"Short and long-term mechanical circulatory support: Management in intensive care"

Dr Ana Hurtado

Consultant Intensivist

Harefield Hospital, UK

Right device for the right patient

why are you doing this?
what do you want to achieve?

“bridge to decision” (non-durable)

“bridge to recovery” (non-durable and durable)

“bridge to transplant” (non-durable and durable)

“destination therapy” (durable)

when do we do it?

Refractory circulatory shock, on maximal medical therapy resulting in organ hypoperfusion

Emergency

Semi-elective

Elective

“exit strategy” and treatment objectives

before AMCS device use, which may include RV support as a bridge to recovery, a bridge to LVAD, biventricular VAD, a total artifcial heart, or a bridge to orthotopic heart transplantation.

Short term support

IABP

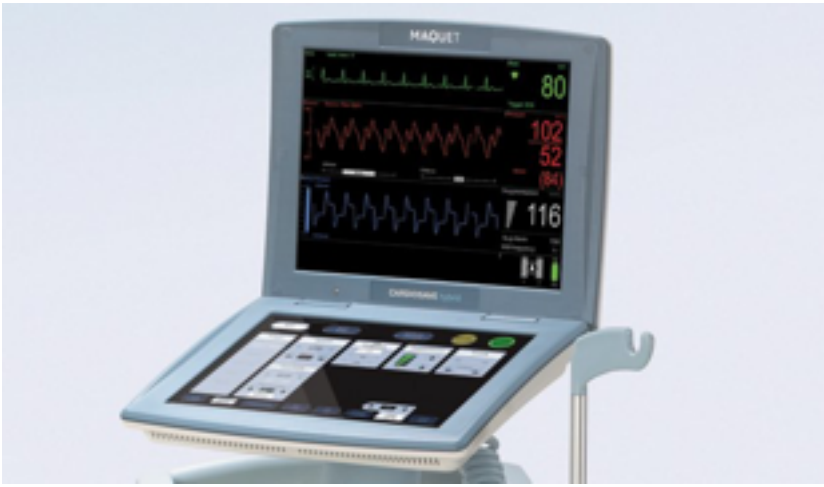
ECMO

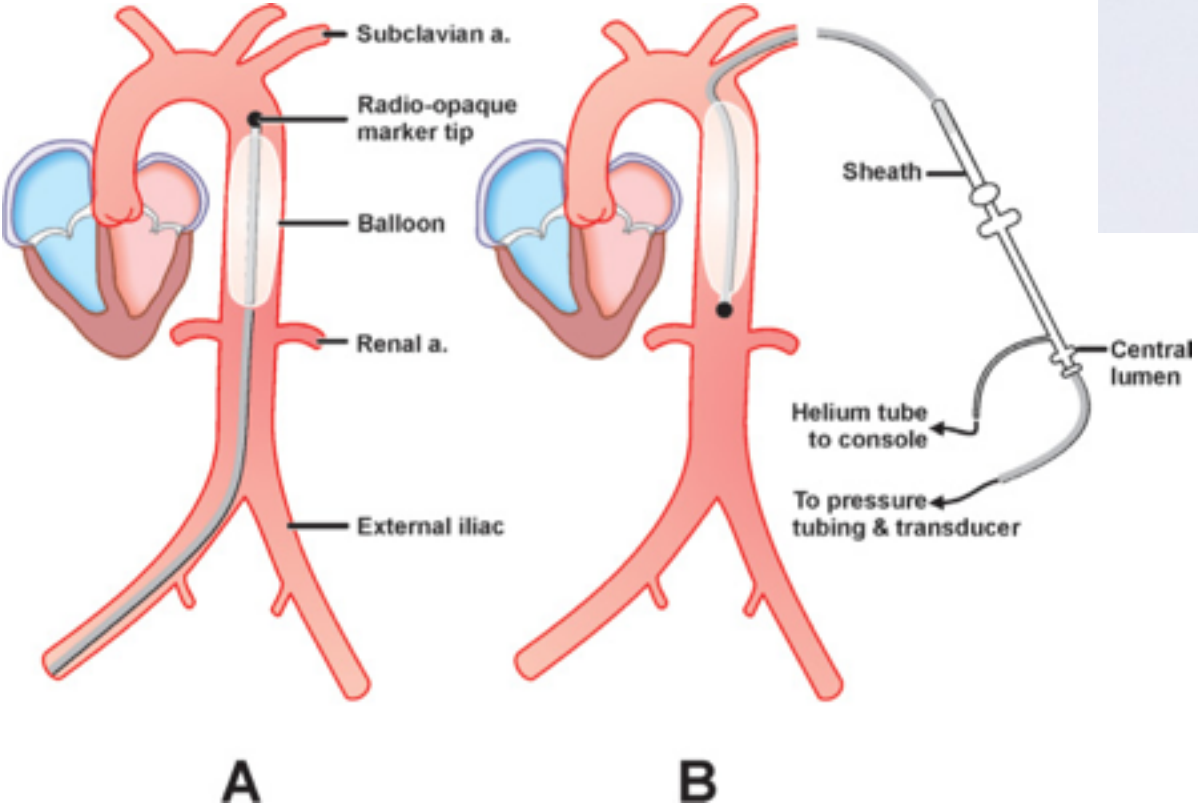
Impella

Univentricular/ Biventricular assist devices

- TandemHeart
- CentriMag
- RotaFlow
- Biomedicus

IABP


MAQUET
80
102
52
116


Subclavian a.
Radio-opaque marker tip
Balloon
Renal a.
External iliac
Sheath
Central lumen
Helium tube to console
To pressure tubing & transducer
A
B

IABP

Implantation (cath lab, bedside by echo or CxR)

Synchronisation (auto/ECG/Arterial waveform)

1:1

Anticoagulation : internal protocols

-UF Heparin (APTT 60-80/Heparin anti Xa 0.2-0.3)

ECMO

Peripheral VA ECMO

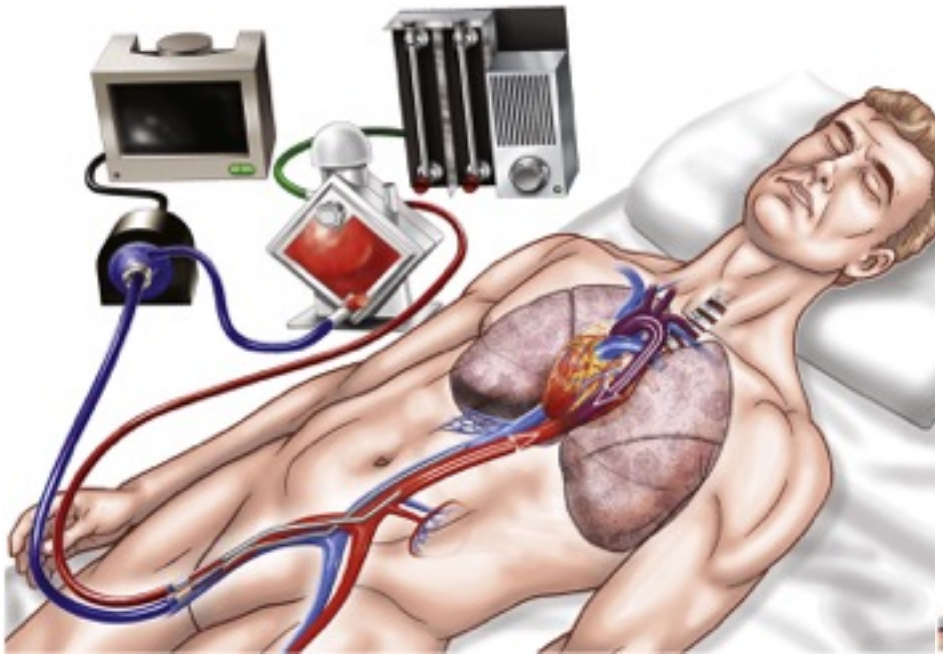
- percutaneous
- cutdown
- reperfusion cannula

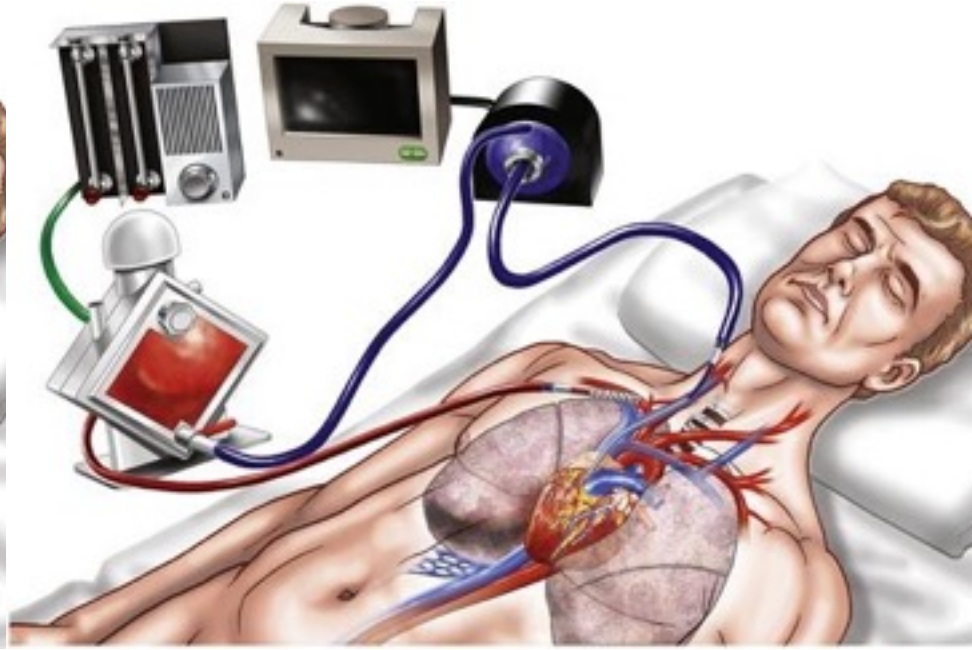
Central VA ECMO

VAV ECMO

VVA …

ECMO





Mechanical circuit complications	Patient complications
Cannula and tubing	Renal
Wrong size	Capillary leak syndrome
Bleeding	Loss of auto regulation
Malposition	Fluid retention
Clotting	Hematological
Dissection	Hemolysis'
Decannulation	Thrombo-occlusive disorders
Bladder	Coagulopathy
Inadequate return	Neurological
Hypovolemia	Intracranial bleed
Increased intra-thoracic pressure	Sinus thrombosis
Venous cannula occlusion	Cerebral Infarction
Capillary leak Syndrome	Seizures
Air embolism	Cardiovascular
High FiO_2	Myocardial stunning
Inlet obstruction	Sub-endocardial ischemia
Gas - blood leak	Poor capillary refilling
Pump	Hypoxia re-perfusion injury
Pump failure	Pulmonary
Loss of occlusion	Pulmonary fibrosis
Oxygenator -	Pneumonitis
Thrombosis – Membrane/Inlet/	Consolidation
Outlet port	Pulmonary hypertension
Fluid in Gas phase	
Failing oxygenator -	
Decreased O_2/CO_2 transfer	
Widened pre- and post-membrane gradient	
Increased hemolysis	
Coagulopathy	
Heat exchanger	
Corrosion and leak	
Hemolysis, dilution and electrolyte imbalance	
Sepsis	
Hyponatremia, Hemolysis and seizures	

