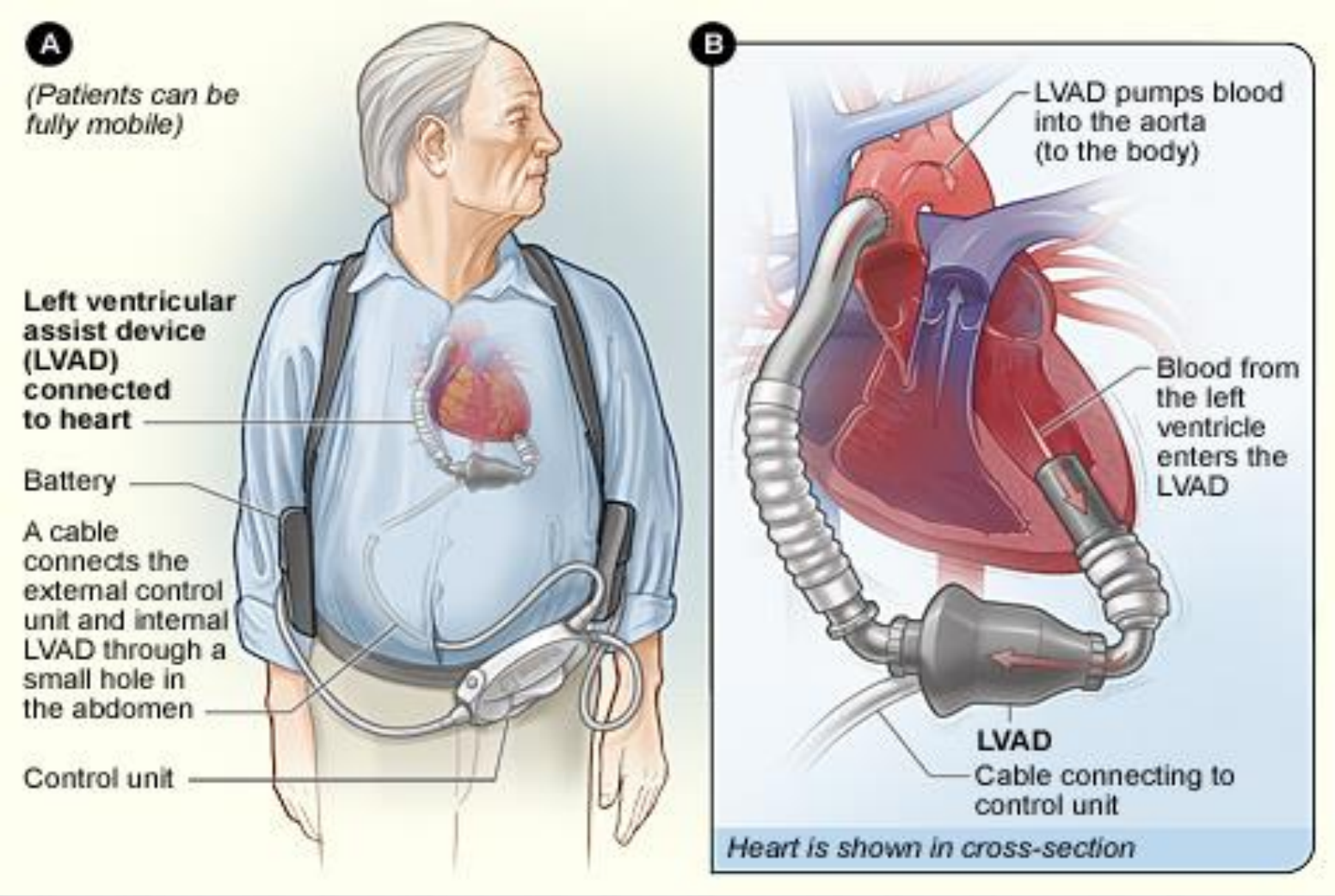


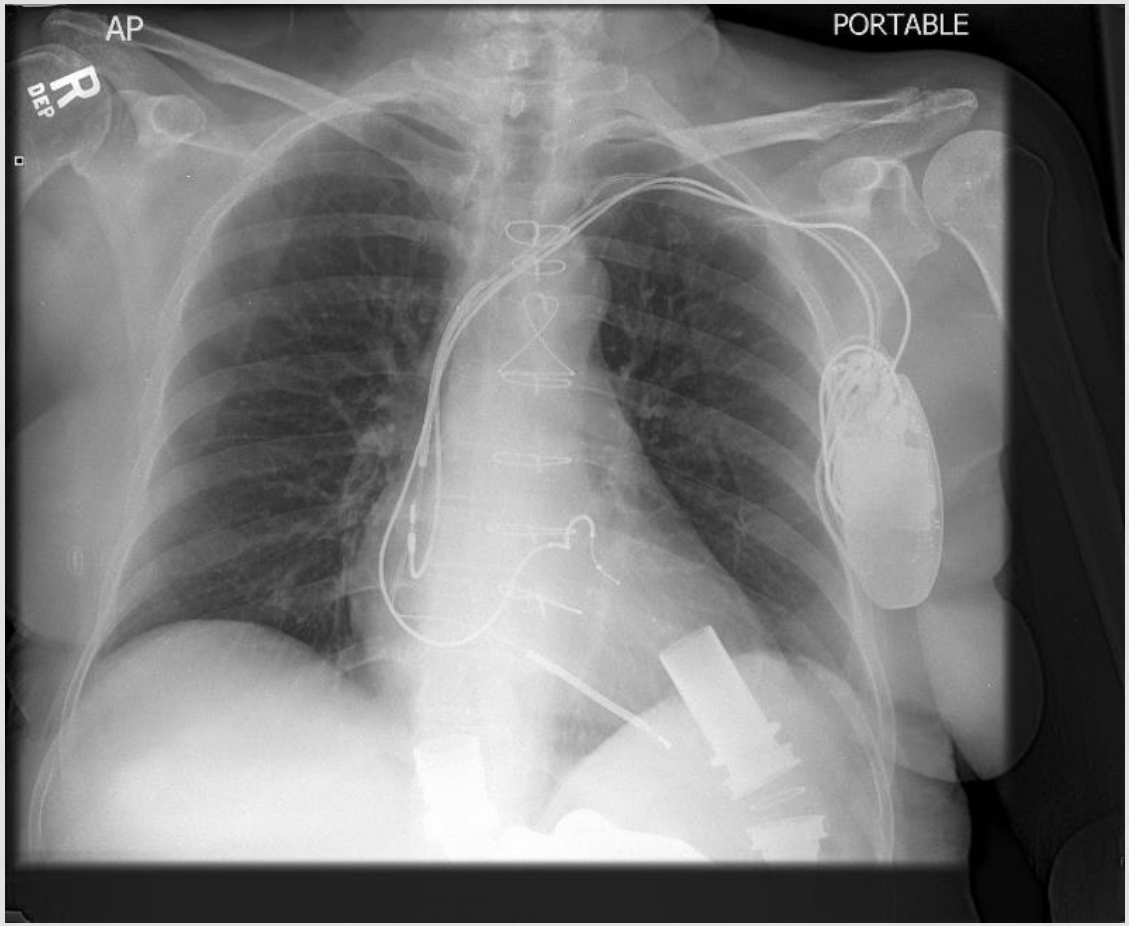
… integrated MCS ECMO

cardiogenic shock …
femoral ECMO … to central ECMO …
to LVAD and oxyRVAD with RV failure…
to long-term Centrimag RVAD support

