Echocardiographic evaluation in HF

Role of Echocardiography in MCS

Role of Echocardiography In Heart transplant

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Spectrum Role of Echocardiography in HF patients

- Diagnostic workup of new onset HF
- Management of Patients with DHF
- Management of patients with Pulmonary Edema
- Management of patients with Isolated RV failure
- Management of patients with Cardiogenic shock
- Management & guiding of Diuretic Therapy in patients with AHF
- Management of patients with Low flow low gradient AS &HF
- Management of patients with severe Secondary MR &HF
- Management of patients receiving Cardiotoxic treatment & HF
- Management of patients with HF before & during pregnancy

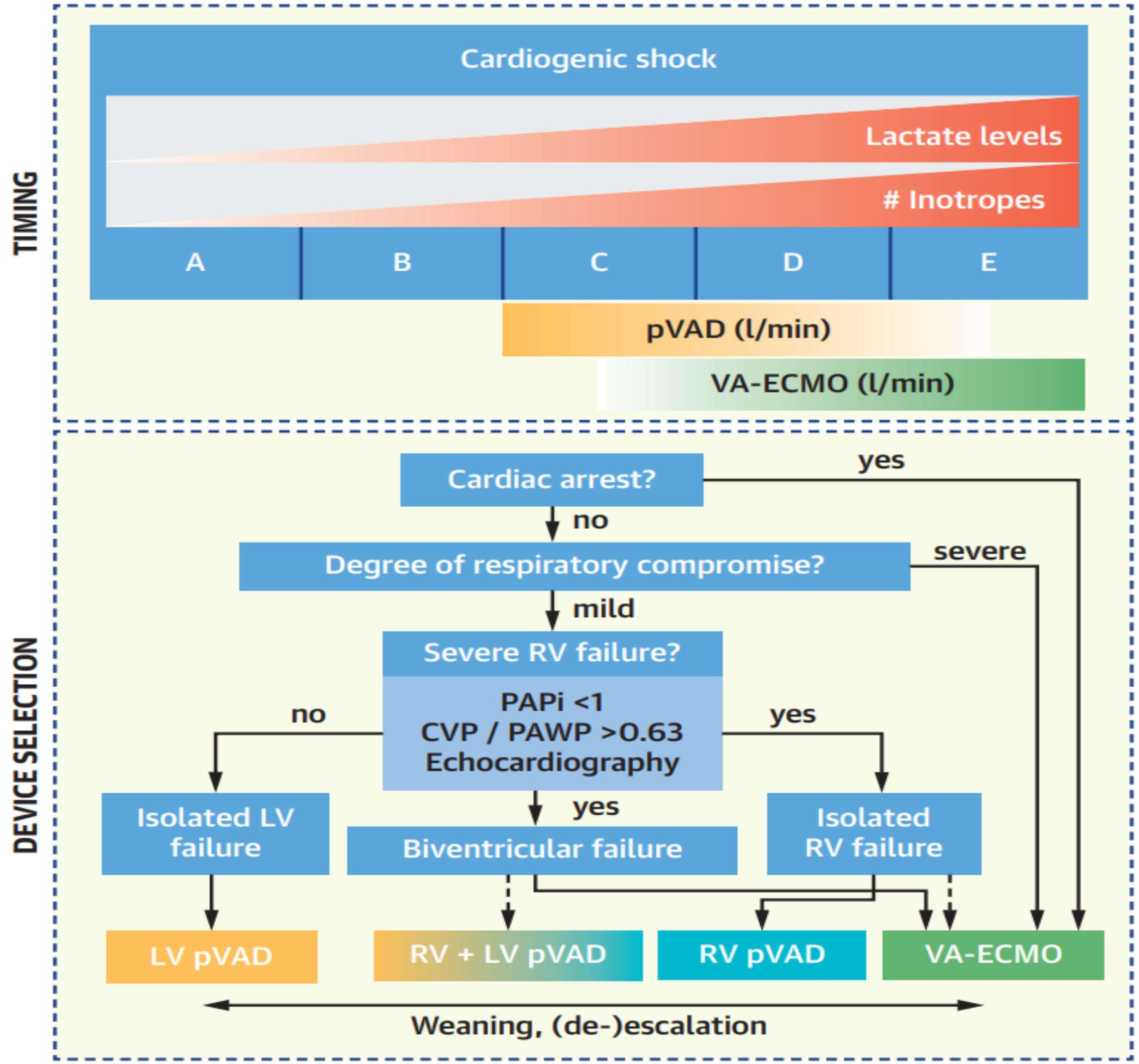
(INTERMACS Profile)

TABLE 59.5 INTERMACS Patient Profiles

PROFILE	DEFINITION	DESCRIPTION
1	"Crashing and burning"	Life-threatening hypotension and rapidly escalating inotropic pressor support, with critical organ hypoperfusion confirmed by worsening acidosis and lactate levels.
2	"Inotrope dependent and worsening"	Shows signs of continuing deterioration in nutrition, renal function, fluid retention, or other major status indicator *or* refractory volume overload, ± evidence of impaired perfusion, with inotropic infusion intolerance due to tachyarrhythmias, clinical ischemia, or other.
3	"Stable on inotropes"	Clinically stable on mild-moderate doses of IV inotropes (or has a temporary MCSD) after repeated failures to wean without symptomatic hypotension, worsening symptoms, or progressive organ dysfunction. May be either at home or in the hospital.
4	"Frequent flyer/resting symptoms"	At home on oral therapy but frequently has symptoms of congestion at rest or with ADLs. May have orthopnea, SOB during ADLs, GI symptoms, disabling ascites, or severe lower extremity edema.
5	"Exercise intolerant"	Comfortable at rest but unable to engage in any activity, living predominantly within the house or housebound. No congestive symptoms, but may have chronically elevated volume status, frequently with renal dysfunction, and may be characterized as exercise intolerant.
6	"Walking wounded"	Comfortable at rest without evidence of fluid overload, but able to do some mild activity. ADLs are comfortable and minor activities outside the home can be performed, but fatigue results within a few minutes of any meaningful physical exertion. Occasional episodes of worsening symptoms; likely to have had a hospitalization for heart failure within the past year.
7	"Advanced NYHA Class III"	Clinically stable with a reasonable level of comfortable activity, despite history of previous decompensation that is not recent. Usually able to walk more than a block. Any decompensation requiring IV diuretics or hospitalization within the previous month should make this person a Patient Profile 6 or lower.

ADLs, Activities of daily living; *GI,* gastrointestinal; *IV,* intravenous; *MCSD,* mechanical circulatory support device; *NYHA,* New York Heart Association; *SOB,* shortness of breath.
From Stevenson LW, Pagani FD, Young JB, et al. INTERMACS profiles of advanced heart failure: the current picture. *J Heart Lung Transplant*. 2009;28:535–541.

FIGURE 2 Algorithm for Device Selection in CS



The **upper panel** illustrates a possible timeline for initiation of mechanical circulatory support. Lactate as well as inotropic support increase when the patient progresses through the shock stages according to the Society for Cardiovascular Angiography and Interventions. When shock severity increases, higher device flows are expected to be needed. The **lower panel** illustrates device selection based on individual hemodynamics and respiratory compromise. CS = cardiogenic shock; CVP = central venous pressure; PAPi = pulmonary artery pulsatility index; PAWP = pulmonary artery wedge pressure; RV = right ventricular; other abbreviations as in **Figure 1**.

IABP counter Pulsation

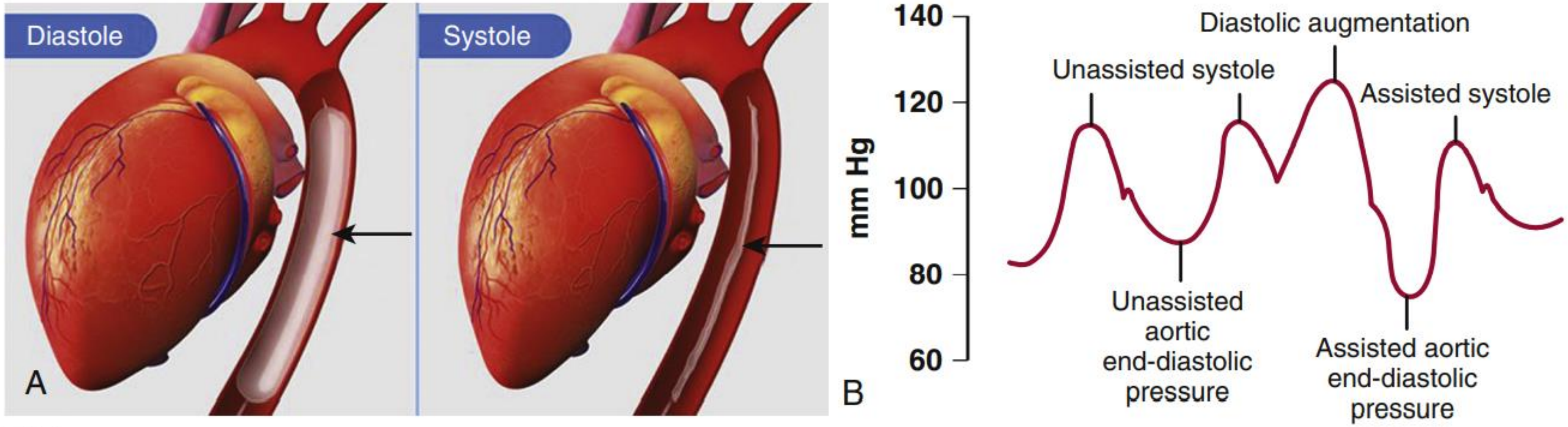
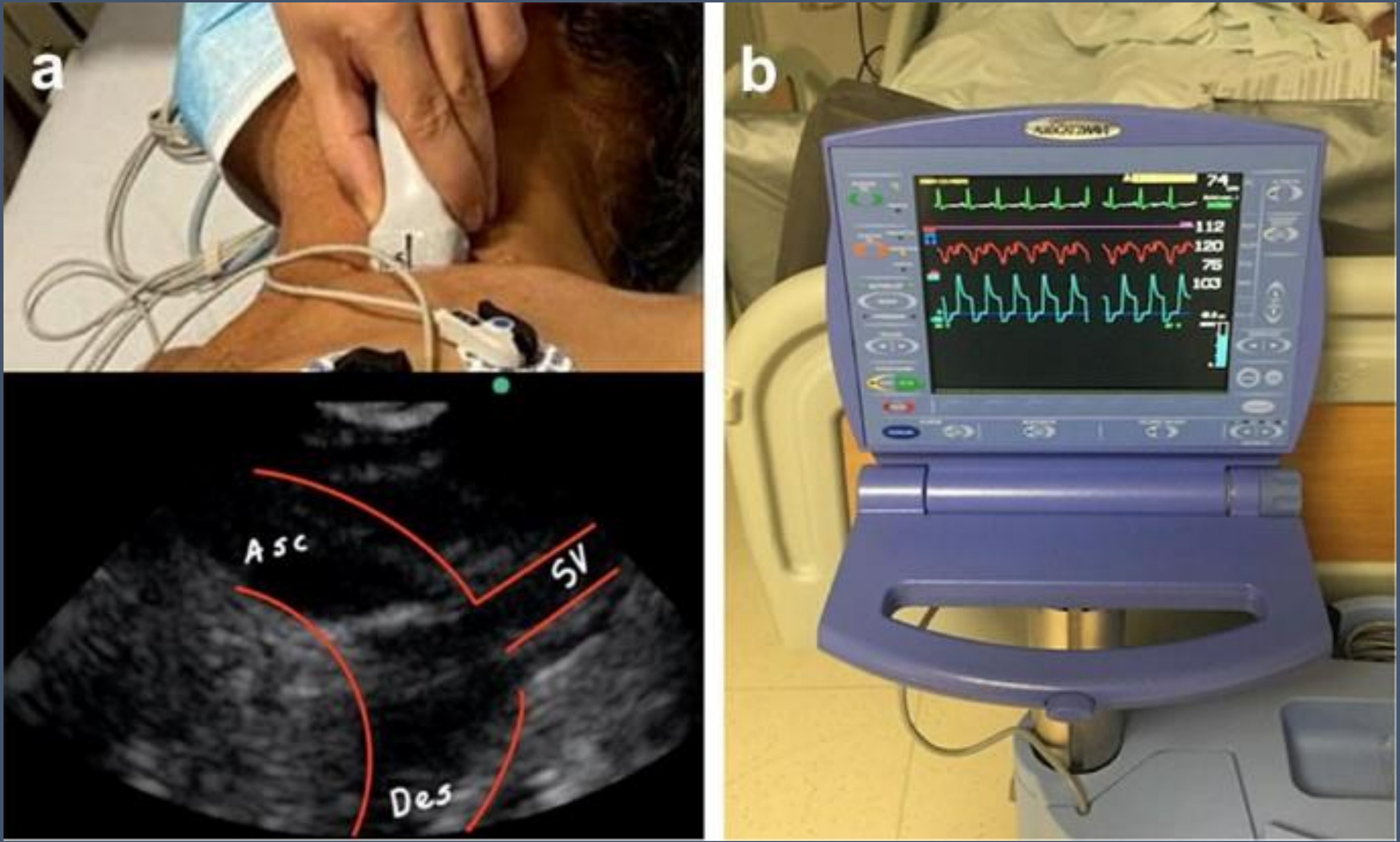


FIGURE 59.1 **A,** Intra-aortic balloon pump (IABP) positioned in descending aorta and inflated during diastole (increasing diastolic blood pressure and coronary perfusion) and deflated during systole (reducing ventricular afterload). **B,** Aortic pressure tracing during IABP support. Balloon counterpulsation is occurring after every other heartbeat (1:2 counterpulsation). With correct timing, balloon inflation begins immediately after aortic valve closure, signaled by the dicrotic notch of the arterial waveform. Compared with unassisted ejection, the pump augments diastolic blood flow by increasing peak aortic pressure during diastole. Balloon deflation before systole decreases ventricular afterload, with lower aortic end-diastolic pressure and lower peak systolic pressure.

Role Of Echocardiography :IABP counter pulsation

- Bed side / Intraoperative Room
- Positioning
- Aortic Size /Atheroma /Dissection
- Cardiac function before and after
- Evaluation of CA ostium/Valvular structure
- Evaluation of Complication
- Response to Therapy/Escalating ,Deescalating Therapy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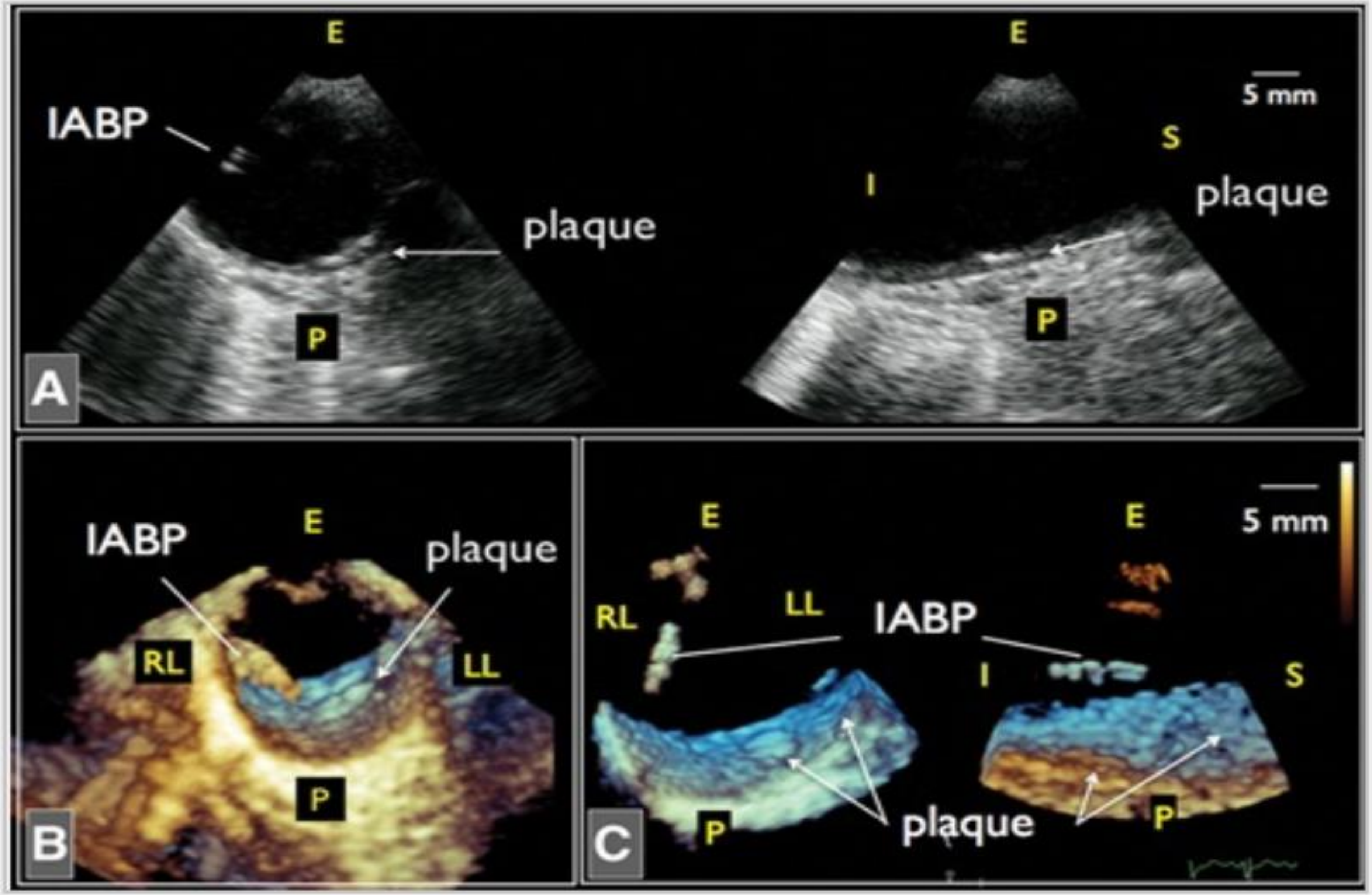
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First successful ECMO patient in1971

Figure 3.4. The first successful extracorporeal life support patient, treated by J. Donald Hill using the Bramson oxygenator (foreground), Santa Barbara, 1971.