HEART LUNG and VESSELS

ORIGINAL ARTICLE

Heart, Lung and Vessels. 2015; 7(4): 320-326

Pitfalls in percutaneous ECMO cannulation

L. Rupprecht[1], D. Lunz[2], A. Philipp[1], M. Lubnow[3], C. Schmid[1]

[1]Department of Cardiothoracic Surgery; [2]Department of Anesthesiology; [3]Department of Internal Medicine II/Pneumology, University Medical Center Regensburg, Regensburg, Germany

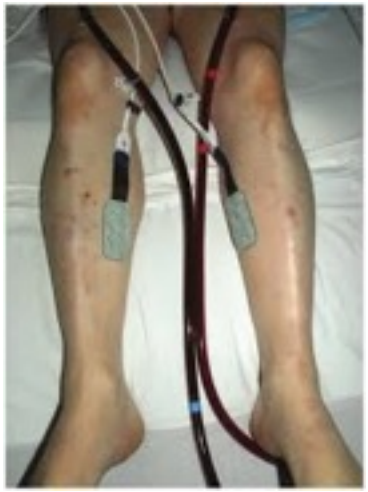
Table 1 - *Conspicuous events and complications during and after percutaneous cannula placement in 159 patients with venous arterial extracorporeal membrane oxygenation.*

Event	Consequence	Incidence
Mild limb ischemia	Clinical control	9.4%
Difficult puncture Bleeding during cannulation Vessel perforation during cannula placement	Multiple attempts Blood transfusion Surgical revision	8.8% 5.7% 1.9%
Upper body hypoxia	Cannula relocation (Subclavian artery)	8.8%
Vascular (femoral) complication	Surgical revision/ contralateral cannula relocation	7.5%
Mild bleeding after cannula removal	No revision	3.8%
Significant bleeding after cannula removal	Surgical revision	3.1%
Cannula dislocation	Cannula reinsertion	0.6%
Wound infection	Wound debridement	0.6%

Limb ischaemia

Femoral arterial cannulation

- Prevention: check vessel size prior to cannula insertion
- Monitoring/regular inspection and palpation of pulses/Doppler
- INVOS monitoring (regional oxygen sat)



ECMO circuit complications

Clots in circuit (turbin, oxygenator)

Air in circuit

Motor failure

Oxygenator failure

Tubing rupture (rare)

Blood loss from circuit (faulty tap)

Hemolysis

Infection (rare)

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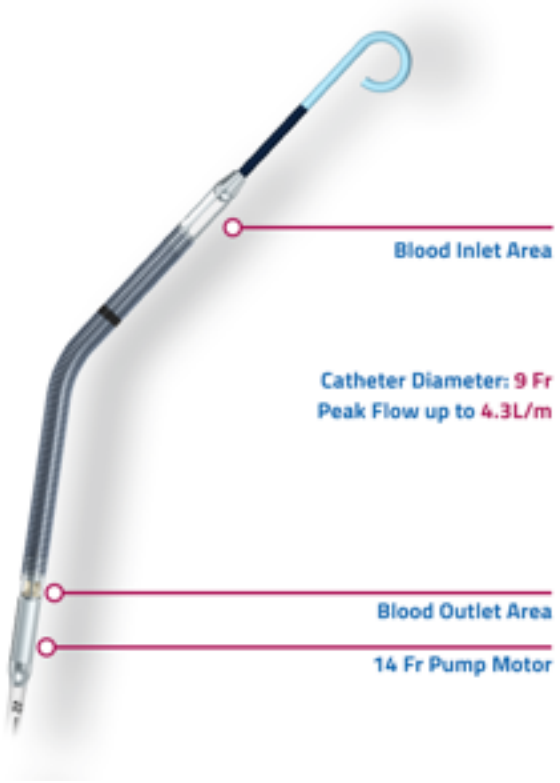
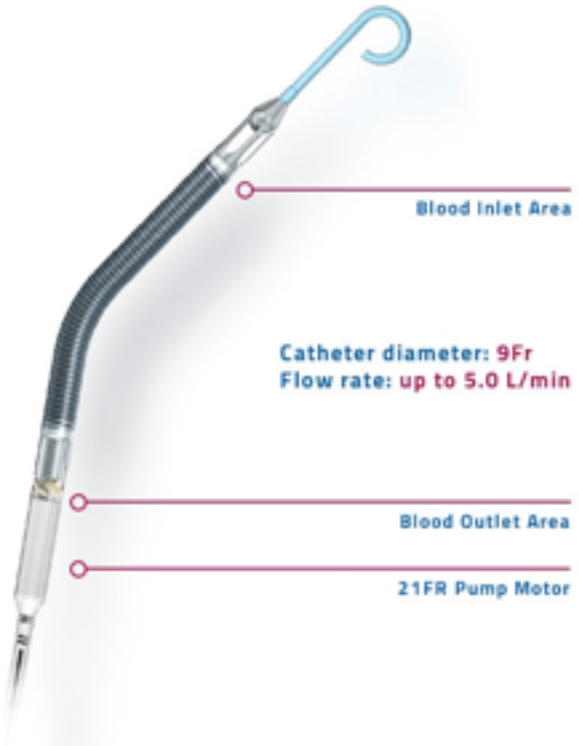
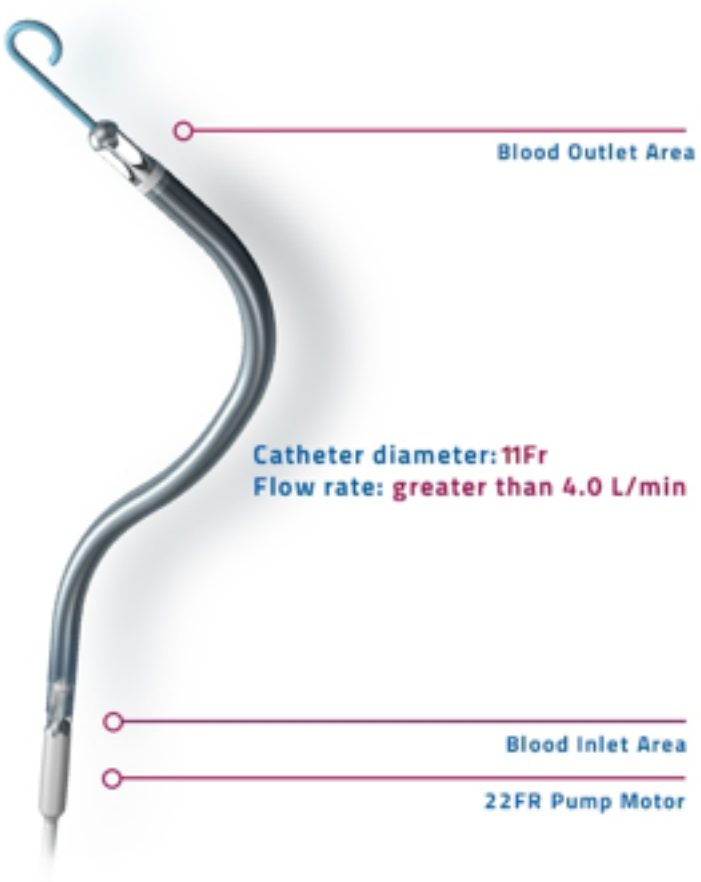
Impella CP®



Impella 5.0®



Impella RP®



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NHS Foundation Trust

Impella®

Position

Anticoagulation: UF Heparin (APTT 60-80, AntiXa 0.2-0.3)

Aortic regurgitation

Thrombosis

Haemolysis: LDH, Plasma Free Hb, Bil, D-dimers

Weaning Impella

Gradual and continuous decrease in pump rate every 12h

Discontinuation when P1 tolerated at least for 2h

Echo: weaning trial Ao VTI>12cm, LVEF >25%, Lat MV peak syst velocity>6cm/s at P1

Weaning trial every 24h

Impossible weaning >2weeks: long term support/transplant

Uni/Biventricular assist devices

TandemHeart

CentriMag

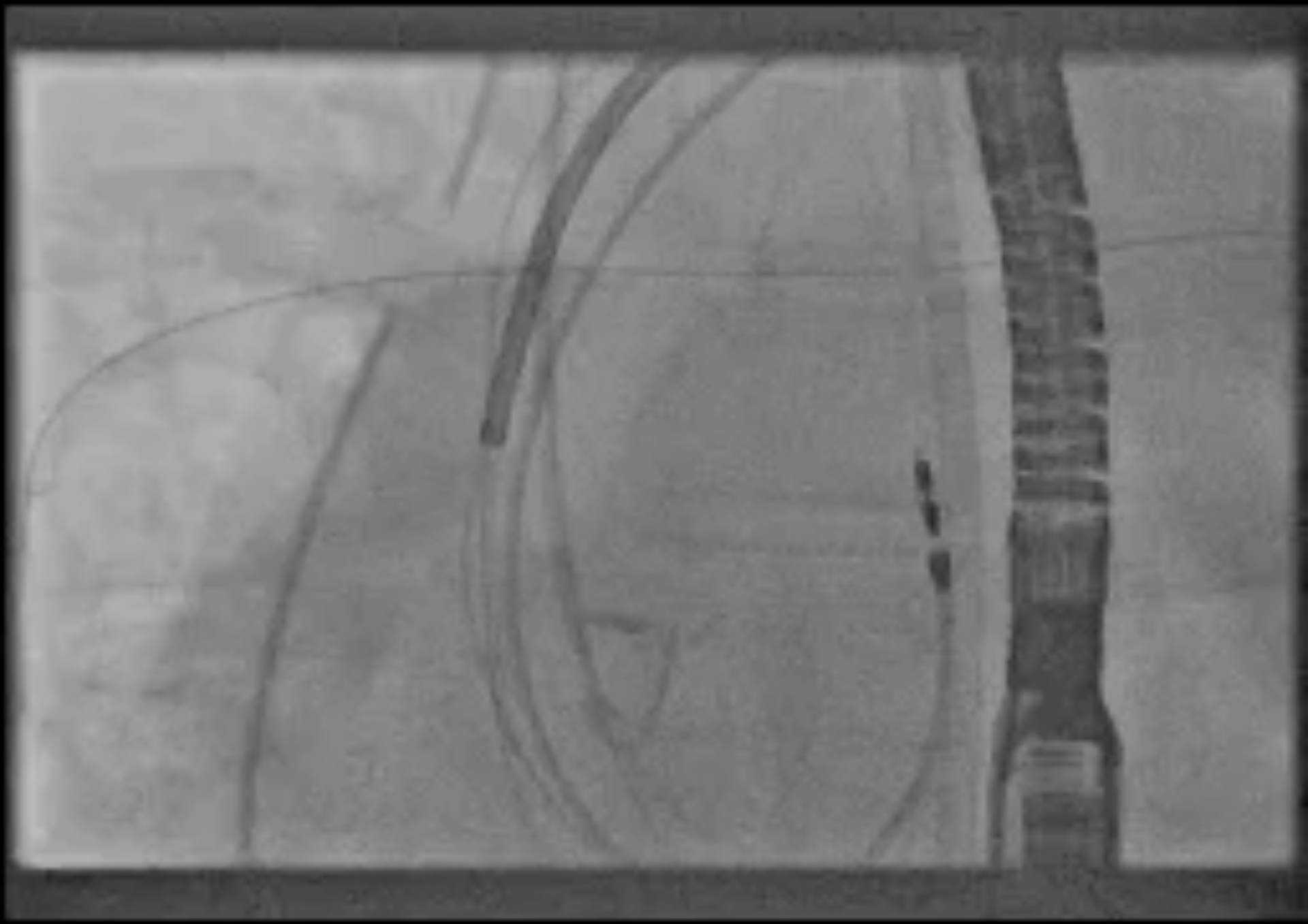
RotaFlow

Biomedicus

CentriMag®


LEVITRONIX
CentriMag
2300
RPM
4.57
LPM
Flow Limits: 0.55/8.0 LPM Normal
Pressure(mmHg) P1= 69 P2= 36 P1-P2= 33
Menu
Set RPM