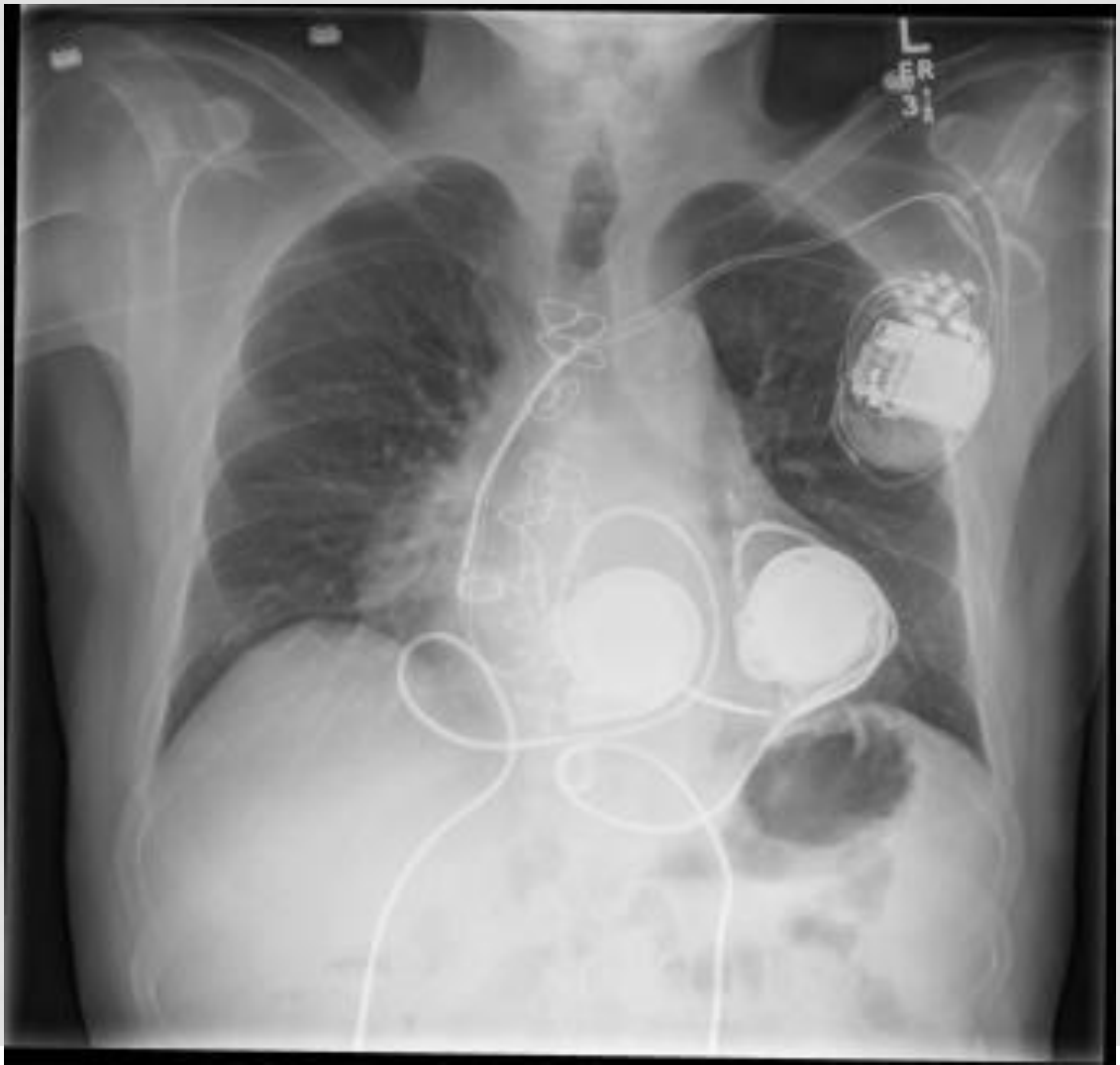
… bridge to transplant

VAD


A
(Patients can be fully mobile)
Left ventricular assist device (LVAD) connected to heart
Battery
A cable connects the external control unit and internal LVAD through a small hole in the abdomen
Control unit
B
LVAD pumps blood into the aorta (to the body)
Blood from the left ventricle enters the LVAD
LVAD
Cable connecting to control unit
Heart is shown in cross-section

