Complications of LVAD and ECMO (TTE)

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Introduction to Echo in Mechanical Circulatory Support

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Mechanical Circulatory Support (MCS)

Intra-aortic balloon pump – IABP

- Temporary

Extracorporeal Membrane Oxygenation – ECMO

- Temporary

Ventricular Assist Devices – LVAD/RVAD

- Durable

Impella

- Temporary

ECMO

Extra**C**orporeal – outside the body

Membrane Oxygenation – introducing oxygen into cells

- Rescue therapy provide respiratory support +/- cardiac support, for critically ill patients
- Maximal medical management has failed

VV (Veno-Venous) ECMO

- Oxygenates and removes CO^2
- Isolated refractory respiratory failure
- Supports lung function

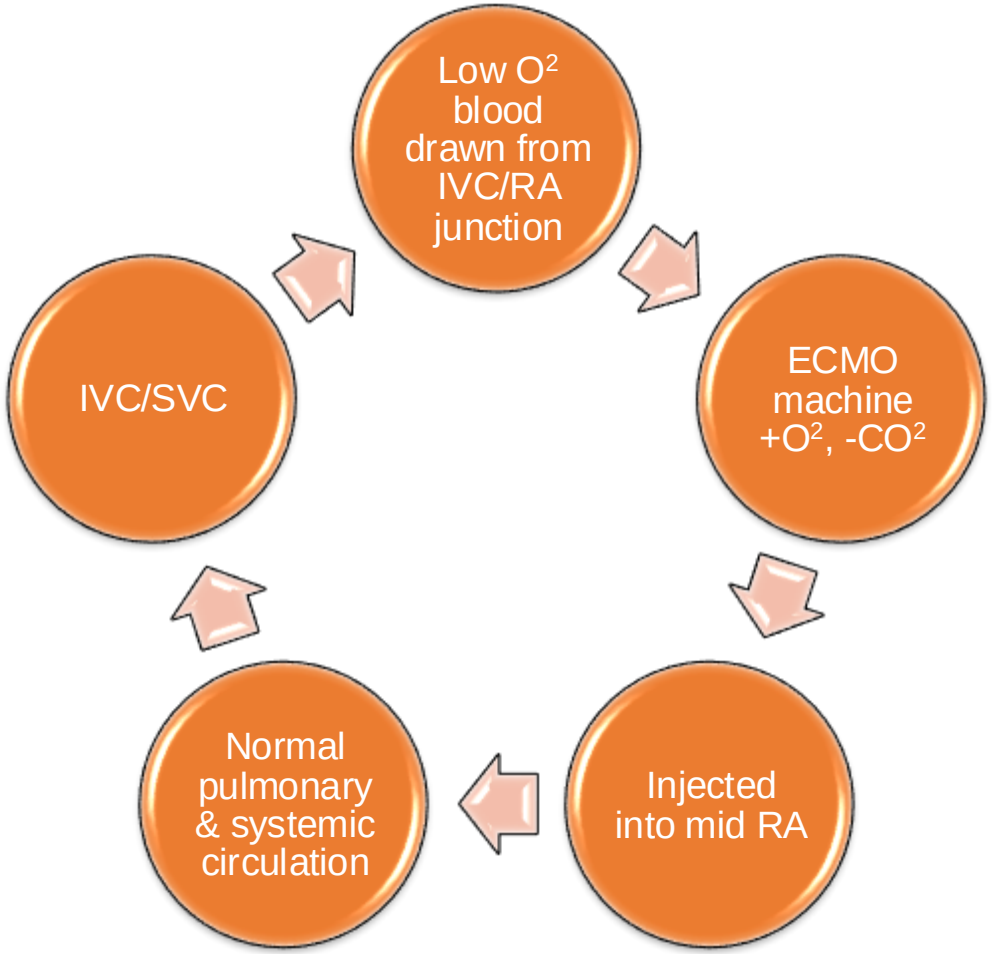
Blood drawn from vein and reinjected into vein

Dual vein cannulation:

- Inflow cannula proximal IVC before RA
- Return cannula in RA (via SVC), clear of IAS and TV

Dual lumen catheter:

- Drainage from IVC/SVC
- Return via RA (from second lumen of catheter)

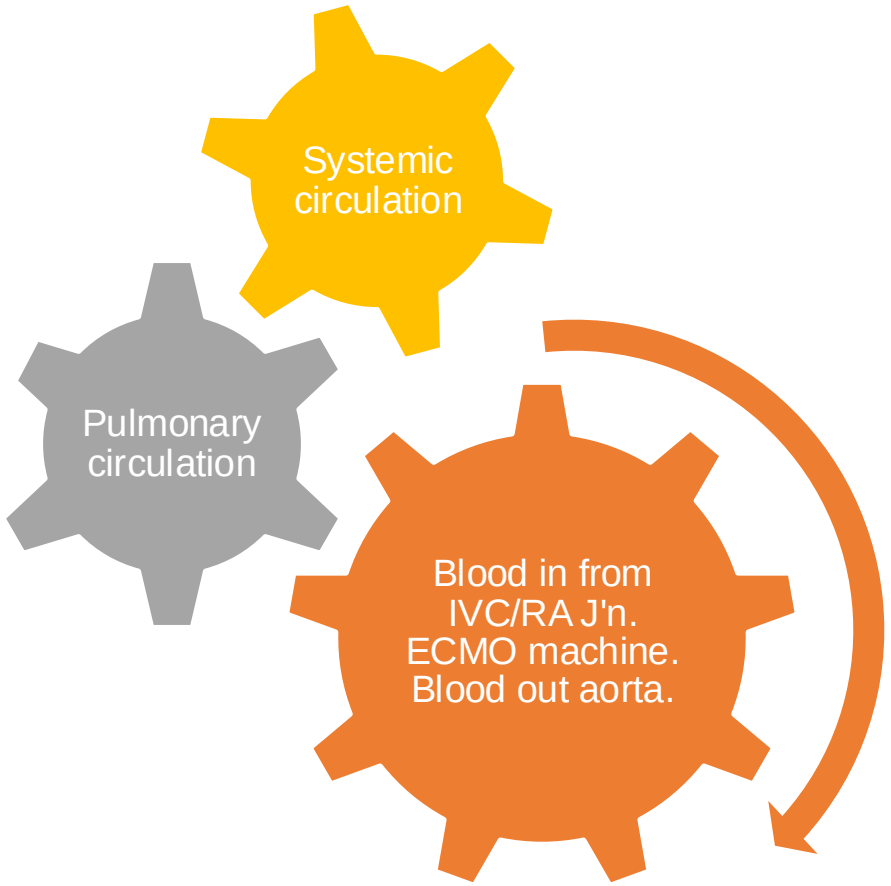


VA (Veno-Arterial) ECMO

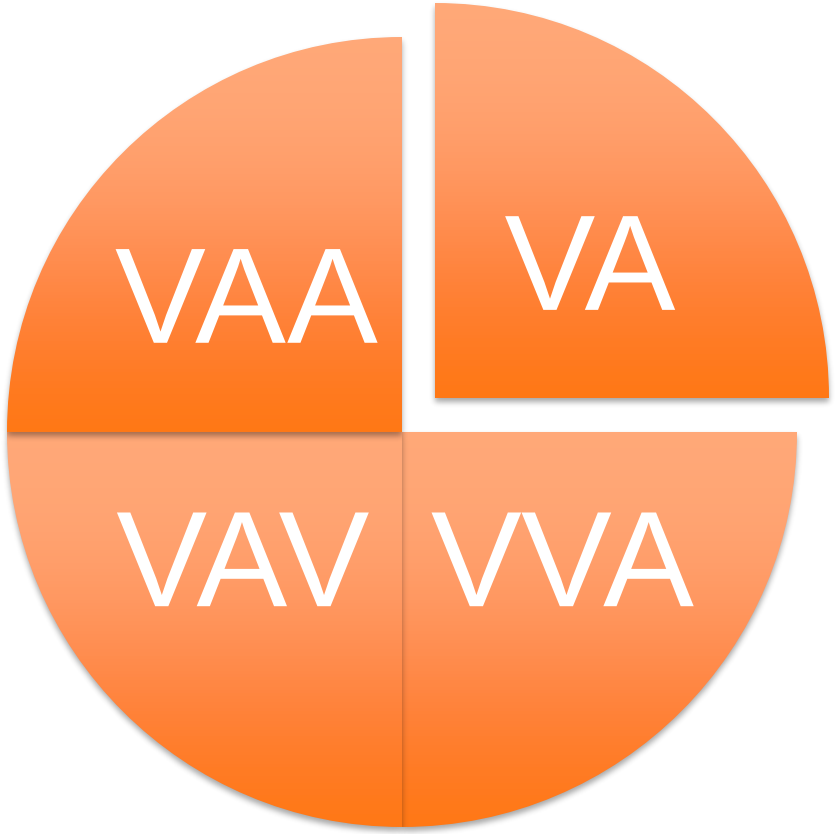
- Supports lung AND cardiac function
- Cardiopulmonary bypass machine

Blood drawn from vein and reinjected into artery:

- Variable cannula locations
- In-flow cannula proximal IVC just before right atrium (RA)
- Return cannula in ascending/ descending aorta



Multiple Other Combinations



Role of Echo – Pre ECMO

Determine aetiology (? VA or VV ECMO), Reversible?

LV function – severe dysfunction warrants VA-ECMO

RV function – function may improve with VV-ECMO due to reduced pulmonary vascular resistance

Valve function:

- Aortic regurgitation - Will increase in severity with VA-ECMO
- Tricuspid stenosis – Inhibits flow from out-put cannula (VV)

Role of Echo – Pre ECMO

Intracardiac shunts:

- Will not cause hypoxia during ECMO but will impact weaning from ECMO

Exclude normal variants such as:

- Prominent Chiari networks, Eustachian valves may interfere with cannula placement
- Persistent left SVC – cannula may be placed in left SVC with blood reinjected toward left arm instead of the RA

Role of Echo – during ECMO (VV and VA)

- LV/RV size and function
- Monitor pre-existing pathology
- Cannula position
- Pericardial effusion
- IVC size and collapsibility (volume status)

Role of Echo – during VA ECMO

Monitor LV dimension

- Ensure adequate unloading

LV systolic function

- Adequate unloading and to detect recovery

Aortic valve opening

- Open / closed or intermittent

Rule out intracardiac **thrombus**

- Intracardiac or Aortic root

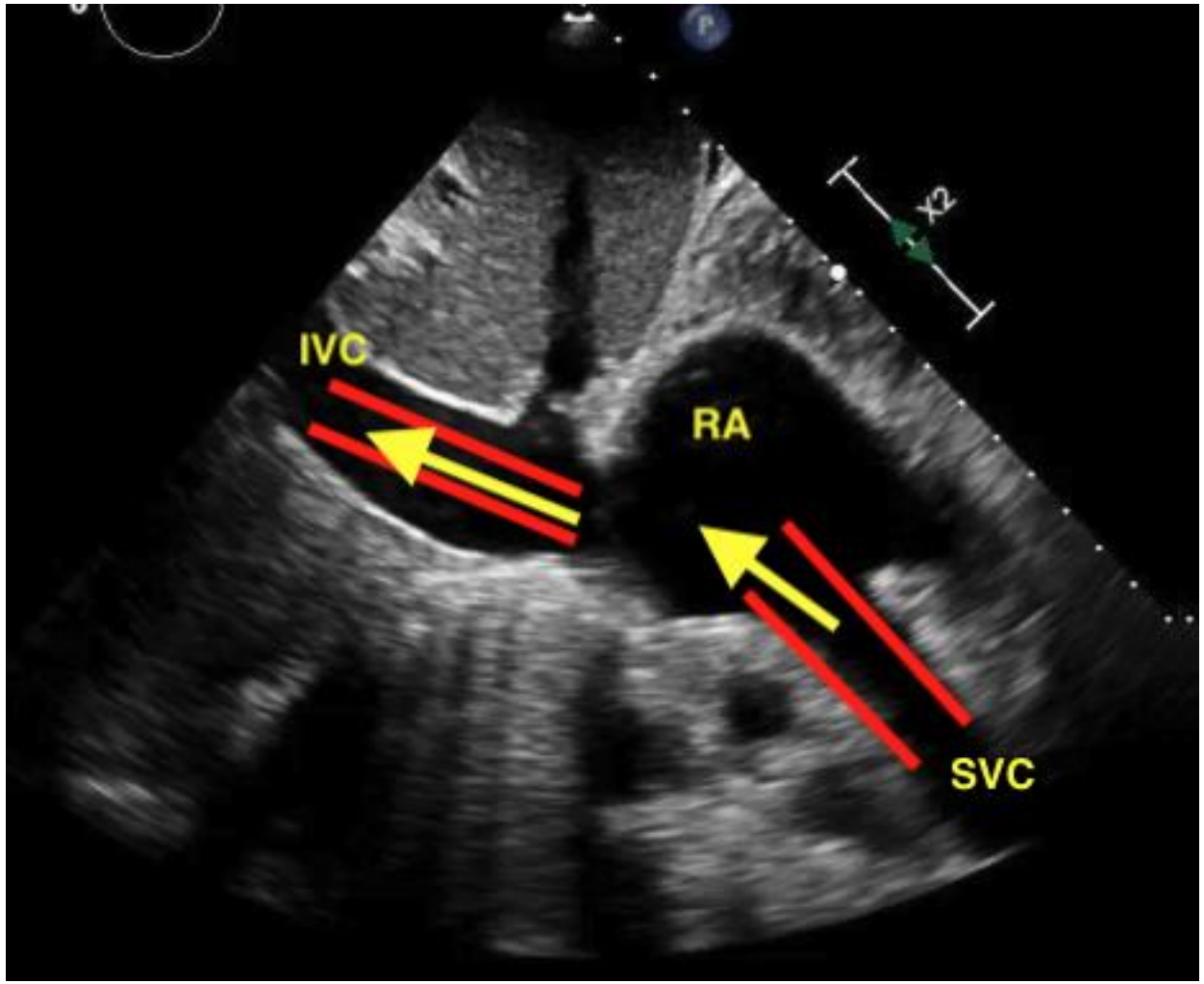
Regurgitation

- Aortic and mitral

Cannula Placement

Cannula location **VV-ECMO** with dual cannula:

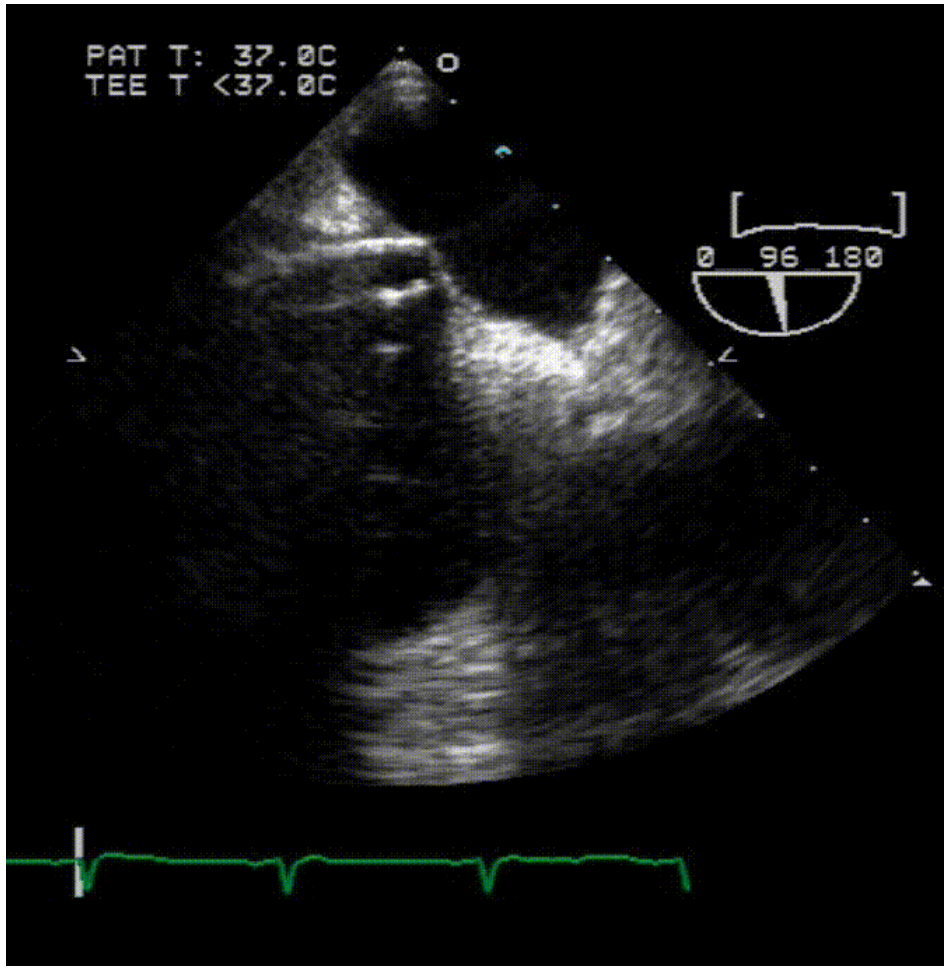
- SVC cannula must not re-inject flow directly toward IVC catheter
- ”blind loop” or Recirculation
- Continual recirculation through ECMO machine and not pulmonary/systemic circulation