Protek Duo® cannula



Long term support

HVAD

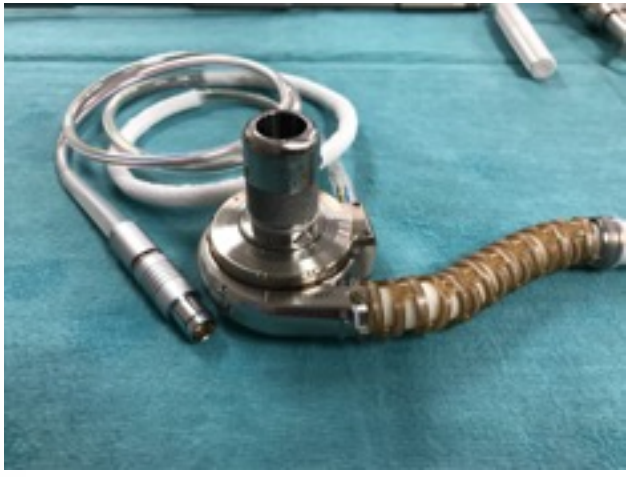
Heartmate 3

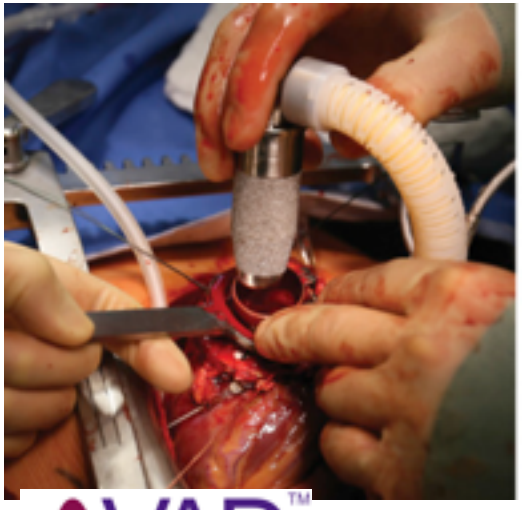
Berlin Heart> EXCOR

AVAD

Total artificial Heart: SynCardia

HVAD/Heartmate 3/AVAD





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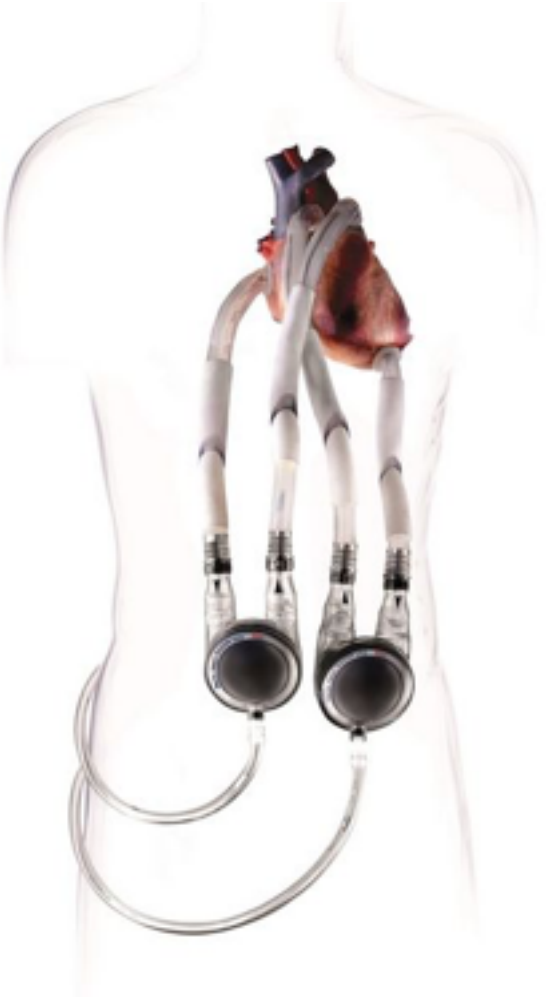
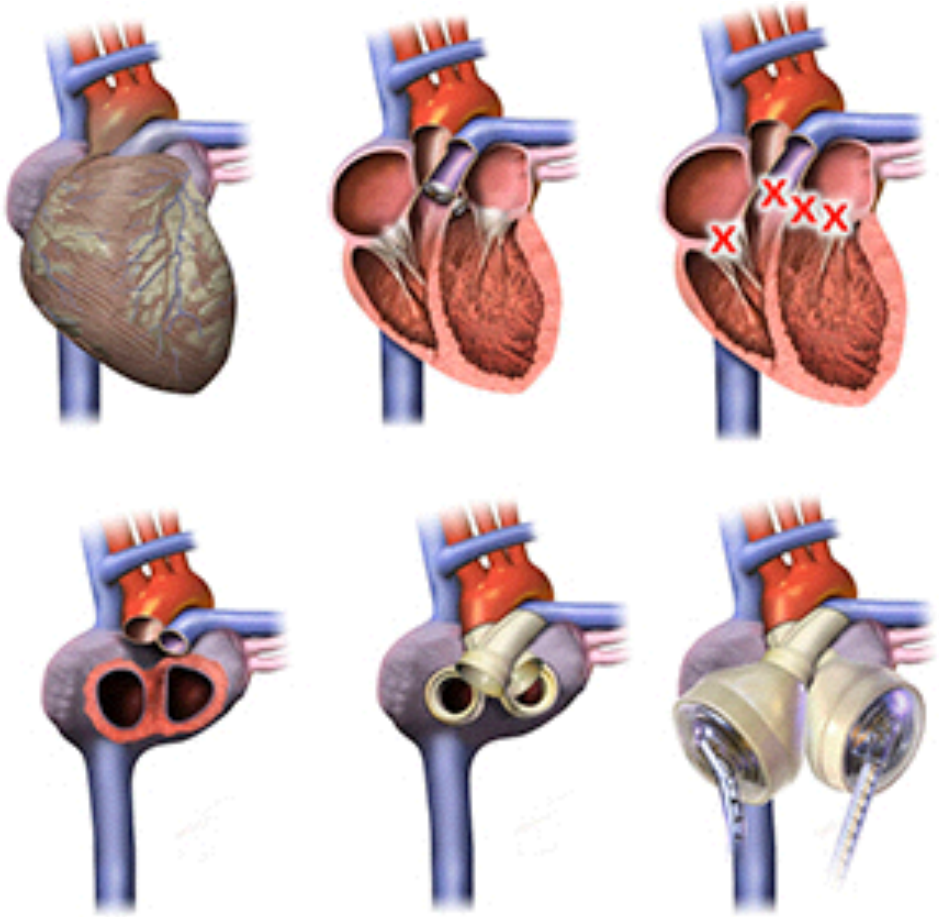
Berlin Heart/EXCOR

Berlin Heart®



Total Artificial Heart

SynCardia SYSTEMS, INC.



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Harefield experience

	AVAD	Berlin Heart	Circulite	Circulite Synergy	C-Pulse	HeartAssist5	Heartware	Heartware Bivad	Heartware RVAD	HM II	Impella	TAH
2011-2012				2		4	12		1	11		
2012-2013			9				16			4		
2013-2014			3				24	1				
2014-2015				1	1		42					5
2015-2016							37			1		3
2016-2017	2	1					23					5
2017-2018	1	1					32				3	5
2018-2019							5					1
Total	3	2	12	3	1	4	191	1	1	16	3	19

which problems are we going to face? (general, device specific, and evolving)

Anticoagulation

- Bleeding
- Thrombosis

RV failure

Haemolysis

Device specific

Infection

Case 1

39 yo female

High BMI (36)

Recent diagnosis of DCM, likely postpartum (normal coronaries)

Presented at local hospital (20/06/2017) on cardiogenic shock

Echo: LV dilated, severely impaired, LVEF 10-15%, RV dilated and severely impaired

Started on inotropes: **Dobutamine (5mcg/kg/min)**

Initial improvement.

Discussed with Harefield Hospital and transferred conventionally

Case 1

Right catheterisation study

	Dobutamine 5mcg/kg/h	Milrinone
PVR	**4.07**	**3.49**
PA	46/36/40	47/33/39
PCWP	31	27
TPG	9	12
CO	2.2	3.4
CI	**1.08**	**1.68**

Case 1

Dobutamine was changed to **Milrinone 0.3 mcg/kg/min**

Developed VT storm > transferred to ITU

Electrolytes replaced, Amiodarone

Already on Milrinone (0.3mcg/mk/min), **Adrenaline** commenced due to hypotension

Lactate rising, worsening metabolic acidosis and LFTs

Case 1

Discussed with patient

Decision for **awake peripheral VA ECMO**

Performed in cath lab under **fluoroscopy, USS guided percutaneous cannulation**:

- 25F multistage right femoral vein
- 17F arterial cannula left femoral artery (no reperfusion cannula)

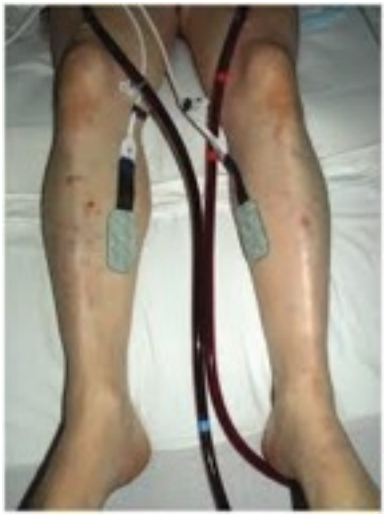
Started ECMO at 3.5lpm and inotropic support maintained

Leg perfusion pVA ECMO

Prevention: check vessel size prior to cannula insertion

Monitoring/regular inspection and palpation of pulses/Doppler

INVOS monitoring (regional oxygen sat)



Case 1

Awake, self ventilated

ECMO at 3.5lpm

Adrenaline 0.05mcg/kg/min

Milrinone 0.3mcg/kg/min

Intermittently stopped ejecting, aortic valve closed

Signs of **pulmonary oedema** with increased work of breathing

Inotropes increased (milrinone 0.4mcg/kg/min, adrenaline 0.15mcg/kg/min)

but

Intubated few hours later…

Pulmonary oedema

Table 1. Hemodynamic Effects of Mechanical Circulatory Support Devices[3,10-12]