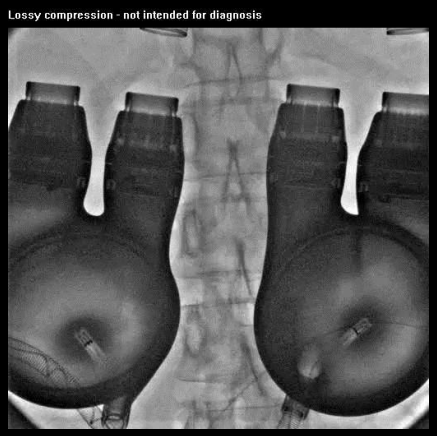

AP
PORTABLE
R
DEP

BIVAD

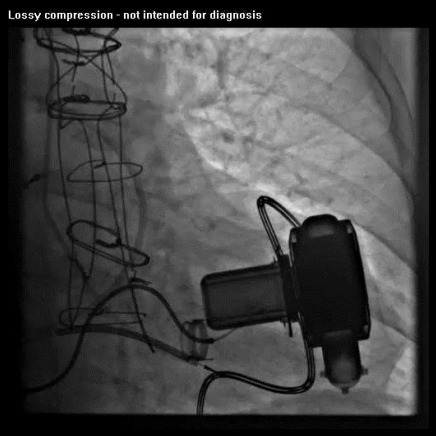


Tufts Medical Center
The CardioVascular Center

2007 → 2017

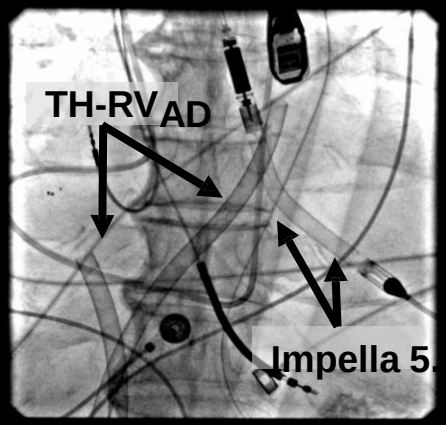


IVADs

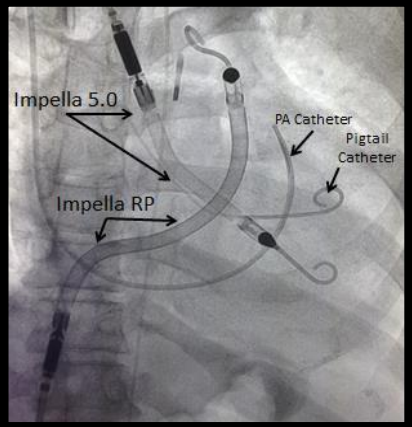


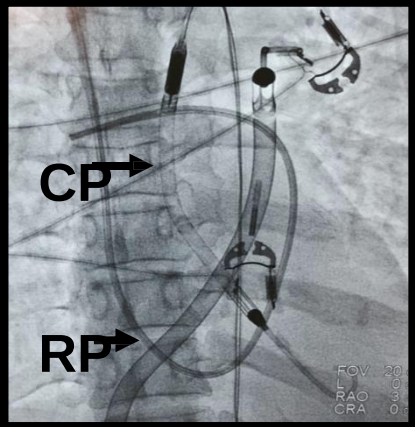
HVAD

Impella CP



TH + 5.0

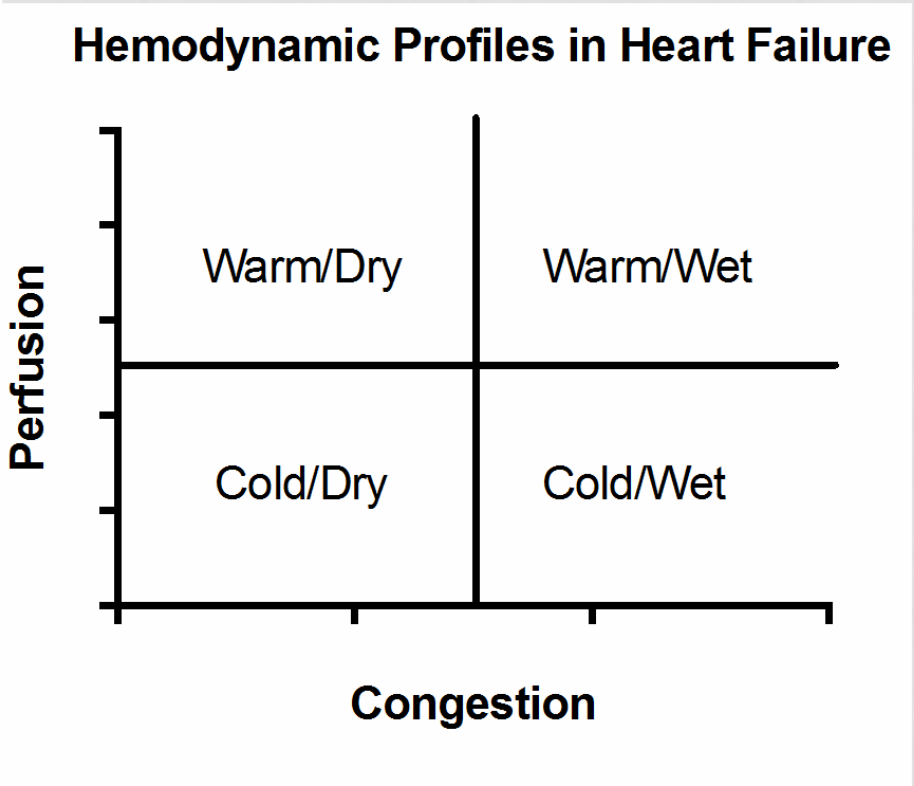


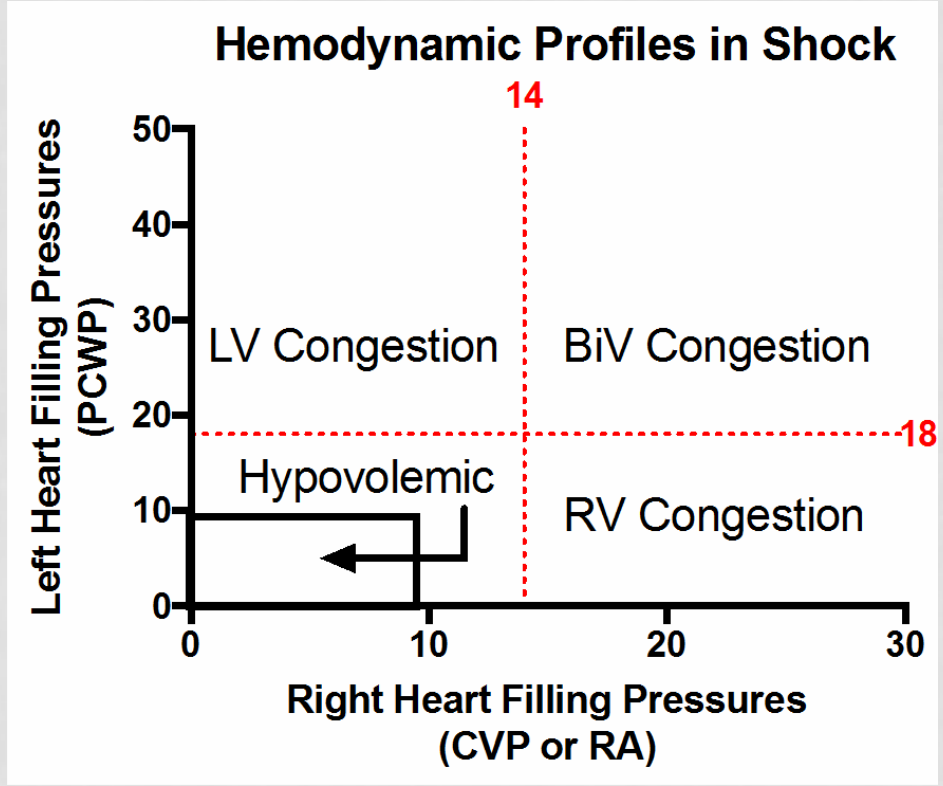


Bi-Pellas

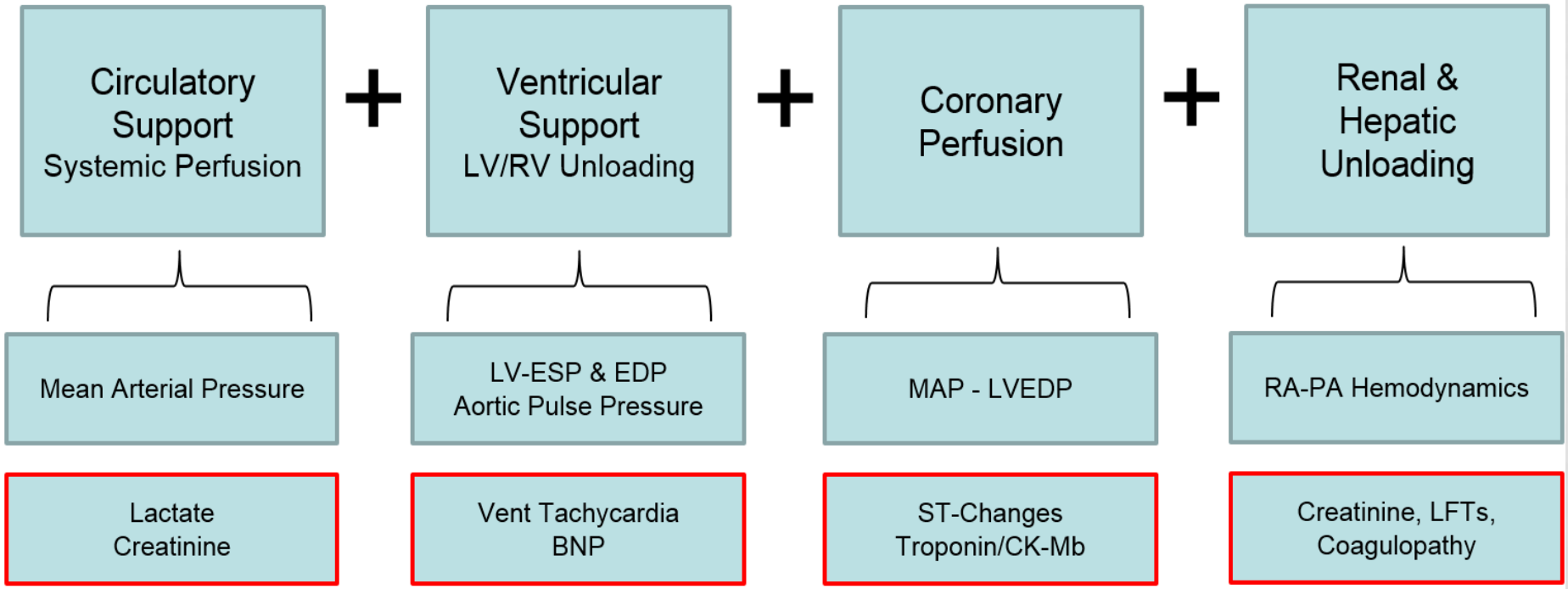
WHO USES VAD'S?

