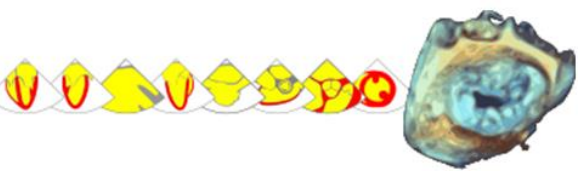
Toronto General Hospital

Perioperative Transesophageal Echocardiography Protocols

Version 4- 2019.10.31

TGH PTE Group



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License and References

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References

1. Hahn R, et al. Guidelines for Performing a Comprehensive Transesophageal Echocardiographic Examination: Recommendations from the ASE and the SCA. J Am Soc Echocardiogr 2013; 26:921-64.
2. Lang RM, et al. Recommendations for Cardiac Chamber Quantification by Echocardiography in Adults: An Update from the American Society of Echocardiography and the European Association of Cardiovascular Imaging. J Am Soc Echocardiogr 2015;28:1-39.
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Outline Cards

These cards are designed as a guide for performing an perioperative TEE exam on cardiac surgery patients at TGH.

- **Cards 1-12** contain a summary and reference values of common cardiac pathologies and procedures.
- **Cards 13-32** provide details for assessing specific cardiac pathologies.
- **Cards 33-34** are an introduction to 3D TEE.

Abbreviations

Abn: abnormal
AF: atrial fibrillation
AI: aortic insufficiency
Ao: aorta
AS: aortic stenosis
ASD: atrial septal defect
AV: aortic valve
AVA: aortic valve area
CPB: cardiopulmonary bypass
CS: coronary sinus
D: diastole
Desc: descending
Diam: diameter
DI: dimensionless index
EF: ejection fraction
EDD: end-diastolic diameter
EDV: end-diastolic volume
EROA: effective regurgitant orifice area
ESD: end-systolic diameter
ESV: end-systolic volume
FAC: fractional area change
FS: fractional shortening
FW Strain: free-wall strain
GLS: global longitudinal strain
HR: heart rate
HV: hepatic vein
IAS: interatrial septum
IVC: inferior vena cava
IVS: intraventricular septum
JW: jet width
LA: left atrium
LAA: left atrial appendage
LV: left ventricle
LUPV: eft upper pulmonary vein
LVAD: left ventricle assist device
LVH: left ventricle hypertrophy
LVOT: left ventricle outflow tract
LVOTO: left ventricle outflow tract obstruction
MAC: mitral annular calcification
MR: mitral regurgitation
MS: mitral stenosis
MV: mitral valve
MVA: mitral valve area
MVI: mitral valve inflow
N: normal
NA: not applicable
P: pressure
ΔP: change pressure
PA: pulmonary artery
PAP: pulmonary artery pressure
PFO: patent foramen ovale
PG: pressure gradient
PHT: pressure half-time
PHTN: pulmonary hypertension
PI: pulmonic insufficiency
PISA: proximal isovelocity surface area
PS: pulmonic stenosis
PulV: pulmonary vein
PVC: premature ventricular contraction
PVF: pulmonary vein flow
PVD: pulmonary vein doppler
PV: pulmonic valve
r: radius
RA: right atrium
RAA: right atrial appendage
RCC: right coronary cusp
Reg: regurgitant
RUPV: right upper pulmonary vein
RV: right ventricle
RVH: right ventricular hypertrophy
RVIO: right ventricle inflow-outflow
RVO: right ventricle outflow
RVSP: right ventricle systolic pressure
RWMA: regional wall motion abnormality
S: systole
SAM: systolic anterior motion
SEC: spontaneous echo contrast
SOV: sinus of Valsalva
STJ: sino-tubular junction
SV: stroke volume
SVC: superior vena cava
TAPSE: tricuspid annulus plane systolic excursion
TR: tricuspid regurgitation
TS: tricuspid stenosis
TV: tricuspid valve
TVA: tricuspid vale area
V: velocity
Vmax: velocity maximum
VC: vena contracta
VR: velocity ratio
VTI: velocity time integral

Common Technical Terms
2D: two-dimensional
③D: three dimensional
CFD: color flow Doppler
CWD: continuous wave Doppler
LAX: long-axis
ME: mid-esophageal
MPR: multi-planar reconstruction
PWD: pulsed wave Doppler
SAX: short axis
STE: speckle tracking echocardiography
TDI: tissue Doppler imaging
TG: transgastric
UE: upper esophageal

TEE Basic Assessment Overview

- ❑ LV size + function
  - ○ Global
  - ○ Regional
- ❑ RV size + function
- ❑ Valvular pathology
  - ○ Mitral
  - ○ Aortic
  - ○ Tricuspid
  - ○ Pulmonic
- ❑ Interatrial Septum
- ❑ Aortic atheroma
- ❑ Diastology (preCPB)
- ❑ Cannulation sites (postCPB)