Impella(Temporary MCS)

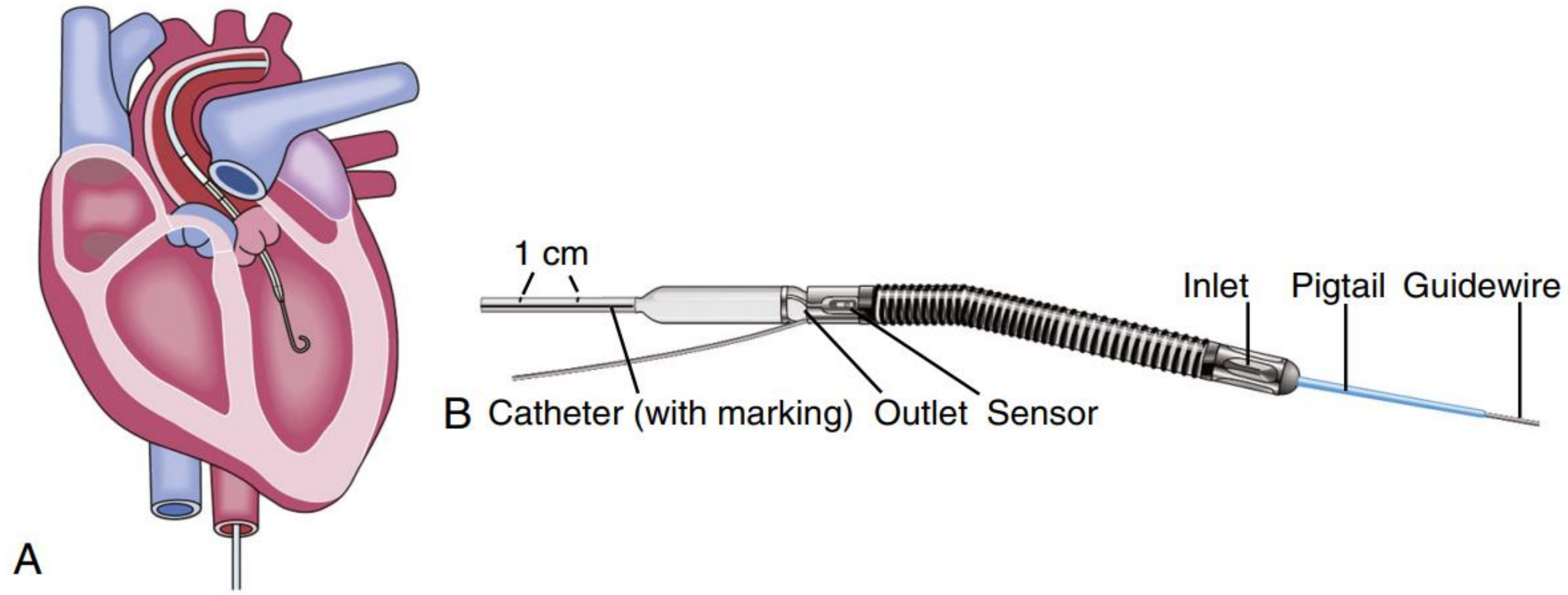


FIGURE 59.3 Temporary mechanical circulatory support: Impella (Abiomed, Inc., Danvers, MA). **A,** The Impella is a continuous-flow, microaxial pump designed to propel blood from the left ventricle into the ascending aorta, in series with the left ventricle. The tip is positioned within the left ventricle, and blood is pumped from the left ventricle into the ascending aorta. **B,** The tip of the catheter is a flexible pigtail loop that stabilizes the device within the left ventricle. The catheter connects to a cannula that contains the pump inlet and outlet areas, motor housing, and pump-pressure monitor. The proximal end of the catheter is connected to the external pump. (From Thunberg CA, Gaitan BD, Arabia FA, et al. Ventricular assist devices today and tomorrow. *J Cardiothorac Vasc Anesth*. 2010;24:656.)

Echocardiography in Impella Ventricular Assist Devices (short-term ventricular assist devices)

- **TTE or TEE echocardiogram : simultaneous visualization of the inlet and outlet areas of the left heart Impella catheters**
- **Normal Position on Echocardiogram**
- **Inlet area should be in the left ventricular outflow tract approximately 3.5 cm below the aortic valve**
- **Outlet area should be distal to the aortic valve in the ascending aorta**.

Correct Position of Left Impella

Fig. 12.4 Correct Impella catheter position on transthoracic echocardiogram parasternal long-axis view

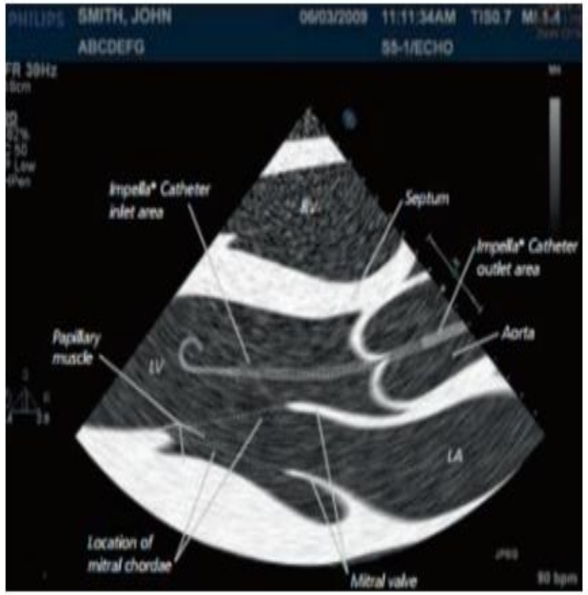


Fig. 12.5 Correct Impella catheter position on transesophageal echocardiogram long-axis view

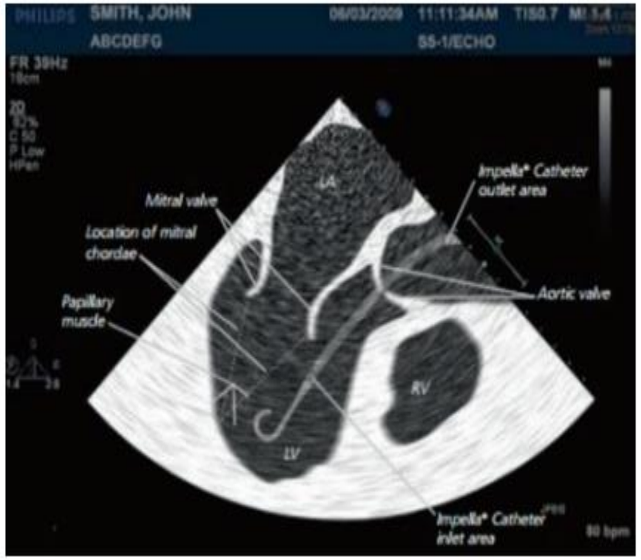
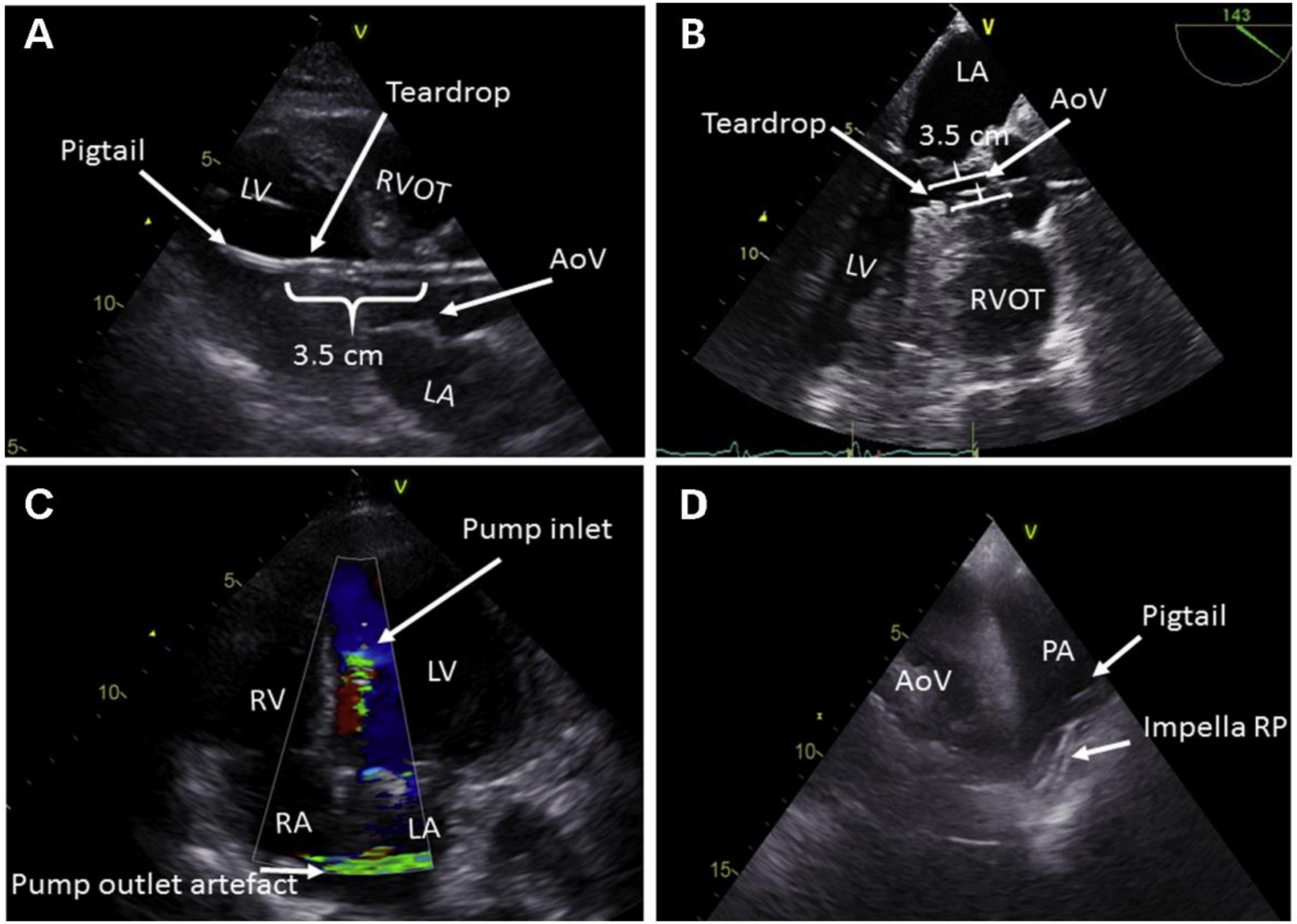


FIGURE 4 **Optimal Device Position on Echocardiography**



(A) Transthoracic parasternal long-axis view with the "teardrop" at 3.5 cm below the aortic valve. **(B)** Transesophageal echocardiography at 143° confirming correct position. **(C)** Modified apical 4-chamber view with color Doppler signaling to identify the pump inlet (flow convergence) and outlet (mosaic artifact). **(D)** Transesophageal echocardiography view of a right percutaneous (RP) device in the pulmonary artery (PA), with pigtail in the left branch. AoV = aortic valve; LA = left atrium; LV = left ventricle; RA = right atrium; RVOT = right ventricular outflow tract.

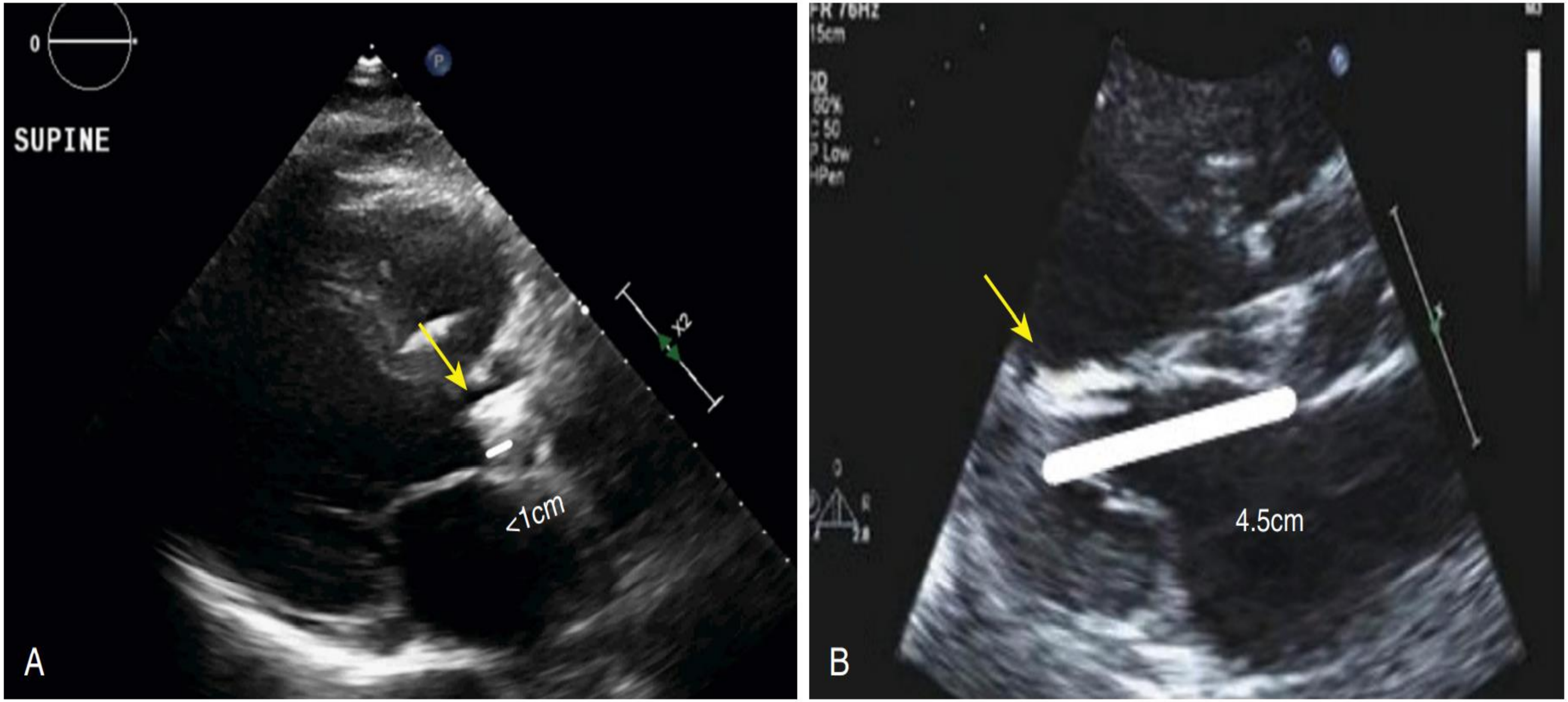
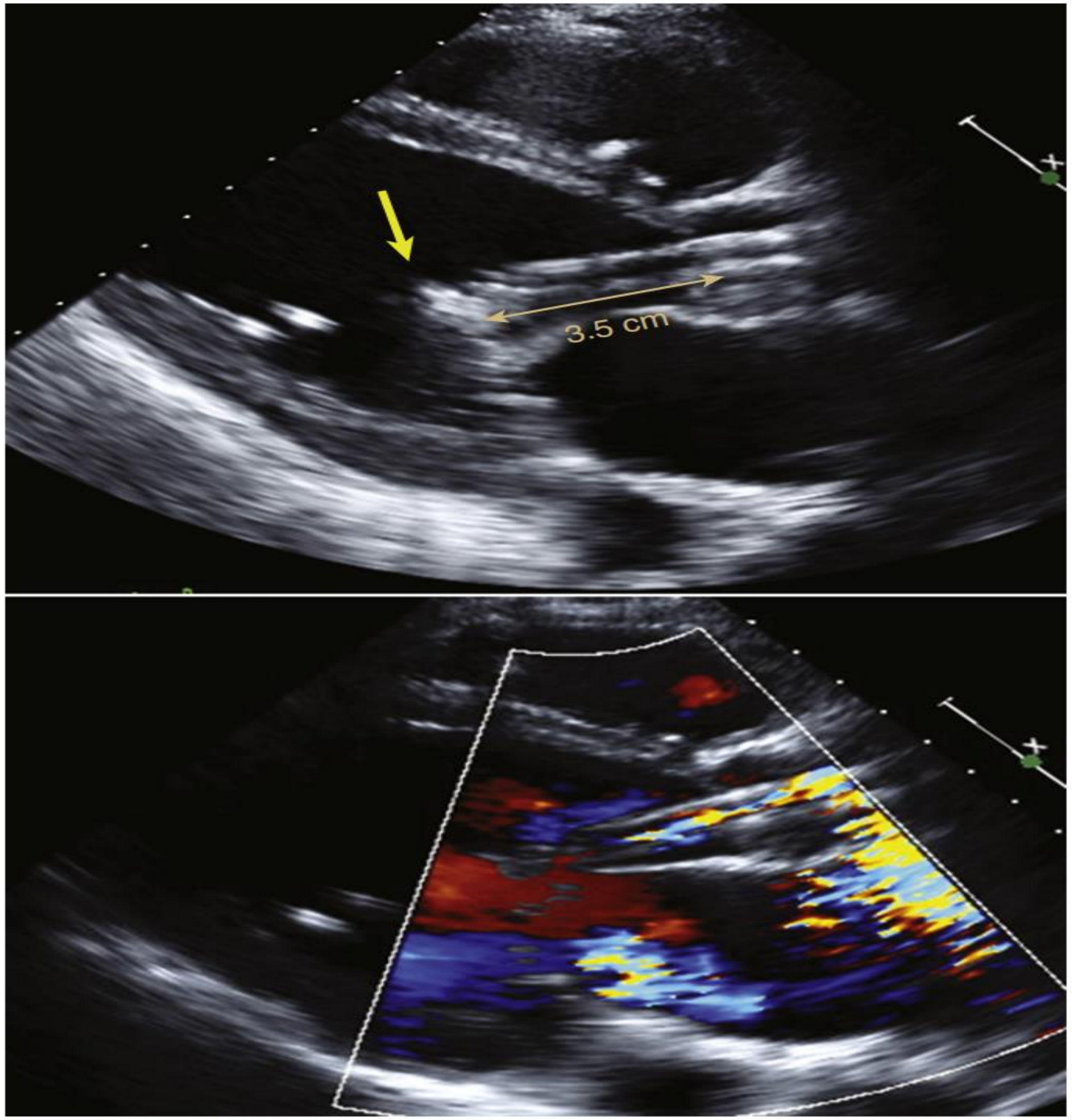


Fig. 16.8 Impella Recover device distance from the aortic annulus. (A) In a parasternal long-axis view, the inflow port of the device (*arrow*, identified as the terminus of the parallel lines of the catheter) is <1 cm below the aortic valve annulus and at significant risk for migrating above the annulus, which would cause the blood to be ineffectually circulated by the device in the aorta. After appropriate initial placement, the device migrated, likely during patient positioning (see Video 16.8A). (B) In contrast, in the parasternal long-axis view, the cannula is placed too far into the LV (4.5 cm) and is at risk for further migration such that both the inflow and outflow ports would be located within the LV (see Video 16.8B).