MATCHING PATIENTS AND AMCS PUMPS THE TUFTS CARDIOGENIC SHOCK ALGORITHM





THE HEMODYNAMIC SUPPORT EQUATION FOR ACUTE MCS
FROM ARITHMETIC TO CALCULUS



Hemodynamic Problem

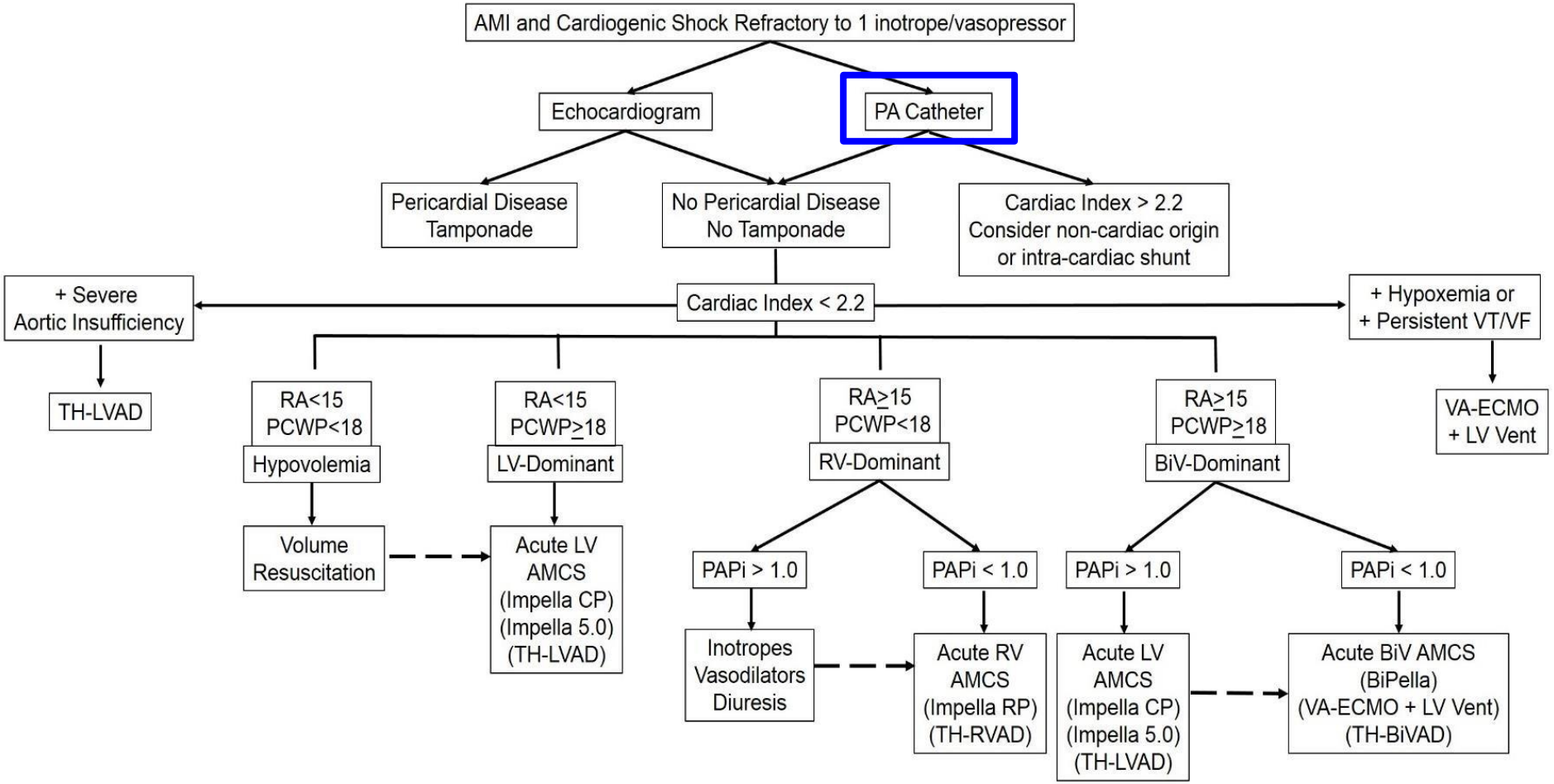
Hemo-Metabolic Problem

Recovery — Time in Cardiogenic Shock — Death

Bridge to Recovery
Detroit Cardiogenic Shock Initiative

It's Too Late for AMCS
Impress Trial

MATCHING PATIENTS AND AMCS PUMPS
THE TUFTS CARDIOGENIC SHOCK ALGORITHM



Hemodynamic Formulas to Assess RV Function

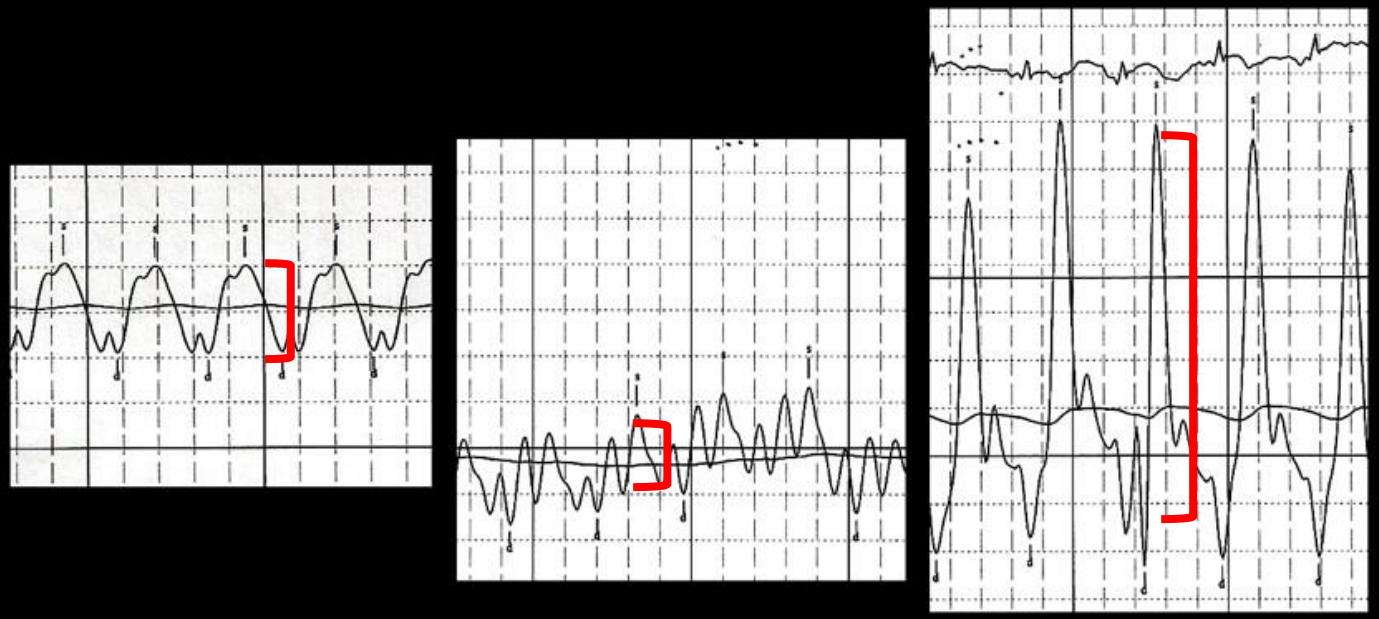
Cardiac Filling Pressures	RA / PCWP	>0.63 (RVF after LVAD) [14] >0.86 (RVF in Acute MI)[31]
PA Pulsatility Index	(PASP-PADP) / RA	<1.85 (RVF after LVAD) [42] <1.0 (RVF in Acute MI) [41]
Pulmonary Vascular Resistance	mPA-PCWP / CO	>3.6 (RVF after LVAD) [16]
Trans-pulmonary Gradient	mPA-PCWP	Undetermined [36]
Diastolic Pulmonary Gradient	PAD - PCWP	Undetermined [36, 37]
RV Stroke Work	(mPAP-RA) x SV x 0.0136	<15 (RVF after LVAD) [16] <10 (RVF after Acute MI) [40]
RV Stroke Work Index	(mPA-RA)/ SV Index	<0.3-0.6 (RVF after LVAD) [14,42]
Pulmonary Artery Compliance	SV / (PASP-PADP)	<2.5 (RVF in Chronic Heart Failure) [39]
Pulmonary Artery Elastance	PASP/ SV	Undetermined [38]

Right atrial (RA); Pulmonary artery (PA); PA systolic pressure (PASP); PA diastolic pressure (PADP); mean PA pressure (mPAP); Pulmonary capillary wedge pressure (PCWP); Right ventricular failure (RVF); Left ventricular assist device (LVAD); Myocardial infarction (MI); Stroke volume (SV)

Kapur, Esposito, and Burkhoff et al Circulation 2017

FROM PULSATILE LOAD TO PA PULSATILITY

Pre-RVAD	RVAD: 7500 RPM (4.0 L/min flow) Day 3	RVAD: 3500 RPM (1.8 L/min flow) Day 5
PA 35/30, 32	PA 27/21, 24	PA 40/19, 27



RAP = 22	RAP = 15	RAP = 7

Kiernan and Kapur. JIC 2009

HEMODYNAMIC SIGNATURES OF RV FAILURE

The Pulmonary Artery Pulsatility Index (PAPi)

$$\text{PAPi} = \frac{\text{PA Pulse Pressure (Systolic – Diastolic)}}{\text{CVP (RA Pressure)}}$$

Table 2: Univariate regression analysis of hemodynamic variables echocardiographic measurements of RV dysfunction.

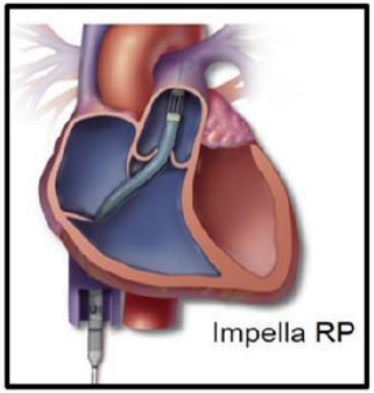
	PaPi	RA:PCWP	RVSW
RA:PCWP	-0.726*		
RVSW	0.331*	-0.481*	
Echo Score	-0.731*	0.511*	-0.365*

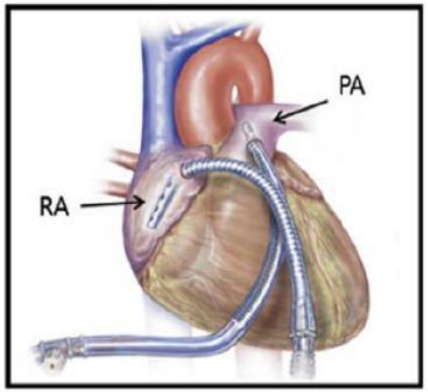
* Significant correlation ($p<0.001$)