Cannula Placement

Catheter must not abut any structures eg. IAS, atrial wall, vena cava wall

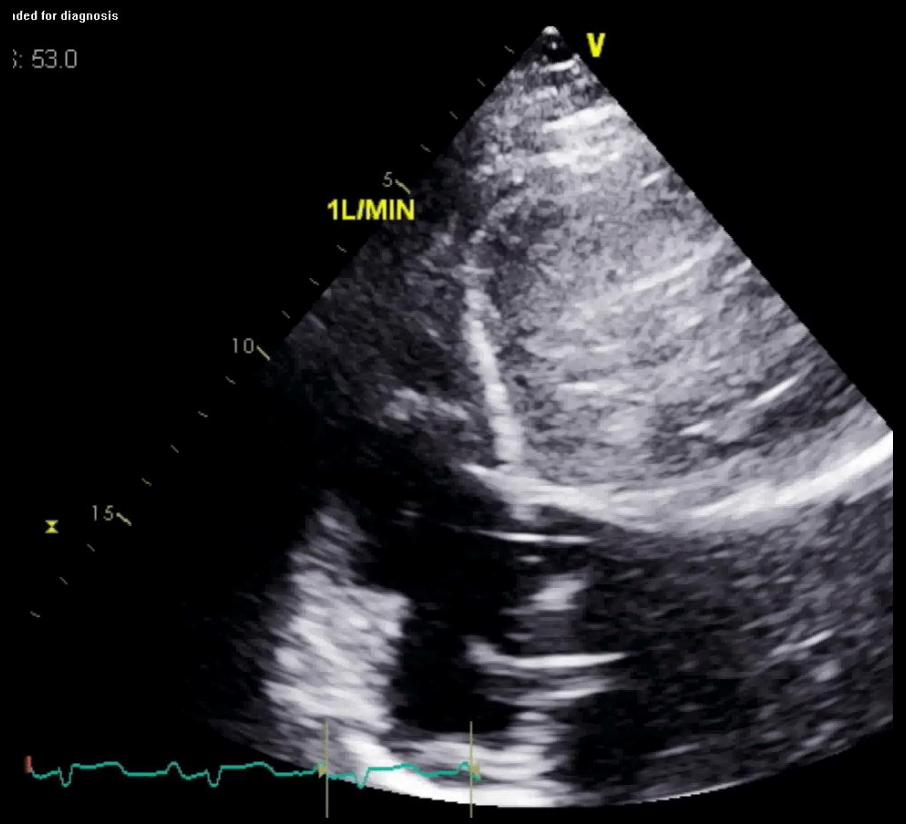
- Can result in puncture – haemorrhagic pericardial effusion, septal defect



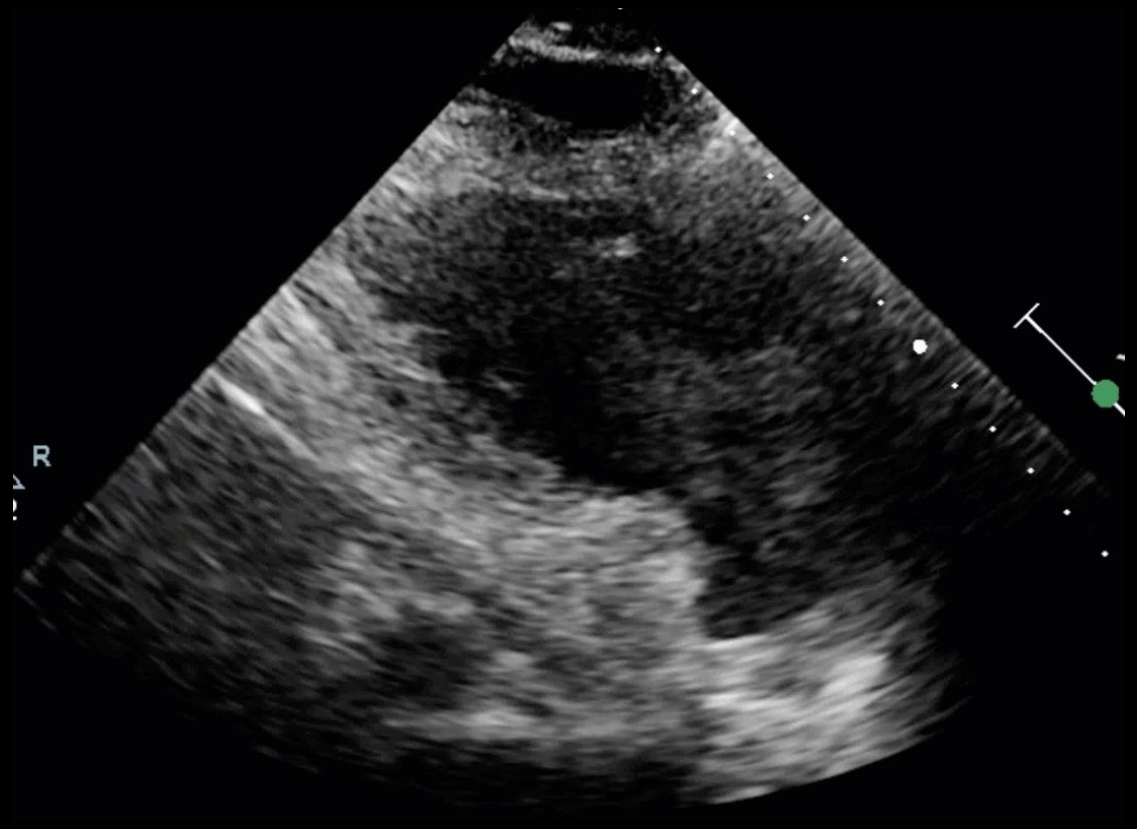
Cannula abutting inter-atrial septum.

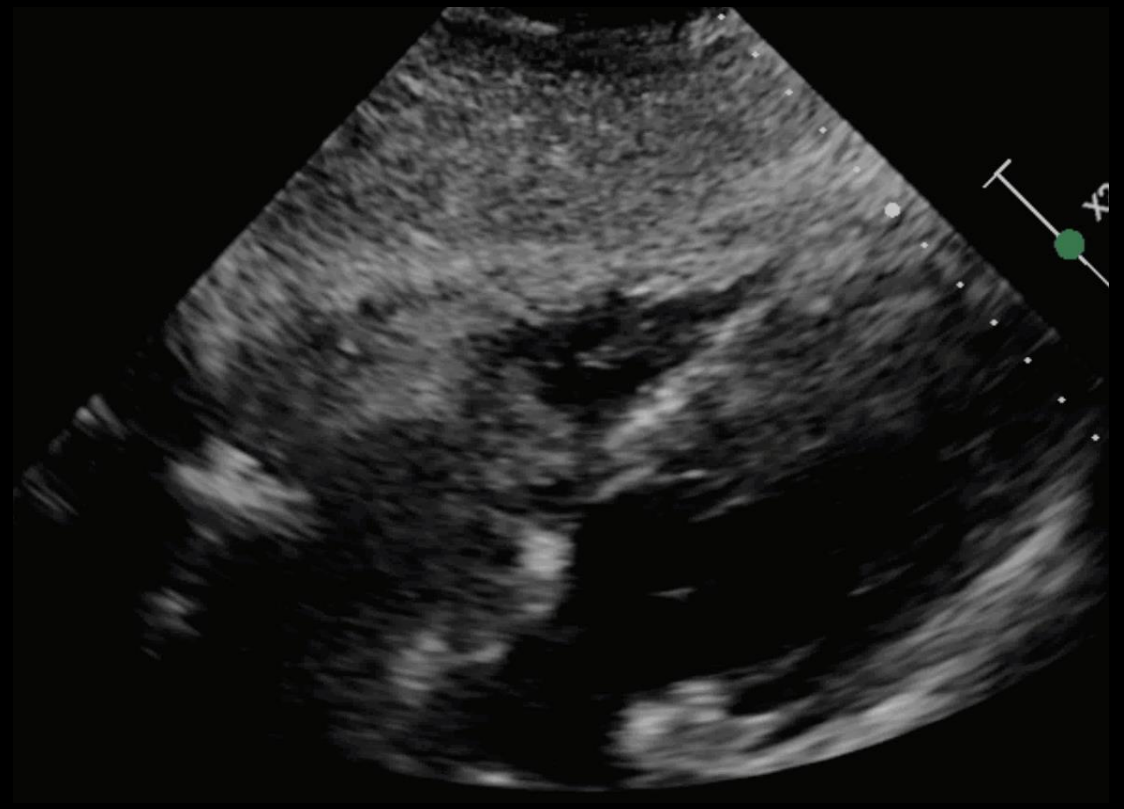
Complications

- Limited flow is a frequent complication
- Often related to patient positioning or hypovolemia
- Echo exclude:
  - Intra-cannula thrombus
  - Blood flow at orifice of drainage cannula with spectral (PW) and colour Doppler
- RA puncture



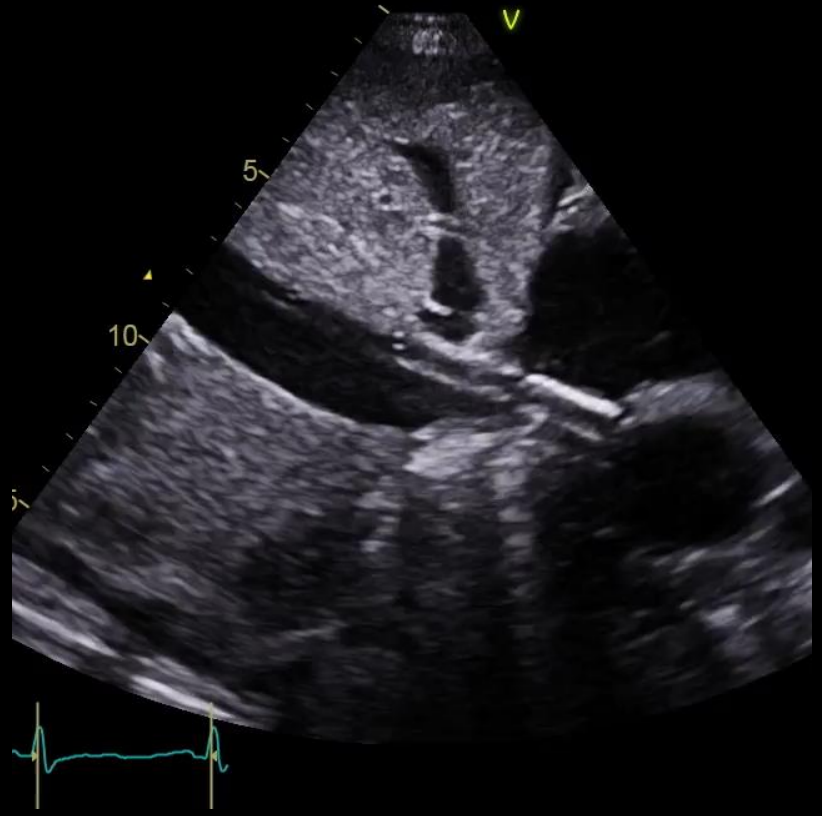
Cannula thrombosis

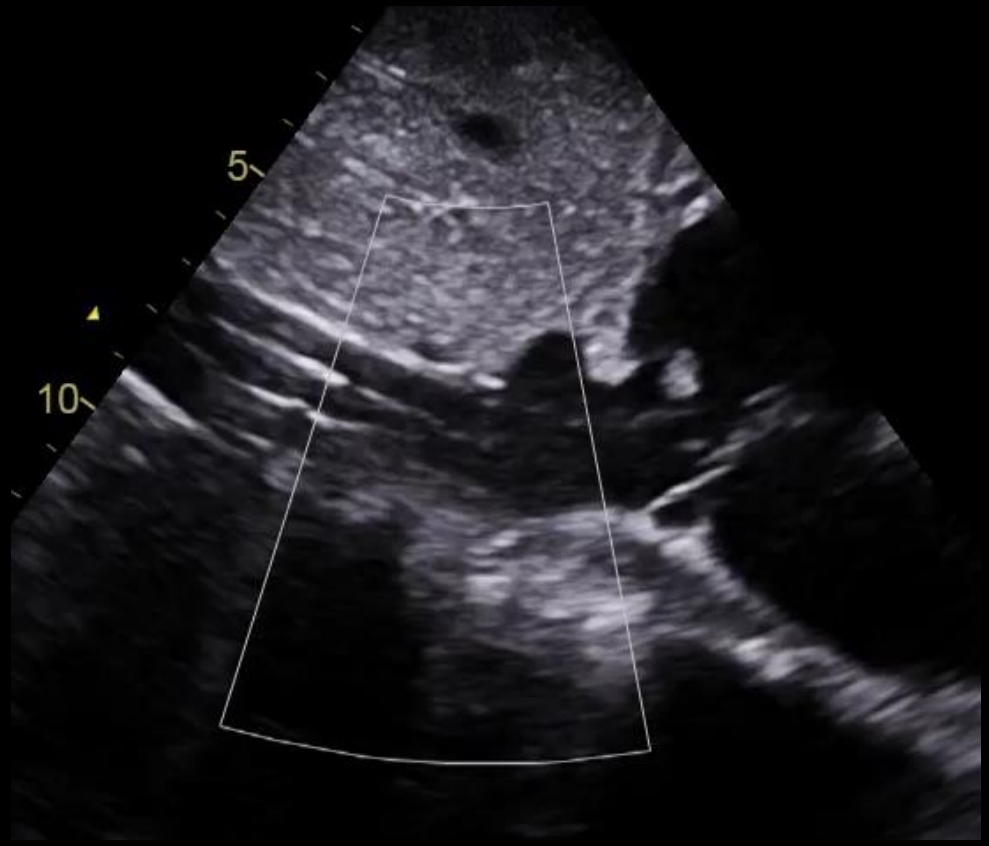




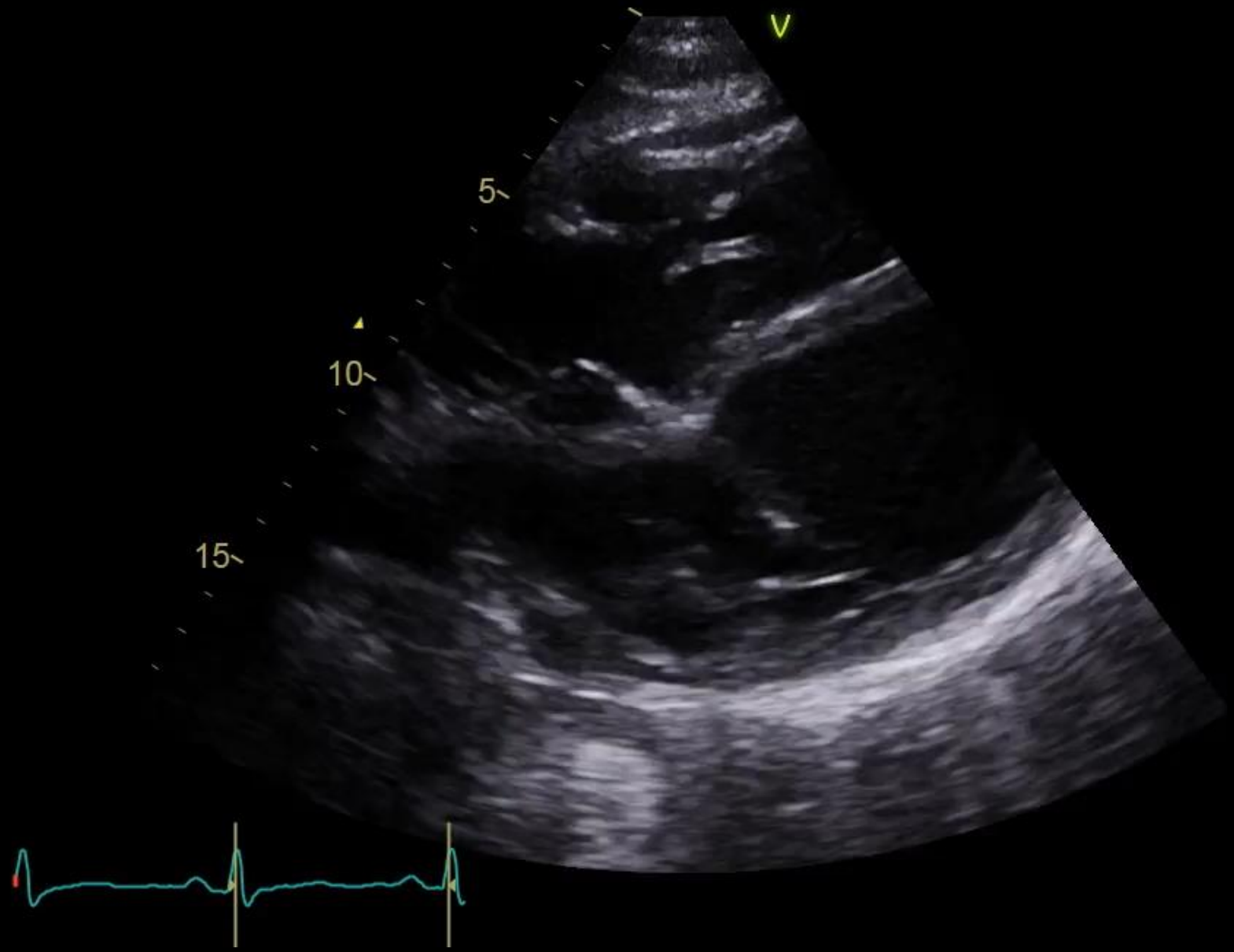
VA ECMO – RA/RV thrombus

Complications





VA ECMO – RA/RV thrombus



What is an LVAD?