Device	Flow	Left Ventricular Preload	Left Ventricular Afterload	Mean Arterial Pressure
Intraaortic balloon pump	0.5 L/min	Slight decrease	Slight decrease	Slight increase
Impella	Up to 5 L/min	Decrease	No change	Increase
TandemHeart	Up to 5 L/min	Decrease	Increase	Increase
Extracorporeal membrane oxygenation	Up to 6 L/min	Decrease	Increase	Increase

Case 1

MDT (Intensive Care, Cardiologist, Transplant surgeons)

-Heart Tx not an option as High BMI and High PVR

-Needs biventricular support, short term RVAD unlikely to work

-Needs implantable system to allow mobilisation, rehabilitation and weight loss

Therefore option is only realistically **TAH SynCardia**

Case 1

SynCardia implanted 27/06/2017

Needed **VV ECMO** post implant due to hypoxia secondary to pulmonary oedema

Renal failure post TAH implant (>70% patients develop AKI) requiring RRT

30/06/2017: VV ECMO explant (3 days of support) and tracheostomy performed
2 weeks to wean from ventilator and being mobile

15/07/2017: Discharged to ward
Renal function recovered

Discharged home December 2017

Case 1

- **Pulmonary oedema** postimplantation
- Need of temporary **VV ECMO** support
- **Bleeding**: Correct coagulation post implant
- Frequently Chest scented post implant during first 24h
- **UF Heparin**: APTT 60-80/Anti Xa 0.2-0.3
- **Aspirin** early when bleeding complications resolved

Selwa

https://www.bbc.co.uk/news/av/uk-england-london-42755505/the-ilford-woman-who-carries-her-heart-in-a-rucksack

Case 2

50 yo male

Idiopathic DCM

08/06/2017: **HVAD** implanted **bilateral thoracotomies** and femoral CPB

Possible **anaphylaxis** when come off bypass

Admitted ITU

TOE post-implant: Reasonable RV function, moderate TR, Poor LV, Mild AR

Harefield recipe

1. Milrinone 0.2-0.5
2. Adrenaline
3. iNO at 20ppm
4. Noradrenaline +/- Vasopressin

Support the right ventricle!!

Case 2

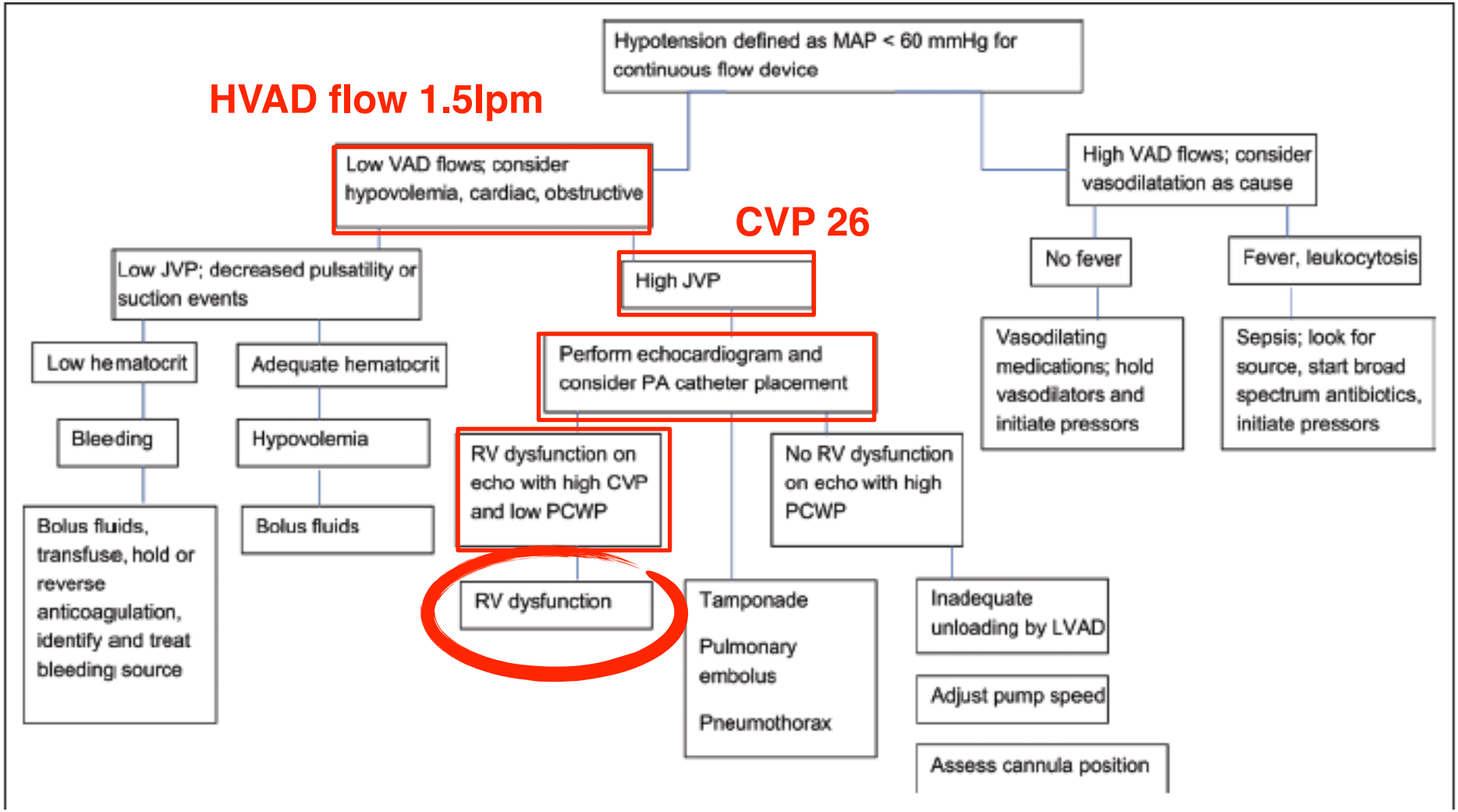
Deterioration overnight

Hypotensive

Worsening metabolic acidosis

LVAD flow dropped to 1.5lpm

Hypotension LVAD



RV failure

- **CVP 25**
- **Low LVAD Flow**
- **Hypotension**
- **Metabolic acidosis**
- **Echo showed severely dilated and impaired RV**

Circulation

American Heart Association.

Mechanical Circulatory Support Devices for Acute Right Ventricular Failure

Navin K. Kapur, Michele L. Esposito, Yousef Bader, Kevin J. Morine, Michael S. Kiernan, Duc Thinh Pham and Daniel Burkhoff

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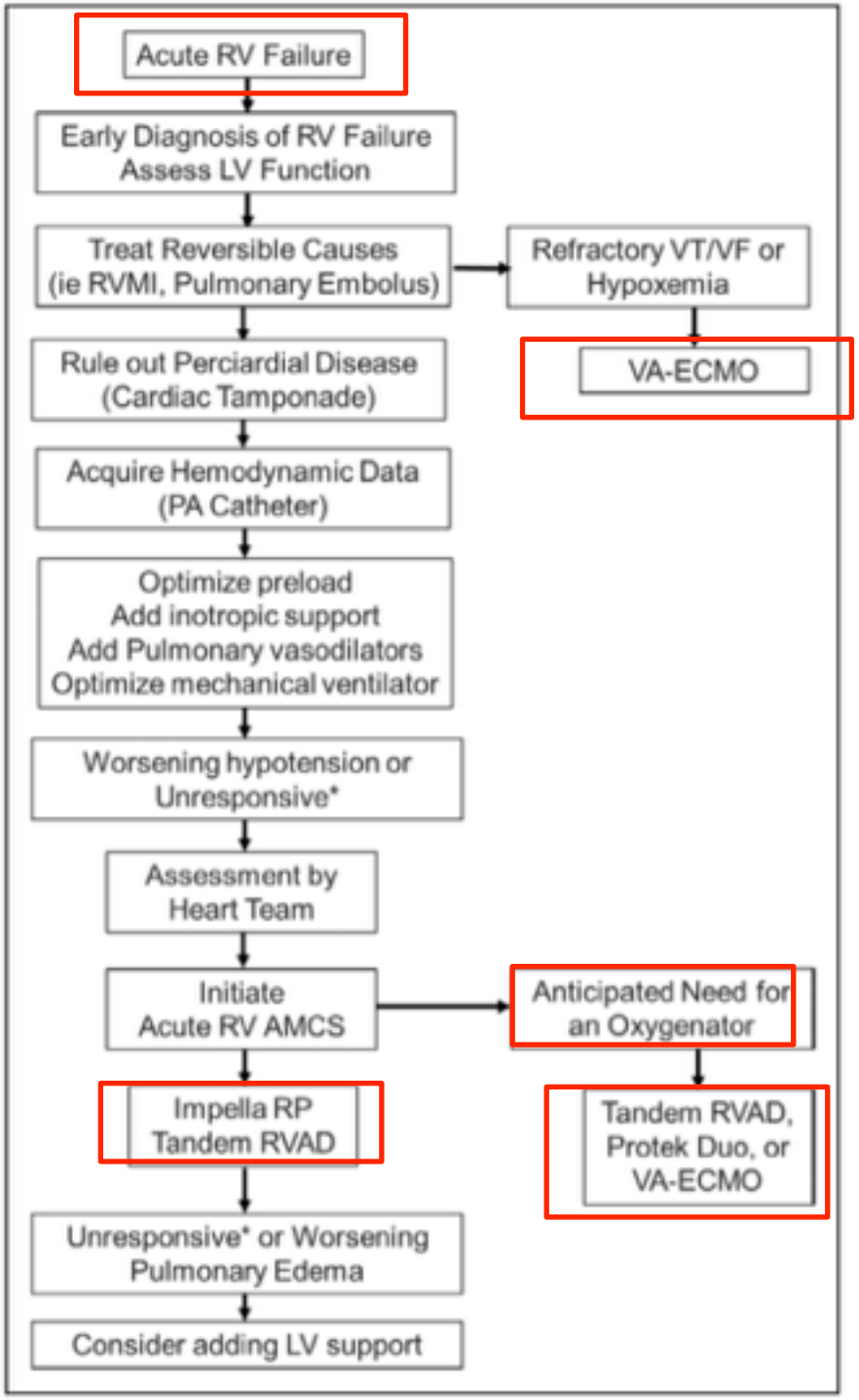

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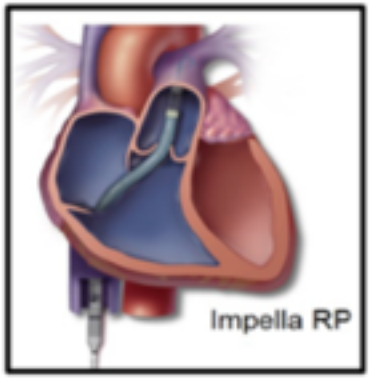
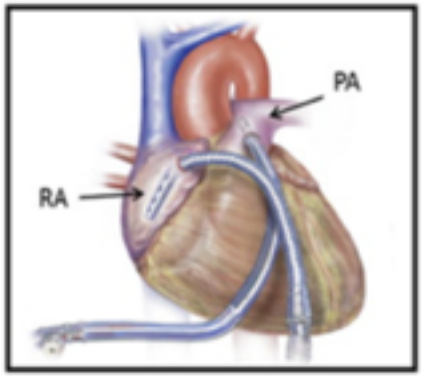
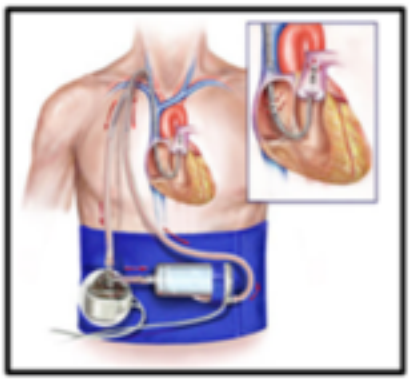
RV Failure