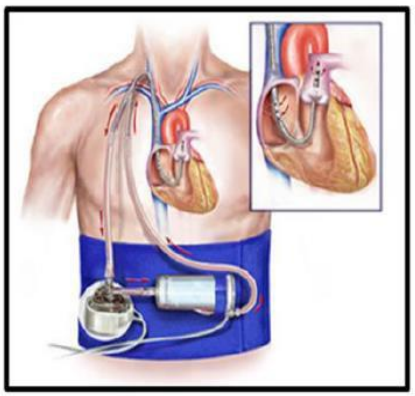
NOT ALL RV AMCS DEVICES ARE CREATED EQUAL

Direct RV Bypass

Indirect RV Bypass



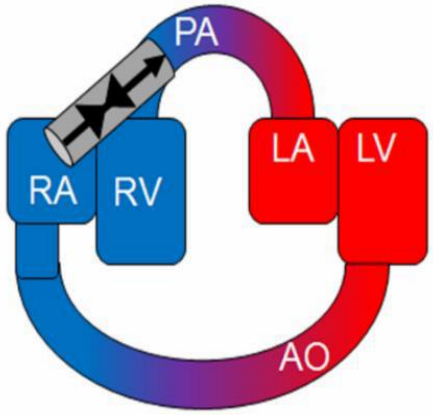




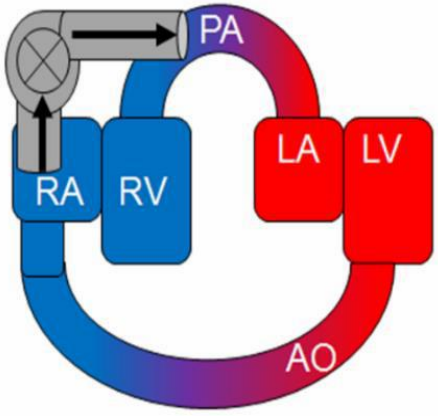
Impella RP | Tandem RVAD | Protek Duo | VA-ECMO

Axial Flow | Extracorporeal Centrifugal Flow

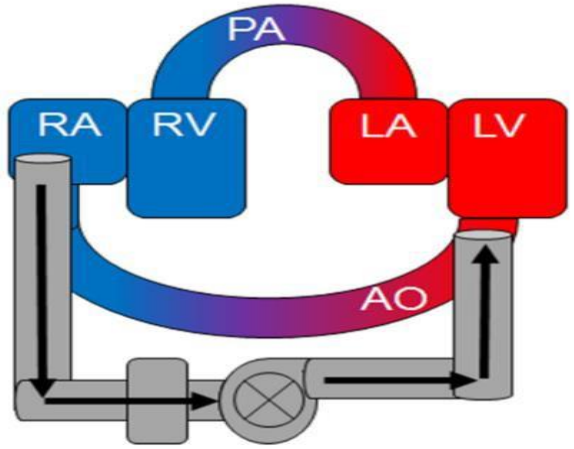
Impella RP



Tandem RVAD



VA-ECMO



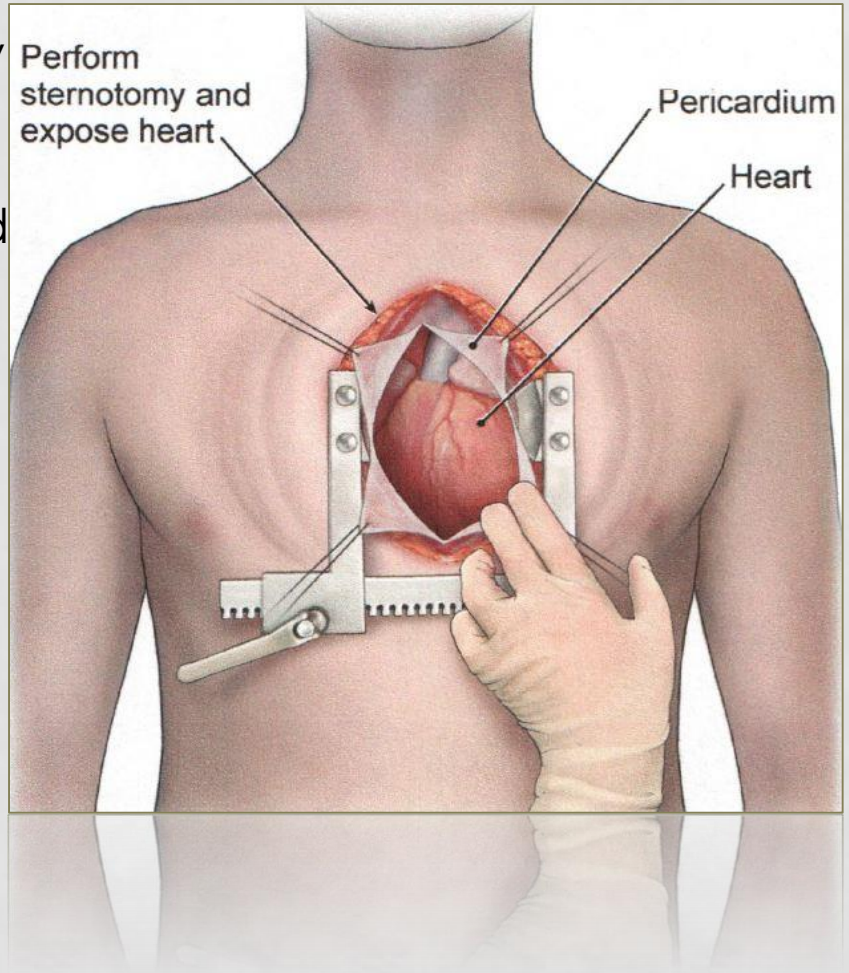
SURGICAL PROCEDURE

Make a standard median sternotomy incision

Open the pericardium to expose and access the LV apex

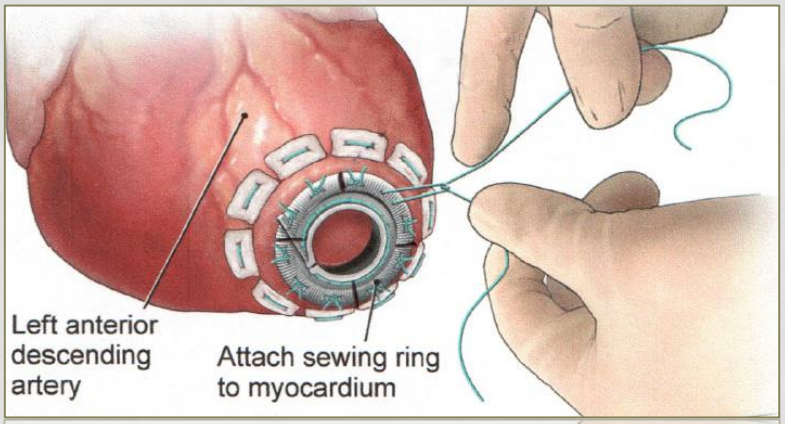
Elevate the LV apex

Select the insertion site for the inflow cannula

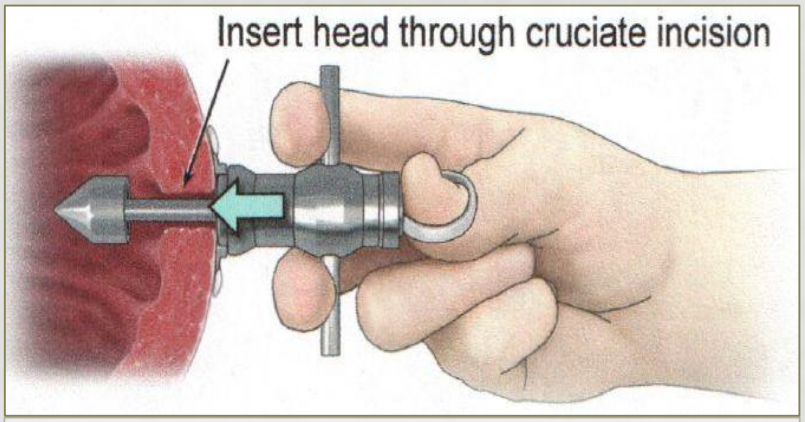


SURGICAL PROCEDURE

Sew the sewing ring to the myocardium using 8-12 pledgeted, double-armed sutures – reinforce with felt strips