EFIGURE 16.23 Impella PVAD, seen on parasternal long-axis window. **Top panel**, The fenestrated inflow portion (*arrow*) of the Impella cannula appears as a more bulbous "teardrop" on echocardiogram, above the more distal thinner and less visible pigtail portion, and should be positioned ~3.5 cm from the aortic annulus. **Bottom panel**, Appropriate positioning is also confirmed by seeing color Doppler flow appropriately within the cannula and above the aortic valve; note there is also mitral regurgitation.

Echocardiography in the Management of Patients with Left Ventricular Assist Devices: Recommendations from the American Society of Echocardiography

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(J Am Soc Echocardiogr 2015;28:853-909.)

Keywords: Echocardiography, mechanical circulatory support, left ventricular assist devices, comprehensive examination

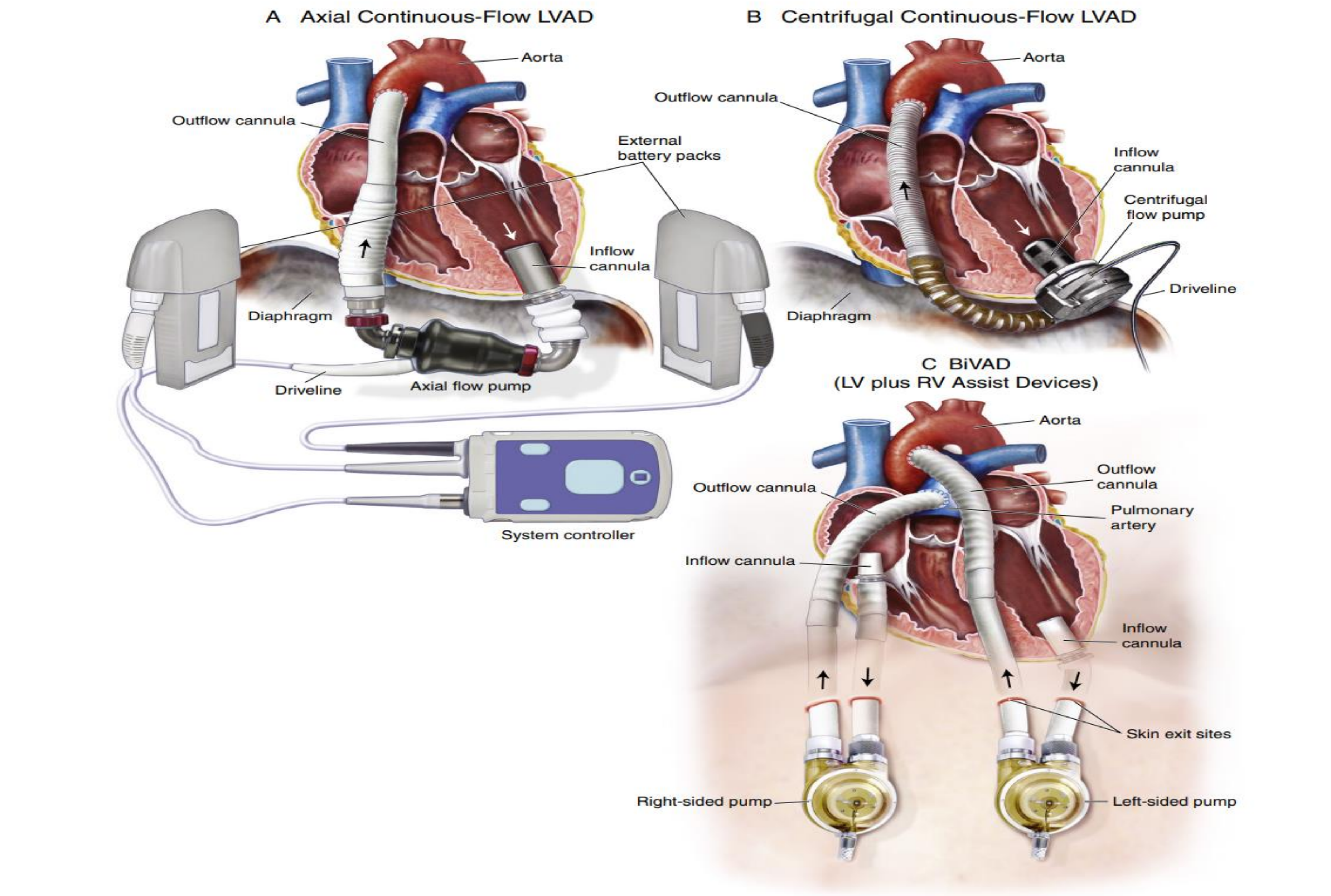


Fig. 16.1 Examples of ventricular assist devices. (A) Axial continuous-flow LV assist device *(LVAD)* (HeartMate II, Abbott, Abbott Park, IL). (B) Centrifugal continuous-flow LVAD (HVAD, Medtronic, Minneapolis, MN). (C) Biventricular assist device *(BiVAD)*.

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

Echocardiography to evaluate appropriate position and function of MCS device(LVAD)

-Routine surveillance

-In response to concerning signs, symptoms

-Device alarms

-optimize LVAD settings as part of a ramp study

Comparisons of serial echocardiograms should also be made in the context of the LVAD speed and blood pressure

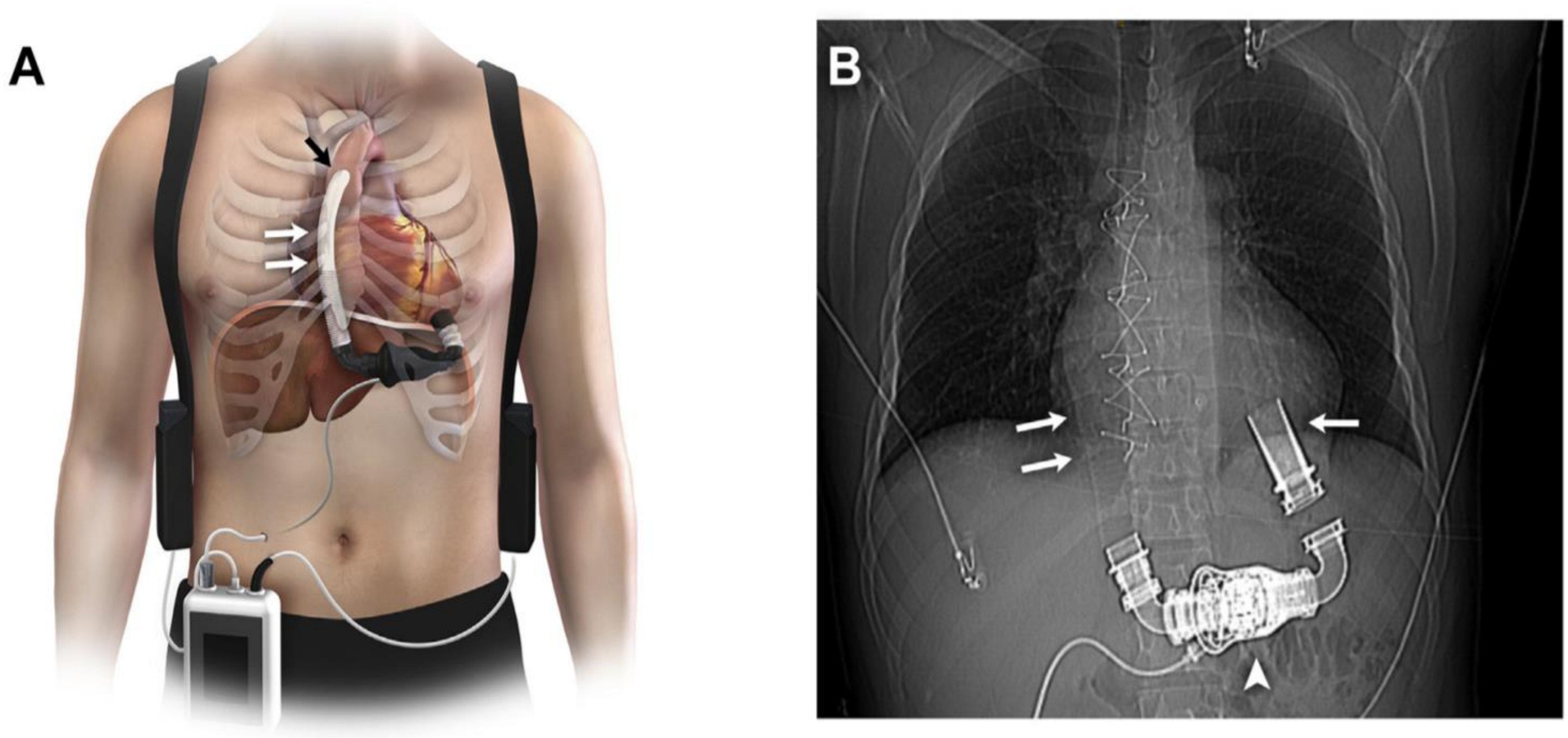


Figure 1 **(A)** Drawing of the HM-II LVAD, showing the subdiaphragmatic pump location, right parasternal outflow-graft position (*double white arrows*), and outflow graft-to-ascending aorta anastomosis (*black arrow*). **(B)** X-ray CT scout image showing the anatomic relationship between the left ventricle and the device inflow cannula (*single arrow*), impeller housing (*arrowhead*), and outflow graft (*double arrows*), controller (*white box*), battery packs (*black boxes*).

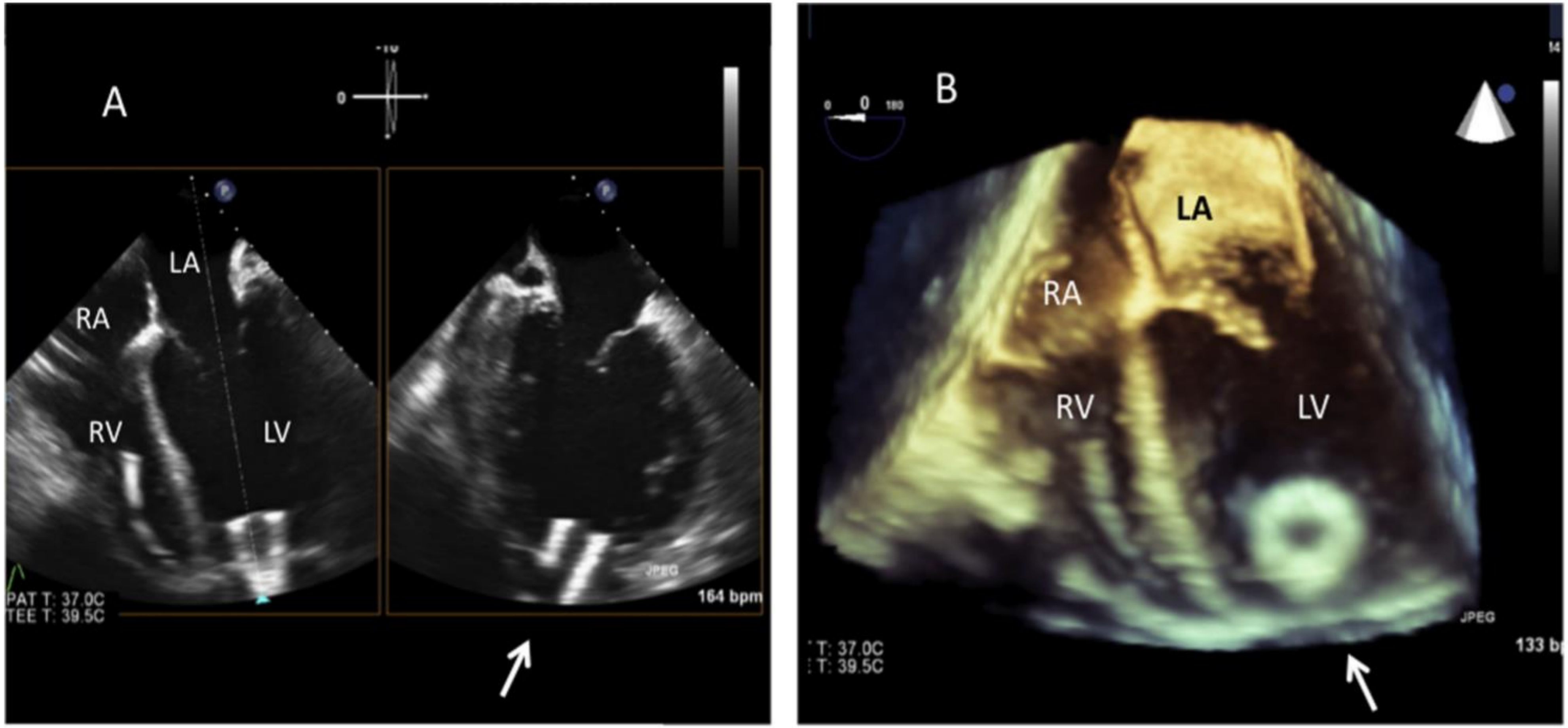


Figure 4 After LVAD implantation, TEE reveals a typical unobstructed inlet-cannula position (*arrow*) by means of simultaneous orthogonal-plane 2D **(A)** and real-time 3D imaging **(B)**. See also Video 4. The relative RV to LV size appears normal. The right ventricle has a pacing lead.

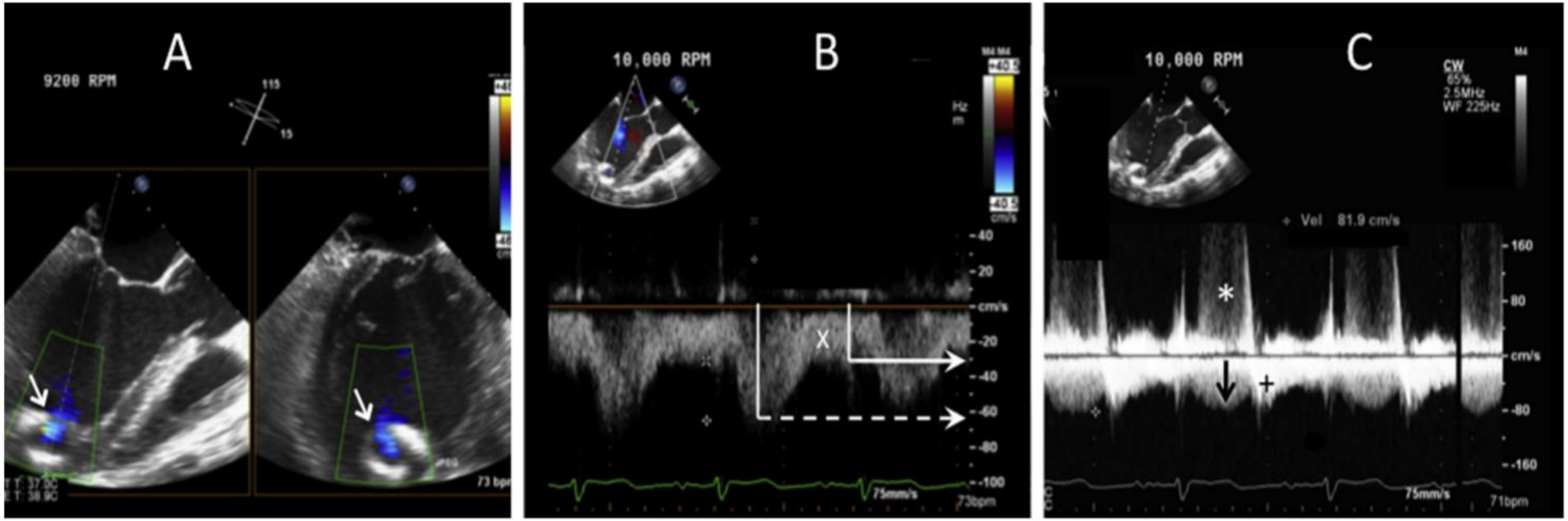
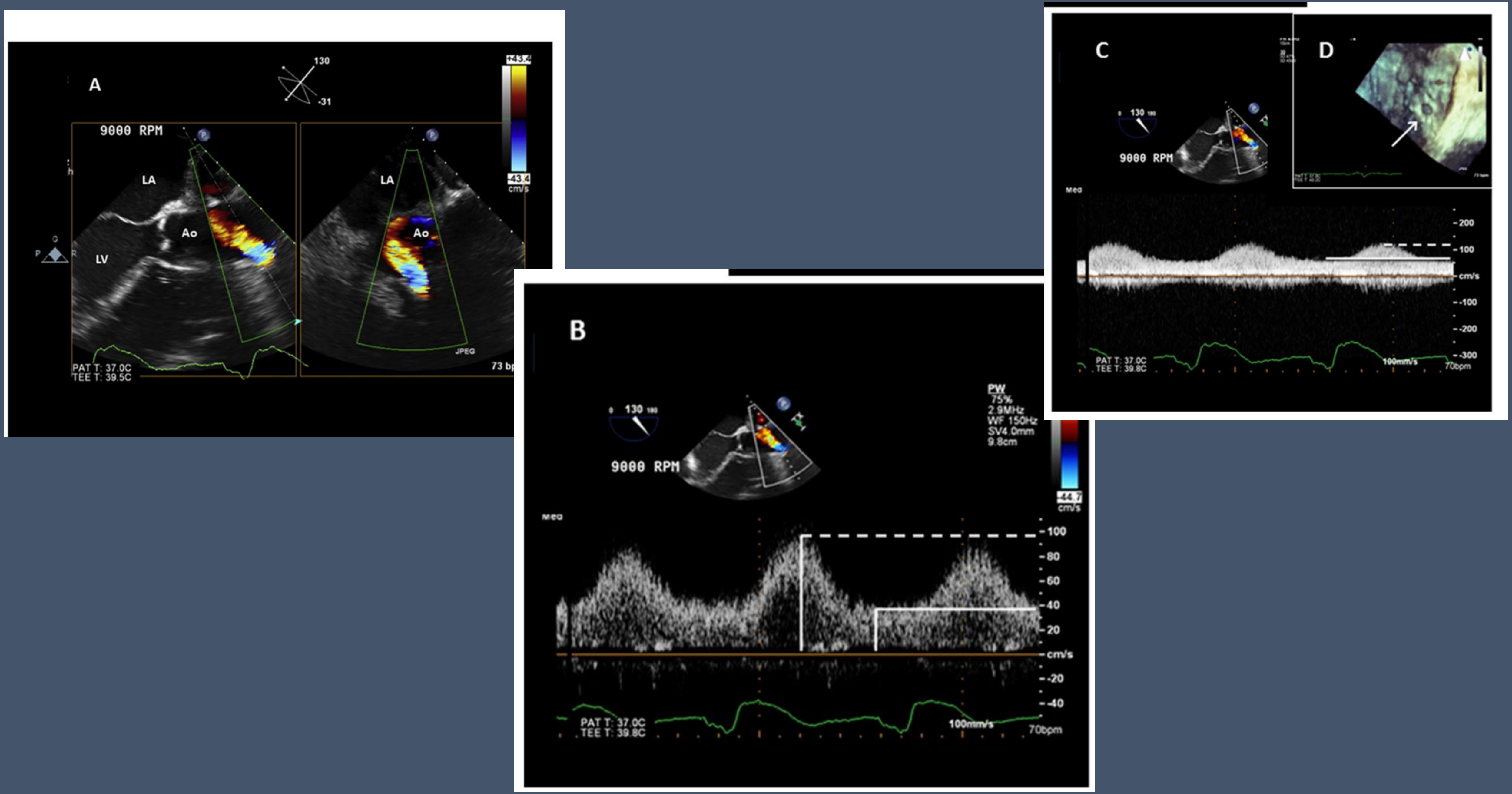