Direct RV Bypass

Indirect RV Bypass







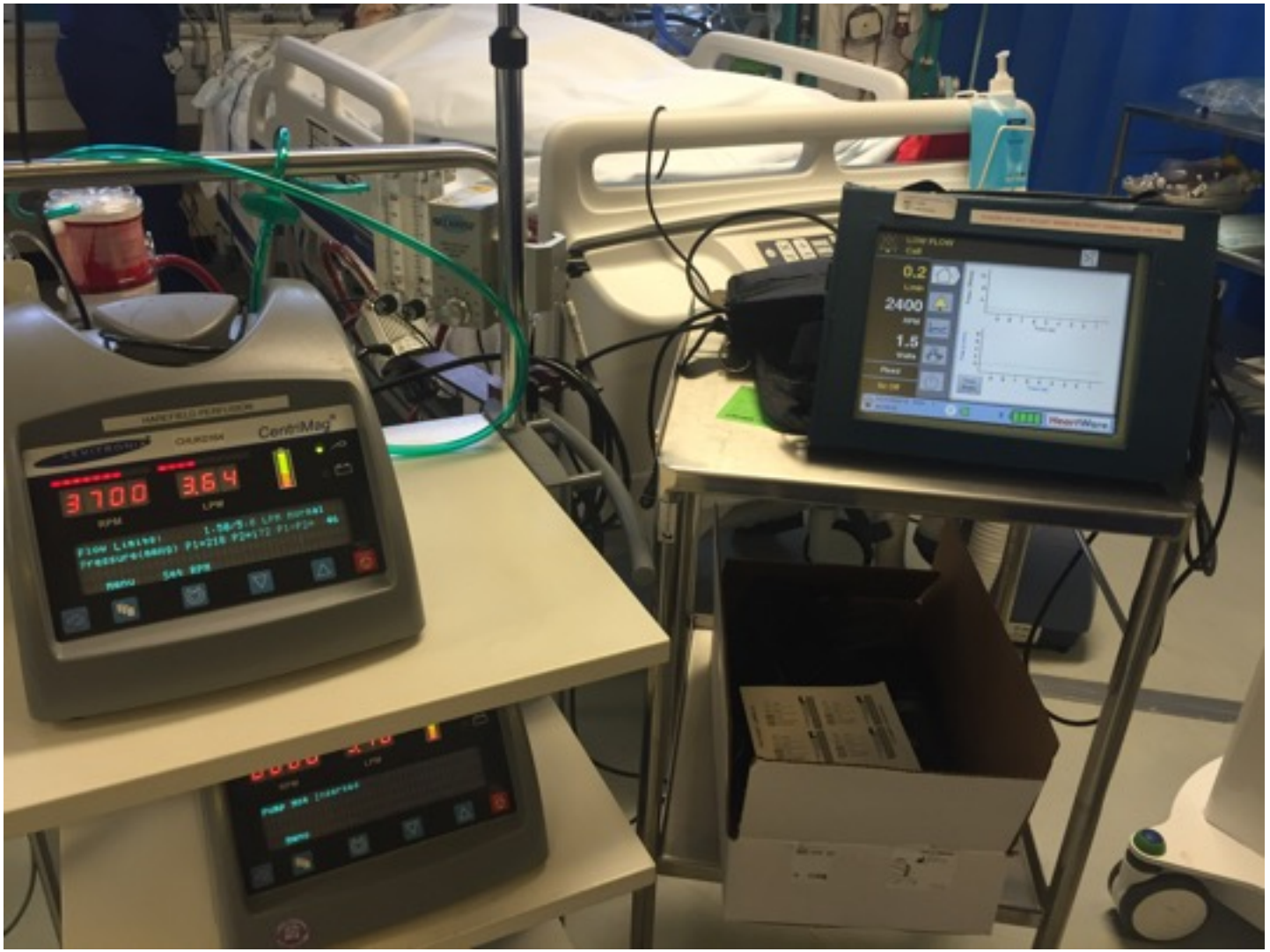
Impella RP | Tandem RVAD | Protek Duo | VA-ECMO

Axial Flow | Extracorporeal Centrifugal Flow

Table 3. Clinical Studies Evaluating the Utility of Acute Mechanical Circulatory Support Systems for Right Ventricular Failure

Device	Patient Population	Outcomes	Study
Impella RP	18 Patients (15 Impella RD, 3 Impella RP) AMI, 39% (n=7) PCCS, 22% (n=4) Post-OHT, 17% (n=3) Post-LVAD, 11% (n=2) Myocarditis, 11% (n=2)	30-d Survival, 72% 1-y Survival, 50% Hemodynamic effects: increased CI, decreased RA pressure	Cheung et al[83]
	30 Patients Post-LVAD (n=18) PCCS/AMI (n=12)	30-d Survival, 73.3% Hemodynamic effects: increased CI, decreased RA pressure	Anderson et al[65]
TH-RVAD	46 Patients Postvalve surgery, 32% (n=15) AMI, 25% (n=12) Post-OHT, 11% (n=5) Post-LVAD, 11% (n=5) Post-CABG, 7% (n=3) Chronic HF, 7% (n=3) Myocarditis, 7% (n=3)	In-hospital mortality, 57% Hemodynamic effects: increased MAP, CI, and PA O_2 saturation; decreased RA and PA systolic pressures No change in number of vasopressors/inotropes	Kapur et al[84]
	9 Patients Sepsis, 11.1% (n=1) PCCS, 22.2% (n=2) IWMI, 66.7% (n=6)	In-hospital mortality 44% Hemodynamic effects: increased MAP, CI, RV stroke work; decreased RA pressure	Kapur et al[82]
VA-ECMO	179 Patients PCCS, 39% (n=70) AMI, 26% (n=46) Primary graft failure, 10% (n=17) ADHF, 13% (n=24)	In-hospital mortality, 38.6% (n=69) Hemodynamic effects: decreased RA pressure and mean PA pressure	Truby et al[85]

Peripheral VA ECMO inserted

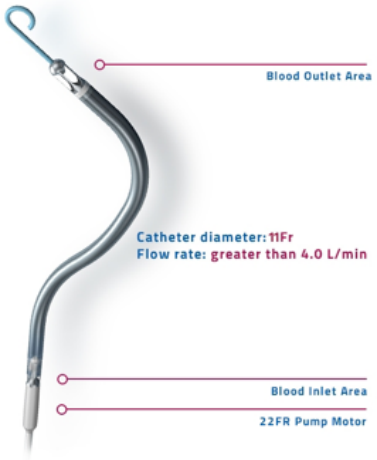


Case 2

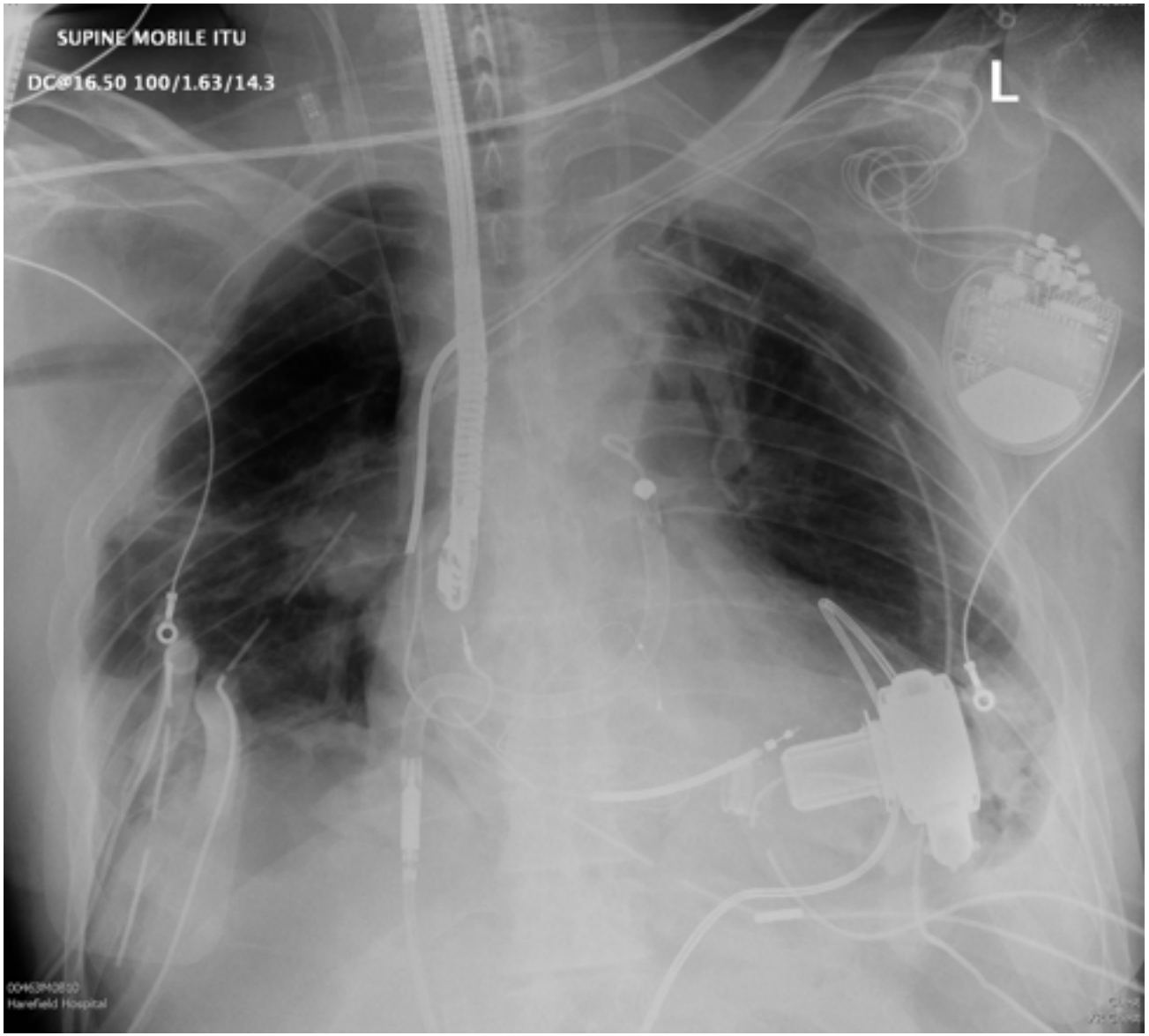
Temporary solution as no flow on LVAD> high risk of thrombosis