- **L**eft **V**entricular **A**ssist **D**evice, and/or RVAD
- Battery operated mechanical pump that helps the left ventricle pump to the systemic circulation
- Short or long term
- HeartMate III (HM3) currently implanted in Australia
- HM3 continuous flow with cyclical speed

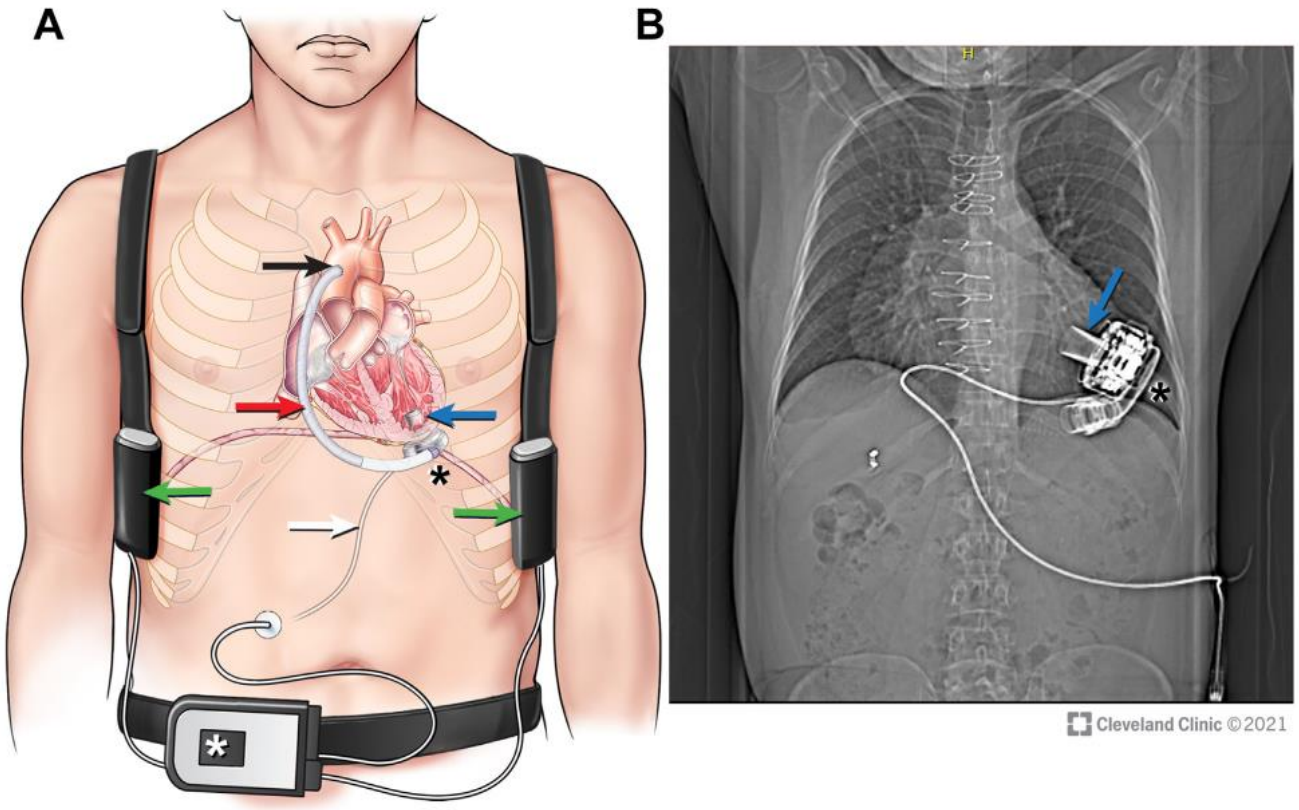
IMAGE: https://www.nhcs.com.sg/news/medical-news-singhealth/left-ventricular-assist-device-lvad

LVAD Components

3 intracorporeal (inside body) components in series:

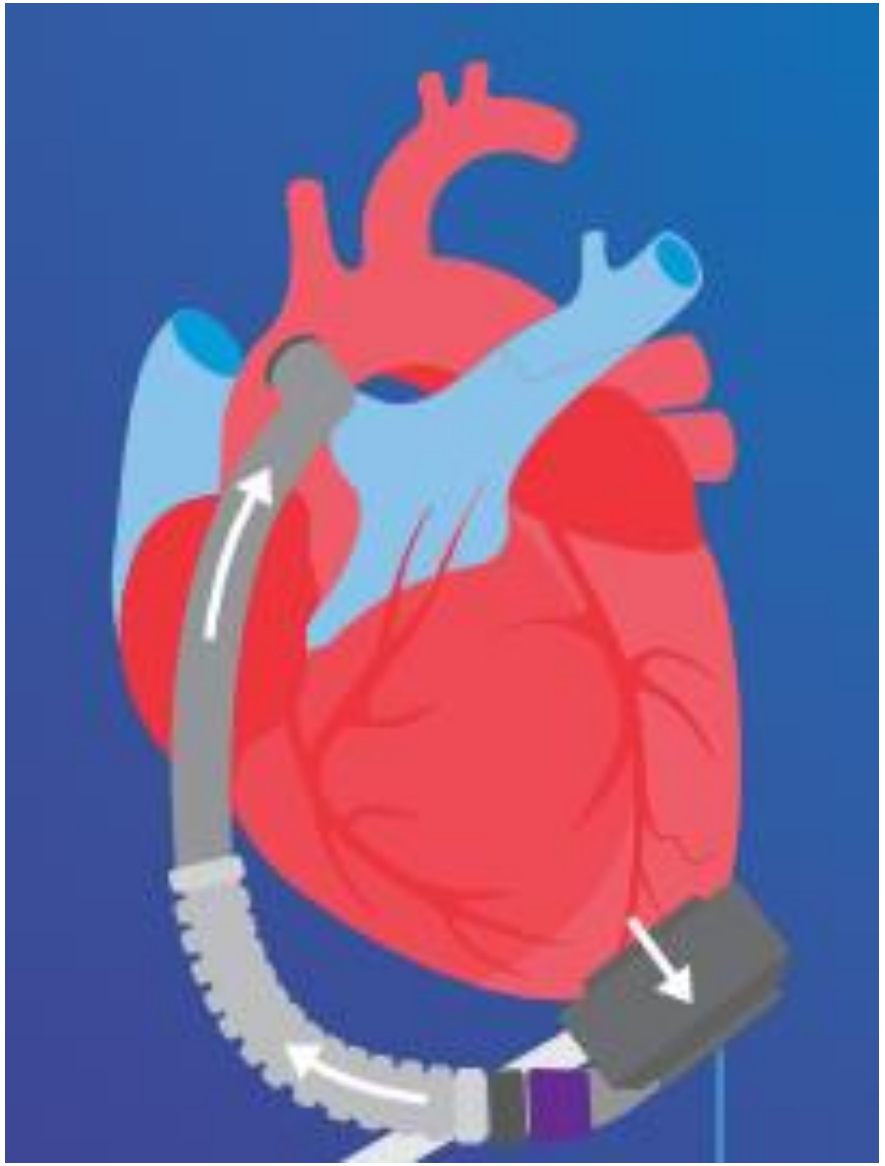
1. **Inflow cannula** in the LV near the apex
2. Mechanical **impeller**
3. **Outflow graft** anastomosed to the ascending aorta

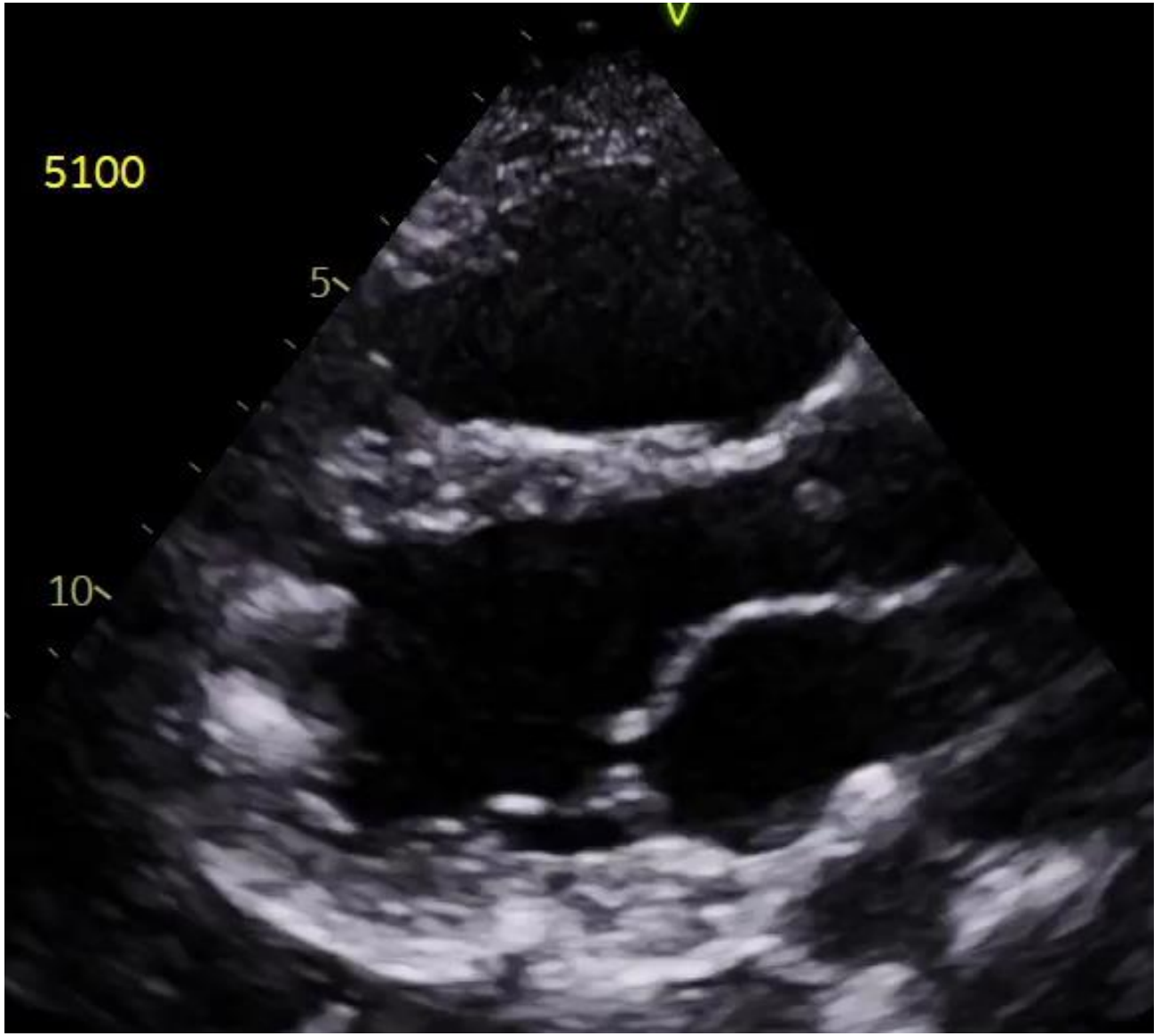
Impeller is attached to an extracorporeal driveline.



HeartMate 3 LVAD. (A) Drawing showing the intrapericardial pump location and impeller housing (black asterisk), inflow cannula (blue arrow), right parasternal outflow graft position (red arrow), and outflow graft–to–ascending aorta anastomosis (black arrow). The white arrow shows the driveline that is connected to the extracorporeal controller (white asterisk) that permits delivery of power to the devices. Green arrows show the battery packs. (B) An x-ray CT scout image showing the anatomic relationship between the LV and the device inflow cannula (blue arrow) and impeller housing (black asterisk)

Recommendations for Multimodality Imaging of Patients With Left Ventricular Assist Devices and Temporary Mechanical Support: Updated Recommendations from the American Society of Echocardiography. https://doi.org/10.1016/j.echo.2024.06.005





[us-hm3-patient-brochure.pdf]

Role of LVADs

Patients with advanced end-stage heart failure

Refractory to medical therapy

Role of LVAD can be:

Bridge to transplantation (BTT) – most common indication	Destination therapy (DT) (Not in Australia)	Bridge to transplant candidacy (BTC)	Bridge to recovery (BTR)

Role of TTE

- Candidate selection
- Surveillance
- RAMP studies
- Complications

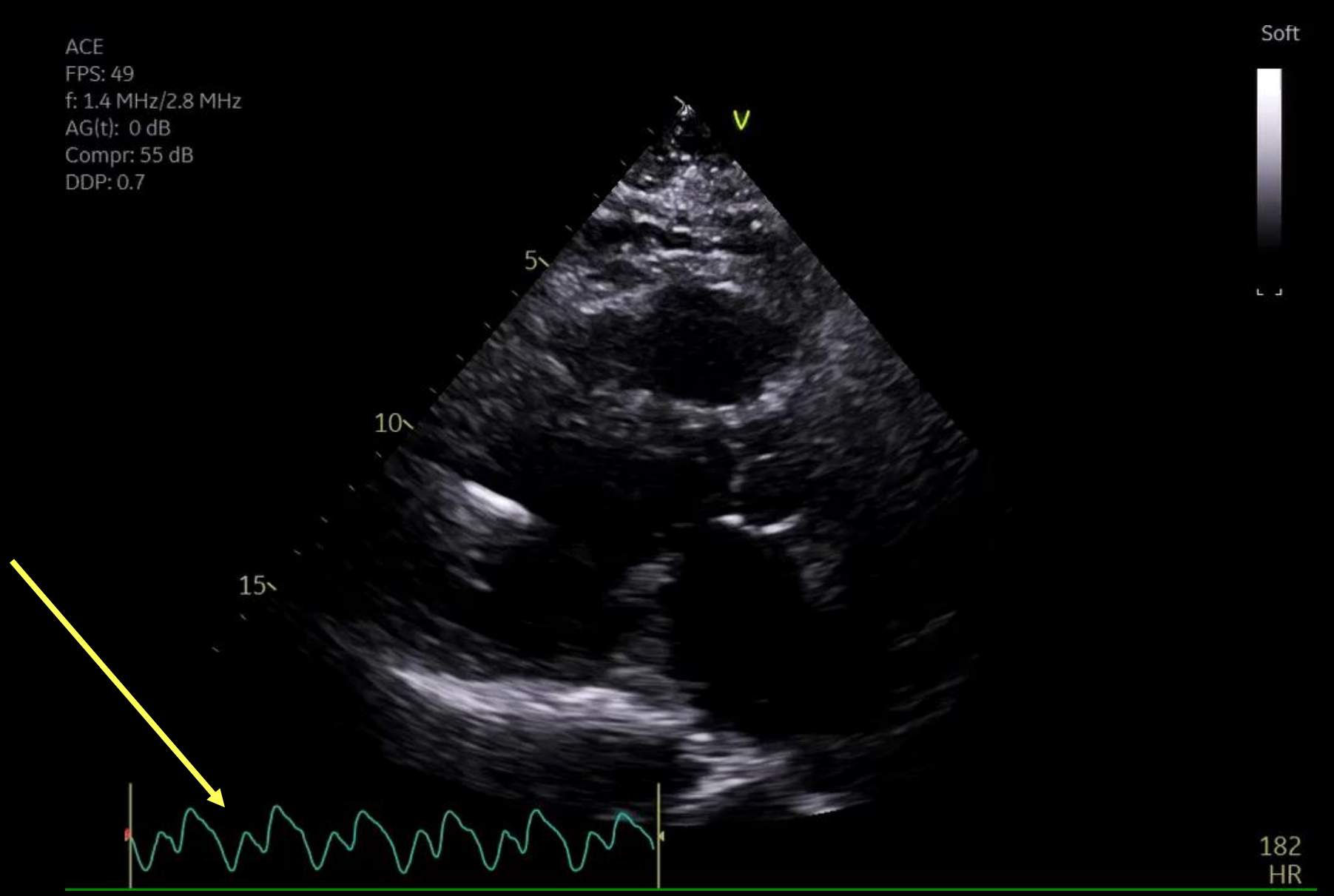
Table 1 Preimplantation TTE/TEE "*red-flag*" findings

Left Ventricle and Interventricular Septum
Small LV size, particularly with increased LV trabeculation
LV thrombus
LV apical aneurysm
Ventricular septal defect
Right Ventricle
RV dilatation
RV systolic dysfunction
Atria, Interatrial Septum, and Inferior Vena Cava
Left atrial appendage thrombus
PFO or atrial septal defect
Valvular Abnormalities
Any prosthetic valve (especially mechanical AV or MV)
> mild AR
≥ moderate MS
≥ moderate TR or > mild TS
> mild PS; ≥ moderate PR
Other
Any congenital heart disease
Aortic pathology: aneurysm, dissection, atheroma, coarctation
Mobile mass lesion
Other shunts: patent ductus arteriosus, intrapulmonary