Figure 5 **(A)** After LVAD implantation, TEE shows that the inflow cannula is somewhat directed towards the ventricular septum (*arrow*). This can be acceptable but may predispose to inflow-cannula obstruction after sternal closure or later reduction in LV size. However, cannula position and flow velocities are shown to be acceptable (*normal*) in this case. Simultaneous orthogonal plane imaging reveals unobstructed, laminar inflow-cannula flow on 2D and color-flow Doppler (*blue*) examination. See also Video 5. **(B)** Pulsed Doppler interrogation of the inflow cannula shows a typical continuous, systolic dominant inflow pattern. Dashed arrow = peak systolic velocity; X = nadir diastolic velocity. **(C)** Continuous-wave spectral Doppler interrogation of the inflow cannula (to screen for inflow obstruction) shows normal inflow-cannula systolic flow (*black arrow*); "+" indicates a hybrid signal that results from overlapping of continuous diastolic inflow-cannula flow and diastolic MV inflow; "*" indicates MR velocity.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70bpm

Echocardiography for Routine Surveillance

- **Trend baseline LVAD and native heart anatomy and function over time to ensure appropriate response to LVAD therapy**
- **To detect subclinical LVAD or native heart abnormalities**
- **After LVAD implantation, surveillance TTE should be performed prior to discharge from index hospitalization**
- **1 month after initial implant**
- **Every 3 months after initial implant in the first year**
- **Every 6–12 months after the first year**

Echocardiography in Response to Signs, Symptoms, or Device Alarms

- low threshold to perform Echo Exam in response to a deterioration in clinical status and/or new controller alarms as LVAD malfunction or inappropriate patient response to LVAD therapy can be fatal if not addressed

- LVAD related complications detectable by Echo : intracardiac thrombus formation, intravascular hemolysis from motor-related shear stress, suction events, new or worsening aortic regurgitation, and inappropriate unloading conditions

Echocardiogram to Optimize LVAD Speed

- **Ramp study: Tracking LVDID,IVS orientation, AV opening, and severity of MR**

-Low speed

-High speed

-Optimum speed

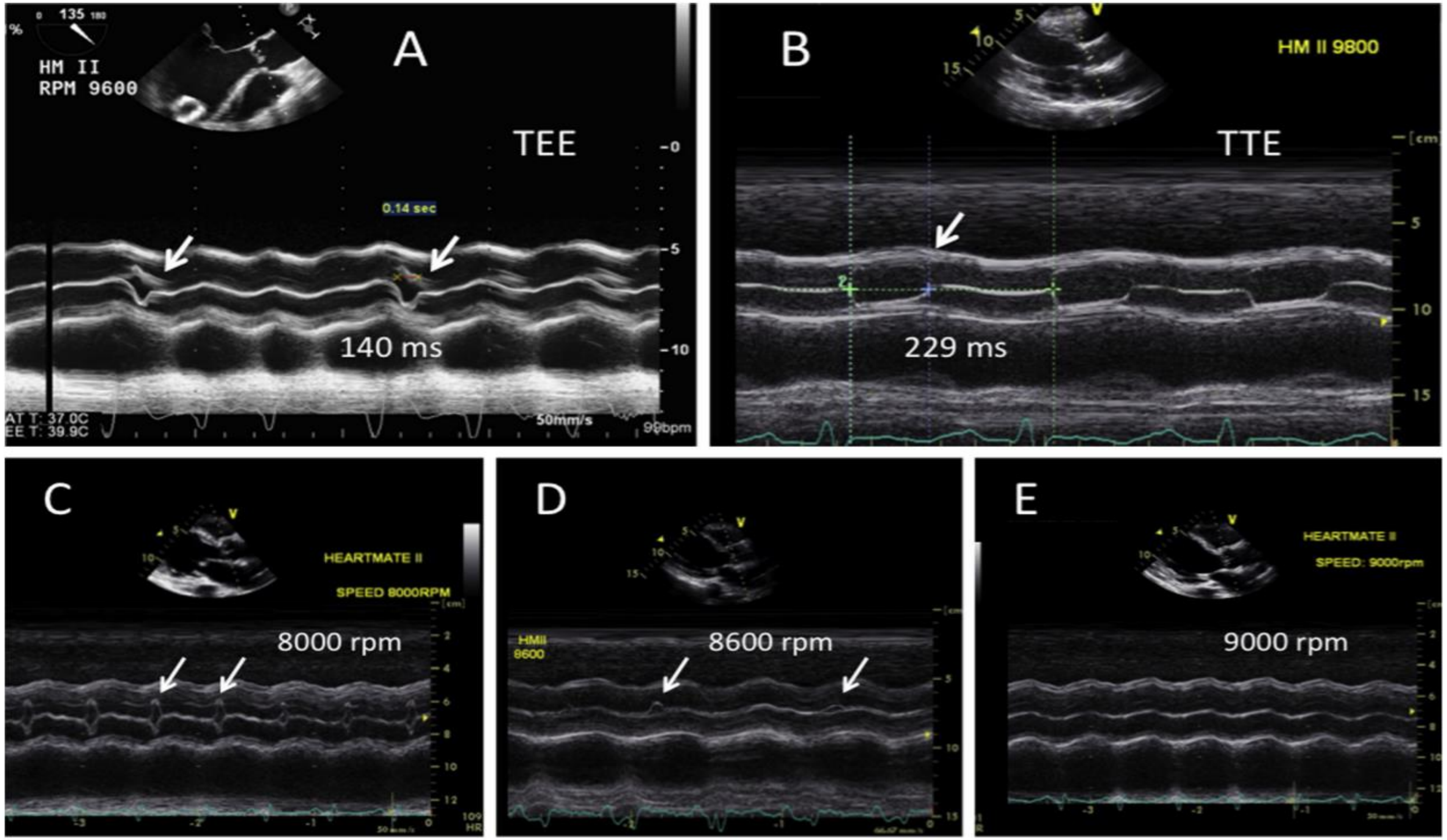


Figure 8 The duration of AV opening during LVAD support can be easily measured using M-mode during either TEE **(A)** or TTE **(B)**. In view A, the AV "barely opens" intermittently (*arrows*); this may, in part, be related to an arrhythmia and suggests normal LVAD function at a pump speed of 9600 rpm. In view B, there is near-normal AV opening, with durations of >200 ms; this may be an abnormal finding at a high LVAD pump speed (9800 rpm). **(C–E)** The expected progressively reduced duration of AV opening in the same patient during a ramp (speed-change) echo exam at different HM-II pump speeds: In view C (8000 rpm), the AV "barely opens"; in view D (8600 rpm), the AV "opens intermittently" (*arrows*); in view E (9000 rpm), the AV "remains closed."

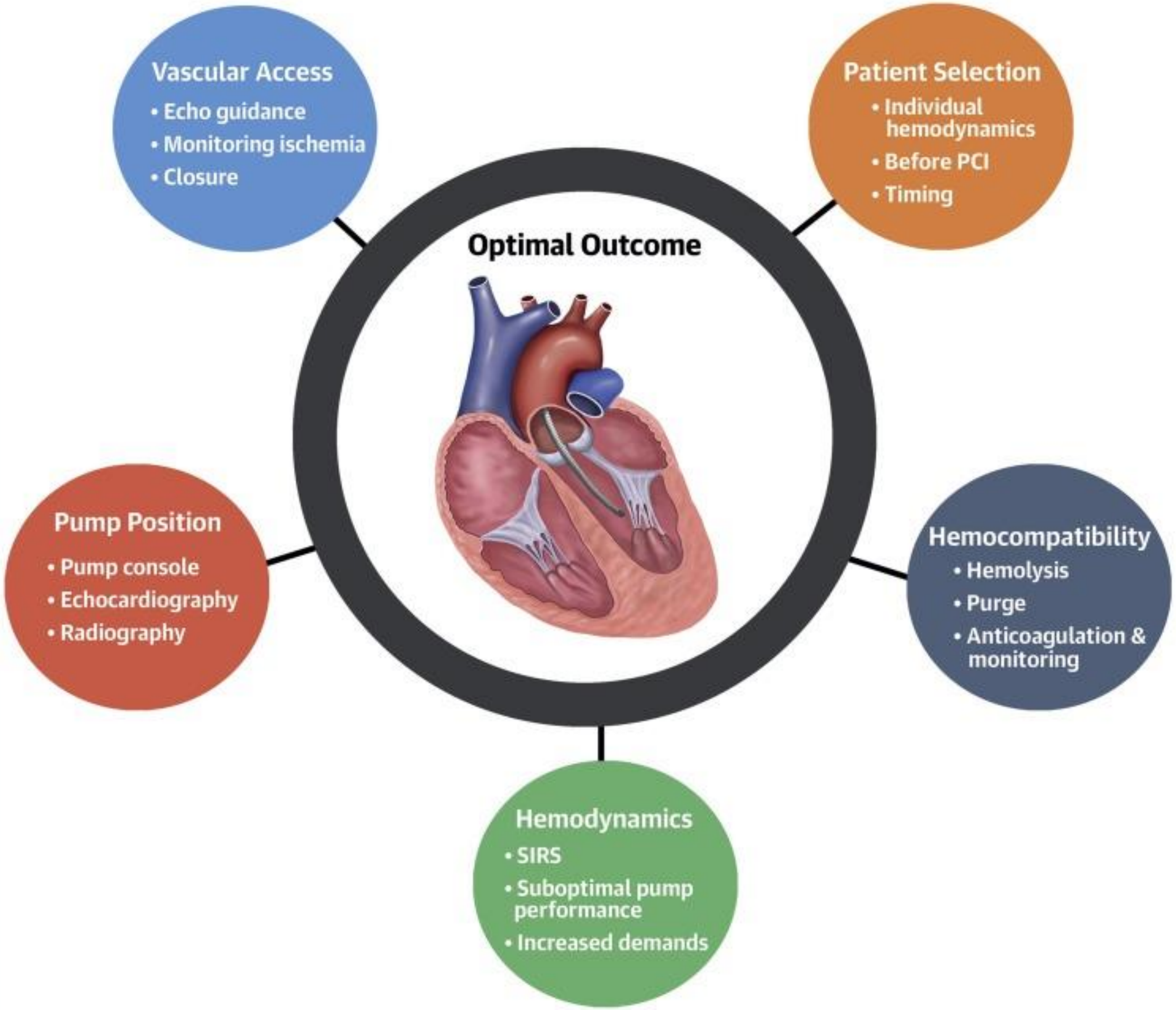
Normal Findings on Echocardiogram
Inflow Cannula

- Should be free of any adherent masses
- Color Doppler assessment :laminar flow from the left ventricle to the Inflow cannula
- Inflow should not be impeded by the interventricular septum
- Pulsed and CW Doppler should demonstrate low-velocity, continuous flow throughout the cardiac cycle

Normal Findings on Echocardiogram Outflow Cannula

- **Waveform mild pulsatility with continuous flow throughout diastole**
- **Although there are no clear benchmarks for abnormal peak systolic velocity at the outflow cannula, normal velocities should generally be less than 2 m/sec1**

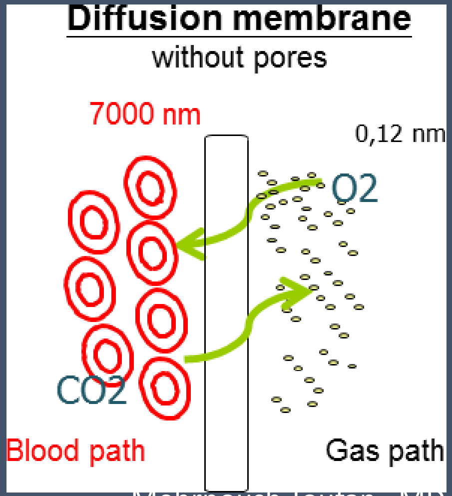
CENTRAL ILLUSTRATION: Optimizing Management of the Percutaneous Ventricular Assist Device-Supported Patient



Balthazar, T. et al. J Am Coll Cardiol. 2021;77(9):1243-56.

ECMO PRINCIPLE

- Desaturated blood is drained via a venous cannula
- CO_2 is removed, O_2 added through an "extracorporeal" device
- The blood is then returned to systemic circulation via another vein (VV ECMO) or artery (VA ECMO).



Echocardiograms performed on ECMO support should include the following features:

- a. Define the cannula locations within the cardiovascular system
- b. Assess for aortic regurgitation in veno-arterial cannulation with a carotid artery cannula - if this is positioned into the ascending aorta the infusion jet may injure the aortic valve and create regurgitation
- c. Assess the right ventricular size, function, and estimated right ventricular pressure
- d. Assess the left atrial size
- e. Assess direction of flow at any residual intracardiac shunts (e.g., atrial septal or ventricular septal defects)
- f. Assess left ventricular function
- g. Assess for pericardial effusion
- h. Assess for thrombus formation on the cannula tips or within the heart

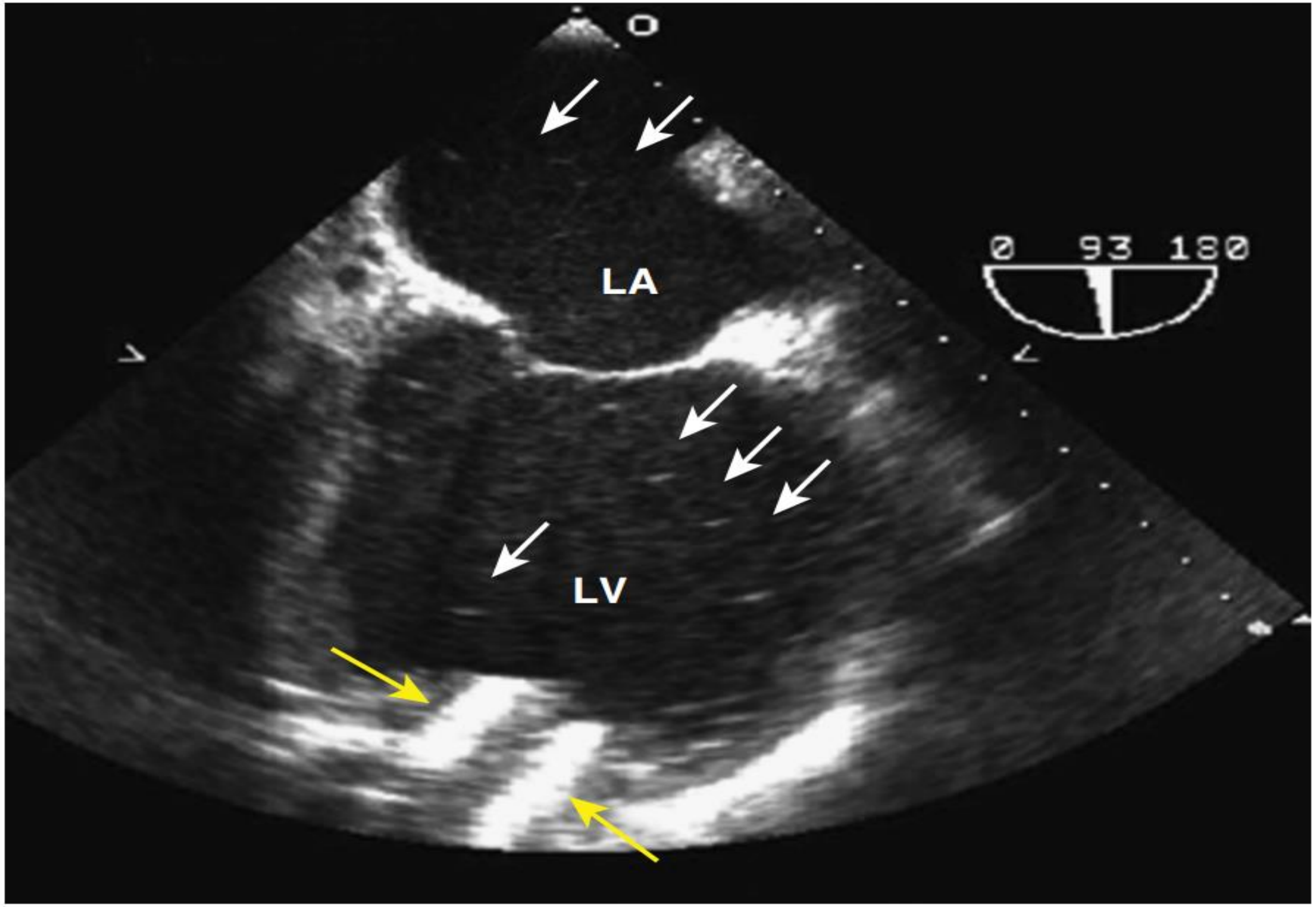


Fig. 16.4 Intracardiac air after LV assist device implantation. This mid-esophageal TEE apex-down 2-chamber view demonstrates air bubbles *(white arrows)* in the LV and LA after placement of an LV apical inflow cannula (sides defined by *yellow arrows*). Echocardiography can detect bubbles arising at anastomotic sites. Ventricular chambers should be deaired before coming off bypass.