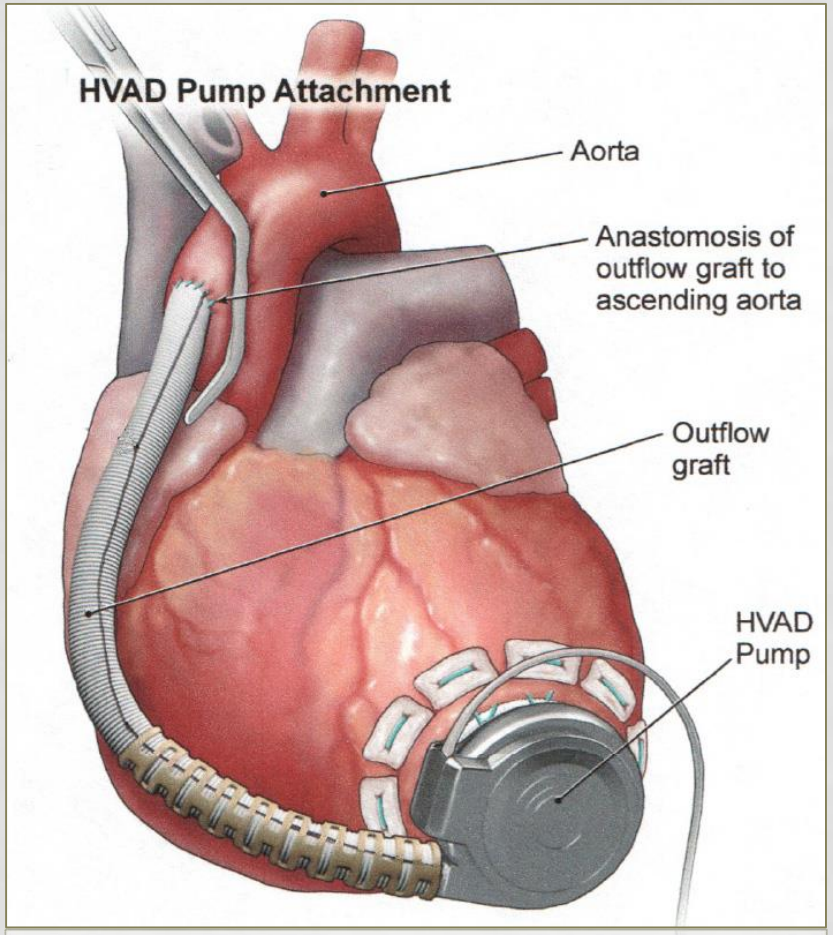


After the cutting head is completely extended, place the cutting head through the myocardium; release tension

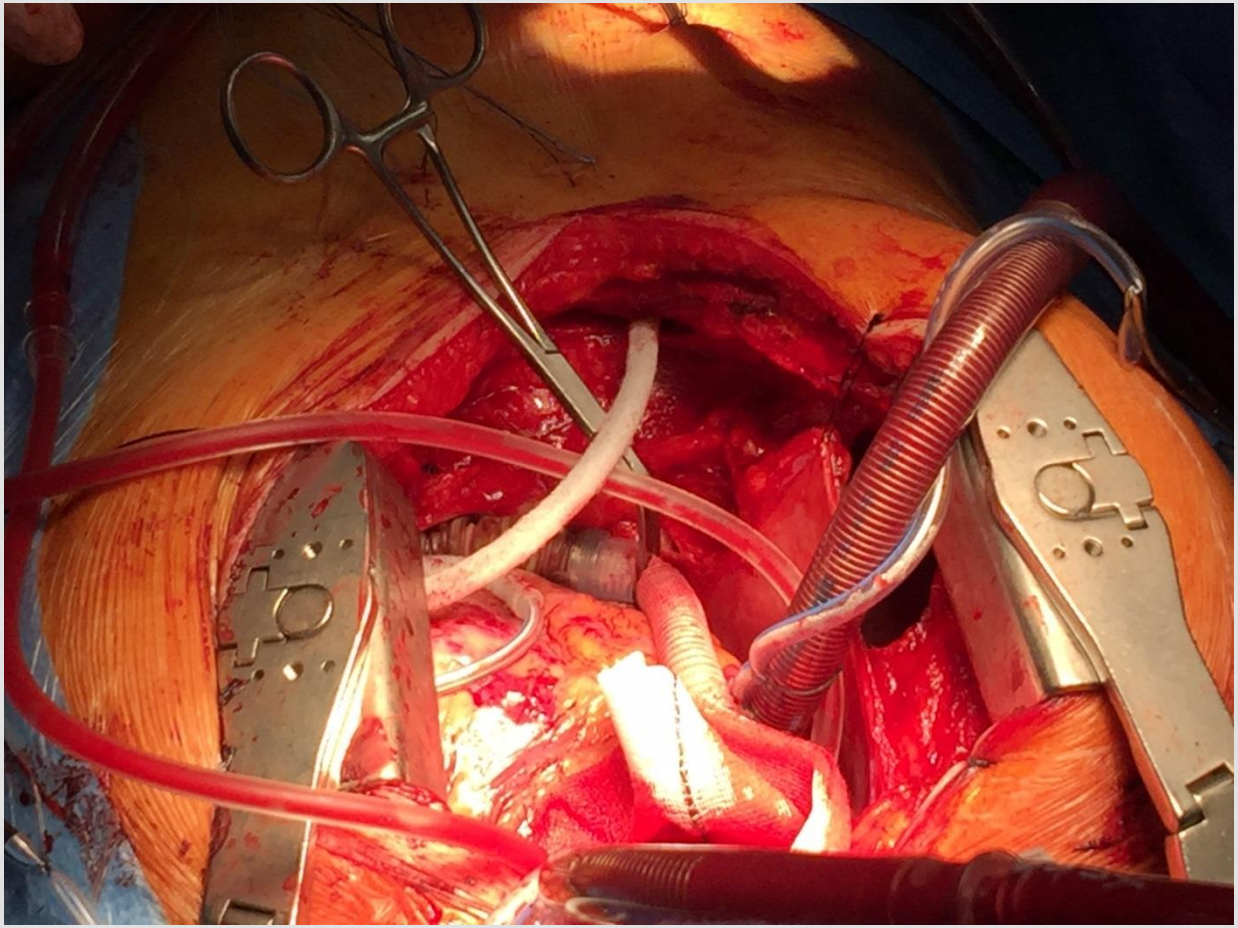


OUTFLOW GRAFT ANASTOMOSIS

Gently stretch outflow graft, measure and cut to length (outflow graft should lie without kinking or overstretching)



ALL IN PLACE



SPECIAL FEATURES HEARTWARE HVAD

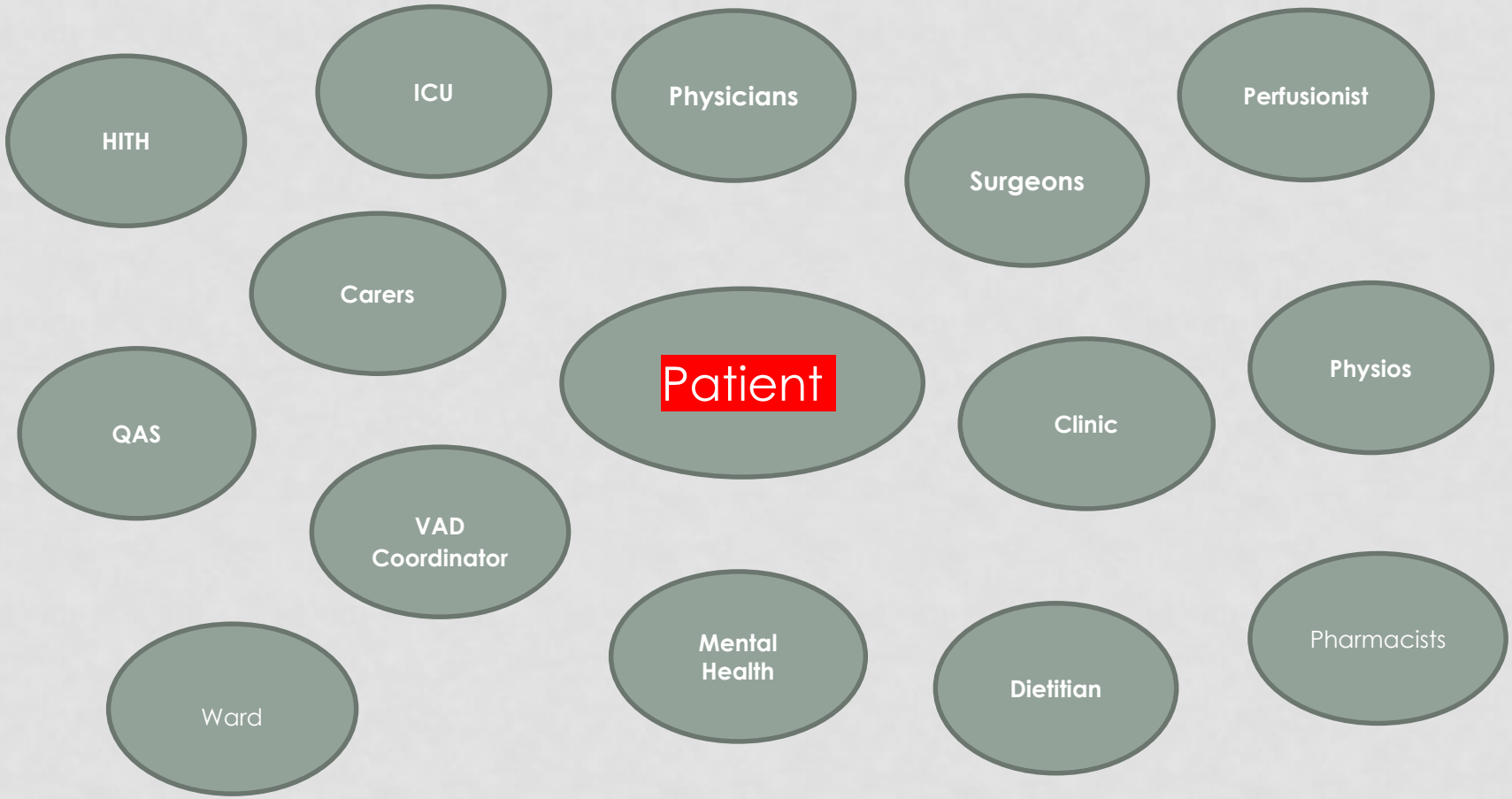
- Pre load dependant
- Afterload sensitive
- Centrifugal Continuous flow pump
- Capable of delivering up to 10 L/min flow
- Weight 160g
- Lavare cycle
- Suction alarm
- Patient friendly system