- A complete intraoperative TEE exam is a study that documents the structure and function of the heart and great vessels before and after CPB.
- A focused or limited study examines a specific structure if time is limited.
- A basic TEE exam assesses specific elements (**Card 5**) recorded using the recommended 2D views (**Card 7**), CFD and spectral Doppler.
- A more detailed TEE study is required to document the presence and severity of specific pathology and findings for specific procedures (**Cards 9-32**).
- The sequence of image acquisition is less important than recording sufficient views to document findings. A sequence that minimizes probe manipulation is preferred.
- Take care to ensure image quality is optimized (gain, depth), an ECG is present and a smooth single or 2 beat video clip is stored.
- The use of 3D TEE (**Cards 33-34**) is encouraged to better display findings.

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TEE Basic Assessment

ME 4C | ME AV LAX | ME Bicaval | TG mid SAX | UE Arch LAX

5 minimum screening views in each study

❑ Left Ventricle
- LVEF/stroke volume/CO
  - Simpson's
  - ③D EF
  - Speckle tracking
- LV strain (GLS, regional)
- LV size (EDD, ESD)
- Wall thickness (LVH)

❑ Right Ventricle
- Function
  - FAC (2D, STE)
  - TAPSE
  - TDI S' velocity TV annulus
  - GLS (free wall)
- RV size (EDD, ESD)
- Wall thickness (RVH)

❑ Valvulopathy
(2D, CFD, Spectral, ③D)
- Mitral
- Aortic
- Tricuspid
- Pulmonic

Morphology
Function

❑ IAS 2D
- CFD: PFO

❑ Aorta 2D
- Atheroma

❑ Cannulation 2D, CFD
- Aorta: dissection
- Vena cava: stenosis

❑ Diastology (PWD)
- MV inflow (MVI)
- Pulmonary vein flow (PVF)
- TDI (lateral annulus MV e')

LV Size + Function [Ref 2]	Abnormal
Ejection Fraction	< 55%
GL strain	< -20%
Size: EDD/ESD	> 6.8/4.5 cm
No longer recommended: Fractional Shortening <25% Fractional Area Change <40% S' velocity MV annulus < 5cm/s	

RV Function [Ref 2]	Abnormal
Fractional Area Change	< 35%
TAPSE	< 17 mm
S' velocity TV annulus	< 9.5 cm/s
GL Strain (free wall)	< -20
Ejection Fraction (③D)	< 45%

Normal	Mitral	Aortic	Tricuspid	Pulmonic
Annulus (mm)	2.7-3.5	1.8-2.3	3.0-3.5	1.8-2.3
Peak Vel (m/s)	<1	<1-1.3	<0.7	<0.8-1
PG (mmHg)	<4	<4-6.7	<2	<2.5-4
Area (cm^2)	4-6	3-4	8-10	4-6

Diastology	I	II	III	IV
MVI: E/A	< 0.75	0.75-1.5	>1.5	>1.5
MVI: DT		> 140	<140	<140
PVF: S:D	S>D	S<D	S<D	S<D
TDI: E/e'	<10	≥10	≥10	≥10

TEE Standardized Basic Exam 2D Views

1. **ME 4C** 2D
   CFD: TV, MV
   PWD: MV
   TDI Lat MV e'
2. **ME 2C** 2D
3. **ME LAX** 2D
4. **ME AV LAX** 2D
   CFD: MV, AV
   PWD: MV
5. **ME AV SAX** 2D
   CFD: AV
6. **ME RVIO** 2D
   CFD: TV, PV
   CWD: TV (RVSP)
7. **ME Bicaval** 2D
   IAS, RAA, RUPV
   CFD: IAS, RUPV
8. **LUPV**: 2D, CFD, PWD
9. **ME LAA**: 2D, CFD, PWD
10. **TG mid SAX** 2D
    LV, RV
11. **TG 2C** 2D
    M-Mode
12. **TG LAX** 2D
    CFD: AV
    CWD: AV, PWD: LVOT
13. **Deep TG 5C** 2D
    CFD: AV
    CWD: AV, PWD: LVOT
14. **TG RV Inflow** 2D
    CFD: TV
15. **Desc Aorta SAX** 2D
16. **Desc Aorta LAX** 2D
17. **UE Arch LAX** 2D
    CFD
18. **UE Arch SAX** 2D
    PWD: PV

★ **5 minimum screening views in each study**

- Use these views to perform a complete exam and screen for pathology.
- Use the card(s) related to specific pathology for a more detailed assessment.
- Biplane images of views can reduce the number of clips recorded.
- Consider color compare to simultaneously record 2D and CFD.