Stainback, et al. "**Echocardiography in the Management of Patients with Left Ventricular Assist Devices: Recommendations from the American Society of Echocardiography**." *Journal of the American Society of Echocardiography* 28.8 (2015): 853-909. Web

Surveillance Echo

- Occurs at pump's baseline speed setting
- Performed regularly
- LVAD type and baseline speed in rpm annotated on screen
- Blood pressure:
  - Influences echo findings and interpretation
  - Pulse may be absent
  - Cuff-based BP difficult (may require audible Doppler interrogation)
  - Mean arterial BP of 65 - 85mmHg recommended
- ECG:
  - Arrhythmia common, including VT/VF


ACE
FPS: 49
f: 1.4 MHz/2.8 MHz
AG(t): 0 dB
Compr: 55 dB
DDP: 0.7
Soft
V
5
10
15
182
HR

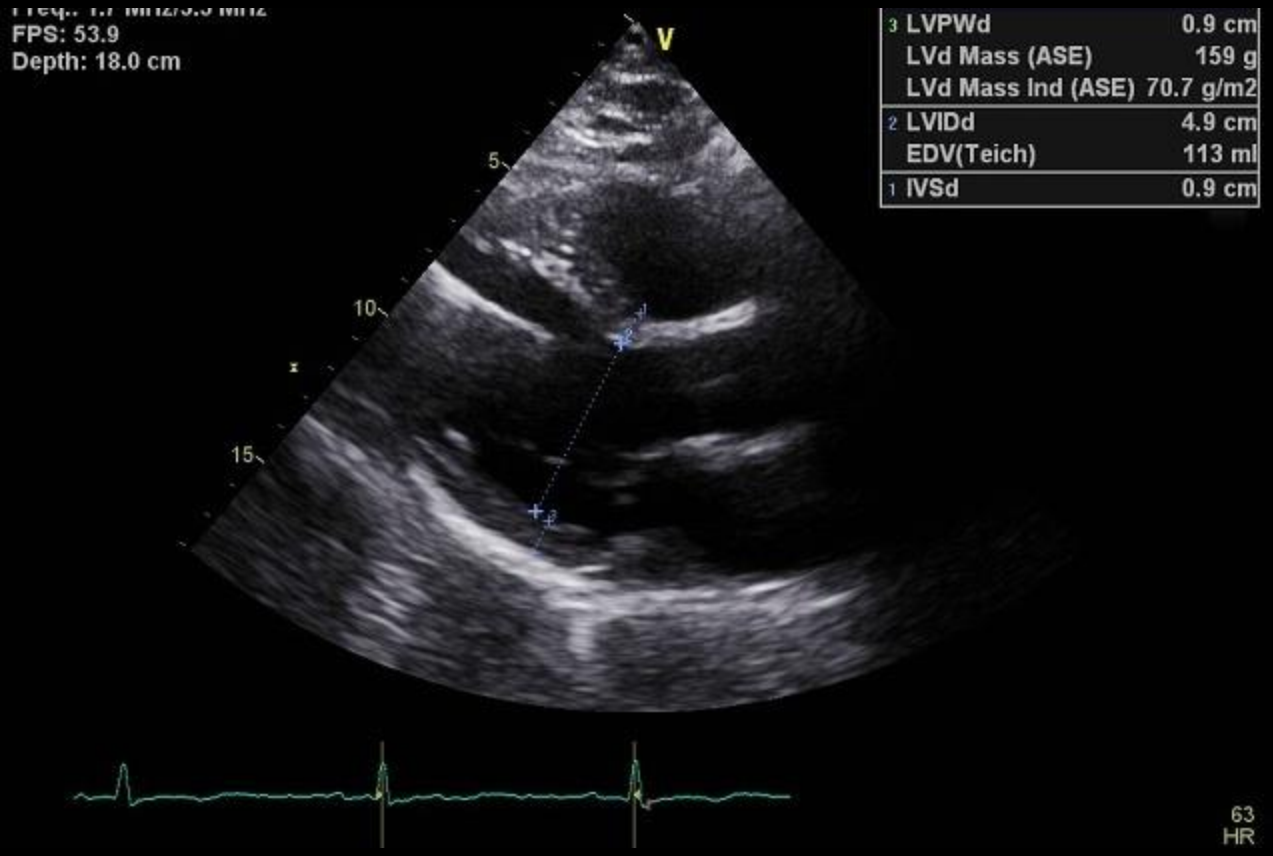
Surveillance Echo

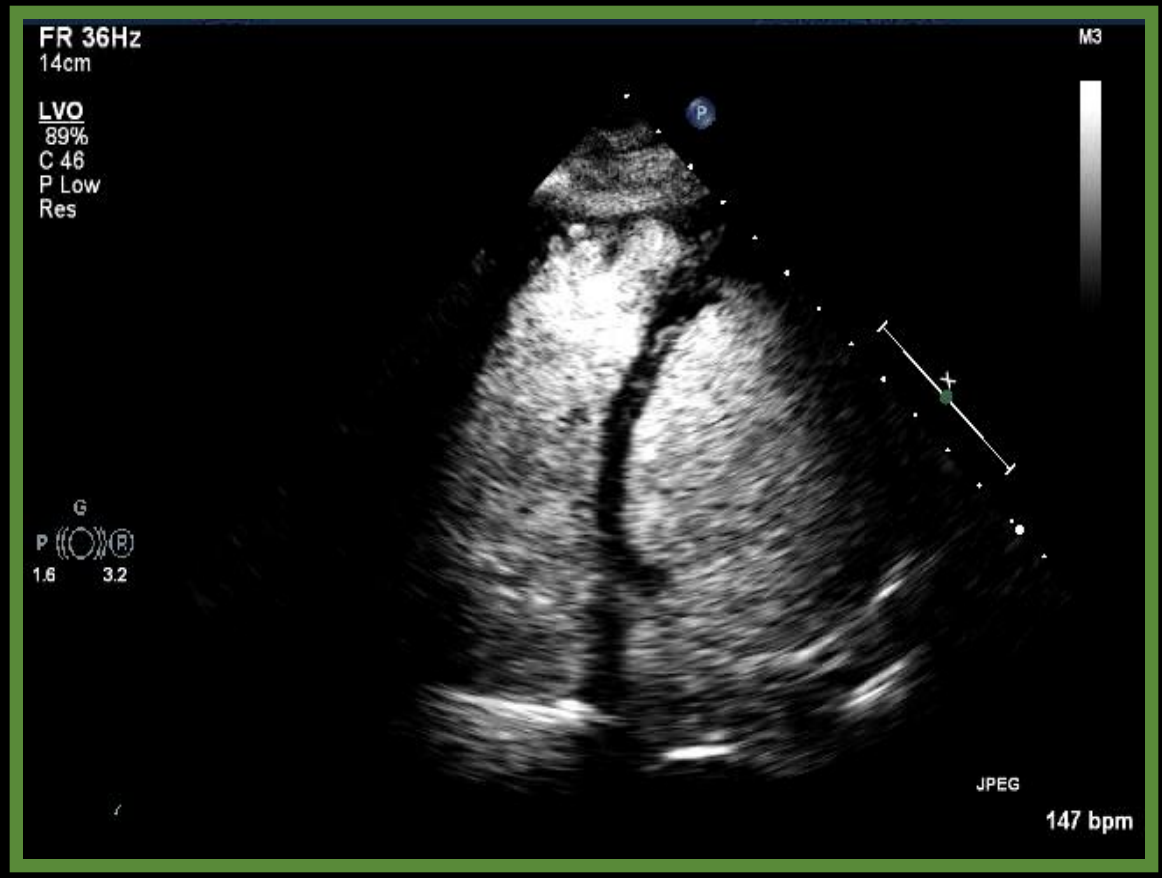
LV size	• LV size may reduce by 15% in 3 months (LVEDd most reproducible)
LV function	• EF challenging, biplane Simpsons, contrast if necessary
RV size and function	• Measure with standard methods
Aortic valve opening	• **Closed, opening** or **Intermittent** AV opening

Surveillance Echo

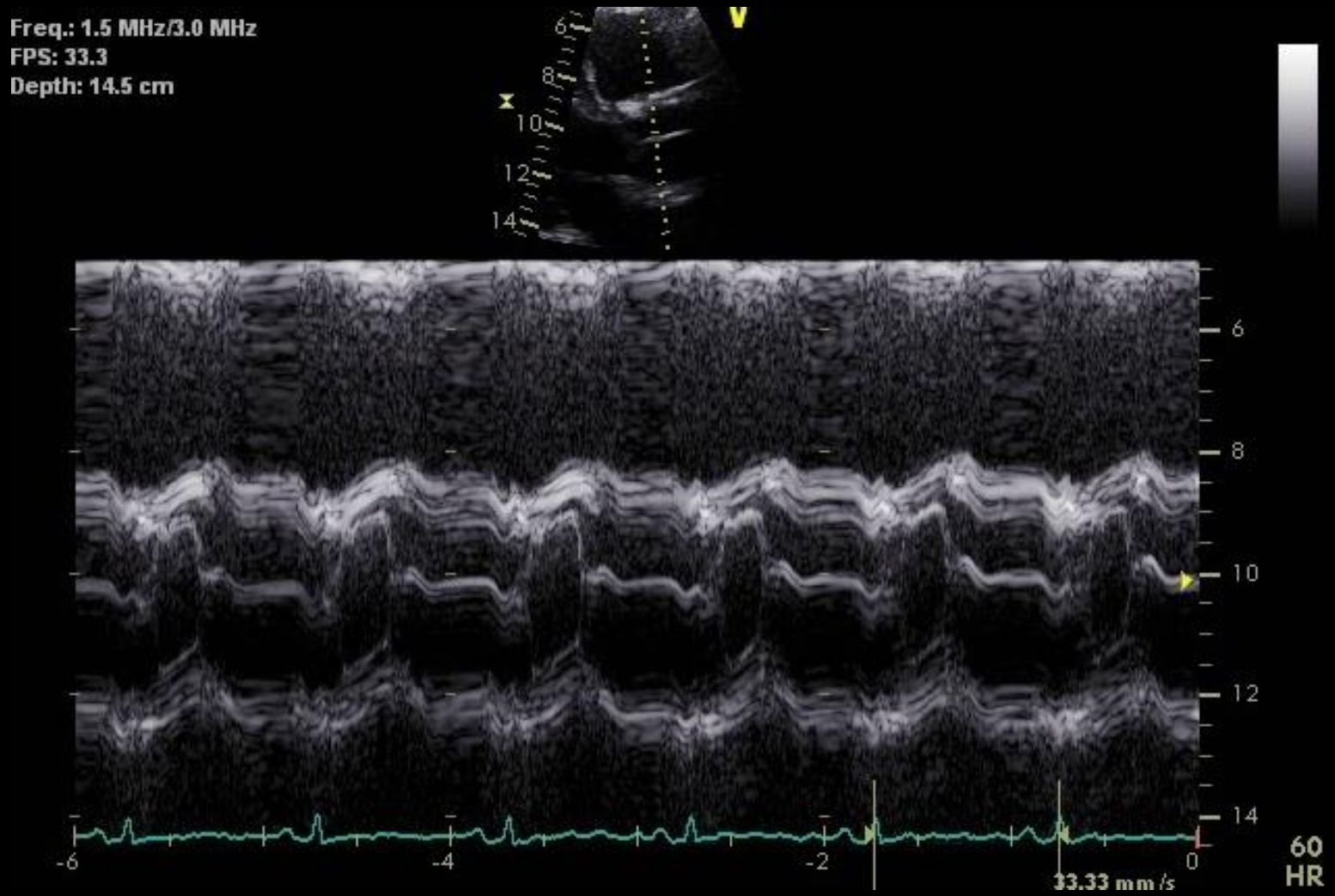
Aortic Regurgitation	• New Aortic regurgitation in 25-33% patients within 12 months
Other valves	• Worsening TR may indicate RV failure • PR affects candidacy for RVAD
Ventricular Septal Position	• Septal position should be neutral
Inflow cannula	• Centrally located, angled toward MV • Inflow colour laminar
Outflow cannula	• Outflow velocity