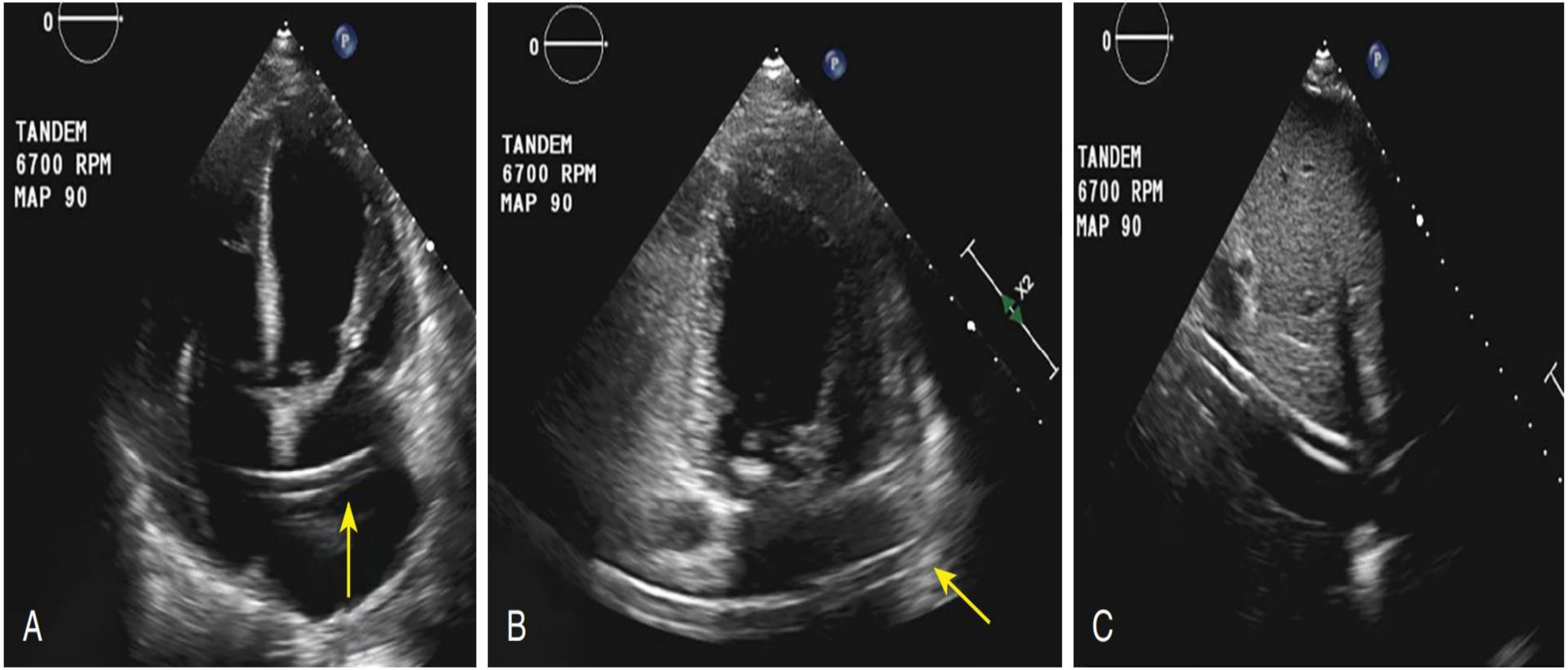
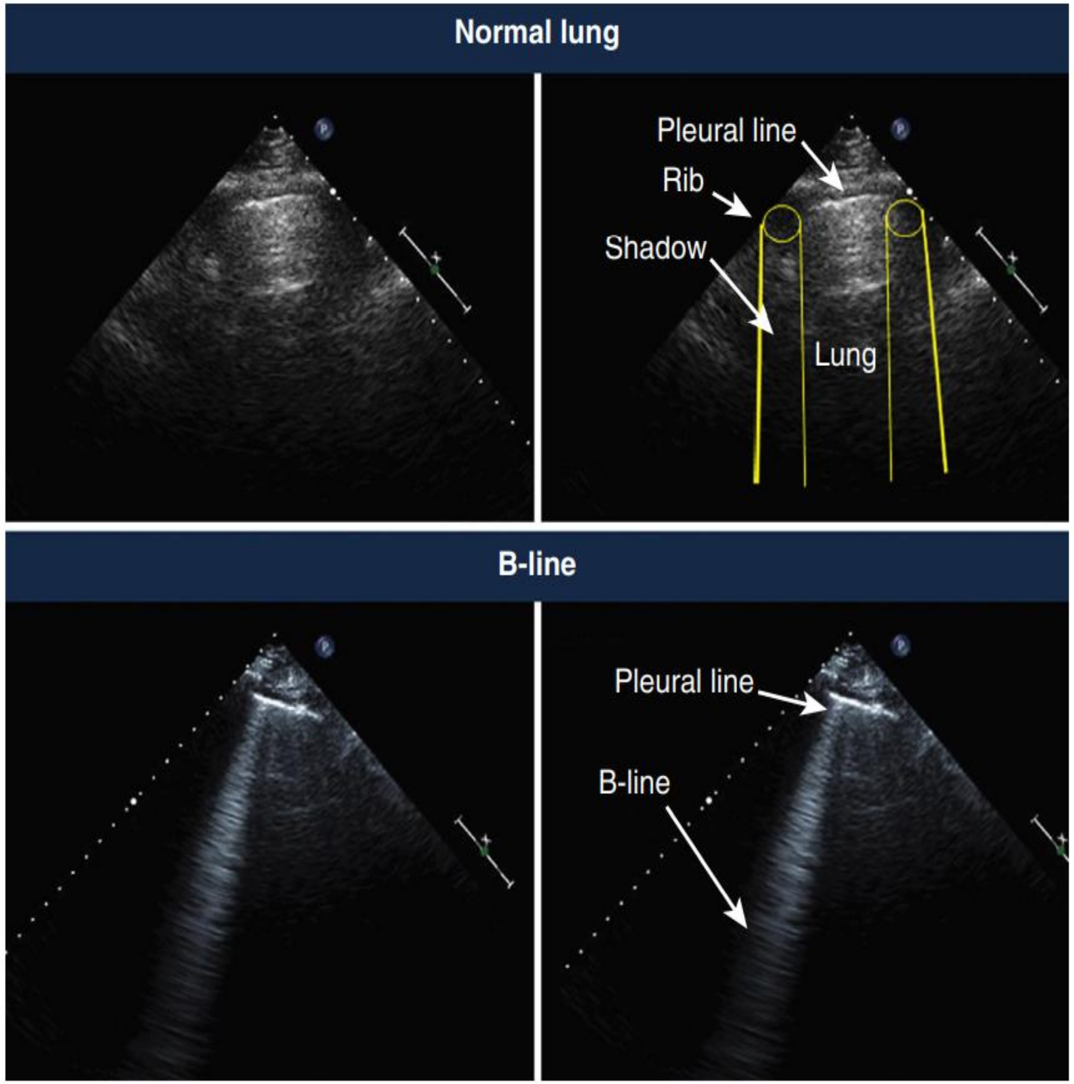


Fig. 16.10 TandemHeart device. (A) The TandemHeart inflow cannula (*arrow*) is seen traversing the interatrial septum in the apical 4-chamber view. (B) In the apical 2-chamber view, the terminus of the TandemHeart inflow catheter (*arrow*) is seen just above the location of the left atrial appendage (LAA). Echocardiography can help to guide the cannula away from any potential LAA thrombus. (C) The TandemHeart inflow cannula is seen in the inferior vena cava in this subcostal view.

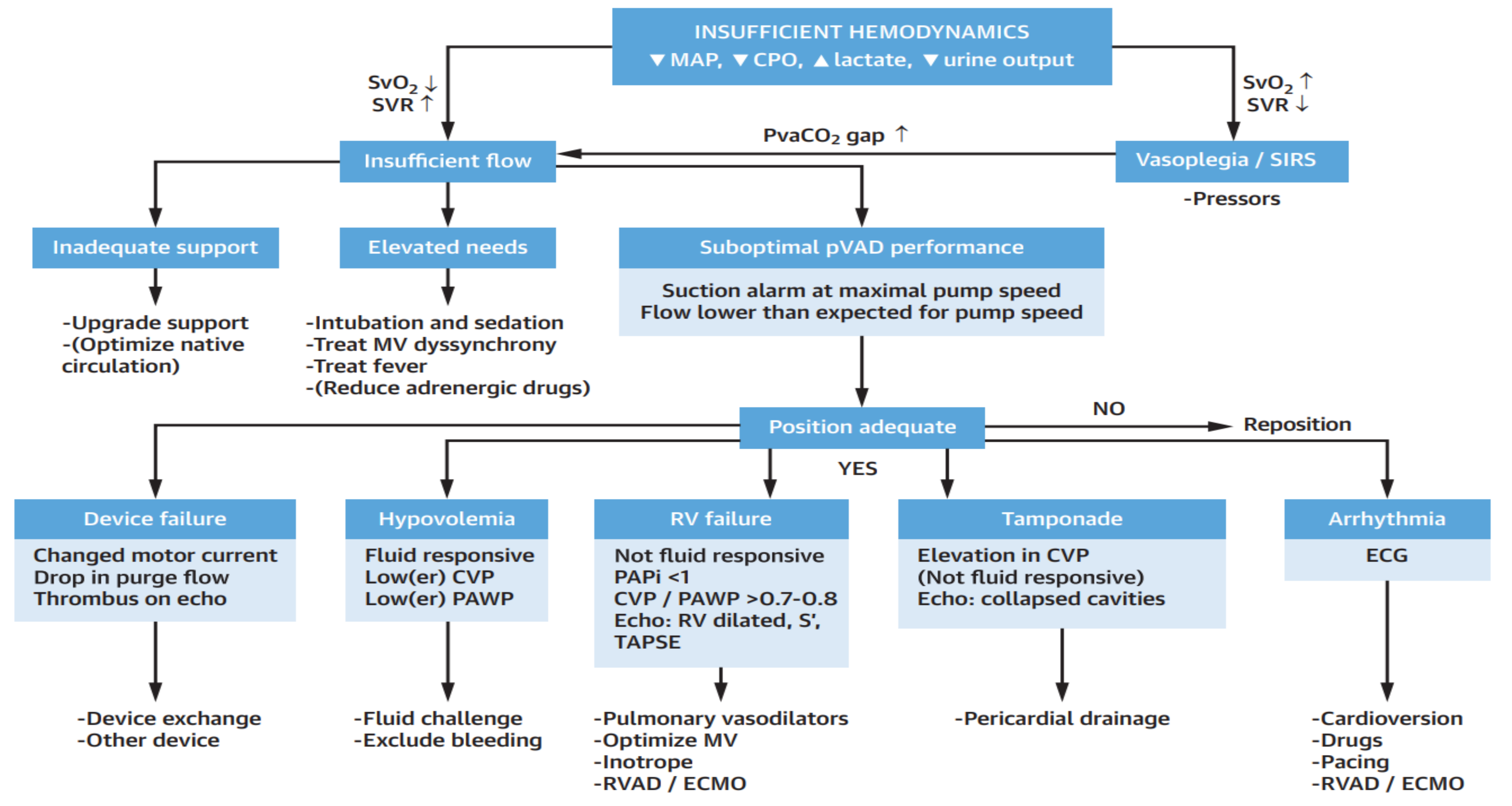


EFIGURE 16.24 B-lines on lung ultrasound. For studies, typically the number of B-lines are summed from two to eight segments of the chest using a 1.5- to 7.5-mHz transducer. **Top panels,** Normal lung. **Bottom panels,** Example of B-line. Annotated images are on the right. (Courtesy Dr. Elke Platz, Brigham and Women's Hospital.)

Echocardiographic findings ; complications of VAD

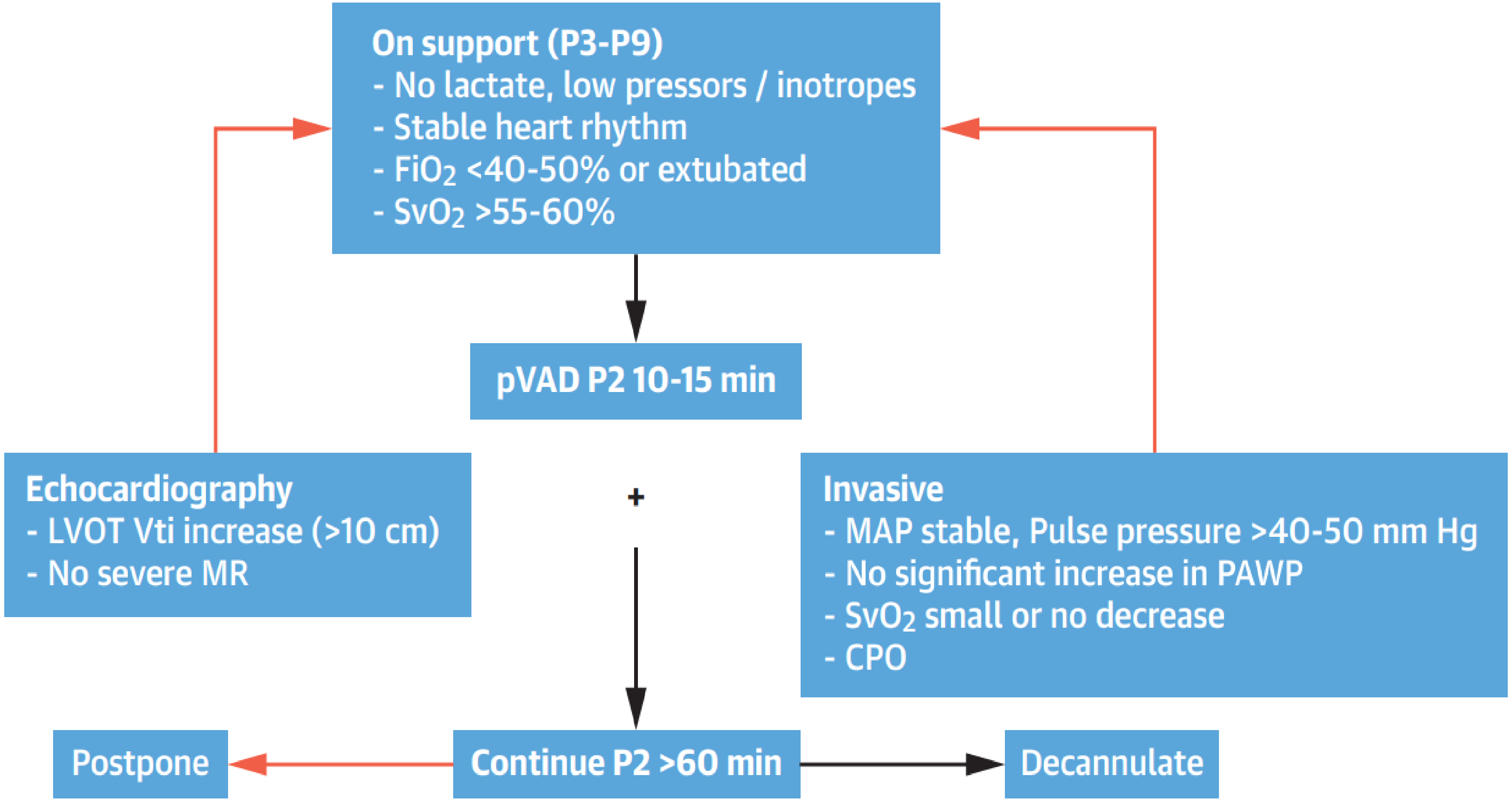
- Thrombus in cardiac chambers/Air in chambers
- Intracardiac shunting
- Aortic Aneurysm , atheroma
- AS(Moderate or severe)
- AR(Moderate or severe)
- MS/MR
- RV dysfunction/VSD
- ASD/ASA
- Heavy LV trabeculation/Aneurysm
- PE/Peripheral vascular disease

FIGURE 5 **Algorithm to Approach Deteriorating Hemodynamics During LV pVAD Support**



First, vasoplegia is differentiated from insufficient flow based on mixed venous oxygen saturation (SvO_2) and systemic vascular resistance (SVR). The specific hemodynamic culprit is then identified by using a structured approach. CPO = cardiac power output; CVP = central venous pressure; ECG = electrocardiogram; MV = mechanical ventilation; PAPi = pulmonary artery pulsatility index; $PvaCO_2$ gap = mixed venous partial pressure of carbon dioxide (Pco_2) minus arterial Pco_2; RVAD = right ventricular assist device; SIRS = systemic inflammatory response syndrome; TAPSE = tricuspid annular plane systolic excursion; other abbreviations as in Figures 1, 2, and 4.

FIGURE 6 Example of a Weaning Algorithm for a Left-Sided pVAD



Once the patient is stable on support, a brief reduction in device flow is proposed to evaluate hemodynamics invasively and with echocardiography. When cardiac output can be maintained without excessive rise in filling pressures and mitral regurgitation, the weaning trial can be prolonged to make sure stability is maintained before proceeding to decannulation. FiO_2 = fraction of inspired oxygen; LVOT = left ventricular outflow tract; MAP = mean arterial pressure; MR = mitral regurgitation; Vti = velocity time integral; other abbreviations as in Figures 1, 2, and 5.