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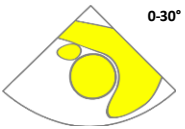
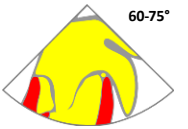
Basic 2D TEE Views [Ref 1]

ME Five Chamber (5C)

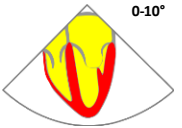


ME Ascending Aorta SAX



ME Left Atrial Appendage (LAA)

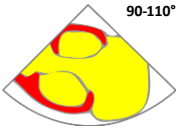
TG Two Chamber (2C)



ME Four Chamber (4C)

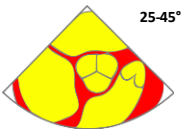
ME R Pulmonary Vein

TG Basal SAX



TG RV Inflow

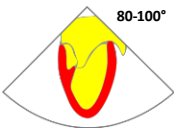
ME Mitral Commissural (MC)



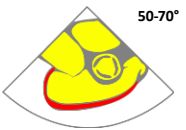
ME Aortic Valve (AV) SAX

TG mid-papillary SAX

TG LAX

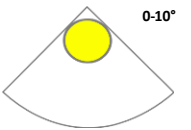


ME Two Chamber (2C)

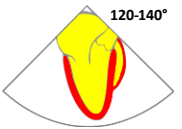


ME RV Inflow-Outflow

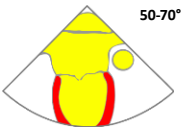
TG Apical SAX



Descending Aorta SAX

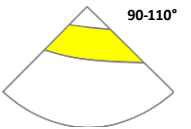


ME LAX



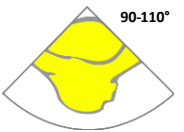
ME Modified Bicaval TV

TG RV Basal



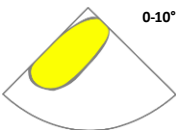
Descending Aorta LAX

ME Aortic Valve (AV) LAX

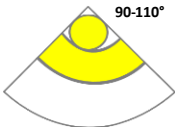


ME Bicaval

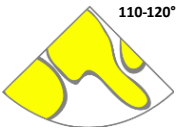
TG RV Inflow-Outflow



UE Aortic Arch LAX

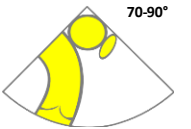


ME Ascending Aorta LAX



UE R + L Pulmonary Veins

Deep TG Five Chamber (5C)

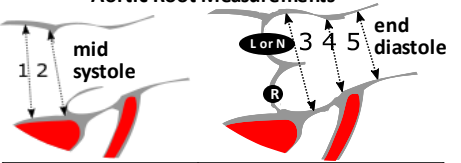


UE Aortic Arch SAX

Aortic Valve Summary

- **ME AV LAX** 2D, ③D
  - Valve morphology
  - CFD AV + LVOT
  - Root Measurements
- **ME AV SAX** 2D, ③D
  - Valve morphology
  - CFD
- **Deep TG 5C/TG LAX** 2D
  - CFD
  - PWD LVOT
  - CWD AV
- **Aorta Desc/Asc** 2D
  - CFD
  - PWD

Aortic Root Measurements



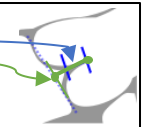
1. LVOT
2. AV Annulus
3. Sinus Valsalva
4. STJ
5. Ascending aorta

ME AV LAX view

For accurate measure of AV annulus use ③D MPR or turn probe so upper cusp is not seen. For Asc Ao withdraw probe + reduce angle to 110°

Valve Sparing Post CPB

- **Coaptation length** (>8mm)
- **Effective AV Height** (>9mm)
- Residual AI
- LV function, RWMA
- AV PG (peak, mean)



Aortic Stenosis

- ❑ **Mechanism** (2D SAX/LAX)
  - Sub/valve/supra: 2D, CFD
- ❑ **Severity**
  - Velocity peak, PG mean
  - AVA: $VTI_{lvot} \times 0.785 D_{lvot}^2 / VTI_{AV}$
  - VR: $Vmax_{lvot} / Vmax_{AV}$
  - DI: VTI_{lvot} / VTI_{AV}
  - Low flow/low gradient AS
  - Planimetry: 2D, ③D
- ❑ **Associated**
  - LV: LVH, function, LVOTO
  - MV pathology, MR
  - Aorta path (aneurysm, coarct)
  - Diastolic dysfunction
  - PHTN, TR

AS Severity [Ref 3]	Mild	Mod	Severe
Velocity peak (m/s)	2.6-2.9	3.0-4.0	≥4.0
PG mean (mmHg)	<20	20-40	≥40
AVA (cm^2)	1.5-2.0	1.0-1.5	<1.0*
AVA Index (cm^2/m^2)	>0.85	0.6-0.85	<0.6
VR or DI	>0.50	0.25-0.50	<0.25

VR, velocity ratio; DI, dimensionless index

Low flow AS (low EF) or low gradient AS (normal EF): AVA ≤1cm^2, Vel peak <4m/s, PG mean <40mmHg