LV Size and Function

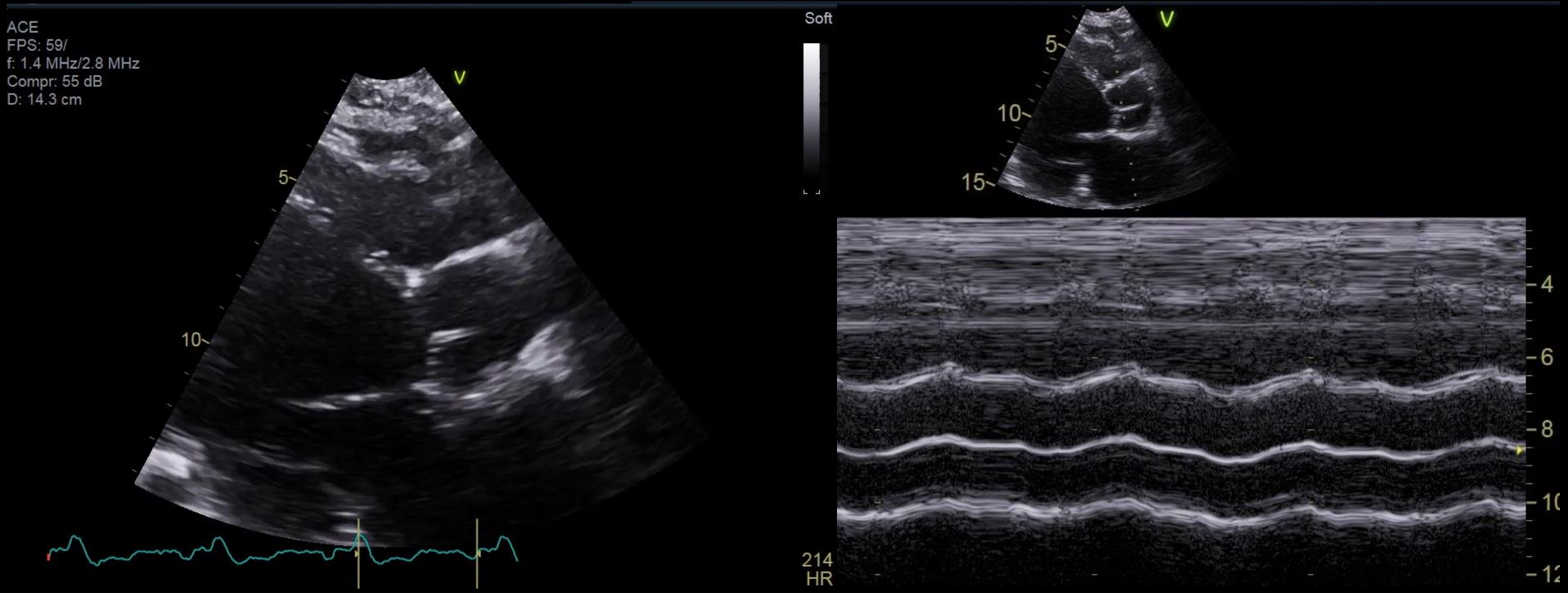




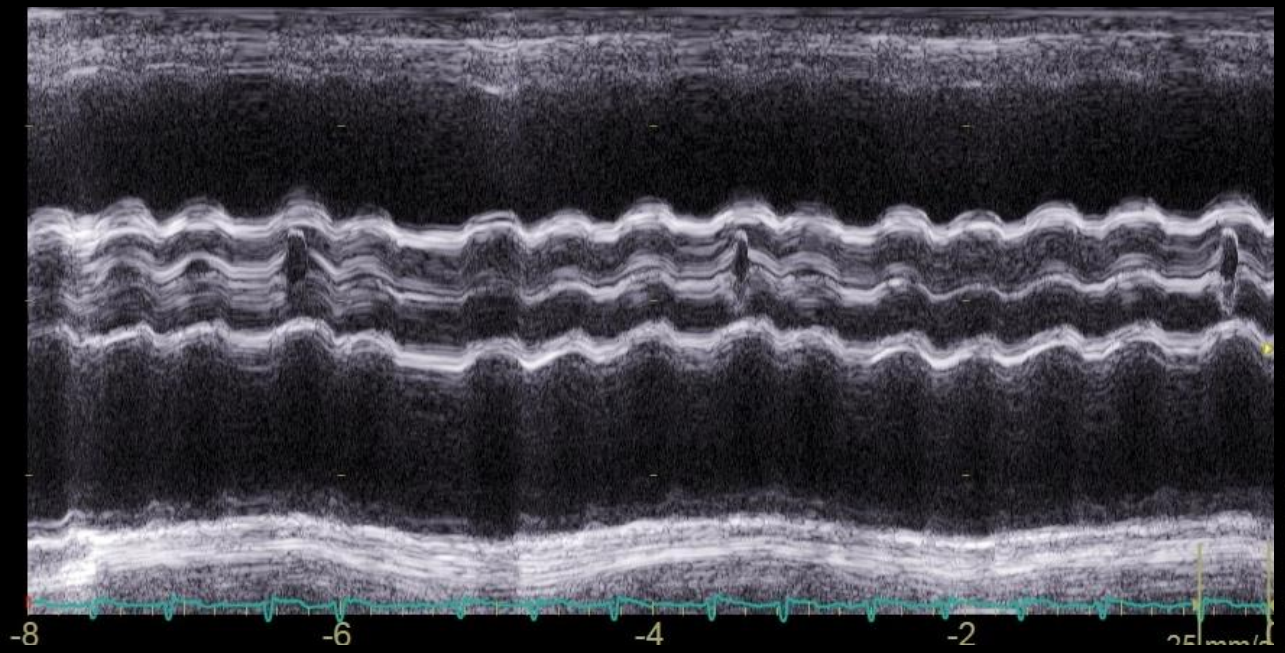
Aortic Valve Opening – Every Beat



Aortic Valve Opening - Closed



Aortic Valve Opening - Intermittent

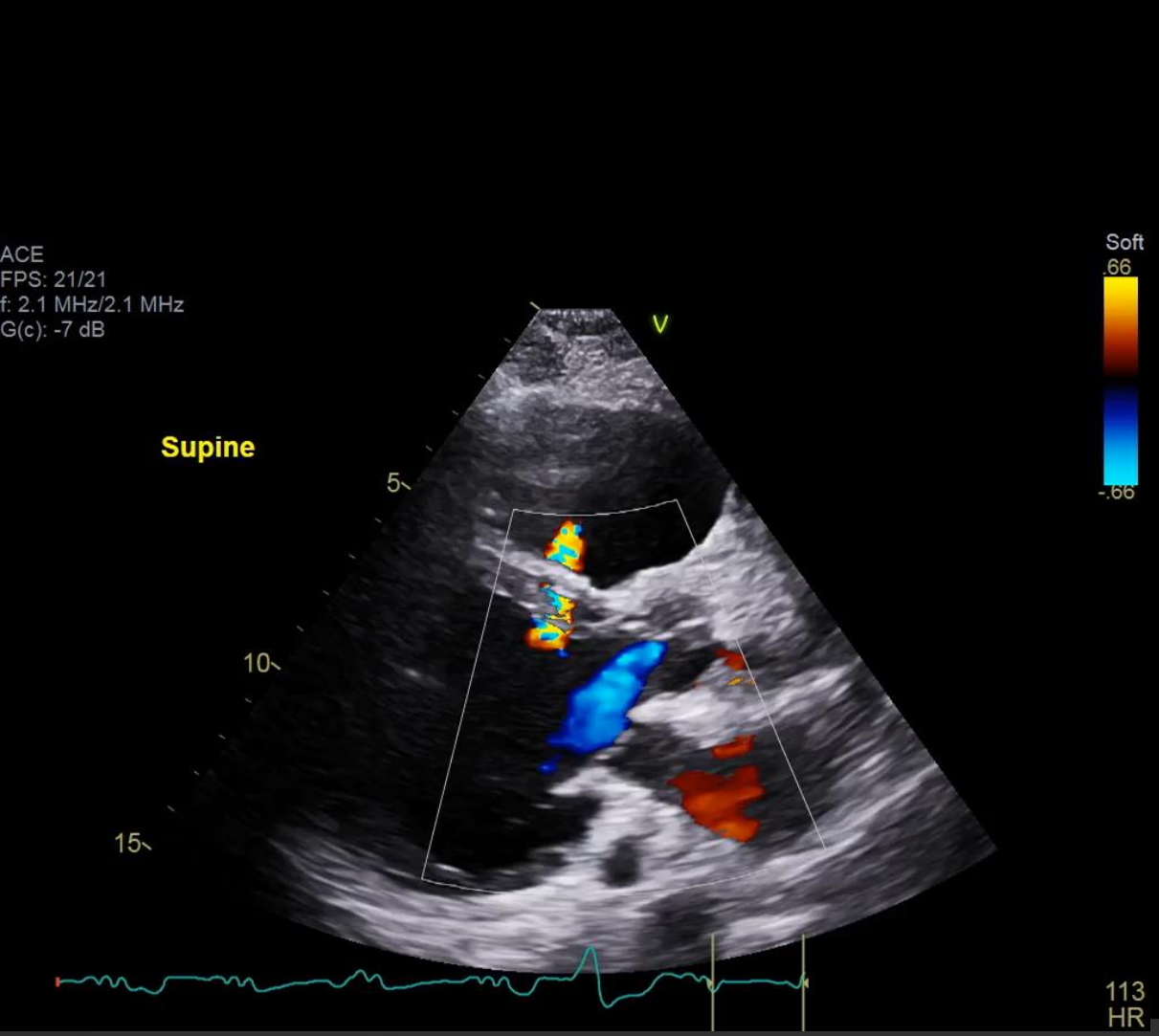


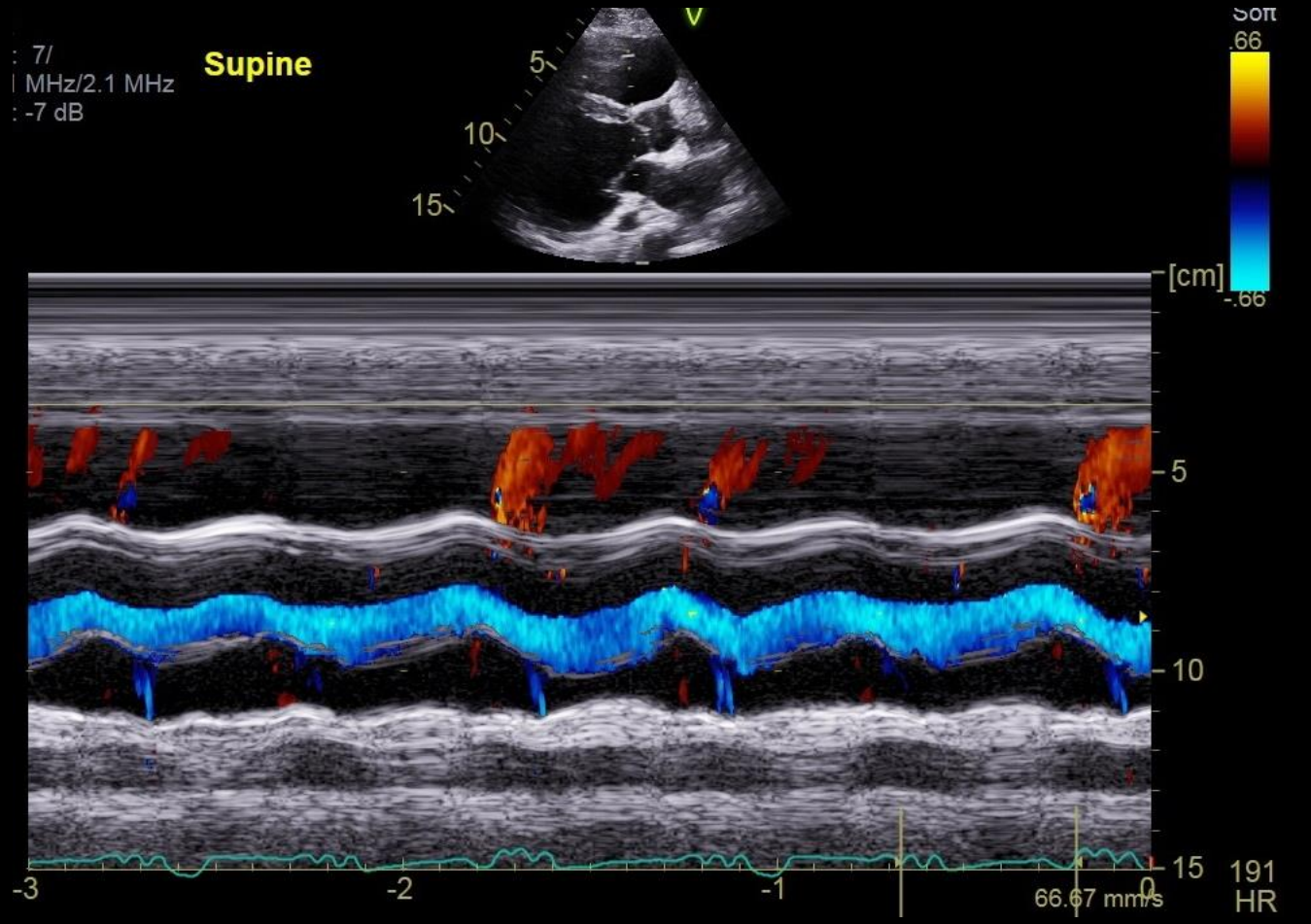
Aortic Root Thrombus

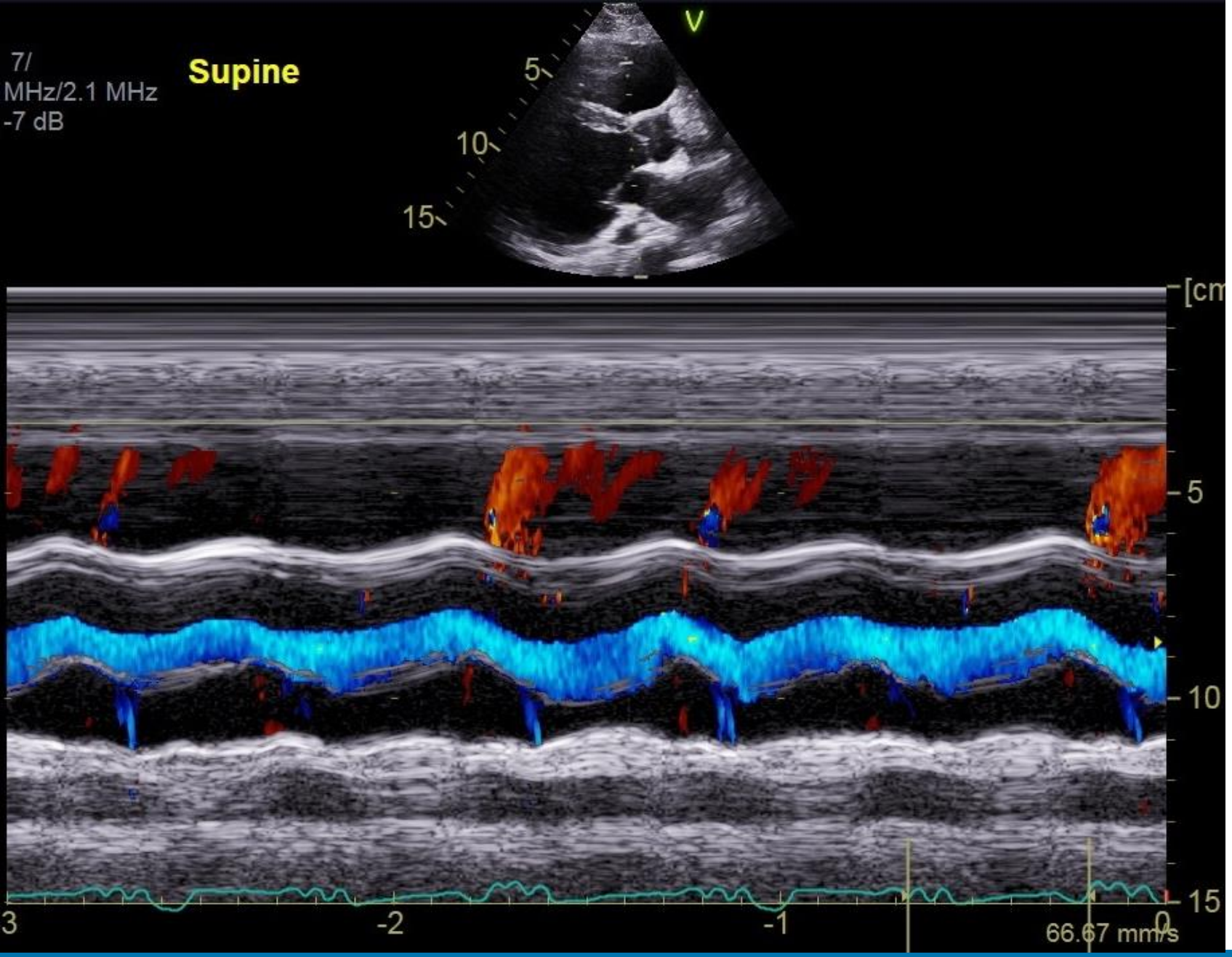
Intermittent opening of AoV can help prevent thrombosis

A and B. Aortic root thrombus.
Estep, J. D. et al. J Am Coll Cardiol Img 2010;3:1049-1064

Aortic Regurgitation







AR Severity

Net cardiac output reduced due to regurgitant volume in blind loop

Grade using multiple parameters:

- Duration
- Vena contracta width
- Jet height/LVOT

Novel parameters:

- S/D ratio in outflow cannula
- Diastolic acceleration of outflow

Not useful

- Flow reversals
- EROA

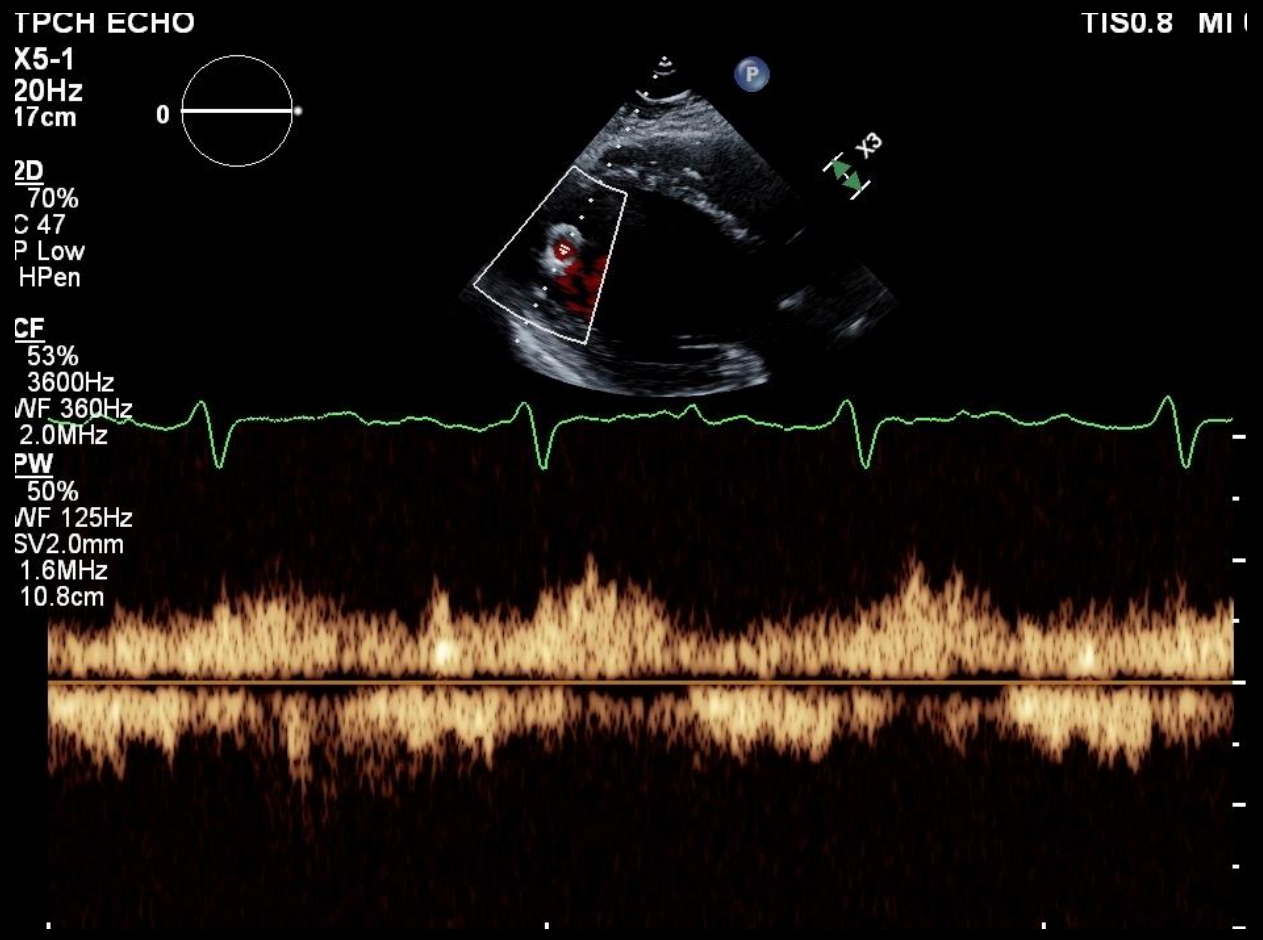
Septal Position – Central / Neutral

Inflow Cannula

Ideal position:

- Central
- Angled toward mitral valve (slightly toward IVS)
- Velocity typically < 1 m/s
- Intermittent peaks up to 1.2 m/s