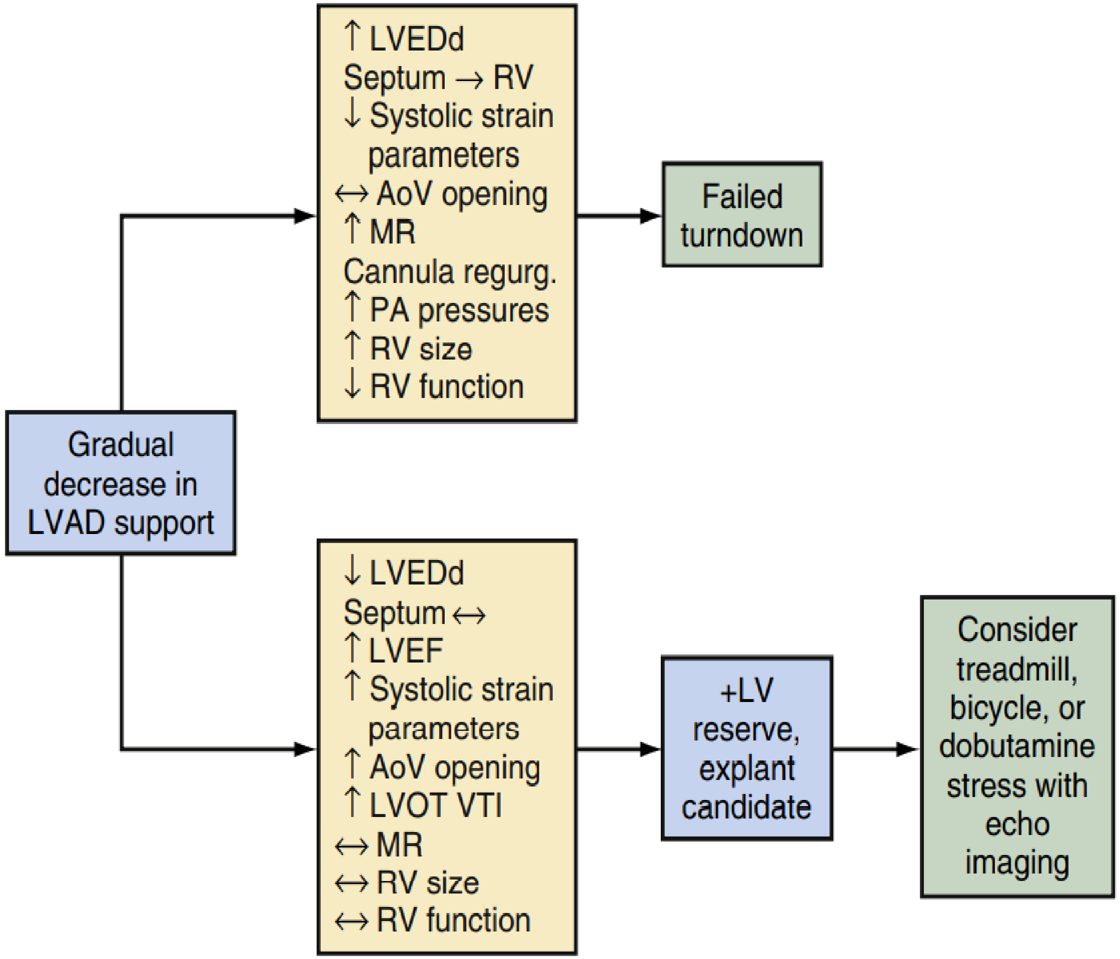


Fig. 16.15 LV assist device weaning. The flow chart outlines echocardiographic parameters that can be used to determine whether a patient has experienced LV recovery and may be a candidate for device explantation. The same parameters used during the turndown phase can be assessed during exercise or dobutamine stress, including LV end-diastolic diameter *(LVEDd)*, septal orientation, LV ejection fraction *(LVEF)*, AV opening, LV outflow tract *(LVOT)*, velocity–time integral *(VTI)*, degree of mitral regurgitation *(MR)*, and RV size and function. Few data exist on the ability of any specific measures to definitively predict recovery. *AoV*, Aortic valve; *echo*, echocardiographic; *LVAD*, LV assist device; *PA*, pulmonary artery.

Echocardiography in Heart Transplant

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RECOMMENDATION PAPER

European Association of Cardiovascular Imaging/ Cardiovascular Imaging Department of the Brazilian Society of Cardiology recommendations for the use of cardiac imaging to assess and follow patients after heart transplantation

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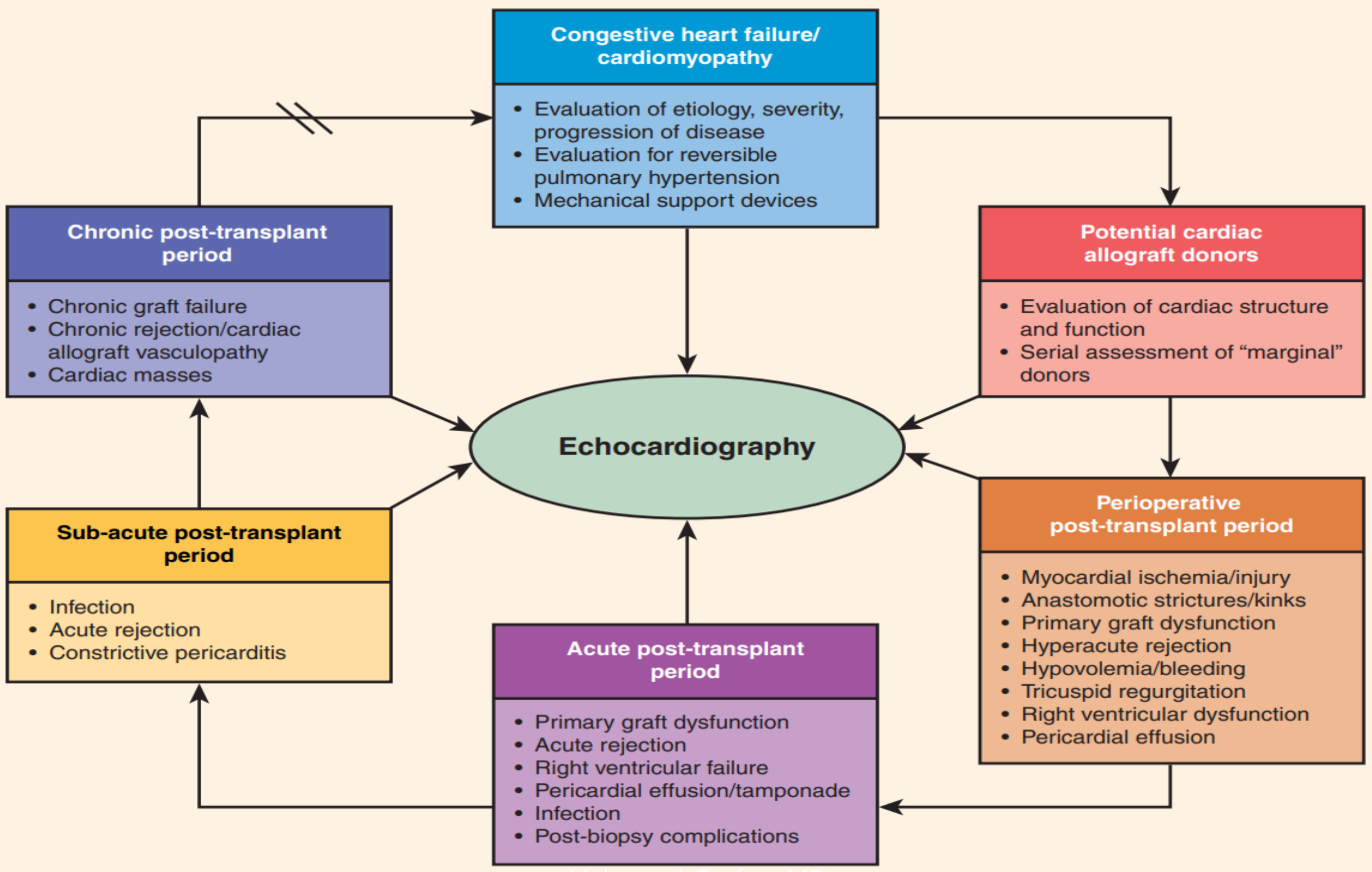
SUMMARY Cardiac Transplantation

Summary: Echocardiography plays a central role in the diagnosis of heart failure patients, their evaluation for cardiac transplantation, and the continued assessment of cardiac graft function to assess for known complications and guide prognosis and clinical management of the patient by the advanced heart failure/transplant team.



Not to use a potential donor
(On base of expert opinion)

- LV EF< 45-50%
- RWMA
- CAD in more than one vessel
- LVH
- Advance age with prolong(>4 hrs.) Ischemic time

TABLE 15.1 Underlying Conditions in Heart Transplant Operations.[a]

Condition	*Proportion of Heart Transplant Operations (%)*
Non-ischemic cardiomyopathy	49
Ischemic cardiomyopathy	35
Restrictive cardiomyopathy	4
Congenital heart disease	3
Hypertrophic cardiomyopathy	3
Retransplantation	3
Valvular cardiomyopathy	2
Other	1

TABLE 15.2 Comprehensive Protocol for Transthoracic Echocardiography After Cardiac Transplantation.

2D View	*M-Mode*	*Doppler*	*Additional or Advanced*
Parasternal Window			
Long-axis	RV, LV, MV, AV, LA	MV and AV (color)	Zoomed LVOT/AV Aortic anastomosis (2D, color, and spectral Doppler) LA anastamosis
RV inflow	—	RV inflow (spectral) TV (color and spectral)	IVC and SVC anastomosis (2D, color, and spectral Doppler) RA anastamosis
Short-axis (base, MV, mid-LV, apex)	AV	AV, TV, PV, MV (color) TV, PV, PA, RVOT (spectral)	PA anastomosis (2D, color, and spectral Doppler)
Apical Window			
4-Chamber	—	MV annulus (TDI) Transmitral LV inflow (spectral) Pulmonary vein (spectral) MV (color and spectral)	Zoomed LA Color M-mode of LV inflow Longitudinal strain 3D LV volume
RV-focused	—	RV inflow (spectral) TV (color and spectral)	IVC and SVC anastomosis (2D, color, and spectral Doppler) RA anastamosis
Short-axis (base, MV, mid-LV, apex)	AV	AV, TV, PV, MV (color) TV, PV, PA, RVOT (spectral)	PA anastomosis (2D, color, and spectral Doppler)
Apical Window			
4-Chamber	—	TV (color and spectral) TV annulus (TDI)	Fractional area change RV longitudinal strain 3D RV volume
2-Chamber	—	MV (color and spectral) MV annulus (TDI)	Zoomed LA Longitudinal strain
Long-axis	—	AV (color and spectral) MV (color and spectral)	Longitudinal strain
Subcostal Window			
5-Chamber	—	LVOT and AV (color and spectral) IVRT	Aortic anastomosis (2D, color, and spectral Doppler)
4-Chamber	—	TV (color and spectral) IAS (color)	—
IVC and hepatic veins	IVC	Hepatic veins (color and spectral)	Sniff IVC anastomosis (2D and color Doppler)
Suprasternal Window			
Aorta	—	Ascending (color and spectral) Descending (spectral)	—

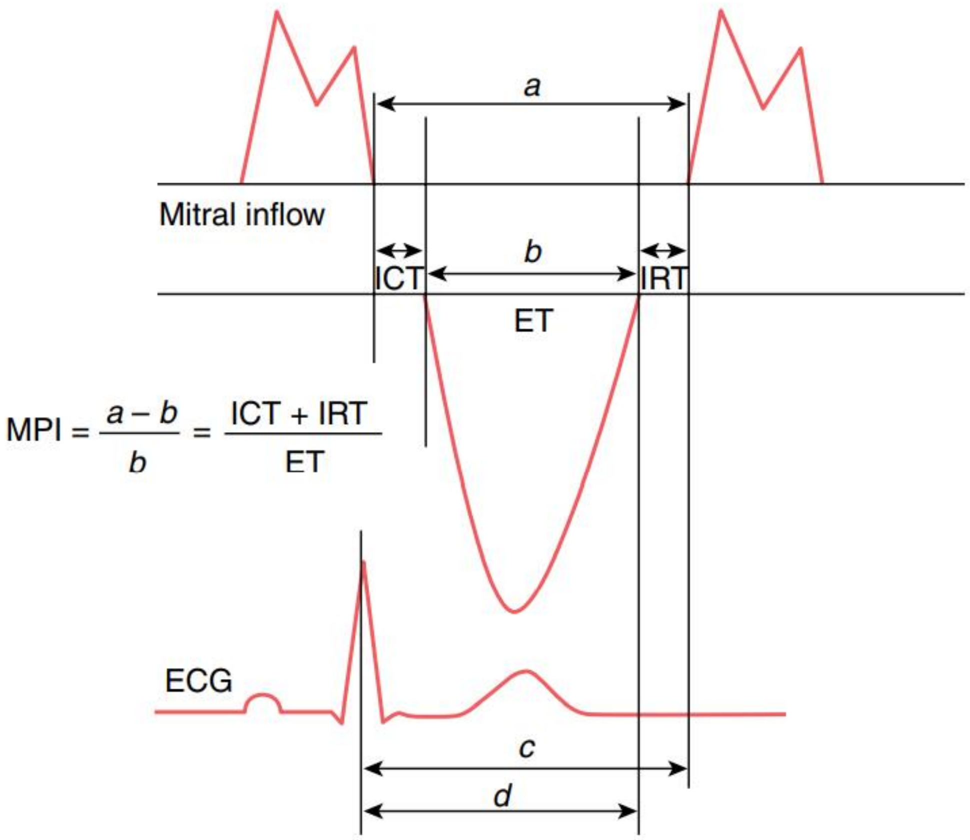


Fig. 15.6 Myocardial performance index schematic. Myocardial performance index *(MPI)* is the sum of the isovolumic contraction time *(ICT)* and isovolumic relaxation time *(IRT)*, divided by the ejection time *(ET)*. (From Toumanidis ST, Papadopoulou ES, Saridakis NS, et al. Evaluation of myocardial performance index to predict mild rejection in cardiac transplantation. *Clin Cardiol.* 2004;27[6]:352–358.)

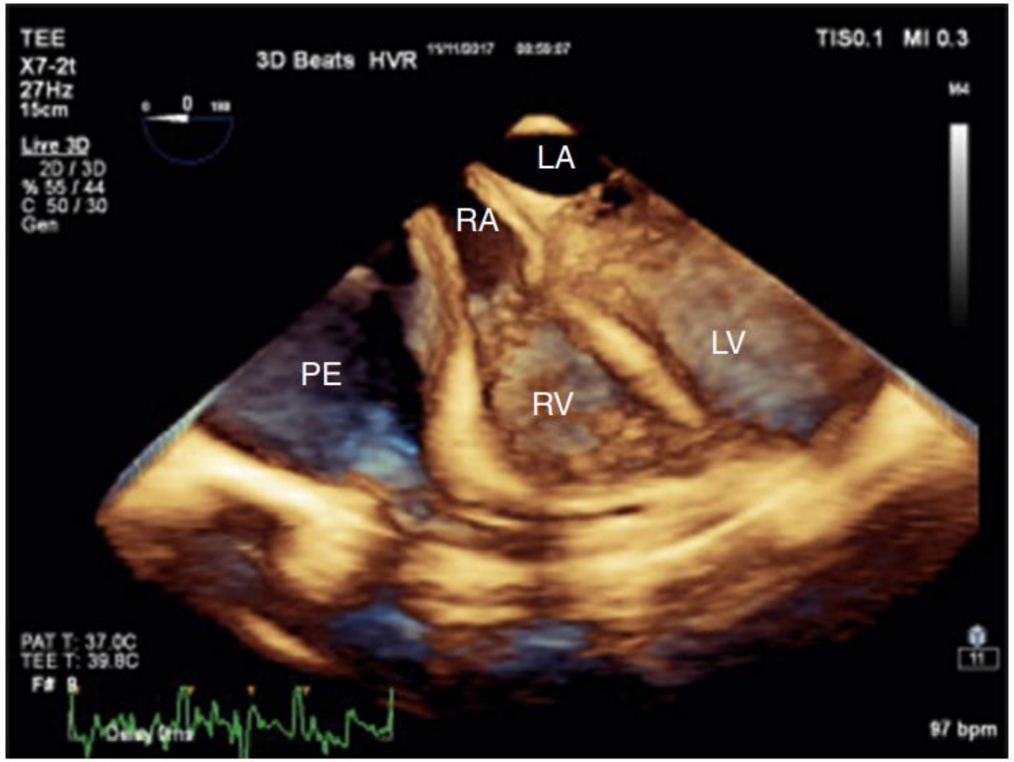


Fig. 15.7 Post-transplantation pericardial effusion (PE) seen on 3D TEE was caused by placement of a normal-size heart within a large pericardial space from a patient with dilated cardiomyopathy with compression of the RA and basal RV. (From Essandoh M. Atypical presentation of a large pericardial effusion after heart transplantation in a patient with dilated cardiomyopathy. *J Cardiothorac Vasc Anesth.* 2018;32[4]:e84.)