- If low EF → Dobutamine echo
- If normal EF → Stroke volume index (SVI) <35cc/m^2

Aortic Insufficiency

- ❑ **Mechanism** (2D SAX/LAX)
  - Valve
  - Aorta
  - Jet direction
- ❑ **Severity**
  - PHT CWD
  - Vena Contracta: 2D, ③D
  - Jet width/LVOT
  - Desc Ao flow reversal
  - Reg Volume, Reg Fraction
  - EROA: 2D, ③D
- ❑ **Associated**
  - LV: size, function
  - MV flutter, closure

AI Severity [Ref 4]	Mild	Mod	Severe
Jet Width (%LVOT)	<25	25-64	≥65
Vena Contracta (mm)	3	3-6	>6
PHT (ms)	>500	200-500	<200
Reg Volume (cc/beat)	30	30-59	≥60
Reg Fraction (%)	<30	30-49	≥50
EROA (cm^2)	<0.10	0.10-0.29	≥0.30

Reg Volume = LV SV – MV SV = $(CSA_{LVOT} \times VTI_{LVOT}) - (CSA_{MV} \times VTI_{MV})$

Reg Fraction = Reg Volume/MV SV

EROA: PISA = $\frac{2\pi r^2 \times \alpha \text{ angle}/180° \times \text{Valias}}{\text{V peak AI}}$ **or** = $\frac{\text{Reg Volume}}{\text{VTI AI}}$

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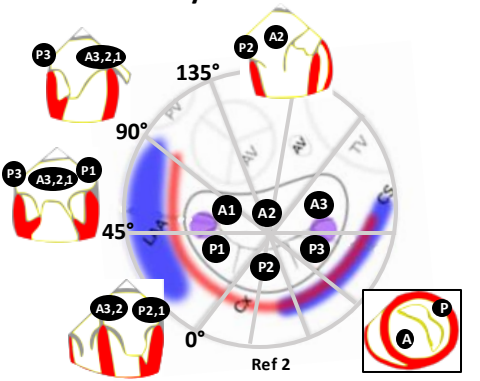
Mitral Valve Summary

- **ME 4C** 2D
- **ME MC** 2D
- **ME 2C** 2D
- **ME AV LAX** 2D
- Zoom or reduce depth
- In any view assess
  - Leaflet motion
  - CFD (50-60cm/s)
  - Annulus diameter
  - PWD MV or CWD MR
- **LAA** 2D, CFD, PWD
- **RUPV/LUPV** CFD, PWD
- **ME Bicaval** 2D, CFD
- **TG Basal SAX** 2D, CFD
- **TG mid SAX** 2D
- **TG 2C** 2D
- **③D MV enface**



Post MV Repair (2D, ③D, CFD, PWD)

- Coaptation point
- Coaptation length
- Residual MR
- MV PG PWD
- SAM, LVOTO
- LV function, RWMA
- New AI
- Cannulation sites

Mitral Stenosis

- ❑ **Mechanism** (2D, ③D)
  - Rheumatic, calcific
- ❑ **Severity**
  - PG mean
  - MVA: planimetry, PHT, PISA
  - PAP (RVSP)
- ❑ **Associated**
  - LA size, SEC, thrombus
  - PHTN, TR, RV dilated
  - MR

MS Severity Ref 4	Mild	Mod	Severe
MVA (cm^2)*	>1.5	1.0-1.5	< 1.0
PG mean (mmHg)**	<5	5-10	>10
PAP (mmHg)	<30	30-50	>50

*ESC guidelines MVA < 1.5 significant MS, < 1.0 severe
**No longer in 2014 AHA guidelines

MVA: PISA = $\frac{2\pi r^2 \times \alpha \text{ angle}/180° \times \text{Valias}}{\text{V peak MS}}$ **or** = $\frac{220}{\textbf{PHT}}$

Mitral Regurgitation

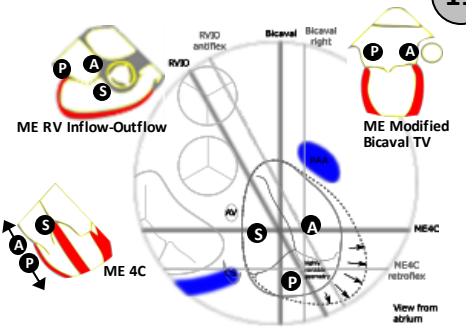
- ❑ **Mechanism** (2D, ③D)
  - Valve (1°)
  - Functional (2°)
- ❑ **Severity**
  - Vena Contracta: 2D, ③ D
  - Flow Convergence (PISA)
  - Pulmonary Vein Doppler
  - Reg Volume, Reg Fraction
  - EROA
  - CWD: signal strength, shape
- ❑ **Associated**
  - LV: size, function
  - LA dilated
  - TV annulus, TR