Inflow Cannula



PLAX

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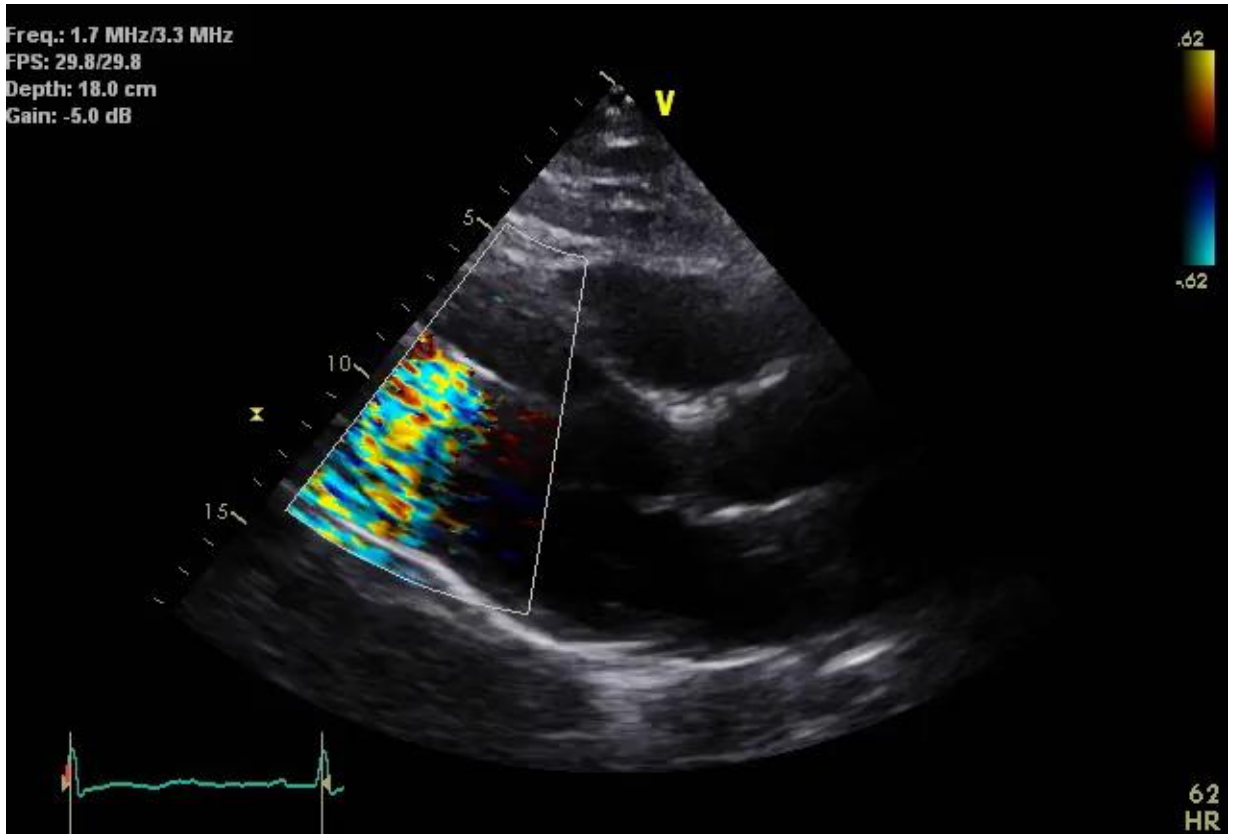
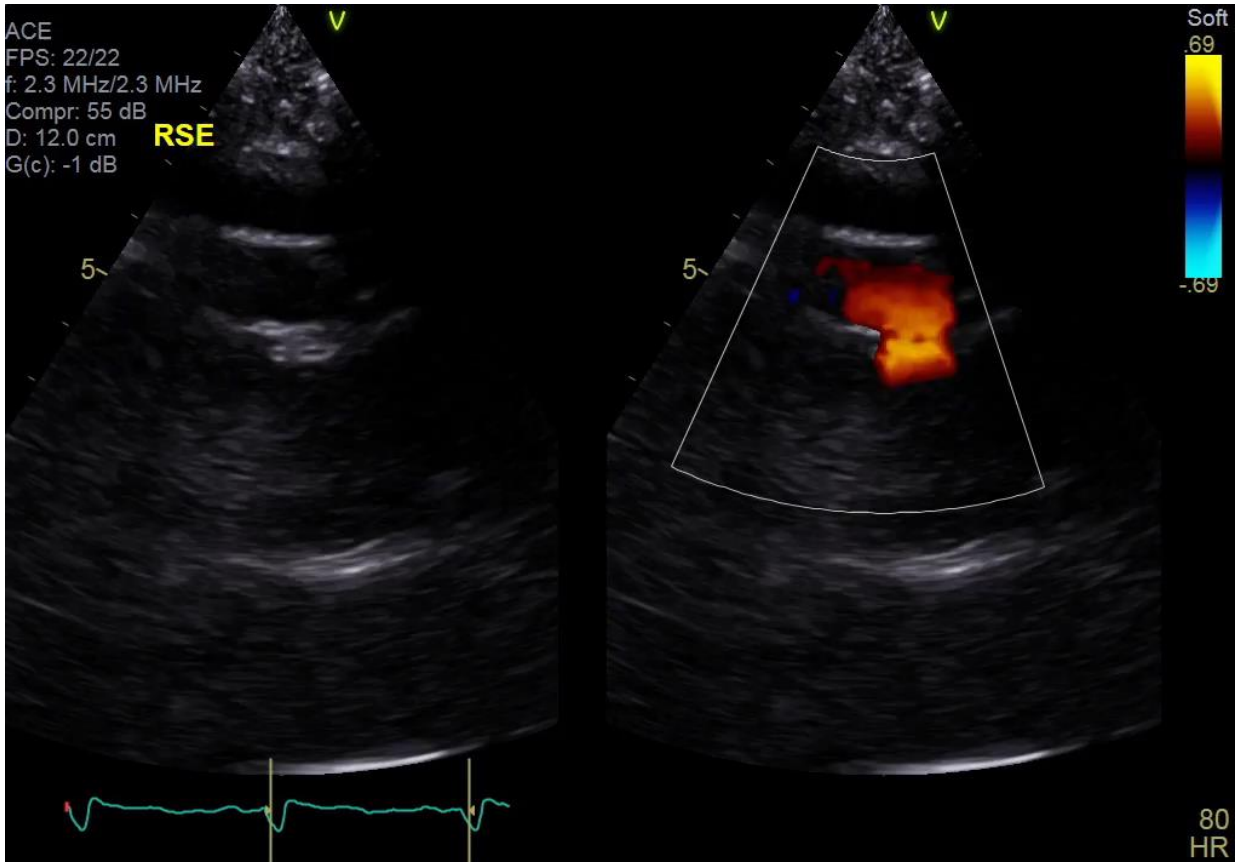
Colour Challenging!

- Waterfall artefact
- Colour of inflow cannula superior on TOE
- Use alternate views to avoid artefact from device



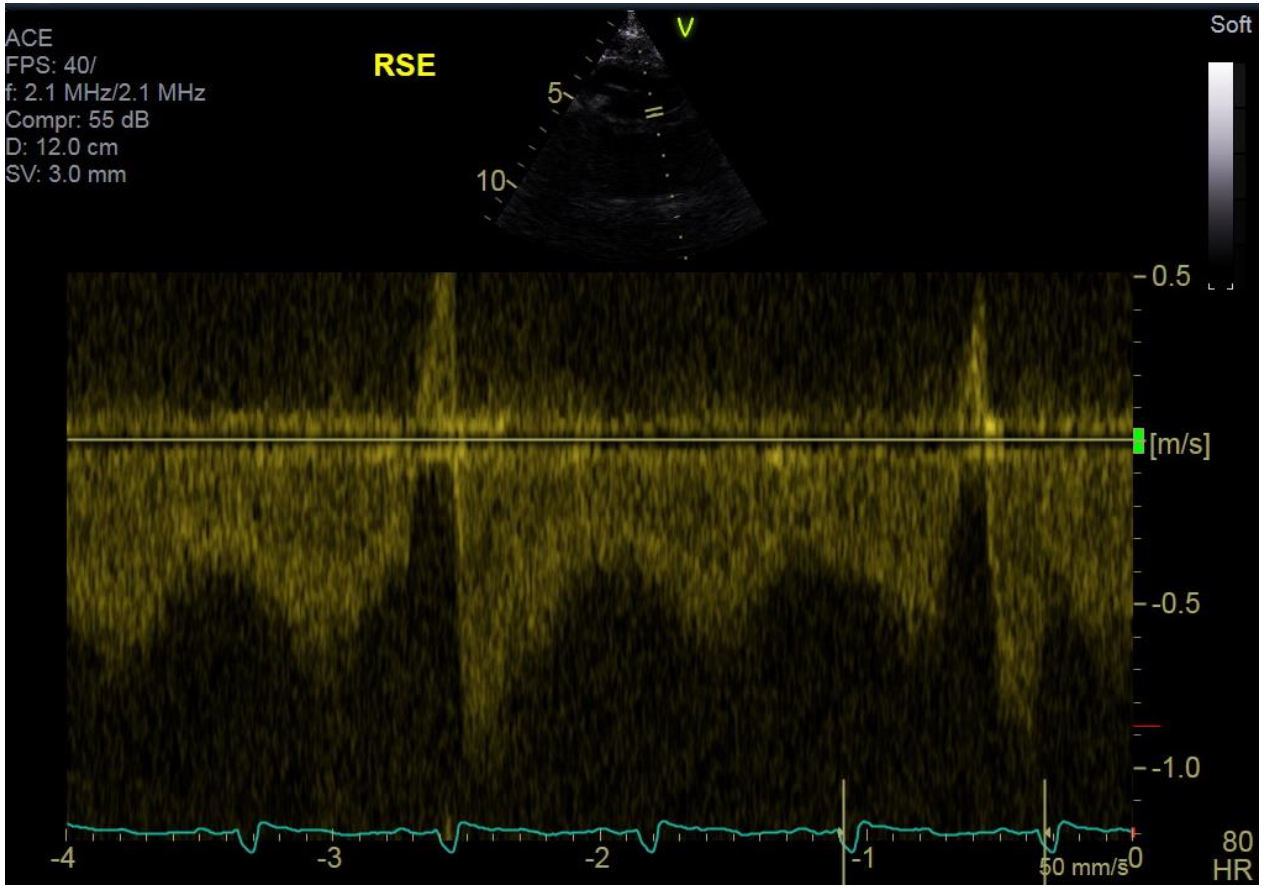
Outflow Graft

- Often difficult to visualise – usually high right parasternal window
- If cannot see graft directly look for laminar continuous flow in ascending/descending aorta
- Velocity < 2 m/s



Outflow Graft

- HM3 cyclically changes rotor speed every 2 seconds (30 times/minute)
- Artificial pulse
- Unique spectral Doppler flow pattern
- Brief velocity > 2m/s normal
- Brief reversal prior to increase in velocity normal



RAMP studies

What is a Ramp study?

- TTE or TOE during LVAD speed adjustments
- Multiple parameters measured at each speed

Aim:

- Neutral/central IVS position
- Intermittent aortic valve opening with minimal AR

Appendix Table 4. Echocardiographic Parameters to Guide Device Pump Speed Optimization

Echocardiographic Views to Guide Parameter Acquisition	Parameters Acquired at Each Pump Speed Change	Baseline and Final Set Pump Speed Report Recommendations
PLAX, Apical 4Ch (2D)	LVIDd	Define LV dilation according to ASE guidelines.
Apical 4Ch RV-focused (2D)	RV diameter at the base and midlevel	Define RV dilation according to ASE guidelines.
Apical 4Ch (2D)	IVS position	Define appearance as midline, bowed to the LV (leftward) or to the RV (rightward) and note if bowing is seen during ventricular systole, diastole, or both.
Apical 4Ch (2D)	IAS position	Define appearance as midline, bowed to the LA (leftward) or to the RA (rightward).
PLAX, PSAX, 5Ch (2D, M-mode, CFD)	AV opening status AR assessment (e.g., jet width of the LVOT and vena contracta)	Define AV opening status and note as opens every beat, intermittent, or persistently closed. AR defined per ASE guidelines and note if presence is seen during diastole or during diastole and systole (continuous AR).
PLAX, Apical 4Ch (2D, CFD)	MR assessment (e.g., central jet % LA involvement and vena contracta)	MR defined per ASE guidelines.
PSAX, Apical 4 Ch (2D, CFD)	TR assessment (e.g., central jet % RA involvement and vena contracta)	TR defined per ASE guidelines.

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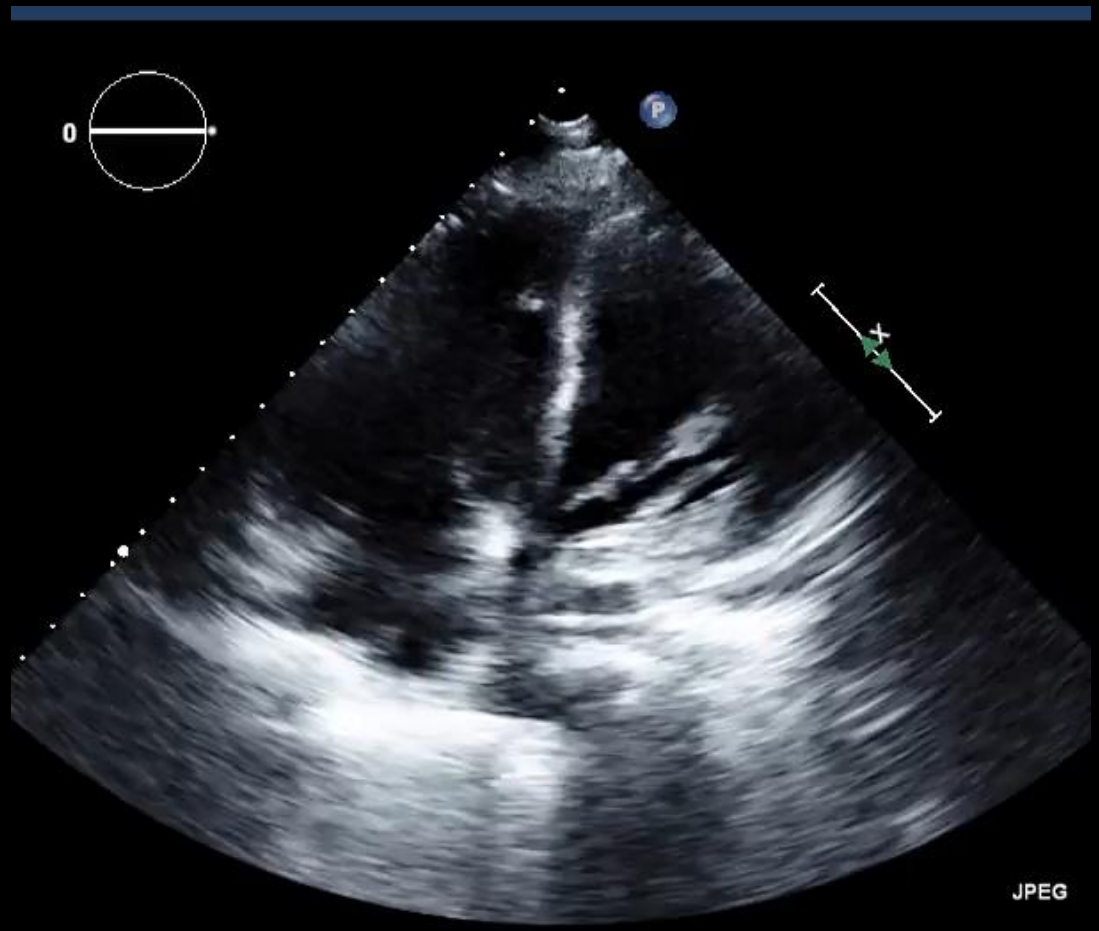
RAMP study



Complications

VAD Specific Issues

- Pump dysfunction
- Pump thrombosis
- Outflow cannula stenosis
- Driveline issues

Patient Related Issues

- Tamponade
- Right heart failure
- Aortic regurgitation
- Cardiac thrombus
- Aortic dissection
- Arrhythmias