Impella RP® placed a few hours after pVA ECMO

ECMO removed later on that day



HVAD
Impella RP
ICD
TOE
Drains
ET tube
CVC
Vas-cath



Ongoing severe haemolysis…

Lab Flowsheet	10/08/2017 08:00	11/08/2017 08:00	12/08/2017 08:00	13/08/2017 08:00	14/08/2017 08:00	15/08/2017 08:00	16/08/2017 08:00
Glucose	8.3	8.0	6.9	7.0	8.6	6.8	6.8
Total Bilirubin	85	80	196	332	240	190	231
Direct Bilirubin							
ALP	39	46	53	81	81	94	120
GGT				23			
ALT	28	27	26	38	36	34	35
Aspartate Transaminase							
Total protein	39	40	41	43	46	48	47
Albumin	23	25	27	28	27	26	24
Creatine Kinase	2373	2814					
Calcium	2.16	2.32	2.36	2.42	2.38	2.39	2.41
Calcium Corrected	2.50	2.63	2.63	2.67	2.65	2.68	2.73
Inorganic Phosphate	1.43	0.90	0.86	1.13	1.05	0.61	1.02
Magnesium	0.93	1.00	0.89	1.17		0.93	0.97
Amylase	107	109	117	89	62	66	89
CRP	89	136	148	204	211	188	170
LDH	1429			3439		1396	1171
Troponin I							
Random Urine Sodium							
Plasma Haemoglobin	3.7			2.6	3.6	3.4	

Impella RP removed

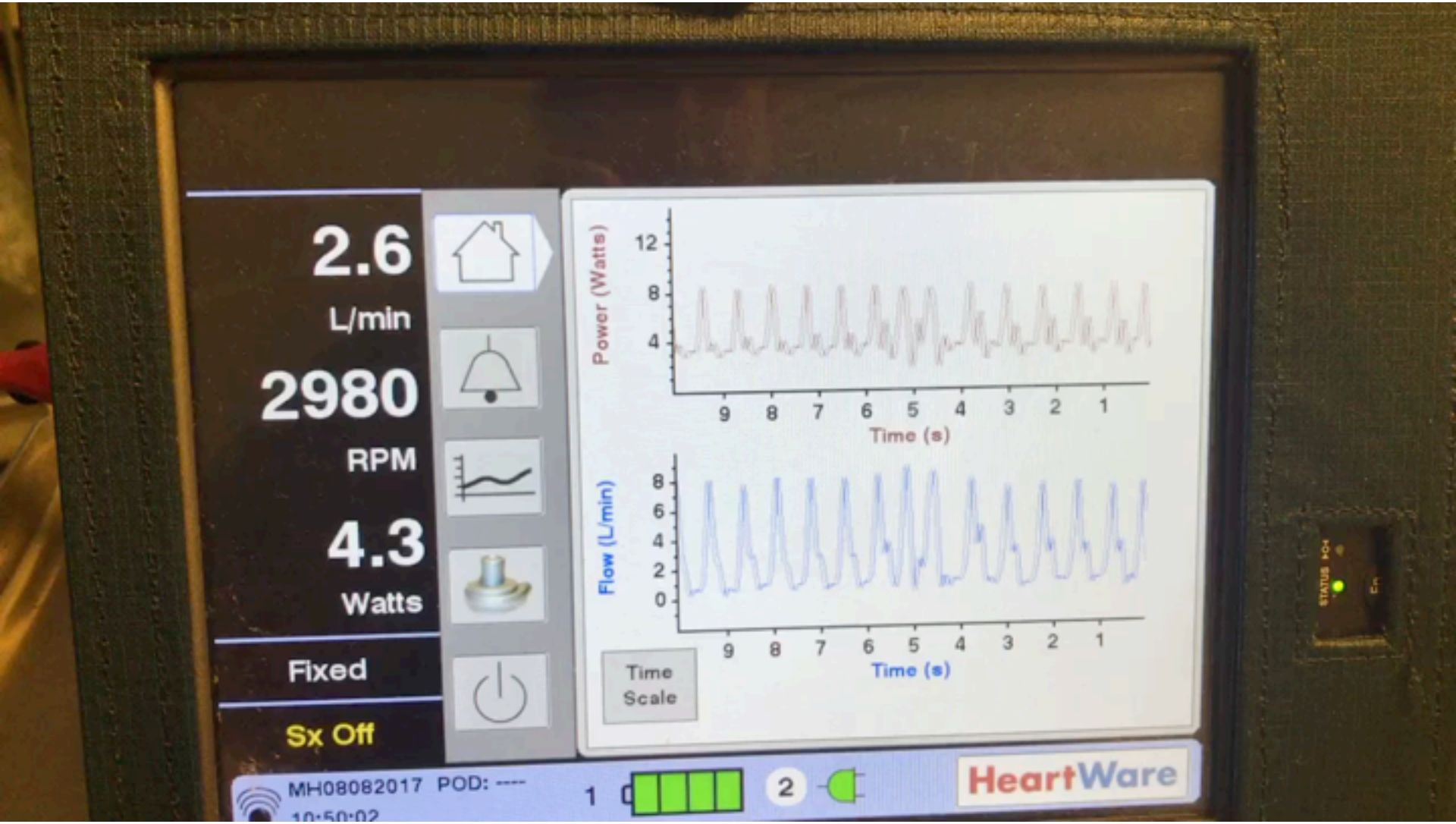
Case 2

On **Milrinone,adrenaline, sildenafil** to facilitate **iNO** wean

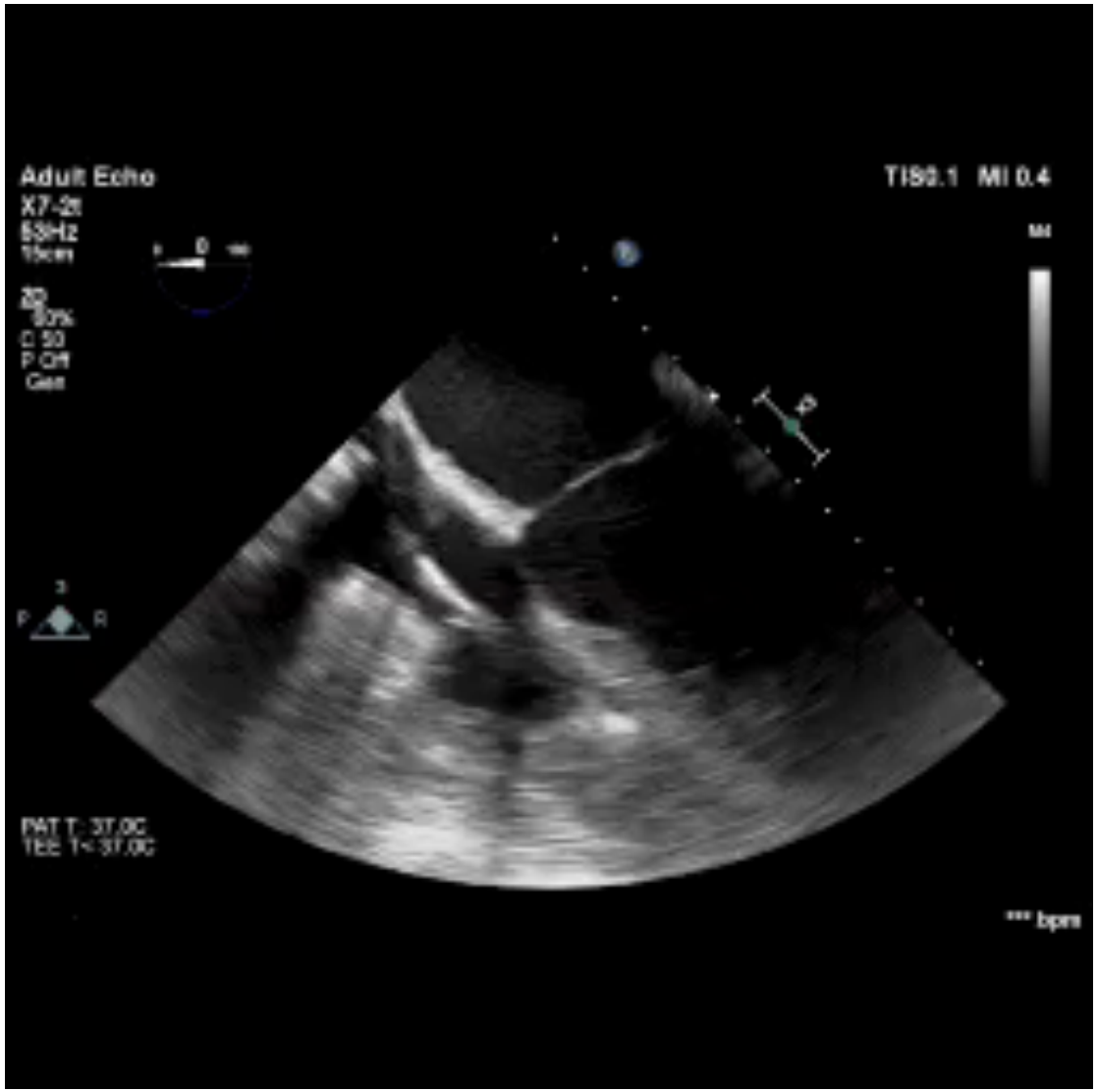
16/08/2017: tracheostomy

Resp wean

23/08/2017: LVAD flow dropped…


2.6
L/min
2980
RPM
4.3
Watts
Fixed
Sx Off
Power (Watts)
12
8
4
9 8 7 6 5 4 3 2 1
Time (s)
Flow (L/min)
8
6
4
2
0
9 8 7 6 5 4 3 2 1
Time (s)
Time Scale
MH08082017 POD: ----
10:50:02
1
2
HeartWare