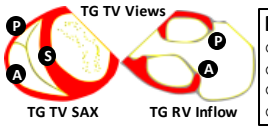
MR Severity Ref 3	Mild	Mod	Severe
Jet Area	small	variable	large
Vena Contracta (mm)	<3	Inter	≥7
Flow Convergence	small	Inter	large
Pulmonary Vein	normal	blunt	reverse
Reg Volume (cc/beat)	<30	30-59	≥60
Reg Fraction (%)	<30	30-49	≥50
EROA (cm^2)	<0.20	0.20-0.39	≥0.40

Reg Volume = LV stroke volume – AV SV or LVOT SV
Reg Fraction = Reg Volume/LV SV
EROA: PISA = $\frac{2\pi r^2 \times \alpha \text{ angle}/180° \times \text{Valias}}{\text{V peak MR}}$ **or** = $\frac{\text{Reg Volume}}{\text{VTI MR}}$

Tricuspid Valve Summary

- **ME 4C** 2D
- **ME RV In/Outflow** 2D
- **ME Bicaval mod TV** 2D
- **ME CS LAX** 2D
- Zoom or reduce depth
- In any view assess
  - Leaflet motion
  - CFD (50-60cm/s)
  - CWD TR
  - Annulus diameter (0°)
- **IVC LAX:** 2D, CFD
  - PWD hepatic vein
- **TG Basal SAX** 2D, CFD
- **TG RV Inflow** 2D, CFD





Post TV Repair
- Annulus size
- Residual TR
- RV function, RWMA
- TV mean PG PWD

Tricuspid Stenosis

- ❑ **Mechanism** (2D)
  - Rheumatic, congenital
- ❑ **Severity**
  - PG mean
  - TV inflow VTI
  - TV Area (PHT, continuity)
  - PHT
- ❑ **Associated**
  - TR
  - RA size, SEC, thrombus
  - IVC dilated

TS Severity [Ref 3]	Significant
PG mean (mmHg)*	≥ 5
TV Inflow VTI (cm)	> 60
PHT (msec)	≥ 190
TVA (cm²)	≤ 1.0

*NSR 70-80bpm

TVA: Continuity = $\frac{\text{AV VTI} \times 0.785(\text{AV diam})^2}{\text{TV VTI}}$ **or** = $\frac{190}{\text{PHT}}$

Supportive: dilated RA ≥ moderate, dilated IVC

Tricuspid Regurgitation

- ❑ **Mechanism** (2D SAX/LAX)
  - Functional (2°):
    - Annulus: 2D, ③D
  - Valve (1°)
- ❑ **Severity**
  - TR CWD density
  - Jet area
  - Vena Contracta: 2D, ③D
  - PISA radius
  - EROA: 2D, ③D
  - Reg Volume
  - Hepatic Vein S wave PWD
- ❑ **Associated**
  - RV: size, function
  - RA size
  - IVC dilated

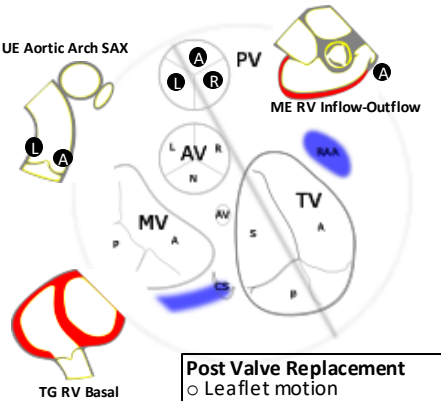
TR Severity [Ref 4]	Mild	Mod	Severe
CWD TR	soft	dense	dense
Jet Area (cm²)	NA	NA	>10
Vena Contracta (mm)	<3	<3-6.9	≥7
PISA radius (mm)	≤5	6-9	>9
EROA (cm²)	<0.2	0.2-0.39	≥0.4
Reg Volume (cc/beat)	<30	30-44	≥45
Hepatic Vein S wave	Norm	Blunted	Reverse
IVC size (cm)	<2	2.1-2.5	>2.5

Reg Volume = TV VTI x TVA – RV (or LV) stroke volume

EROA: PISA = $\frac{2\pi r^2 \times \alpha \text{ angle}/180^\circ \times \text{Valias}}{\text{Peak V TR}}$ **or** = $\frac{\text{Reg Vol}}{\text{VTI TR}}$

12 Pulmonic Valve Summary

- **ME RVIO** 2D
- **UE Ao Arch SAX** 2D
- **TG RV Basal** 2D
- Zoom or reduce depth
- In any view assess
  - Leaflet motion
  - CFD (50-60cm/s)
  - Annulus diameter
  - PWD/CWD PV Inflow
- **Asc Aorta SAX**
  - PA CWD
- **ME 4C** 2D
  - TV: CFD, CWD, annulus
  - RV: size, function



Post Valve Replacement
- Leaflet motion
- PG mean PWD
- Valvular or paravalvular leak
- RV function, RWMA
- LV RWMA: LAD, Left main