Pump-Patient Interface

- Infective endocarditis
- Stroke
- Acquired VWD
- Pump thrombosis

Complications – Suction event

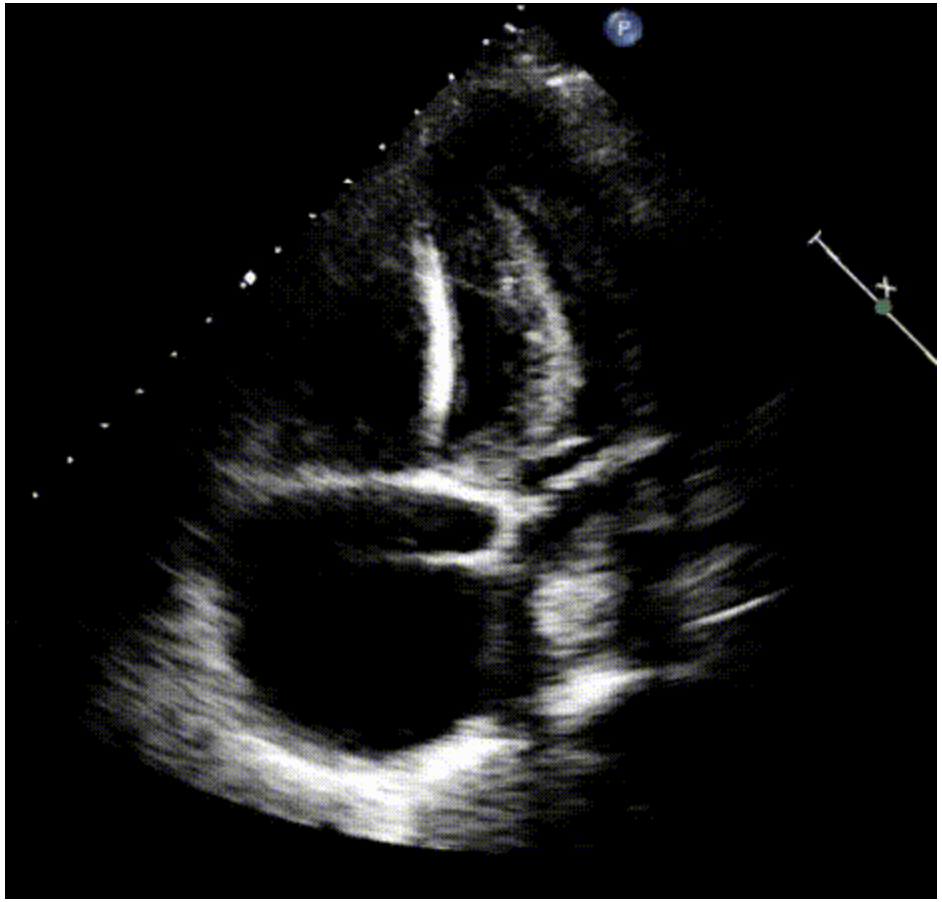
Contact of inflow cannular with endocardium (septum)

Underfilling due to:

- RV failure
- Hypovolaemia
- High pump speed

LV collapses

Leftward septal shift



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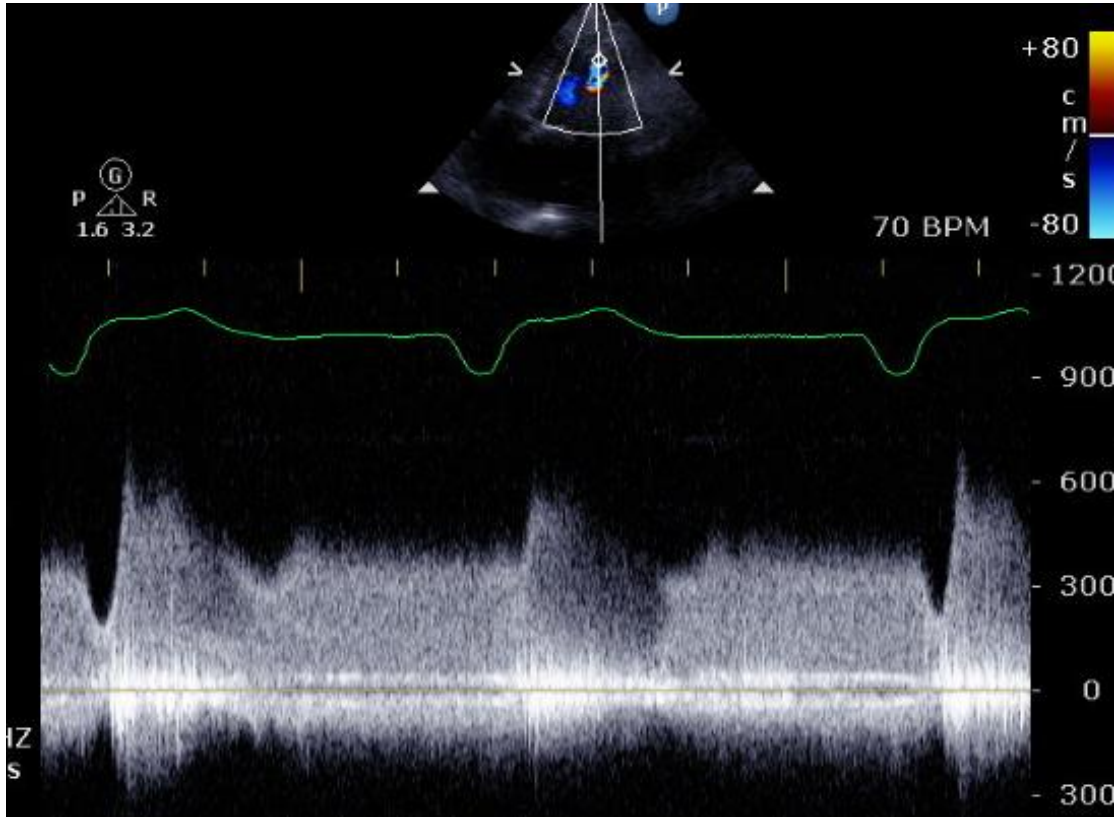
Complications – Inflow Obstruction

Thrombus

Vegetations

Suction events

- Increased Velocity
- Turbulent flow



Inflow cannular velocity increased at 6 m/s due to thrombosis.

Stainback, et al. "**Echocardiography in the Management of Patients with Left Ventricular Assist Devices: Recommendations from the American Society of Echocardiography**." *Journal of the American Society of Echocardiography* 28.8 (2015): 853-909. Web.

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Complications – Outflow Obstruction

Obstruction of outflow

- Kinking
- External compression
- Thrombosis

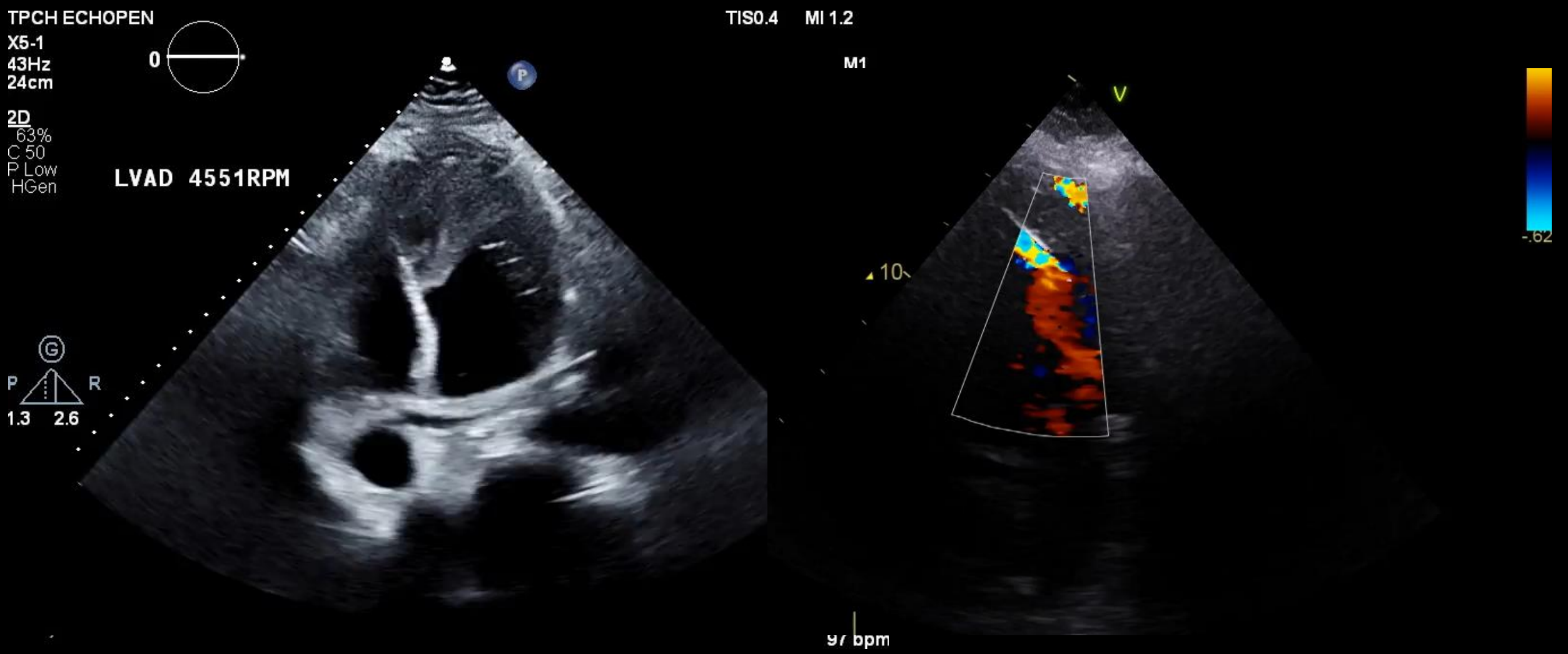
Increased Velocity

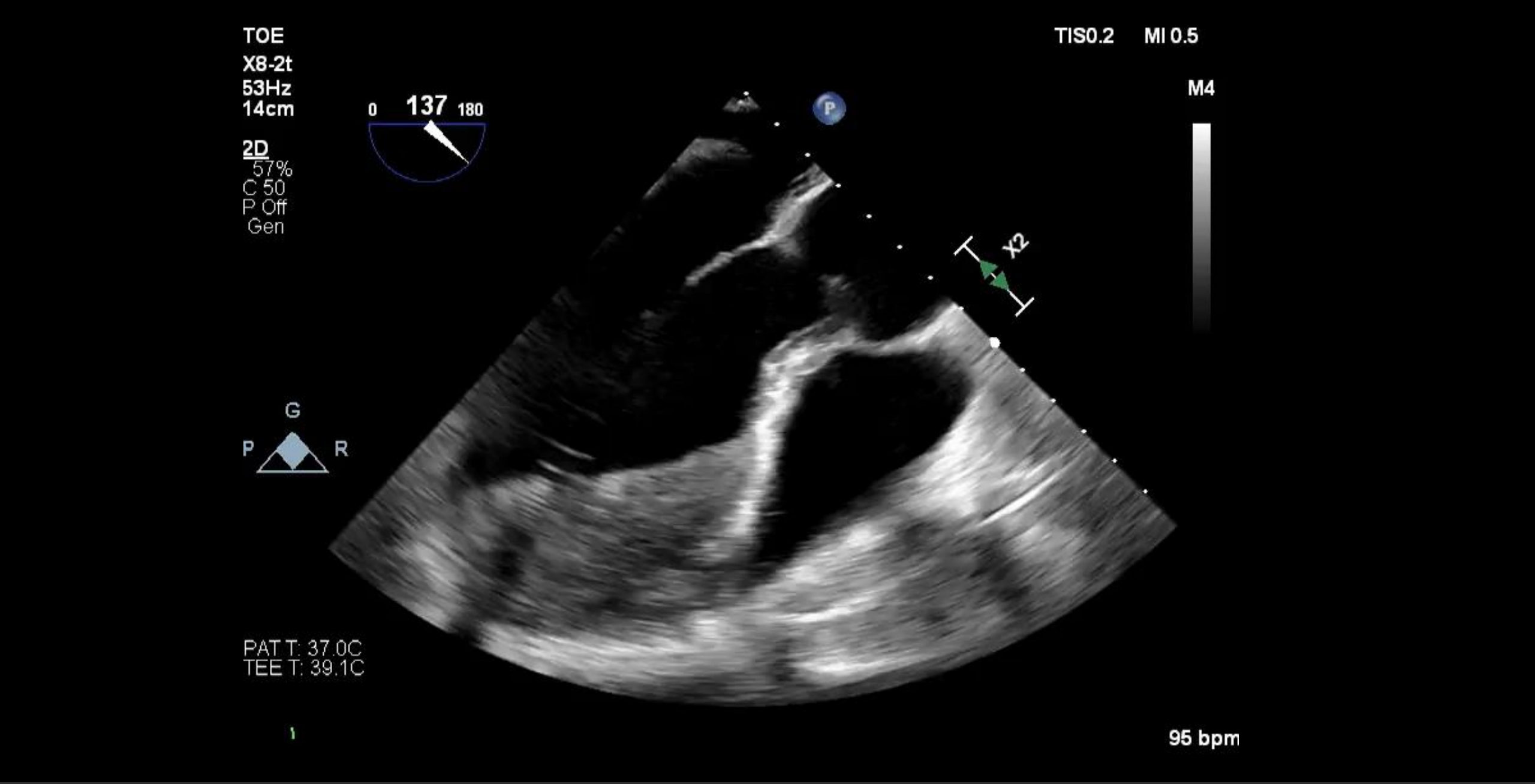
Turbulent flow

Other Complications

- RV dysfunction
- Tamponade
- Significant AR
- Endocarditis
- Thrombus – Intracardiac, aortic root

LV Thrombus


TPCH ECHOPEN
X5-1
43Hz
24cm
2D
63%
C 50
P Low
HGen
LVAD 4551RPM
TIS0.4 MI 1.2
M1
1.3 2.6
-.62
97 bpm


TOE
X8-2t
53Hz
14cm
2D
57%
C 50
P Off
Gen
0
137
180
TIS0.2
MI 0.5
M4
X2
G
P
R
PAT T: 37.0C
TEE T: 39.1C
95 bpm