TABLE 15.4 **Common Echocardiographic Parameters and Their Association With Acute Cellular Rejection as Confirmed by RV Biopsy in Heart Transplant Patients.**

Echocardiographic parameter	*No ACR*[a] (n = 173)	*ACR Grade = 1R*[a] (n = 50)	*ACR Grade ≥ 2R*[a] (n = 12)	P[b]	P[c]	P[d]	*Overall P Value*[e]
LVEF (%) (Simpson)	63.6 ± 8.10	63.4 ± 7.5	62.2 ± 9.6	1.00	1.00	1.00	0.88
Septal thickness (mm)	11.3 ± 1.8	12.3 ± 2.2	12.6 ± 1.4	0.01	0.59	0.02	0.001
TAPSE (mm)	14.6 ± 3.9	13.9 ± 3.9	12.6 ± 3.5	0.09	0.83	1.00	0.18
RV wall thickness (mm)	5.3 ± 1.1	5.6 ± 1.2	6.0 ± 1.7	0.11	0.84	0.28	0.13
E/A ratio	2.1 ± 0.7	2.0 ± 1.1	2.5 ± 0.8	0.42	0.35	1.00	0.32
DT (ms)	150.8 ± 40.3	156.5 ± 42.7	126.9 ± 41.4	0.16	0.08	1.00	0.09
IVRT (ms)	93.7 ± 17.6	83.1 ± 20.2	74.2 ± 12.9	0.01	0.38	0.01	<0.001
TDI lateral E (cm/s)	13.0 ± 3.6	12.1 ± 3.3	9.9 ± 3.0	0.01	0.05	0.41	0.04
Lateral E/E′ ratio	6.8 ± 2.8	7.1 ± 3.0	9.6 ± 3.6	0.004	0.02	1.00	0.006
Systolic velocity tricuspid annulus (cm/s)	10.4 ± 2.4	9.9 ± 2.2	9.2 ± 2.3	0.30	1.00	0.36	0.11
LV radial strain (%)	22.5 ± 7.1	20.1 ± 8.0	18.0 ± 6.5	0.56	1.00	0.55	0.20
LV circumferential strain (%) (absolute value)	19.1 ± 3.6	18.5 ± 3.3	17.3 ± 3.9	1.00	1.00	1.00	0.51
LV longitudinal strain (%) (absolute value)	17.8 ± 3.4	15.1 ± 3.7	13.7 ± 2.7	<0.001	0.68	<0.001	<0.001
RV longitudinal strain (%) (absolute value)	19.9 ± 3.8	16.2 ± 3.7	15.2 ± 1.7	<0.001	1.00	<0.001	<0.001
RV free wall longitudinal strain (%) (absolute value)	23.3 ± 5.2	16.9 ± 3.0	16.6 ± 3.6	<0.001	1.00	<0.001	<0.001

[a]Data are expressed as mean ± SD.
[b]No ACR vs. ACR grade ≥ 2R.
[c]ACR grade 1R vs. ACR grade ≥ 2R.
[d]No ACR vs. ACR grade 1R.
[e]Analysis of variance global *P* value between groups.
ACR, Acute cellular rejection; *DT*, deceleration time; *TDI*, tissue Doppler imaging; *IVRT*, isovolumic relaxation time; *LVEF*, left ventricular ejection fraction; *TAPSE*, tricuspid annular plane systolic excursion.
From Mingo-Santos S, Moñivas-Palomero V, Garcia-Lunar I, et al. Usefulness of two-dimensional strain parameters to diagnose acute rejection after heart transplantation. *J Am Soc Echocardiogr*. 2015;28(10):1149–1156.

TABLE 15.3 Echocardiographic Correlates of Cardiac Complications in the Transplant Patient.

Complication	*Echocardiographic Correlations*	*Comments*
Perioperative		
Myocardial ischemia/injury	Regional wall motion abnormalities	Coronary artery embolism or compression/ligation by a suture
Anastomotic kinks/strictures	Anastomotic narrowing Turbulence on color Doppler High spectral Doppler velocities	IVC, SVC, PA, pulmonary veins, and/or aorta anastomosis involvement
Primary graft dysfunction	LV or RV systolic dysfunction in the absence of other causes	Hemodynamic instability
Hyperacute rejection	Diffuse graft dysfunction	Hemodynamic instability
Bleeding/hypovolemia	Underfilled heart, small IVC	—
Tricuspid regurgitation	Assess RA, RV size/function, PASP	More than mild at completion of intraoperative TEE associated with increased mortality
RV dysfunction	Dilated RV Low TAPSE, tricuspid S′ velocity, RV FAC High RAP Assess PASP	More than mild at completion of intraoperative TEE associated with increased mortality May be related to irreversible pHTN, rapid changes in hemodynamics, or ischemic time
Pericardial effusion/tamponade	May be located anterior and lateral to RA requiring TEE imaging	Can occur despite pericardium not being closed after transplantation

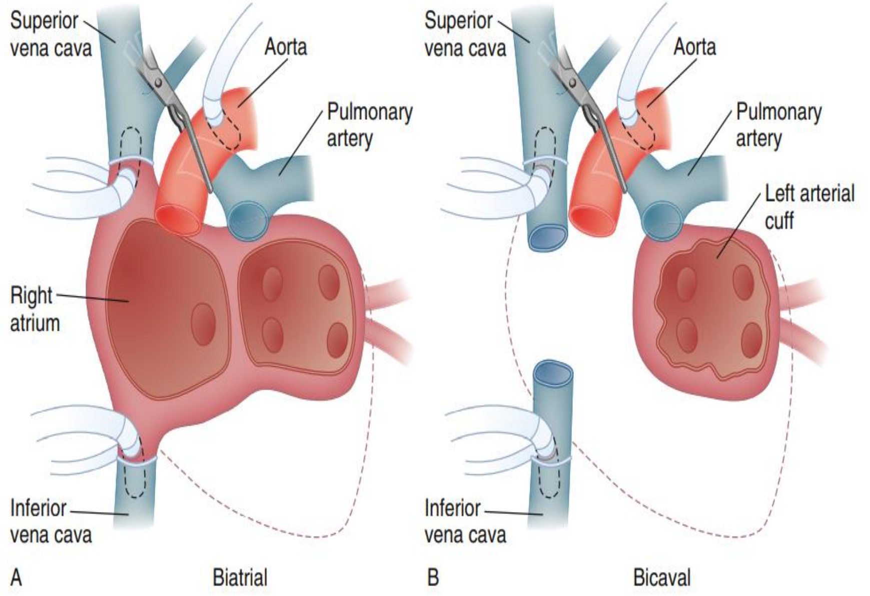
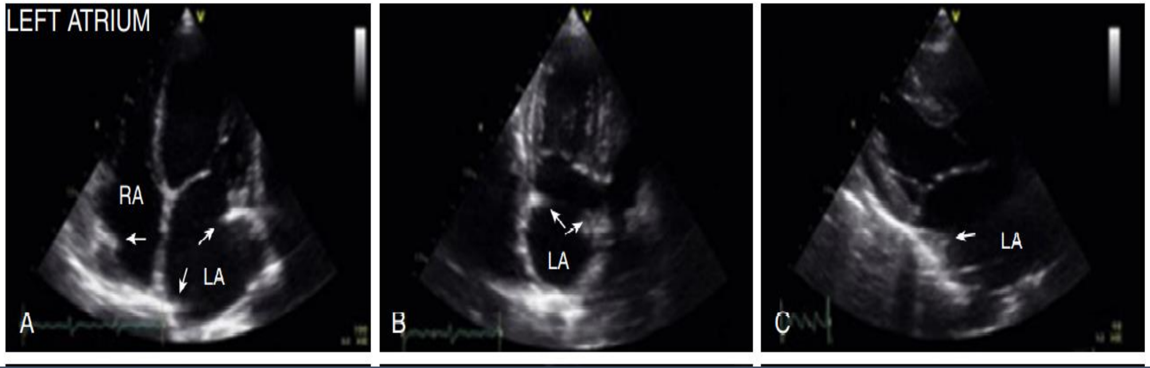


Fig. 15.1 Schematics of the (A) biatrial and (B) bicaval anastomosis surgical techniques for cardiac transplantation. (From Badano LP, Miglioranza MH, Edvardsen T, et al. European Association of Cardiovascular Imaging/Cardiovascular Imaging Department of the Brazilian Society of Cardiology recommendations for the use of cardiac imaging to assess and follow patients after heart transplantation. *Eur Heart J Cardiovasc Imaging.* 2015;16[9]:919–948.)



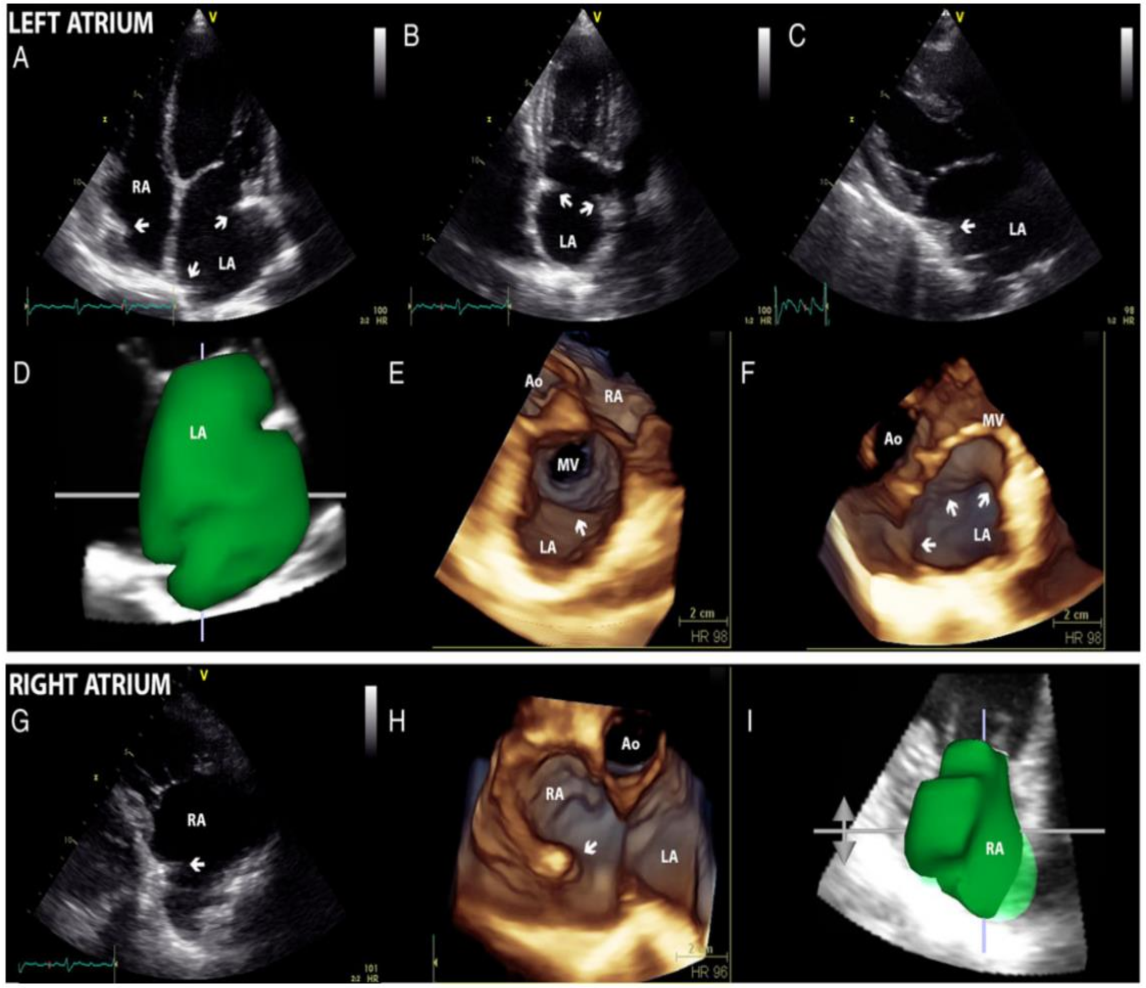


Figure 2 Two- and three-dimensional echocardiography acquisitions in a patient who underwent heart transplant using the standard technique. Both the left and right atria are grossly enlarged and the atrial sutures (arrows) are visualized giving the left atrium the typical 'snowman' shape. Arrow, suture lines, Ao, aorta, LA, left atrium; LV, left ventricle; MV, mitral valve; RA, right atrium.

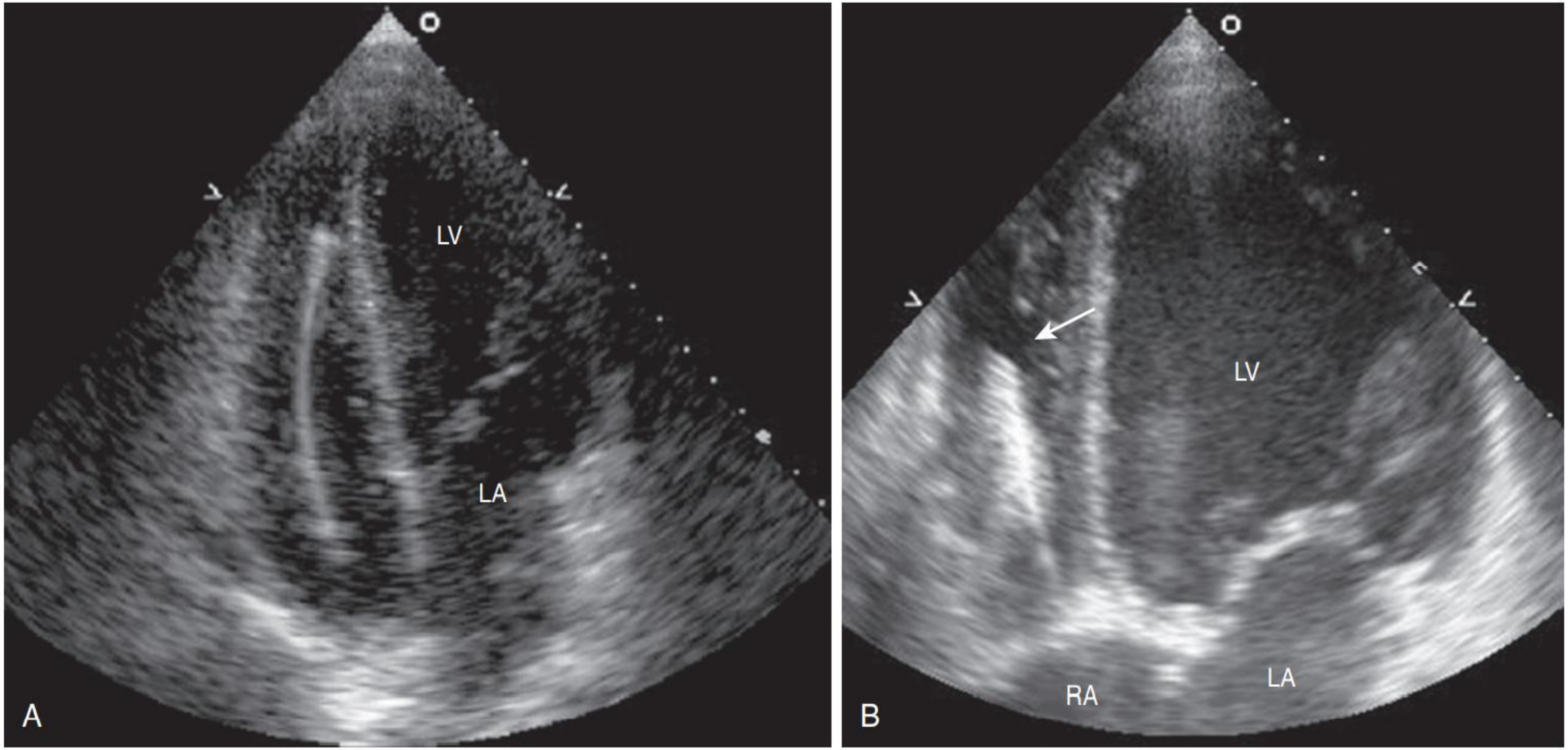
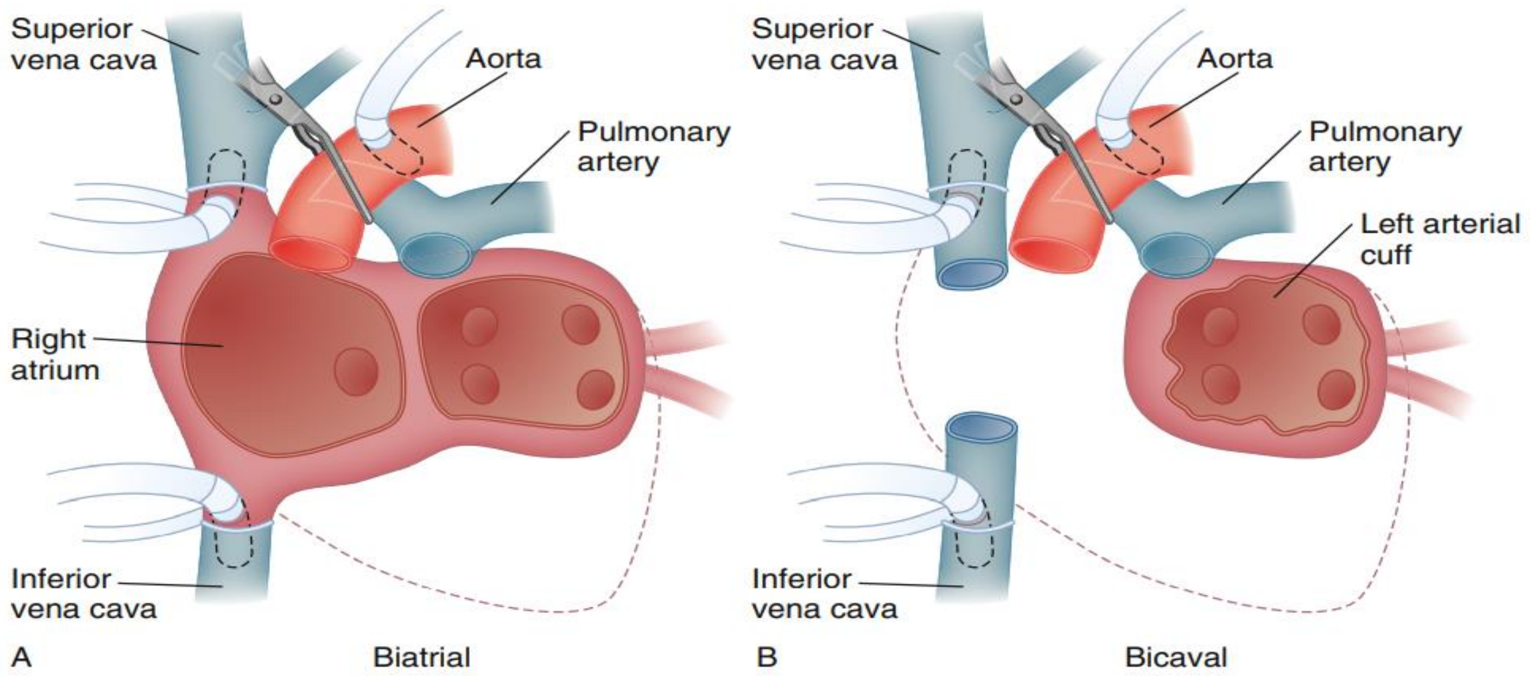


Fig. 15.11 **TTE guidance of RV biopsies with (A) optimal bioptome placement at the interventricular septum and (B) suboptimal bioptome placement *(arrow)* with inability to visualize bioptome tip at the septum.** (From Silvestry FE, Kerber RE, Brook MM, et al. Echocardiography-guided interventions. *J Am Soc Echocardiogr.* 2009;22[3]:213–231; quiz 316.)