Pulmonic Stenosis
- ❑ **Mechanism** (2D)
  - Calcific, congenital
  - Previous surgery
- ❑ **Severity**
  - Velocity peak
  - PG peak
- ❑ **Associated**
  - RV size, RVH
  - RV function
  - PI
  - TV morphology
  - TR (RVSP)
  - PA morphology

PS Severity Ref 3	Mild	Mod	Severe
Leaflets	N	Abn	Abn
RV Hypertrophy	N	Mild	Mod
Velocity peak (m/s)	<3	3-4	>4
PG peak (mmHg)	<36	36-64	>64

Pulmonic Insufficiency
- ❑ **Mechanism** (2D)
  - Valve
    - Previous surgery
  - Functional (PHTN)
- ❑ **Severity**
  - Jet width (JW)/RVOT diam
  - Ratio PI VTI / LVOT VTI
  - CWD density, DT, PHT
  - PA flow reversal
- ❑ **Associated**
  - RV size: EDD, ESD
  - RV function
  - RA size
  - TR (RVSP)
  - TV morphology
  - PA morphology

PI Severity Ref 4	Mild	Mod	Severe
Leaflets	N	± Abn	Abn
RA/RV/annulus size	N	± Abn	Dilated
JW/PV annulus (%)	NA	NA	>70
PI VTI/ LVOT VTI	↑		↑↑
Reg Fraction (%)	< 20	20-40	>40
CWD signal	Soft	Dense	Dense
Deceleration rate	Slow	Variable	Steep

Other Indicators Severe PI
- CFD: broad origin of jet, variable penetrance into RV
- PWD: PI jet deceleration time (DT) < 260ms (short)
- PWD: Pressure half-time of PI jet <100 msec
- PWD: PR index <0.77 = duration PR/duration diastole
- PWD: Diastolic flow reversal in main or branch PA

Prosthetic Valve [Ref 5]

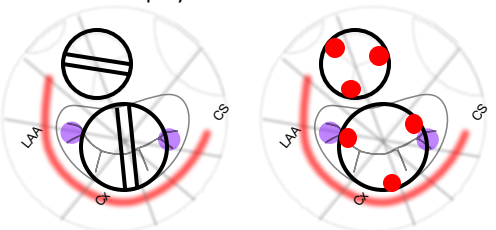
Post Valve Replacement (2D, ③D, CFD, PWD)

Valve
- Leaflet motion
- Washing jets
- Velocity
- Pressure gradients
  - Peak, mean

Complications
- RV function
- LV function, RWMA
- Paravalvular leak
  - Location (2D, ③D)
  - Severity
- Mobile sutures
- Cannulation sites

Valve Orientation

As displayed in MV enface view



Bileaflet Mechanical **Stented Bioprosthetic**

Prosthetic Valve Pressure Gradients

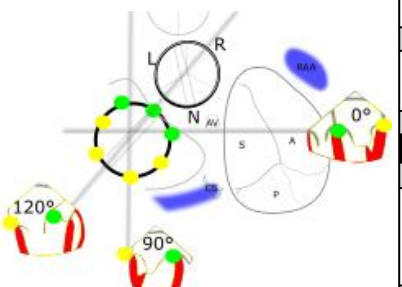
Type	Mitral			Aortic*		
	Vmax (m/s)	Pmax (mmHg)	Pmean (mmHg)	Vmax (m/s)	Pmax (mmHg)	Pmean (mmHg)
Bileaflet	1.6 ± 0.3	10 ± 3	4 ± 1	2.4 ± 0.3	25 ± 5	12 ± 6
Tissue	1.5-1.8±0.2	9-12 ± 3	4-6 ± 2	2.5 ± 0.5	23 ± 8	14 ± 5
Stentless	none	none	none	2.2	19	3 ± 1

*PG varies with valve size (aortic position): 19mm (20mmHg), 23mm (12mmHg).

Paravalvular Leak

Mitral Position

Use multiple 2D views or single 3D enface view with CFD, location by clock face or native valve



Aortic Position

Best examined in ME AV SAX/LAX or TG views
Report leaks in relation to AV SAX

Tissue

Stented

Porcine	Bovine Pericardium
CE Duraflex	CE Perimount
Medtronic Hancock	CE Magna Ease
Medtronic Mosaic	Medtronic Avalus
SJM Epic	SJM Trifecta

Stentless

Edwards Prima Plus (porcine)
Medtronic Freestyle (porcine)
TAVR: Edwards Sapien, Medtronic CoreValve

Homograft: aortic, mitral

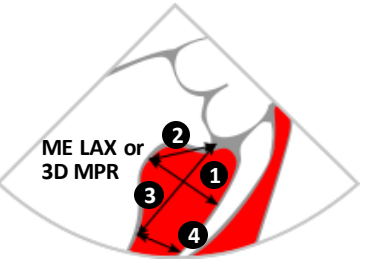
Mechanical

Tilting Disc	Bileaflet
Medtronic Hall	Edwards MIRA
Sorin Allcarbon	On-X
	Sorin Bicarbon
	SJM Regent
	Sorin Carbomedics