PATIENT MANAGEMENT

Prevention and treatment of common post operative complications

- Bleeding
- Tamponade
- Cardiac arrhythmias
- Right heart failure
- Infection
  - Driveline, local or sepsis
- Anticoagulation / Thromboembolic events

IT TAKES A VILLAGE……



BLEEDING

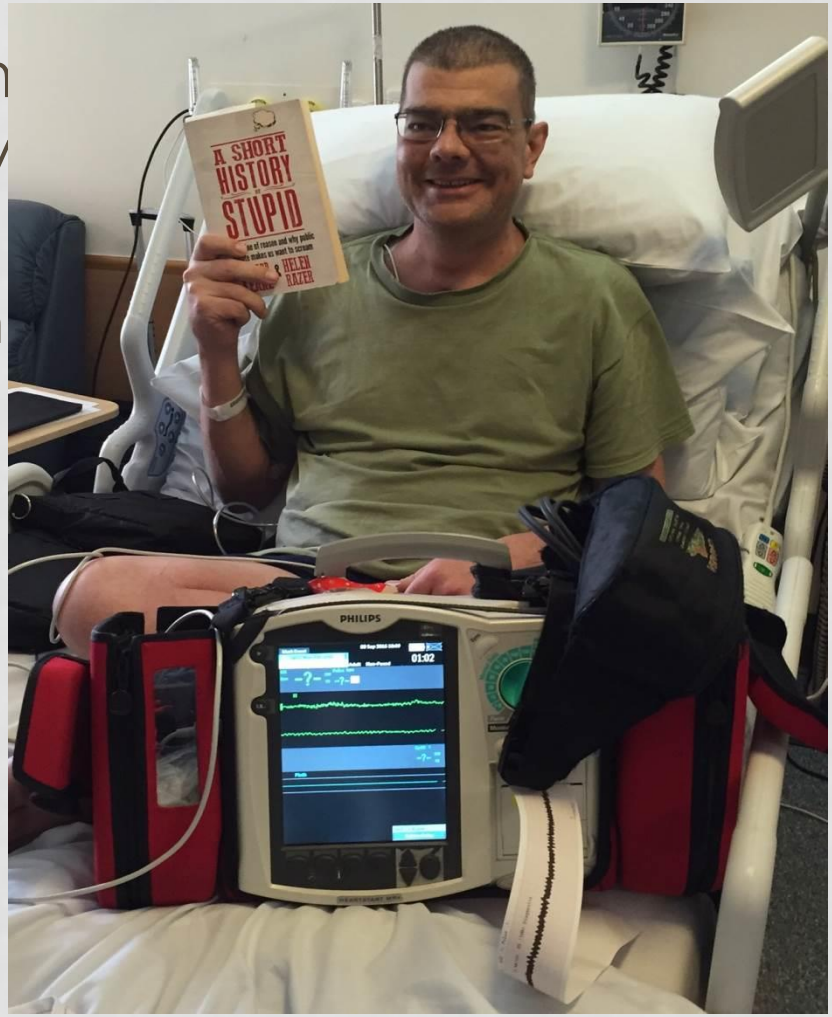
- Pre-implant, abnormal coagulation is expected due to hepatic dysfunction, inotropic drugs and the use of anticoagulation or antiplatelet medications
- Minimize CPB time to reduce negative effects of extracorporeal circulation on platelets
- Normothermia should be maintained

TAMPONADE

- Usually occurs in the first 24 hours but may also occur later
- Tamponade is a consequence of bleeding and may be difficult to diagnose
- TEE/TOE can be helpful in making the differential diagnosis
- Hemodynamic changes consistent with tamponade:
  - Decreased MAP
  - Increased CVP
  - Decreased VAD flow
  - Decreased pump pulsatility

CARDIAC ARRHYTHMIAS

- Arrhythmias affect RV function and decrease LV preload, flov may be reduced
- Arrhythmias are common in th immediate post op period
- Anti-arrhythmic drugs, pacemakers, and ICDs are compatible with the HeartWare® System



RIGHT HEART FAILURE

- Lowering pulmonary vascular resistance to maximize right ventricle function
- Aggressive volume management to minimize RV work load
- Use of inotropes
- Temp RVAD's

INFECTION

- After HVAD® Pump implantation, continue systemic antimicrobials prophylaxis for 48 to 72 hours
- Early extubation, removal of monitoring lines, and patient ambulation are encouraged

- Daily dressing to exit site
  - patient and carer responsible
  - medi honey used
  - must be immobilised

INFECTED DRIVELINE

FIELD CONSIDERATIONS

- Treat patient as an adult with special health care needs.
- Find family member or aide who is familiar with equipment
- Always treat the patient!

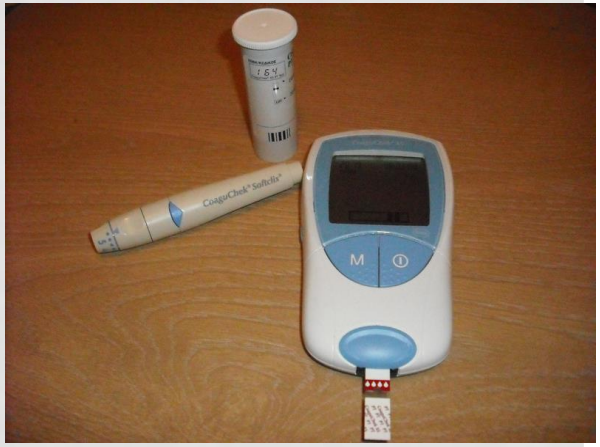
FIELD CONSIDERATIONS

ANTICOAGULATION

FIELD CONSIDERATIONS

ANTICOAGULATION

- Anticoagulation should be individualized for each patient
- Chest tube drainage should be less than 40 ml/hr for approximately three hours
- In general, begin low-dose heparin
- Gradually increase the heparin dosage to maintain the PTT in a range of 50-60 seconds
- Daily Aspirin 100mgs
- Warfarin to maintain INR 2 – 3
- Use Coaguchek to monitor at home



FIELD CONSIDERATIONS

- If patient has an LVAD and it is working properly, it is providing most of the patient's cardiac output.
- Patient's **EKG rate may not equal** pulse rate. Utilize the EKG rate for determining a pulse as the VAD pump is continuous.
- A **Doppler** is required to obtain an accurate BP.
  - Utilize **skin parameters** and **mental status** to assess perfusion.

FIELD CONSIDERATIONS

- All VADs are dependent on **adequate preload** in order to maintain proper functioning
- Pump can "**cavitate**" if there is a decreased preload
- **Volume resuscitation** in an unstable VAD patient is the first line of therapy before vasopressors. When in doubt… Give Fluids!!!!