Tamponade/Effusion

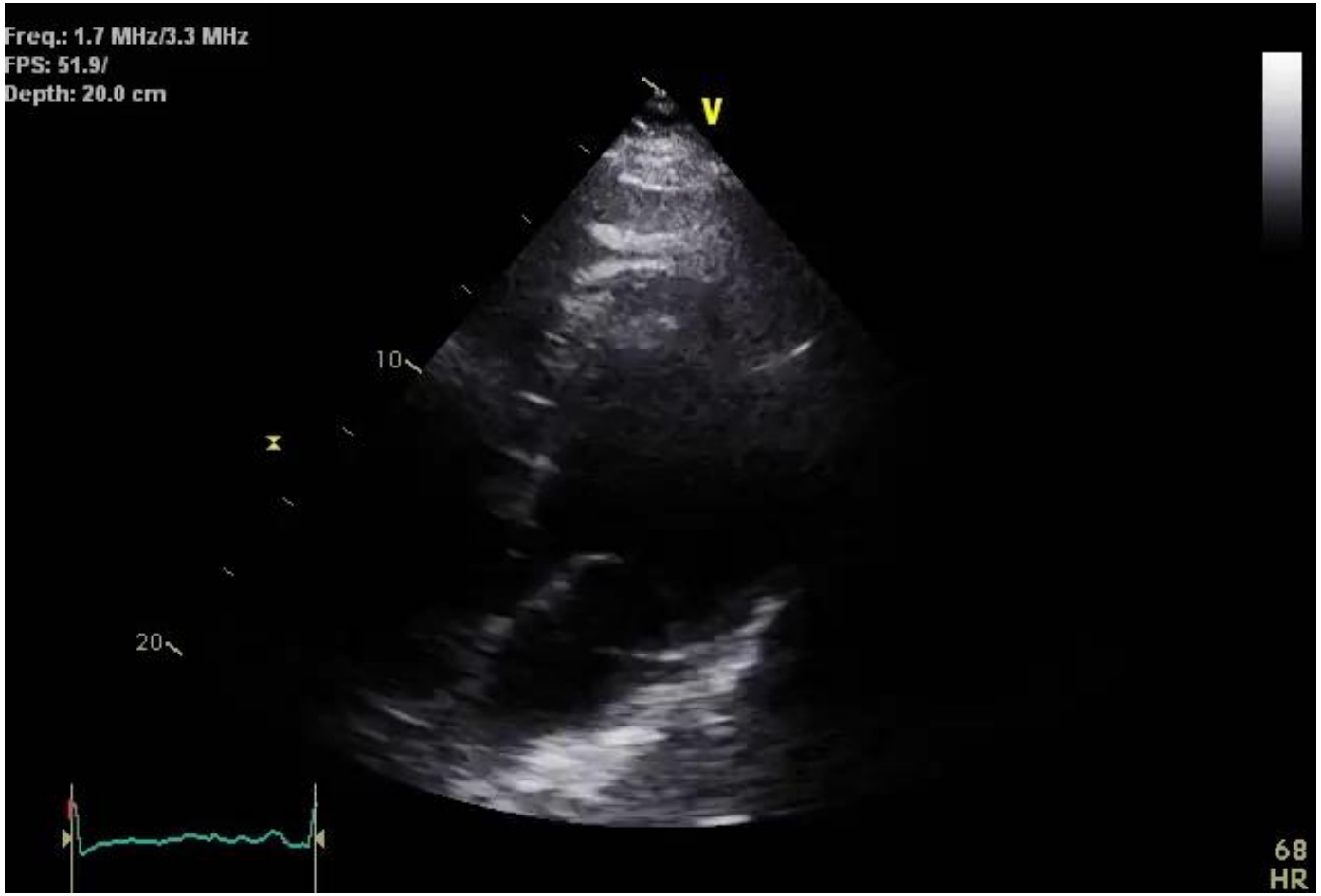
- Effusion often organised
- Haematoma

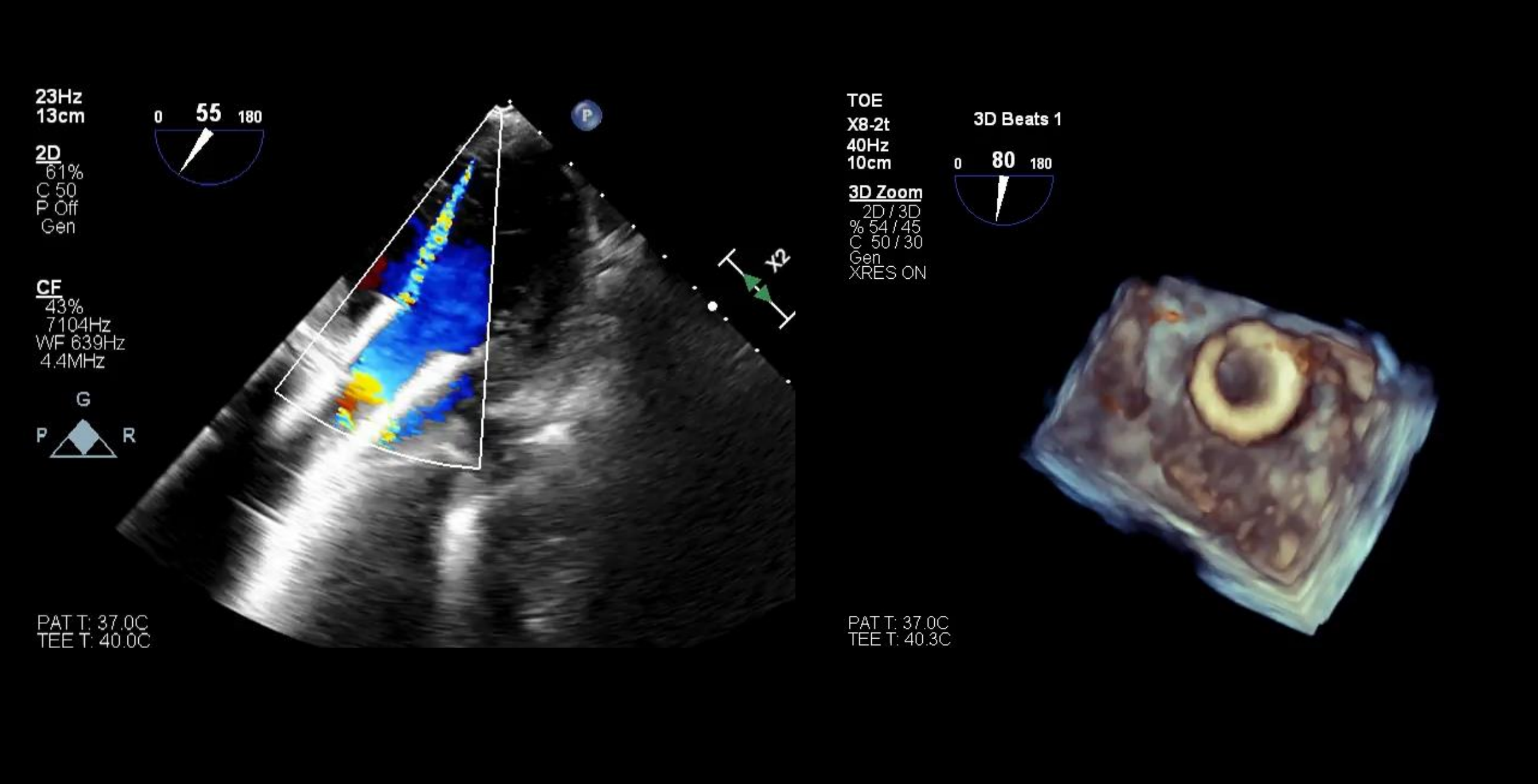
Features of Pump Dysfunction

- Dilated LV
- Rightward shift of IVS
- Regular AV opening
- Increased MR
- SEC or thrombus in LA/LV
- Severe cases: Retrograde flow if aortic diastolic pressure > LV diastolic pressure

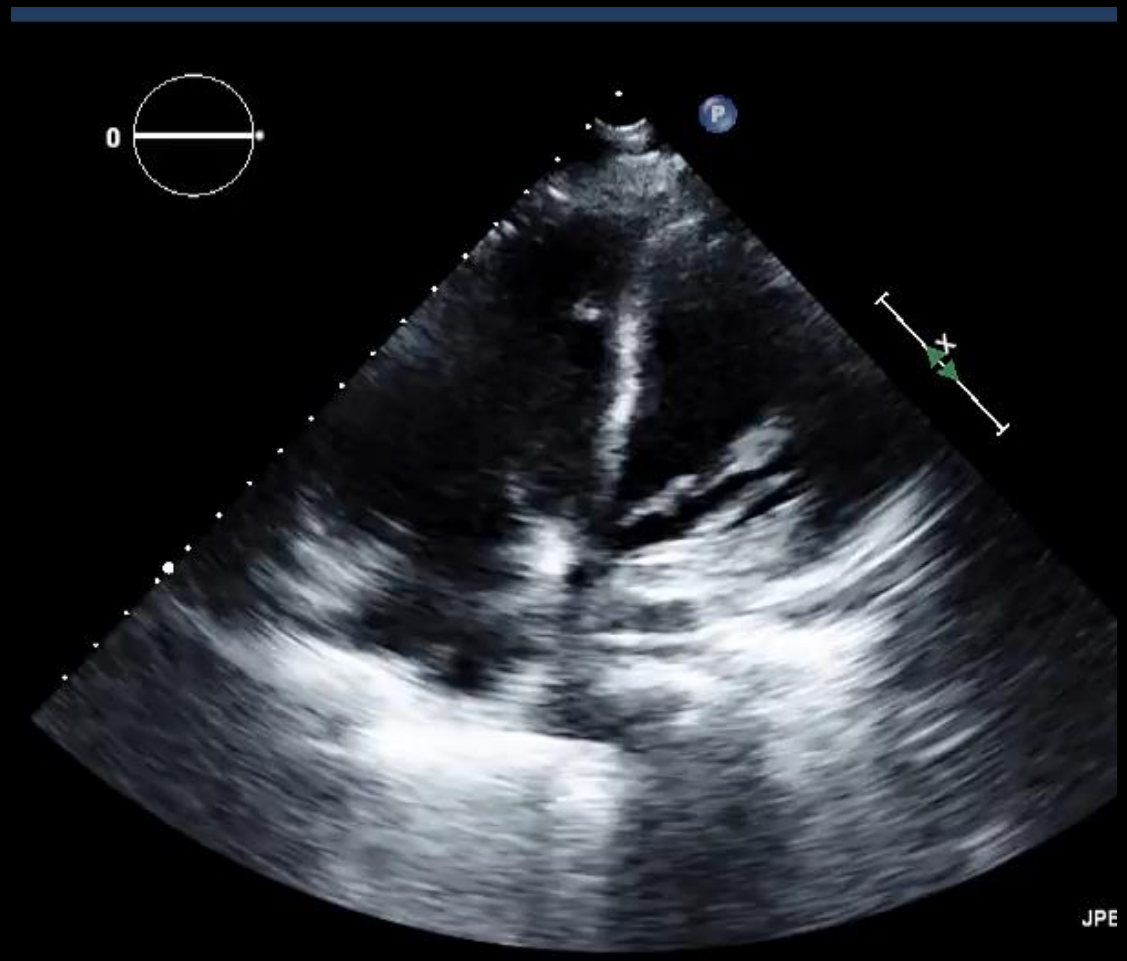
Imaging LVAD can be HARD!

- Try alternate patient positioning
- Annotate position on screen (so can be repeated)
- Use off axis imaging



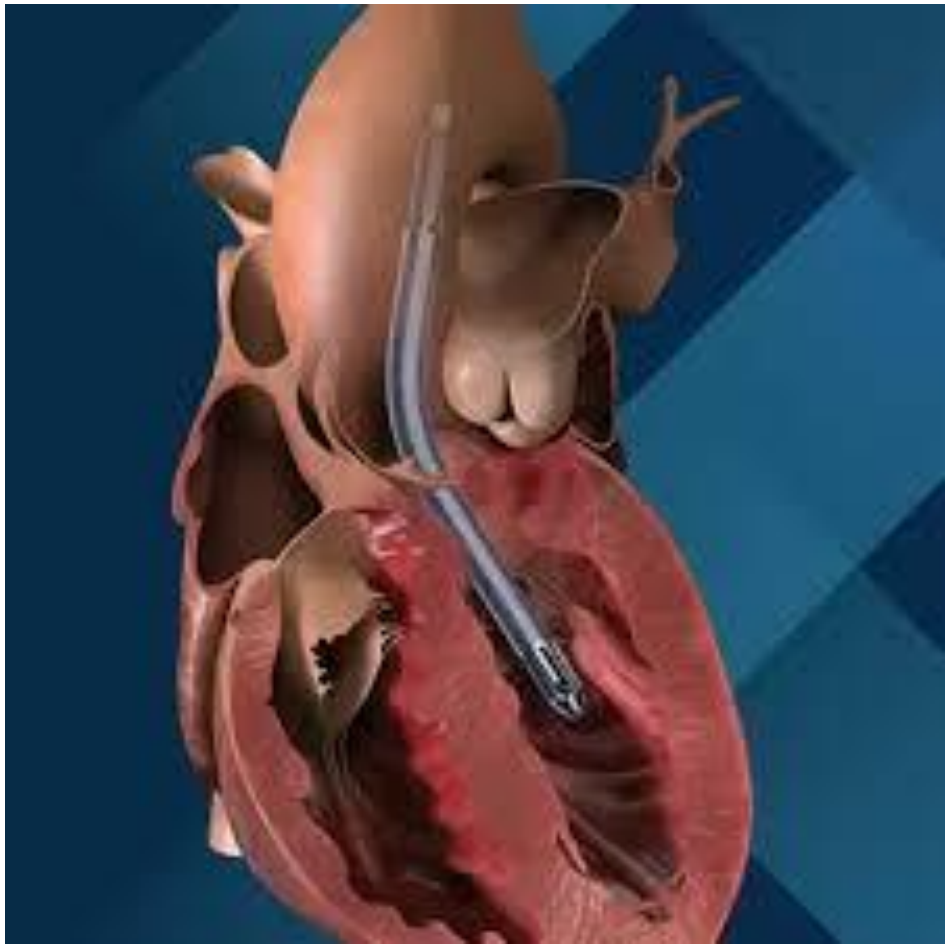

23Hz
13cm
0 55 180
2D
61%
C 50
P Off
Gen
CF
43%
7104Hz
WF 639Hz
4.4MHz
G
P R
X2
PAT T: 37.0C
TEE T: 40.0C
TOE
X8-2t
40Hz
10cm
3D Beats 1
0 80 180
3D Zoom
2D / 3D
% 54 / 45
C 50 / 30
Gen
XRES ON
PAT T: 37.0C
TEE T: 40.3C

Same Patient Post Transplant

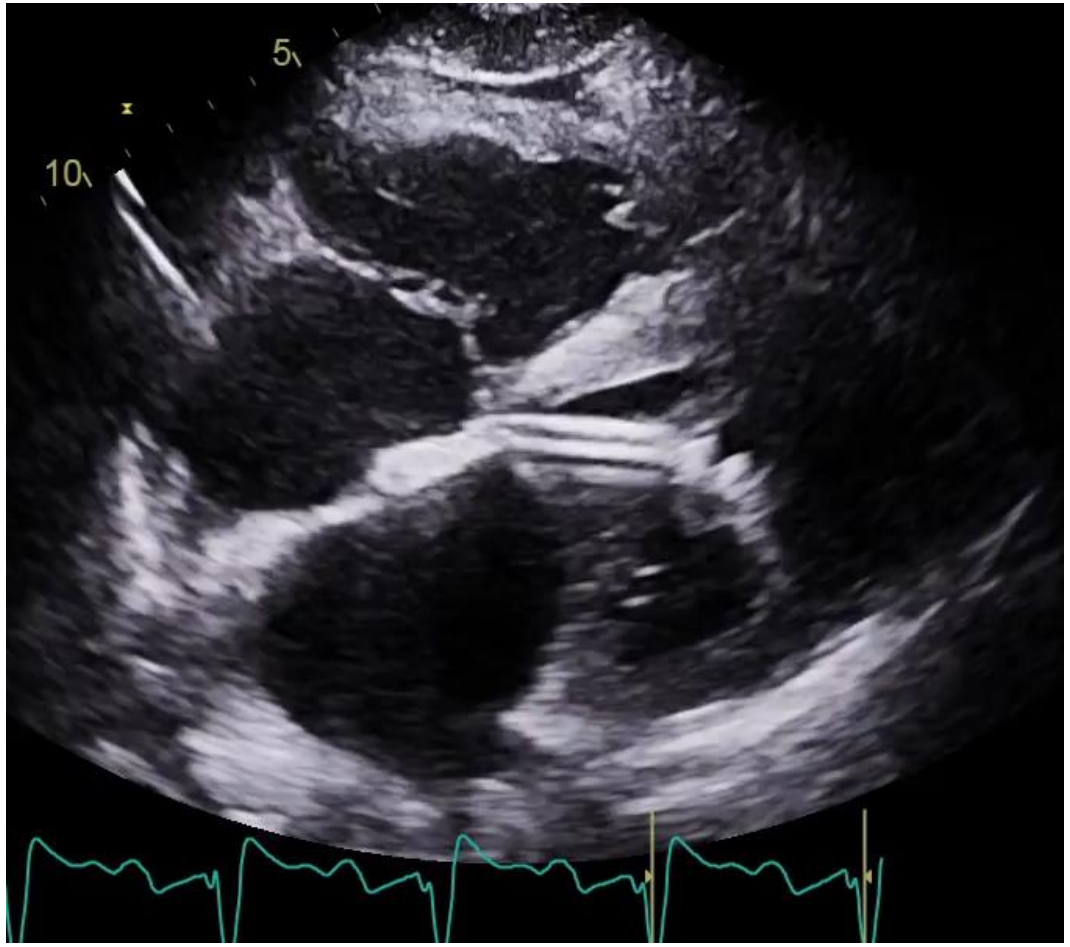


Impella

- Microaxial Impella pump in a catheter
- Inflow LV – outflow ascending aorta
- Temporary mechanical LV (or RV) support



Role of TTE



Cannula placement

- Free of obstruction (MV apparatus, myocardium)
- Right heart function
- Pericardial effusion

Combinations of MCS

ECMO + IABP

ECMO + Impella

Impella + IABP

. . .

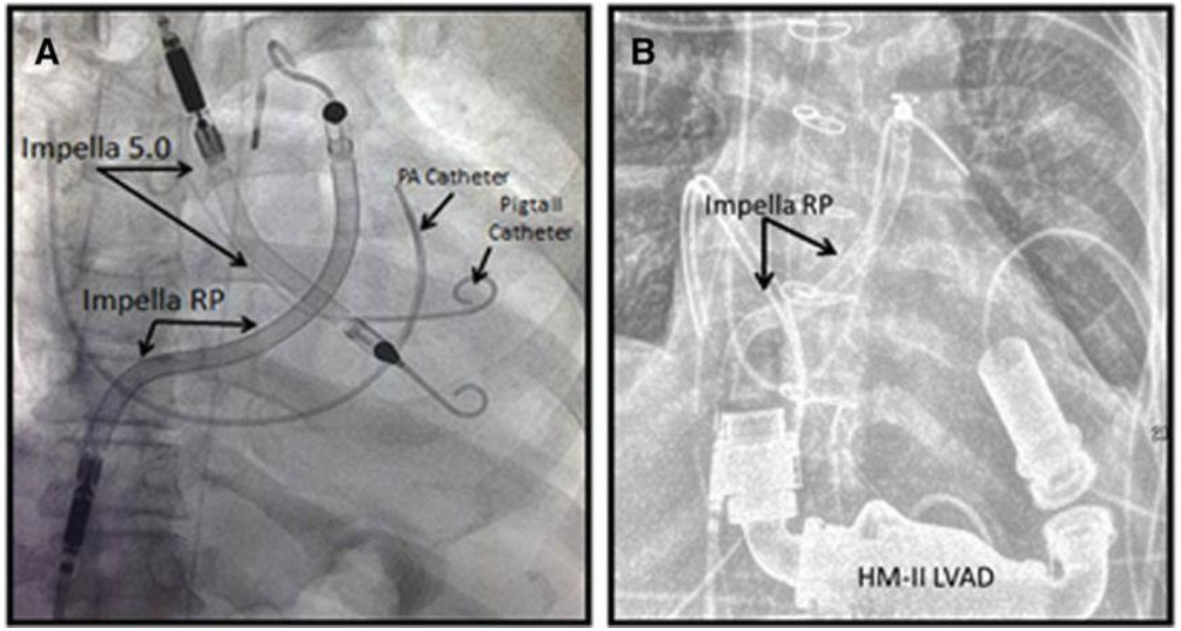


Image: Kapur et al. **First Successful Use of 2 Axial Flow Catheters for Percutaneous Biventricular Circulatory Support as a Bridge to a Durable Left Ventricular Assist Device.**
https://doi.org/10.1161/CIRCHEARTFAILURE.115.002374

TTE in MCS

- Do not be intimidated
- Know what extra things to looks for
- What devices are in place and where?
- Use all available windows
- Review previous scans BEFORE starting

End