These valves are no longer implanted
- Stentless: SJM T-SPV
- Caged Ball: Starr-Edwards
- Tilting Disc: Bjork-Shiley

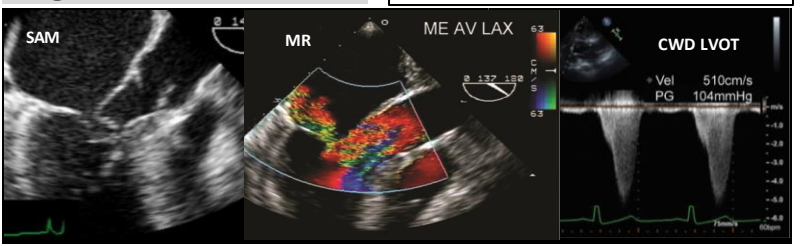
14 Septal Myectomy Procedure

- **ME AV LAX** 2D
  - CFD (50-60cm/s)
    - LVOT: turbulence
    - MV: MR
    - AV: AI
    - Mid-cavitary turbulence
  - Leaflet motion MV: SAM
  - Measurements septum
  - CWD: mid-cavitary PG
  - Papillary muscle anomaly
- **ME 4C** 2D
  - CFD MV, LVOT
  - SAM
- **ME LAX** 2D
  - CFD mid cavity, LVOT
- **Deep TG 5C/ TG LAX** 2D
  - CWD LVOT/AV
- **TG SAX** 2D
- **±③D AoRoot + LVOT**



Measure end-diastole: AV + MV closed
Imaging plane perpendicular to IVS
Define extent of myectomy

1. Septal thickness
2. Distance from RCC base
3. Length of thickening
4. Distal septal thickness



PreCPB Assessment

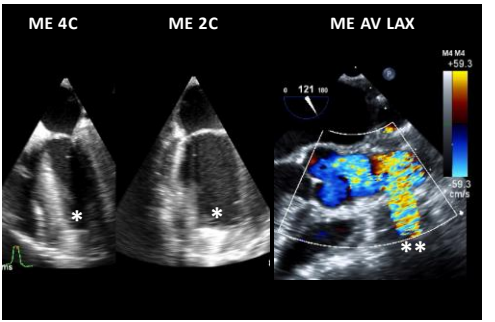
- ❑ **Severity**
  - LVOT Velocity peak
  - LVOT PG peak
  - Septal thickness
  - SAM
  - MR: severity, jet direction
- ❑ **Associated**
  - LVH
  - LV function
  - Papillary muscle insertion
  - AV cusp flutter
  - Diastology

PostCPB Assessment

- ❑ **Assessment**
  - Laminar LVOT flow
  - No residual SAM
  - LVOT PG (rest, post PVC)
  - Residual MR (severity)
  - Septal thickness
- ❑ **Complications**
  - VSD iatrogenic
  - LV function, RWMA
  - AI (AV injury)
  - Septal perforators
  - Papillary muscle injury

LVAD Implantation Procedure [Ref 6]

- **ME 4C** 2D
  - LV apex
  - RV size, function
  - CFD (50-60cm/s)
    - TV: TR
    - MV: MS
    - IAS: PFO
  - CWD TR (RVSP)
- **ME RV In/Outflow** 2D
  - RV function
  - CFD TV, PV
- **ME 2C** 2D
  - LV apex
  - LAA: CFD, PWD
- **ME AV LAX** 2D
  - CFD AV: AI
- **ME Bicaval**
  - CFD IAS, bubble study
- **TG SAX** 2D
  - RV function



LV Cannula* (Inflow)	Aortic Cannula** (Outflow)
○ Center of LV apex ○ Directed towards MV ○ Orifice free of LV walls ○ CFD: laminar ○ PWD ≤ 1.5m/s	○ Ascending aorta ○ CFD: turbulent ○ PWD ≤ 2m/s
Note: **Heartware** device unable to obtain flow measurements due to artifact	

PreCPB Assessment (S.T.A.R.T.)