FIELD CONSIDERATIONS

- Nitrates / Diuretics can be detrimental to a **VAD** patient because of the reduction in preload
  - Results in decreased pump efficiency
  - Consult with medical control before administering per protocol
- Initiate IV therapy with all **VAD** patients if possible
- Think FLUIDS!!!

FIELD CONSIDERATIONS

- A patient can be in a lethal arrhythmia and be asymptomatic.

  Treat the patient not the monitor.

- Do not **cardiovert/defib** unless the patient is unstable with the arrhythmia.

- If you must cardiovert/defib, place pads anterior and posterior to avoid potential damage to equipment.

FIELD CONSIDERATIONS

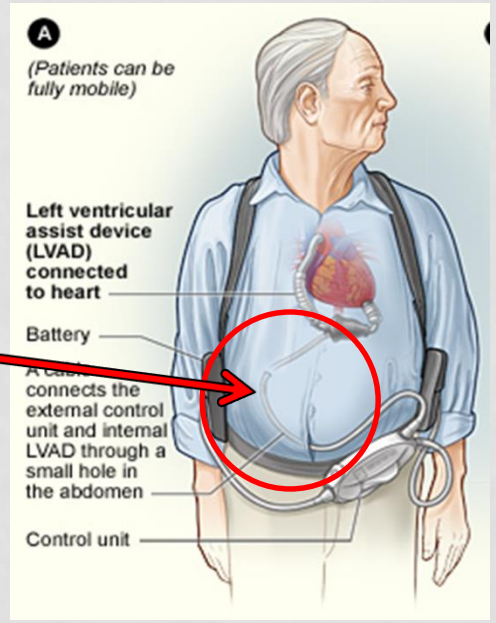
- Chest compressions are utilized as a last resort only. If VAD device not functioning and patient obviously dead, initiate compressions.

FIELD CONSIDERATIONS

- Trauma Patients
  - **Avoid cutting driveline for VAD device when exposing.**
  - **Avoid pinching driveline under backboard/patient.**
  - **Some VAD's have DC power supply for vehicles. Ensure that it is not plugged in prior to removing patient from car.**

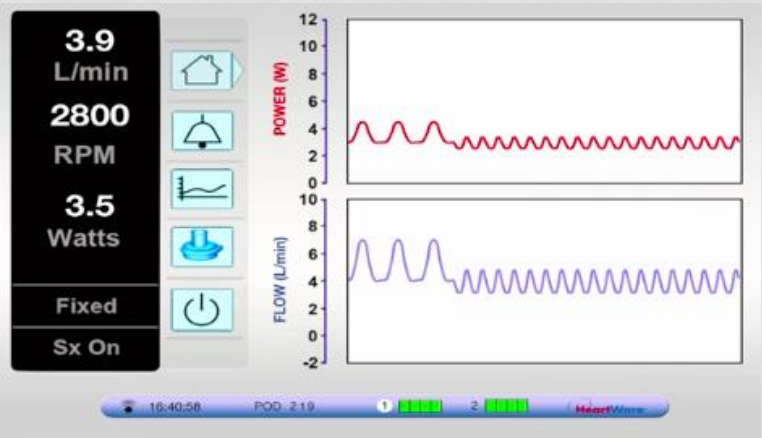
VAD Driveline

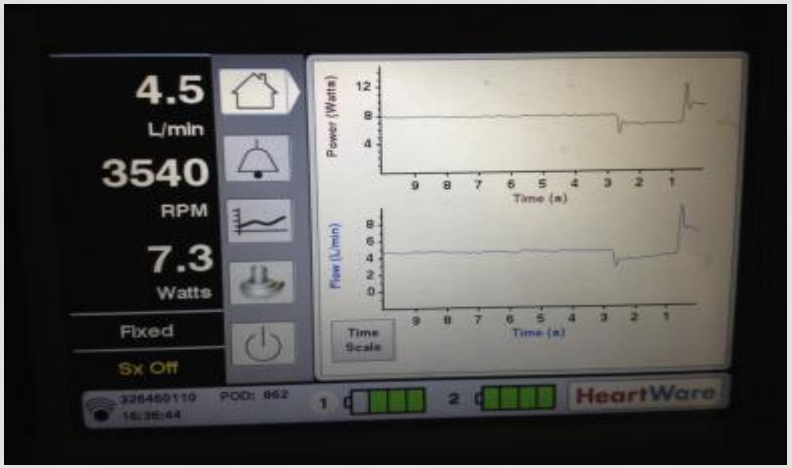
- Cable that runs from VAD controller to the internal pump.



EMERGENCY PROCEDURES

- OK to defibrillate HeartWare® System patients
- Institute appropriate ACLS protocols
- If chest compressions have been administered, confirm function with TOE and positioning of HVAD® Pump





FIELD CONSIDERATIONS

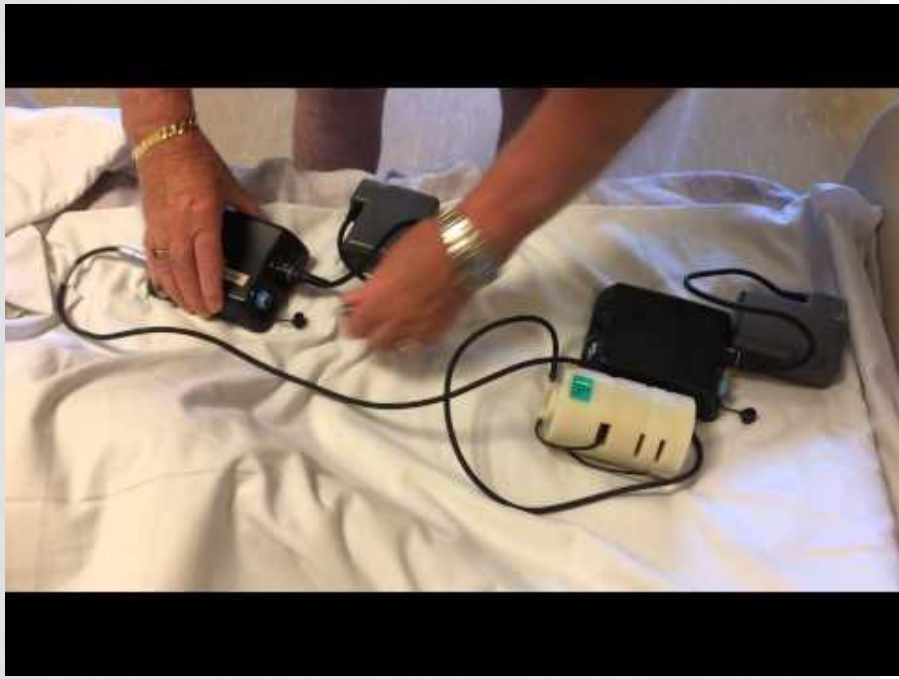
TRANSPORT CONSIDERATION

- If able, transport the patient with any other pertinent equipment needed for the VAD pump.
  - Batteries
  - Charging unit
  - Base Station

FIELD CONSIDERATIONS

DISCHARGE PREPARATION

- Must reside within 2 hours drive from TPCH
- 24 / 7 Carer and support system for first 3 months
- Formal education to ensure confidence and competence with device
- Use of mock loop



FIELD CONSIDERATIONS

CLINIC REVIEW

- Seen weekly then up to monthly if applicable

Investigations:

- ECG
- Bloods
- 3 monthly Right heart Catheters
- 3 Monthly ECHO/ CXR
- TOE as required

CLINIC REVIEW

- Regular clinic review includes:
  - alarms
  - observations
  - medications
  - dressing
  - photos and swabs
  - equipment check
  - log file download

REHAB GYM

- Twice weekly onsite rehab gym
- Weekly once certain criteria met
    - Strong quad strength
    - Independent exercise at home (compliance)
    - Monitoring improvement

Focus

- 20 minutes cardiovascular training using bike and treadmill
- 40 minutes working on strength
    - Weights / leg press / free weights
    - Step ups / sit to stand
    - Squats
- Fitball for core strength


DANGER
DANGER

RE-ADMISSION / TRANSPLANTATION

- Training to QAS and ICP's at local station
- QAS Management plan in place for all patients
- Guidelines outlined and on QAS communication system
- Lasts for 1 year
- FAQ with patients at all times

QUESTIONS???

SOURCES

- http://www.mayoclinic.org/heart-transplant/vad.html
- http://www.medicinenet.com/left_ventricular_assist_device_lvad/page2.htm
- www.mfri.org/dom/Drill_pdf/DM_0911.ppt
- http://www.uchospitals.edu/specialties/heart/services/heart-failure/assist-devices.html