TOE showed large left pleural effusion and pericardial collection



Case 2

Cardiac tamponade and re-exploration in theatre

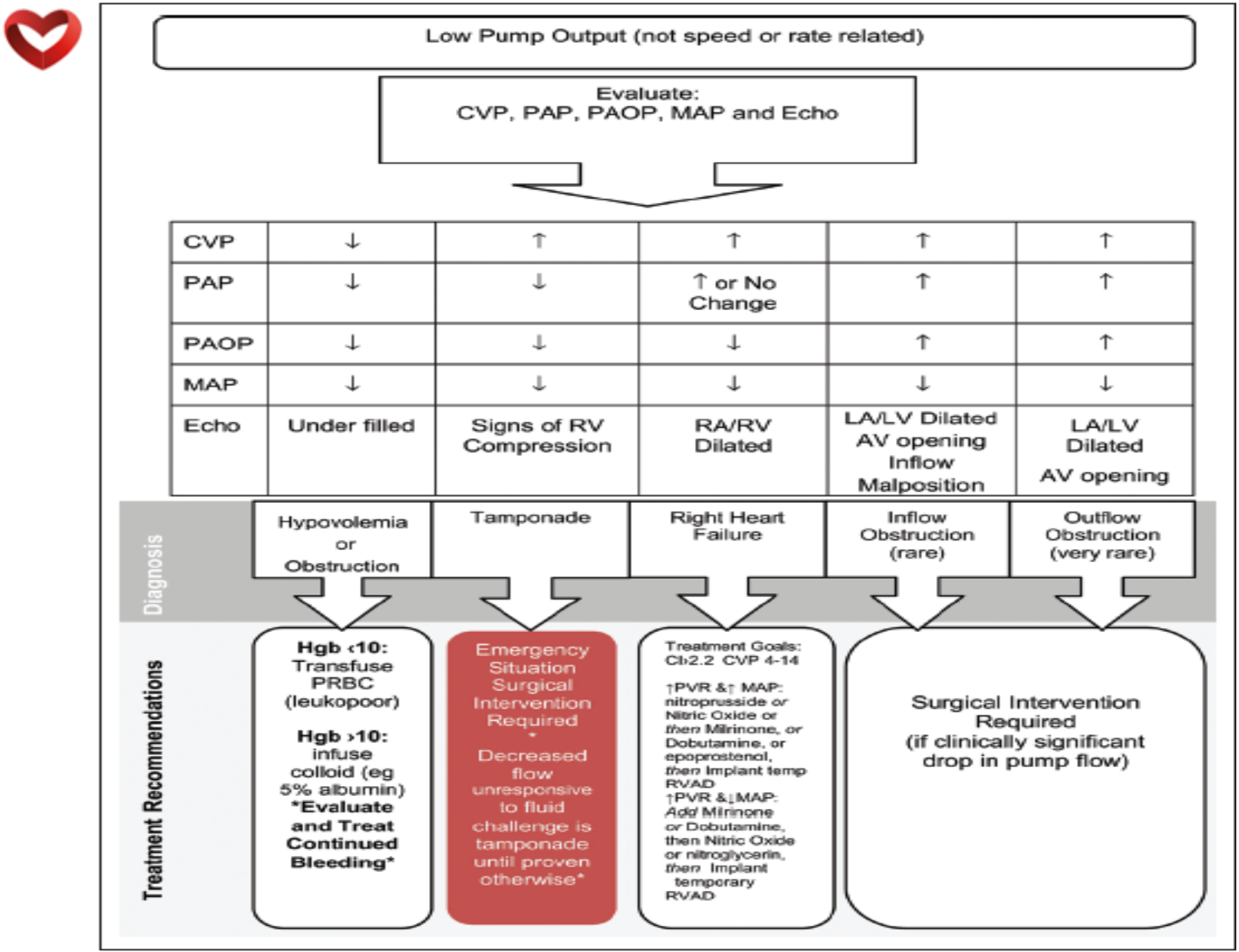
Improved since then

Heparin re-started 12h after re-exploration> Anti Xa 0.2-0.3

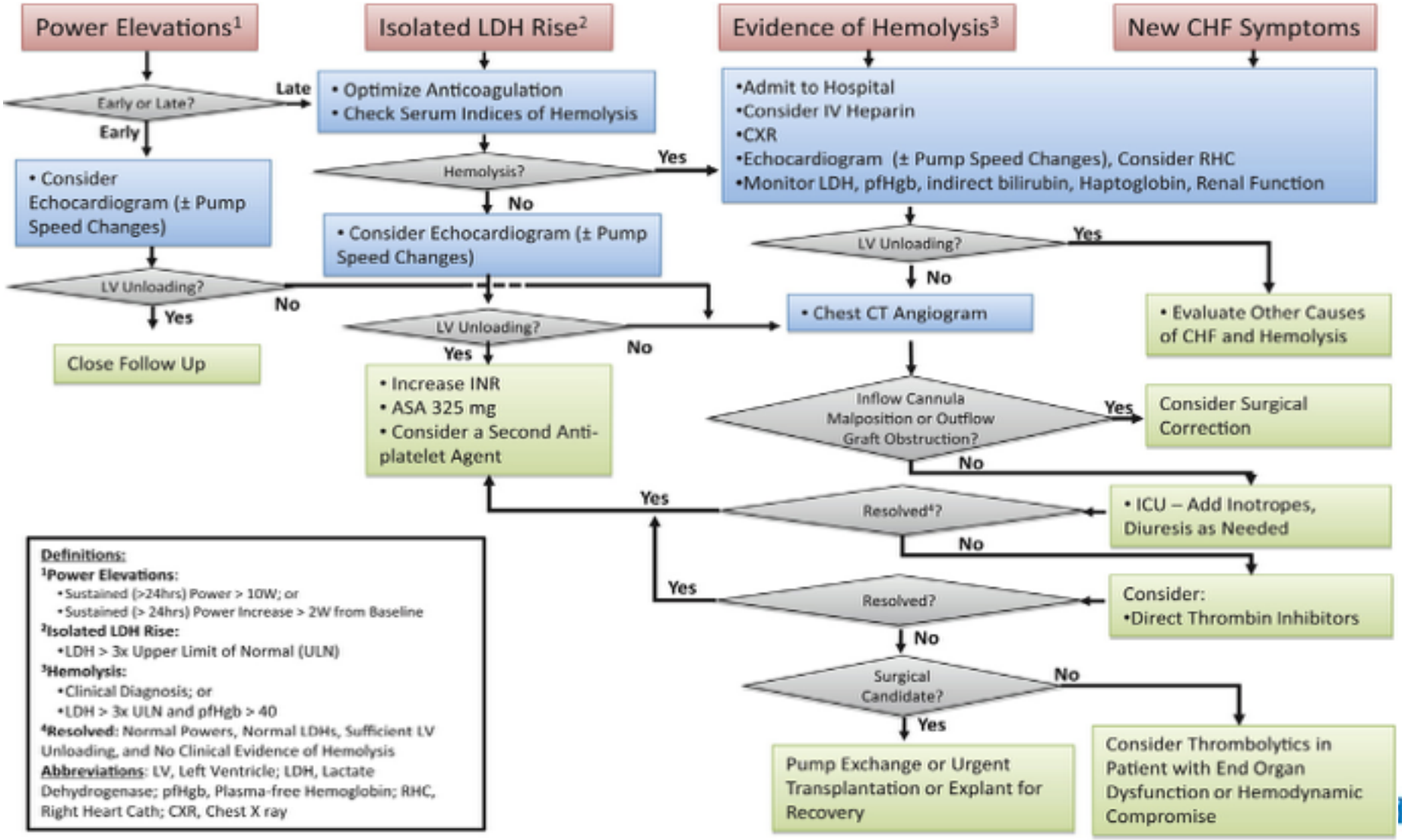
Wean off ventilator

Recovered renal function

Discharged to ward


Low Pump Output (not speed or rate related)
Evaluate:
CVP, PAP, PAOP, MAP and Echo
CVP ↓ ↑ ↑ ↑ ↑
PAP ↓ ↓ ↑ or No Change ↑ ↑
PAOP ↓ ↓ ↓ ↑ ↑
MAP ↓ ↓ ↓ ↓ ↓
Echo Under filled | Signs of RV Compression | RA/RV Dilated | LA/LV Dilated AV opening Inflow Malposition | LA/LV Dilated AV opening
Diagnosis
Hypovolemia or Obstruction
Tamponade
Right Heart Failure
Inflow Obstruction (rare)
Outflow Obstruction (very rare)
Treatment Recommendations
Hgb ‹10: Transfuse PRBC (leukopoor)
Hgb ›10: infuse colloid (eg 5% albumin)
Evaluate and Treat Continued Bleeding
Emergency Situation Surgical Intervention Required
*
Decreased flow unresponsive to fluid challenge is tamponade until proven otherwise*
Treatment Goals: CI›2.2 CVP 4-14
↑PVR &↑ MAP: nitroprusside or Nitric Oxide or then Milrinone, or Dobutamine, or epoprostenol, then Implant temp RVAD
↑PVR &↓MAP: Add Milrinone or Dobutamine, then Nitric Oxide or nitroglycerin, then Implant temporary RVAD
Surgical Intervention Required (if clinically significant drop in pump flow)

Thrombosis post-LVAD



Definitions:

[1]Power Elevations:
- Sustained (>24hrs) Power > 10W; or
- Sustained (> 24hrs) Power Increase > 2W from Baseline

[2]Isolated LDH Rise:
- LDH > 3x Upper Limit of Normal (ULN)

[3]Hemolysis:
- Clinical Diagnosis; or
- LDH > 3x ULN and pfHgb > 40

[4]Resolved: Normal Powers, Normal LDHs, Sufficient LV Unloading, and No Clinical Evidence of Hemolysis

Abbreviations: LV, Left Ventricle; LDH, Lactate Dehydrogenase; pfHgb, Plasma-free Hemoglobin; RHC, Right Heart Cath; CXR, Chest X ray

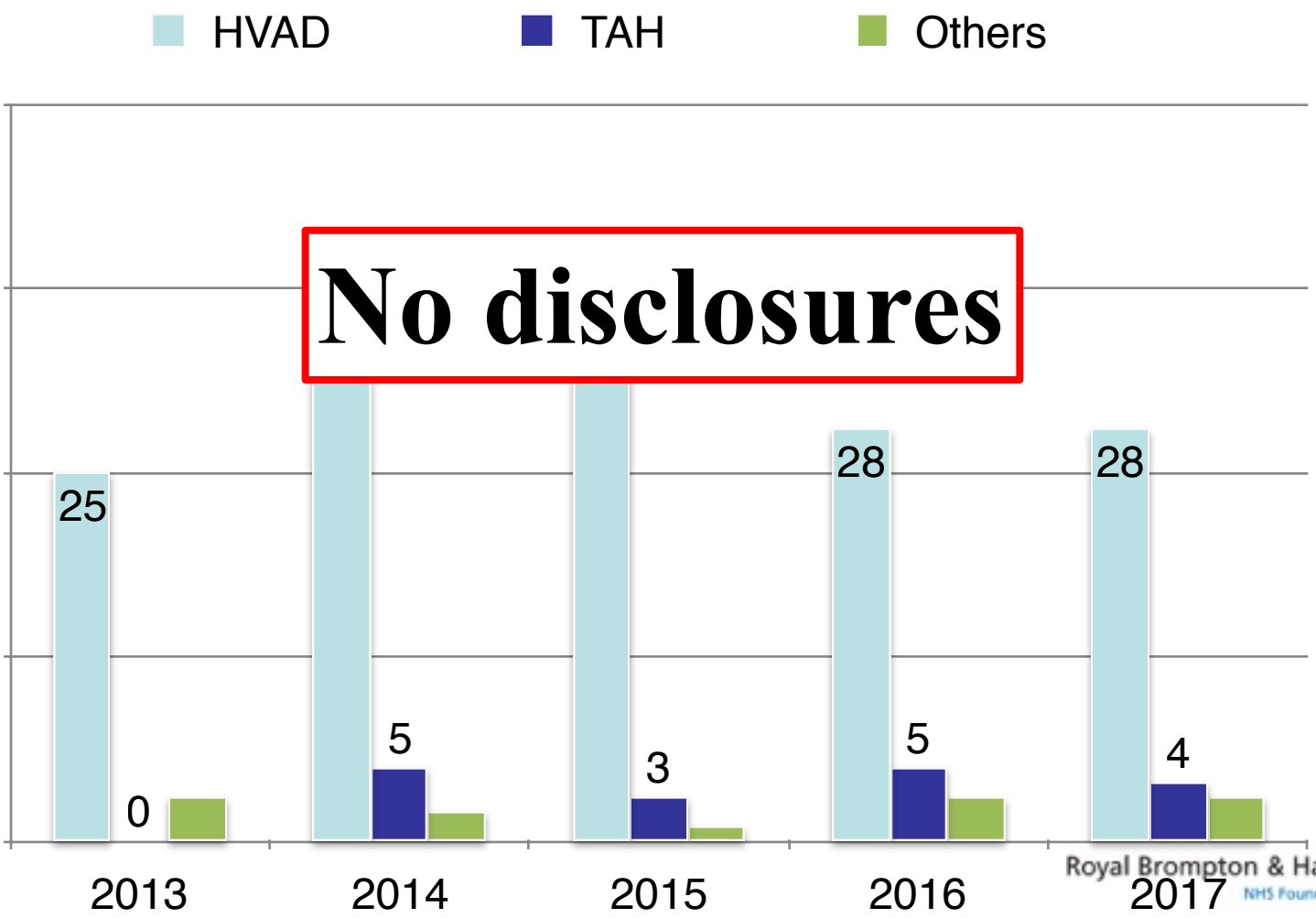
Thrombosis

Sustained increase in LVAD power
Signs of heart failure
Cardiogenic shock
Blood test: increasing LDH/plasma Free Hb
Auscultation of pump