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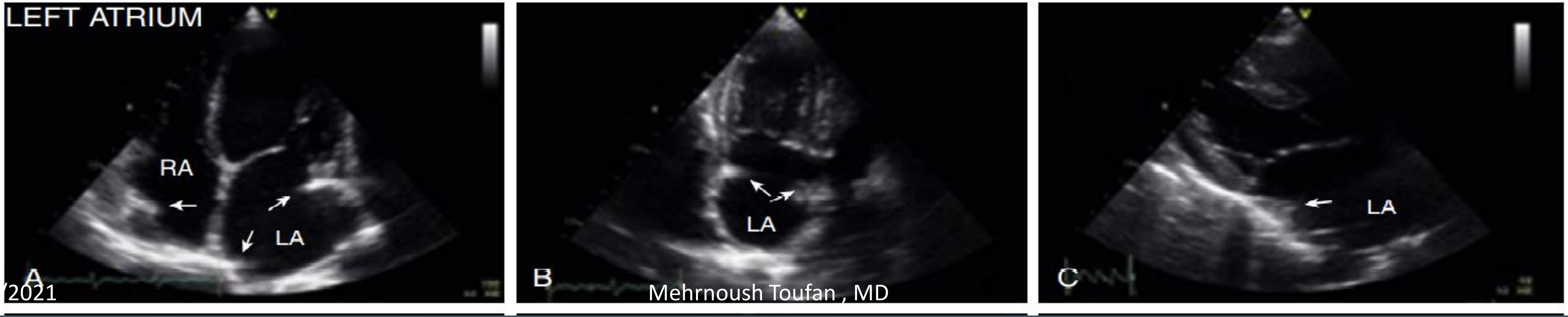

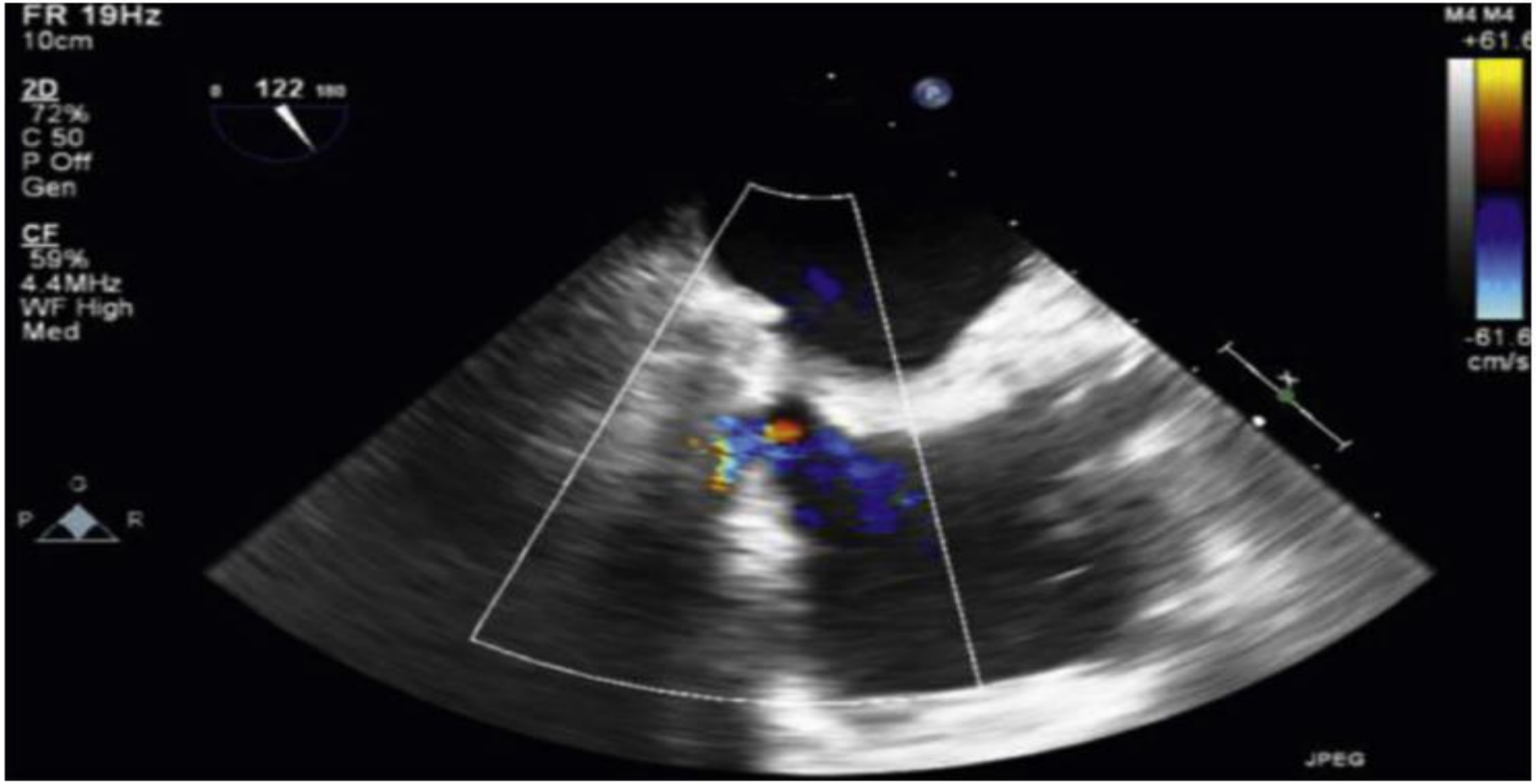

Fig. 15.5 TEE in the mid-esophageal bicaval view shows turbulence by color Doppler at the inferior vena cava anastomosis to the RA, discovered on postoperative day 7 after cardiac transplantation during evaluation for refractory shock. (From Chaney MA, Lowe ME, Minhaj MM, Santise G, Jacobsohn E. Inferior vena cava stenosis after bicaval orthotopic heart transplantation. *J Cardiothorac Vasc Anesth.* 2019;33[9]:2561–2568.)

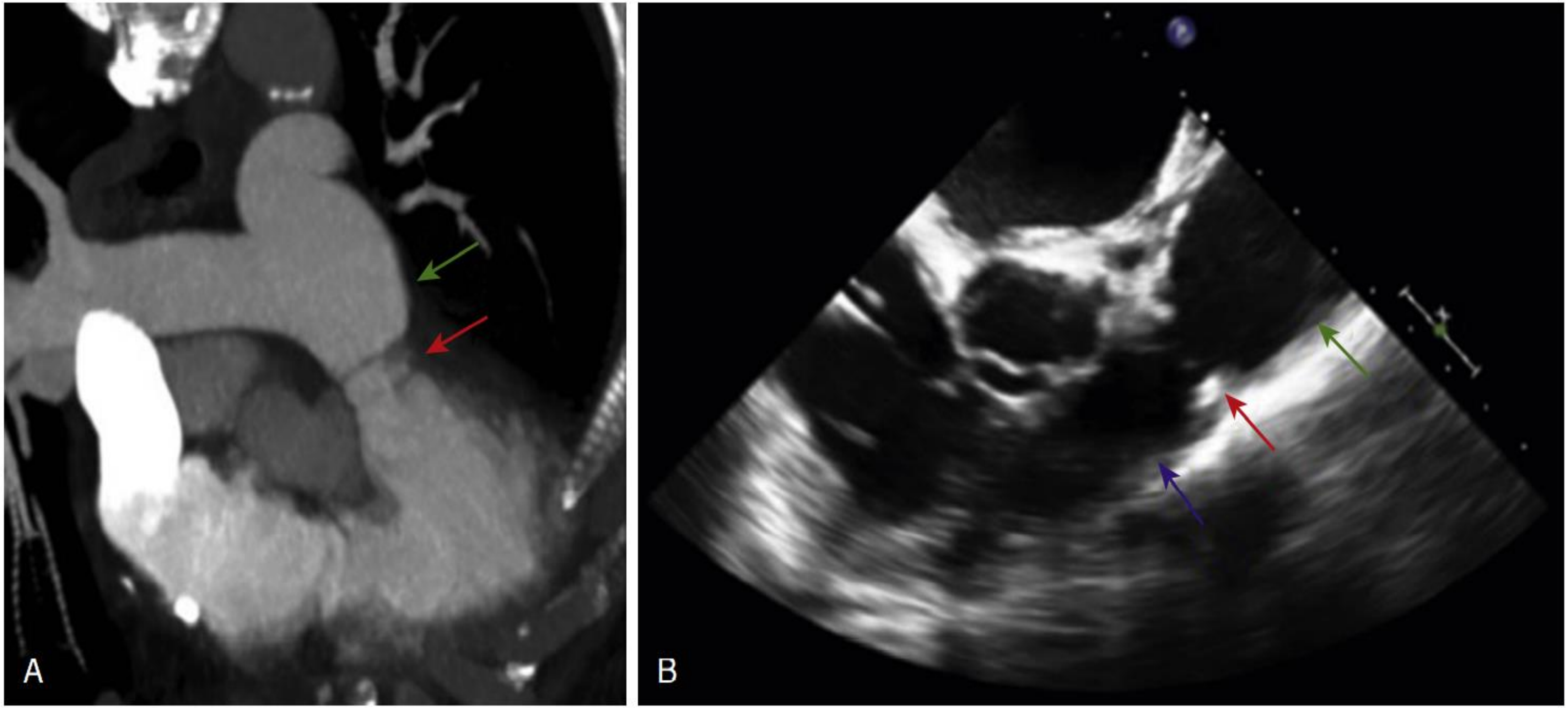

Fig. 15.4 **Images obtained after cardiac transplantation show a pulmonary anastamotic stricture.** (A) Computed tomography angiogram demonstrates the proximal main pulmonary artery stenosis *(red arrow)* and poststenotic dilatation *(green arrow)*. (B) TEE at the mid-esophageal short-axis view shows the supravalvular anastamotic stenosis *(red arrow)*, pulmonary valve *(blue arrow)*, and poststenotic dilatation *(green arrow)*. (From Lee JZ, Lee KS, Abidov A, Samson RA, Lotun K. Endovascular stenting of suture line supravalvular pulmonic stenosis after orthotopic heart transplantation using rapid pacing stabilization. *JACC Cardiovasc Interv.* 2014;7[8]:e91–e93.)

Acute (<1 mo)		
Primary graft dysfunction	Reduced LVEF or RV systolic dysfunction with low cardiac output and high filling pressures without secondary causes	Leading cause of early mortality
Acute rejection	LV diastolic dysfunction Impaired GLS Reduced LVEF (late finding) Increased LV wall thickness or mass Pericardial effusion	Variable sensitivity and specificity for each parameter Normal echocardiogram has highest NPV
RV failure	Low TAPSE, tricuspid S′ velocity, RV FAC High RAP Assess PASP	3D may be better than 2D assessment of RV function after transplantation
Pericardial effusion/tamponade	May be located anterior and lateral to RA requiring TEE imaging	Can occur despite pericardium not being closed after transplantation
Infections	Can occur with valves and anastomosis sites	Difficult to discern anastamotic infective endocarditis, thrombus, and sutures from TTE
Post-biopsy complications	Tricuspid regurgitation Pericardial effusion Coronary fistulas	Echocardiographic guidance of biopsy has equivocal complication rates compared with fluoroscopic guidance

Subacute (1–12 mo)		
Infection/endocarditis	Can occur with valves and anastomosis sites	Leading cause of death in subacute period
Acute rejection	LV diastolic dysfunction Impaired GLS Reduced LVEF (late finding) Increased LV wall thickness/mass Pericardial effusion	More common in highly allosensitized and noncompliant patients
Constrictive pericarditis	Exaggerated respirophasic variation Tall E waves, short deceleration time Mitral TDI annulus reversus High RAP Usually normal biventricular function	Can occur with parietal or visceral pericardium
Chronic (>12 mo)		
Chronic graft failure	LV diastolic dysfunction Impaired GLS Reduced LVEF Wall motion abnormalities Increased LV wall thickness/mass	Major cause of mortality in chronic period Caused by CAV or repeated acute rejection or infection
Cardiac allograft vasculopathy	Wall motion abnormalities LV or RV dysfunction Impaired GLS Increased LV wall thickness Abnormal DSE	50% of transplant patients at 10 years Often asymptomatic DSE has variable sensitivity and specificity CFR may be most sensitive
Cardiac masses	Differential diagnosis includes malignancy, thrombus, endocarditis	Multimodality imaging may be needed

CENTRAL ILLUSTRATION Key Points for Modalities Used in the Screening and Detection of CAV and ACR

Cardiac Allograft Vasculopathy

Coronary Angiography
- ISHLT recommended modality
- Prognostic for outcomes
- Invasive
- Provides information only on lumen patency
- Does not assess arterial wall thickness

Stress Echo
- Noninvasive
- Requires pharmacological stressor due to diminished exercise response of allograft
- Moderate sensitivity for detecting angiographically significant CAV on DSE

IVUS
- Identifies angiographically silent lesions
- Detects intimal thickening
- ≥0.5 mm intimal thickening within 1st year associated with adverse outcomes

OCT
- Very high spatial resolution for detecting intimal thickening
- Spatial resolution ˜10 µm
- Experimental modality
- Uncertain whether outcome benefit over IVUS

SPECT/PET
- Perfusion imaging modalities
- Exclude hemodynamically significant CAV
- Predictive of adverse outcomes
- Only available at high volume centers

CTA
- Detects lesions in up to 50% more segments than angio
- Accurate for detecting luminal irregularities
- Absence of CTA-defined CAV linked to good 5-year outcomes

Acute Cellular Rejection

EMB
- "Gold standard" for rejection monitoring
- Invasive procedure with ˜6% complication rate
- low concordance among pathologists for high grades of rejection

Echocardiography
- First-line non-invasive modality for assessing heart allograft
- LV morphology associated with outcomes but non-specific
- LVEF preserved in early ACR
- Doppler indices of mitral inflow are limited for detecting ACR

TDI
- Strain and strain rate parameters of myocardial deformation
- Excludes higher rejection grades
- Poor reproducibility

STE
- Myocardial deformation
- LV GLS and RV free wall strain predict ≥2R grade rejection
- LV torsion predicts significant ACR
- Low frame rate can miss events

CMR
- T_2 relaxation time proportional to myocardial water content
- T_2 relaxation has high NPV for significant rejection
- LGE patterns on contrast CMR detect myocardial fibrosis

Olymbios, M. et al. J Am Coll Cardiol Img. 2018;11(10):1514–30.

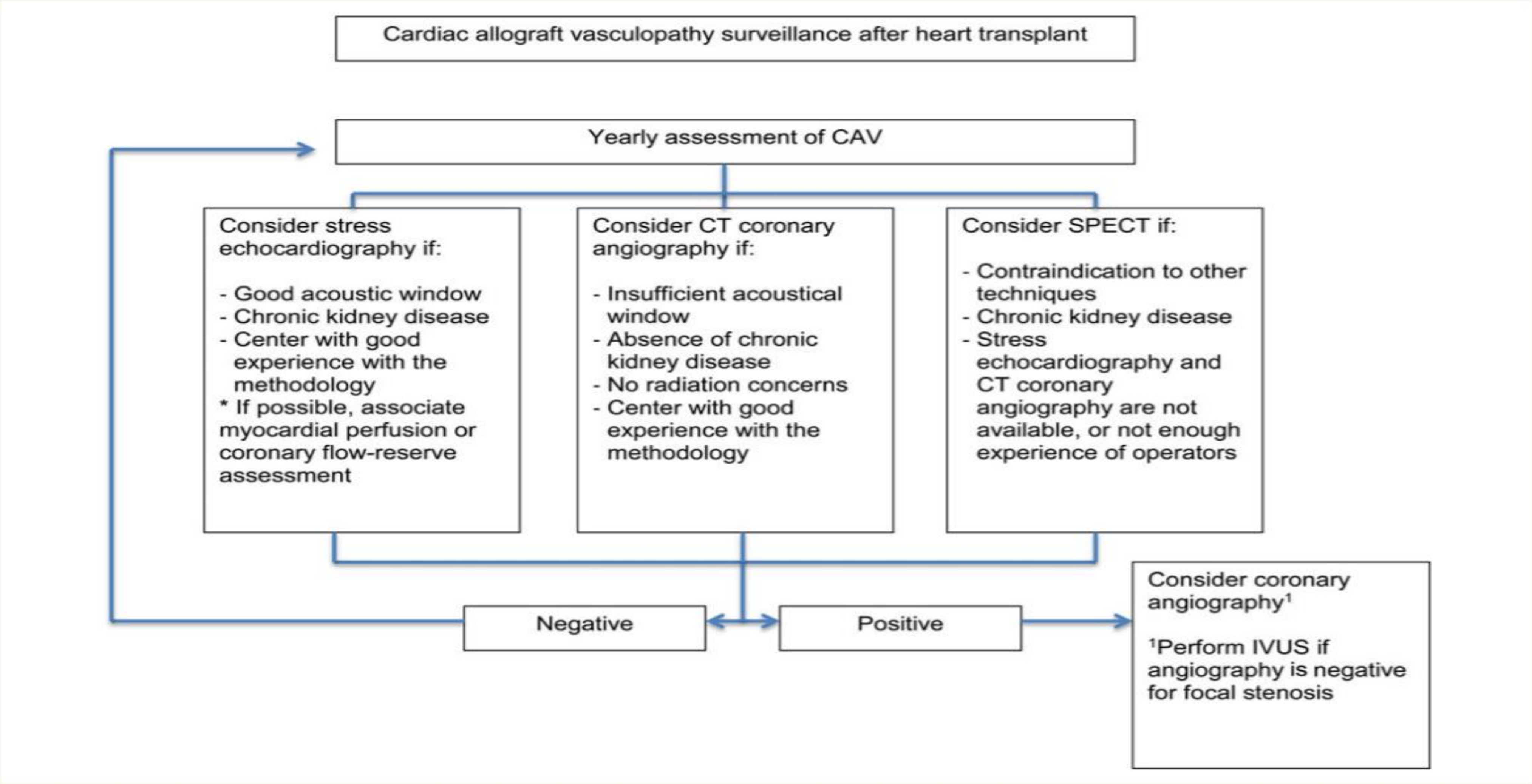

Figure 5 Flow chart summarizing the timing and imaging modalities used to monitor cardiac allograft vasculopathy after heart transplant. CAV, cardiac allograft vasculopathy; CT, computerized tomography; IVUS, intravascular ultrasound; SPECT, Single Photon Emission Computerized Tomography.

Thank You

Comment & Question