Tea-colored urine: **severe haemolysis**

- LDH >x3 upper limit
- Plasma free Hb >40mg/dL (>0.3)
- Low Haptoglobin level

Harefield experience



Royal Brompton & Harefield NHS
NHS Foundation Trust

Thrombosis

1. **CXR**
2. **CT**
3. **Echocardiography:** dilated ventricle, severe MR, frequent aortic valve opening

– **"ECHO Test/ Ramp speed test":** Serial echocardiography recording of LV end-diastolic diameter (LVEDD) with increasing LVAD speed

– If **VAD thrombosis**, LVEDD fails to decrease in response to increasing LVAD speed

Echo + LDH : specific and sensitive test for the dx of VAD thrombosis with flow obstruction

Thrombosis

If suspected VAD thrombosis not discharge or readmit to ITU, high possibility of rapid progression

Treatment:

- **IV Unfractioned Heparin**
- Diuretics/inotropic support
- **Aspirin high dose 325mg/d**
- **2nd antiplatelet therapy (Tirofiban)**
- **Thrombolytics**: Alteplase (systemic, **intraventricular**)
- **Pump exchange**

Reason to be moved into high-priority transplant waiting status, because of the increased mortality associated with this complication.

Conclusions

VA ECMO

Imperfect but viable option

Improvement in cannula design

Eliminate need for back flow cannulation (peripheral)

Less thrombotic risks/heparin

Technological solutions to:

- minimise after load
- increase/promote AV opening
- minimise LV distension/minimally invasive LV venting strategies

Conclusions

Improve durability of short term VADs

?Impella/ access/position/haemolysis

More options for long term biventricular support

Long term RVAD

Anticoagulation ?targets

Thank you

Harefield experience

HVAD mortality ~5-7% at D60

BTT main indication

DT not funded by NHS > number will increase

Private LVAD increasing

TOE in Intensive Care

1. Assist in fluid management
2. Diagnose cardiac tamponade
3. Assess LV decompression
4. Guide fixed speed selection
5. Identify RV dysfunction
6. Identify valvular pathology/ AV opening
7. Diagnose “suction events”/volume status/collections
8. Guide therapy

RV failure

When medical treatment fails….

Mechanical support

The need for an RVAD is associated with worse outcomes, but elective implantation of an RVAD correlates with better long-term survival than does an emergency implantation.

RVAD implant at the time of LVAD implant also improves survival to transplant compared with delayed RVAD insertion

Table 1. Hemodynamic Formulas to Assess Right Ventricular Function

Hemodynamic Formulas to Assess RV Function		
Cardiac filling pressures	RAP/PCWP	>0.63 (RVF after LVAD)[13] >0.86 (RVF in acute MI)[30]
PA pulsatility index (PAPi)	(PASP–PADP)/RAP	<1.85 (RVF after LVAD)[31] <1.0 (RVF in acute MI)[32]
Pulmonary vascular resistance	mPAP–PCWP/CO	>3.6 (RVF after LVAD)[15]
Transpulmonary gradient	mPAP–PCWP	Undetermined[33]
Diastolic pulmonary gradient	PADP–PCWP	Undetermined[33,34]
RV stroke work	(mPAP–RAP)× SV×0.0136	<15 (RVF after LVAD)[15] <10 (RVF after acute MI)[35]
RV stroke work index	(mPAP–RAP)/SV index	<0.3–0.6 (RVF after LVAD)[13,31]
PA compliance	SV/(PASP–PADP)	<2.5 (RVF in chronic heart failure)[36]
PA elastance	PASP/SV	Undetermined[37]

RV failure

PA catheter +/- TOE

Goal **CVP<15mmHg**

- CVP >15: furosemide, RRT or decrease LVAD flow
- CVP<10: fluid boluses

Reduce PVR (avoid hypoxia, hypercarbia, and acidosis)
RV dysfunction +/- high PVR: adrenaline, milrinone early

- If high PVR (>3 Wood Units): pulmonary vasodilator (iNO, sildenafil, epoprostenol,iloprost)
- If low SVR (<800 dyn/s/cm-5): inotropic support + vasopressors to increase perfusion of the RV (MAP-CVP)

Options

1. **RVAD CentriMag (Levitronix)**
2. **Percutaneous RVAD > Protek Duo®**
3. **Impella RP®**
4. **ECMO**
5. **TAH**

Requirement of an RV assist device (RVAD) or >14 consecutive days of intravenous (IV) inotropic support, has an estimated prevalence of 13% to 44% and is associated with significant morbidity and mortality

Anticoagulation

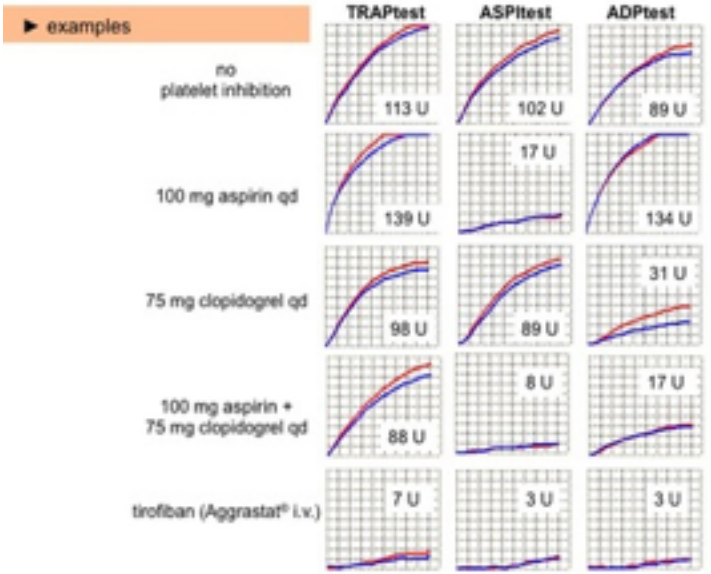
- **Anticoagulation therapy is required**
- **Starting anticoagulation too early is a common mistake**
- **Adequate haemostasis should be achieved before anticoagulation is initiated**
- **Modification of the anticoagulation regimen may be required in the face of bleeding.**

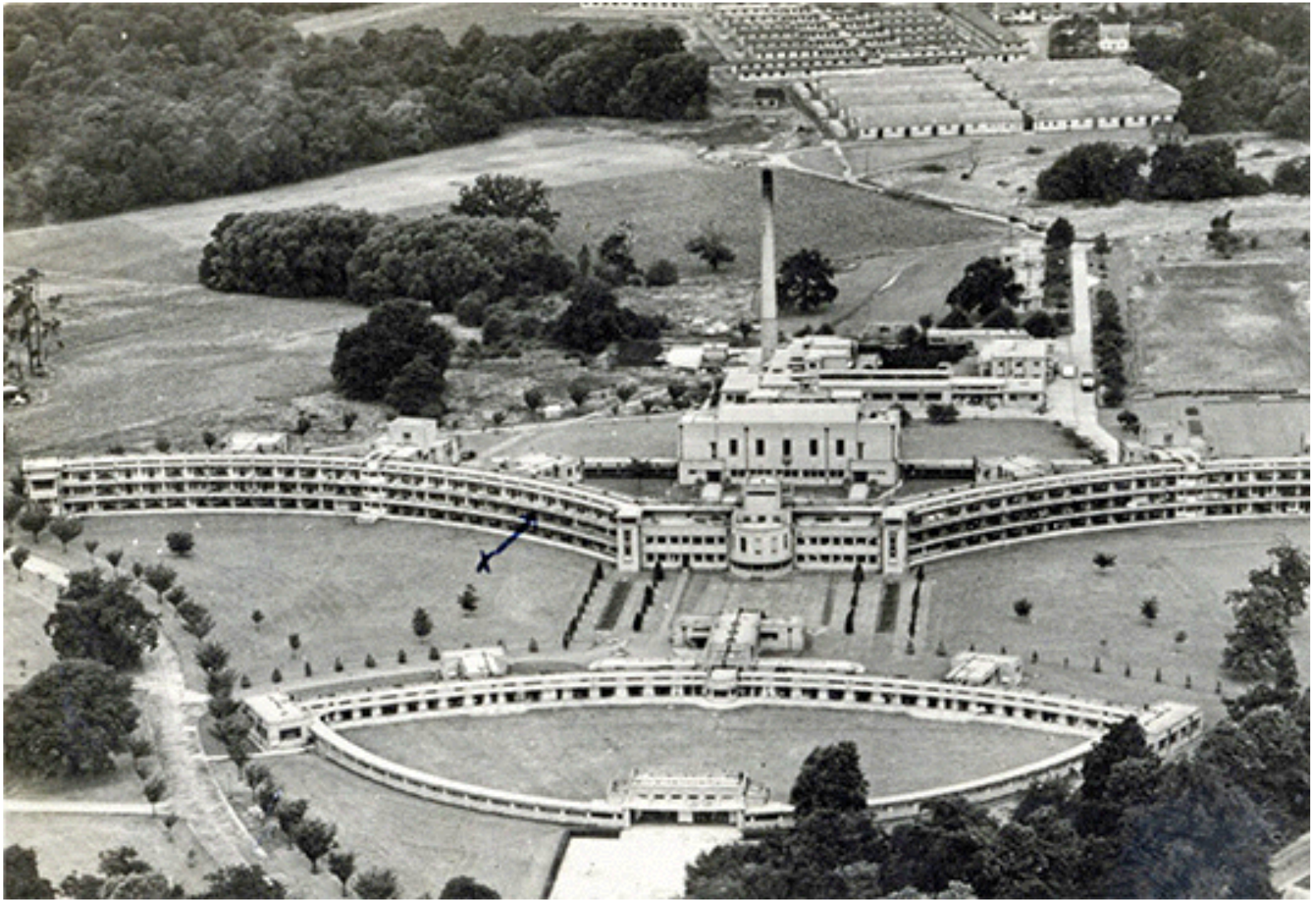
Titrating Anticoagulation

-Unfractionated Heparin > infusion APTT/Anti Xa every 6h

-Aspirin > We titrate aspirin dose

Multiplate®platelet function analysis





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