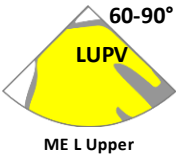
- ❑ **Shunts**: IAS (PFO, ASD)
  - CFD
  - Bubble study
- ❑ **Thrombus**: LV, LAA
  - Zoom LV apex, LAA
  - ± Contrast
- ❑ **Aortic Insufficiency**
  - CFD (ME AV LAX, SAX)
    - > mild: fix
- ❑ **RV** size, function
- ❑ **TV** annulus size, TR
  - CFD TR: vena contracta
    - Mod-severe: fix
  - Annulus measure (2D, ③D)
    - > 43mm: fix
  - CWD TR (RVSP)
- ❑ **Other**
  - MS (< mod), PI (< mod)
  - Aortic pathology
  - Prosthetic valves

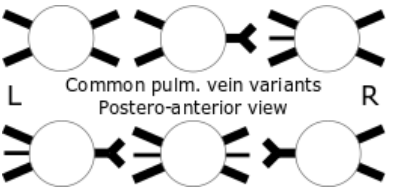
PostCPB Assessment

- ❑ **Assessment**
  - Air
  - LV decompression
    - Septum midline
  - RV size, function
  - TV: TR, RVSP
  - AV opens (1/x beats)
    - AI severity
  - PFO
- ❑ **Cannula**
  - Inflow (LV)
  - Outflow (aorta)
    - Position 2D
    - CFD
    - CWD/PWD
- ❑ **Complications**
  - Suction event
    - LV cavity obliterated
  - Effusion, Tamponade
  - Cannula occlusion

Lung Transplantation Procedure

- **ME 4C** 2D
- **ME RVIO** 2D
  - RV size, function
  - CFD (50-60cm/s)
    - TR: vena contracta
    - IAS
  - CWD TR (RVSP)
- **Asc Ao SAX** 2D
  - PA: PWD → Vmax, ΔPpeak
  - PV: PWD → Vmax, ΔPpeak
- **Pulmonary Veins**
  - 2D
  - CFD
  - PWD
- **TG SAX** 2D
  - RV function
  - LV function





PreCPB/Implant Assessment

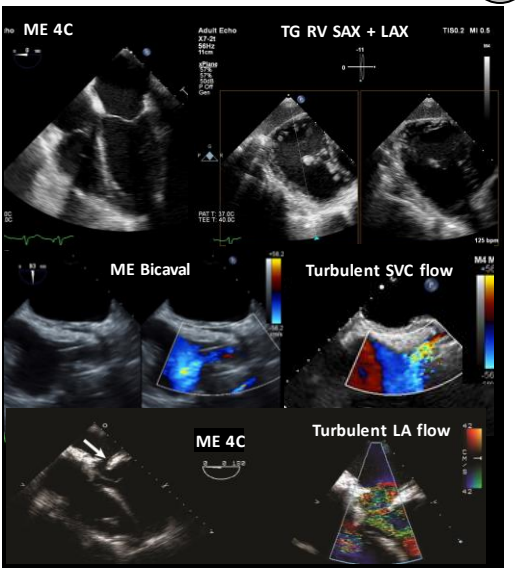
- ❑ **RV** size, function
- ❑ **TV**
  - CFD TR
  - CWD TR (RVSP)
- ❑ **PV**
  - CFD: PI
- ❑ **Shunts**: IAS (PFO,ASD)
  - CFD
  - Bubble study
- ❑ **Pulmonary veins**
  - CFD
  - PWD
- ❑ **PA 2D, CFD**
  - Size 1.0-1.7cm
- ❑ **Other**
  - LV function
  - Valve disease

PostCPB/Implant Assessment

- ❑ **RV** size, function
- ❑ **TV**
  - CFD TR
  - CWD TR (RVSP)
- ❑ **PV**
  - CFD: PI
- ❑ **Pulmonary veins stenosis if:**
  - Size: < 5mm
  - PWD: > 1m/s (peak velocity)
  - PV to LA PG (>10-12mmHg)
- ❑ **Pulmonary artery stenosis if**
  - Size: < 75% of 1.1-1.7cm
  - CFD: turbulent flow
- ❑ **ECMO**
  - Venous cannula: IVC, RA
  - Arterial cannula
- ❑ **Complications**
  - Pulmonary vein obstruction
  - Pulmonary artery obstruction
  - LV dysfunction

Heart Transplantation Procedure

- **ME 4C** 2D
  - Ventricular Function
    - Smoke, thrombus
  - CFD (50-60cm/s)
    - TV: TR
    - MV: MR
  - CWD TR (RVSP)
- **ME RV In/Outflow**
  - RV function
  - CFD TV, CWD TR
- **ME 2C** 2D
  - LV size, function
- **ME LAX** 2D
  - LV size, function
- **ME Bicaval**
  - SVC flow
  - IVC flow
- **ME Asc Aorta SAX**
  - Main PA flow
- **TG SAX** 2D
  - RV + LV function



PreCPB Assessment
(Minimal preCPB study pre explant)

- ❑ **Dilated Ventricles**
  - Thinned myocardium > 6mm
  - Smoke, thrombus
- ❑ **Caval Size**
- ❑ **Persistent Left SVC**
- ❑ **Tricuspid Regurgitation (TR)**
  - Estimate PASP, PVR
- ❑ **VAD Explant (LVAD, BiVAD)**
- ❑ **Pleural Effusion**
- ❑ **Pacer wires**

Complications

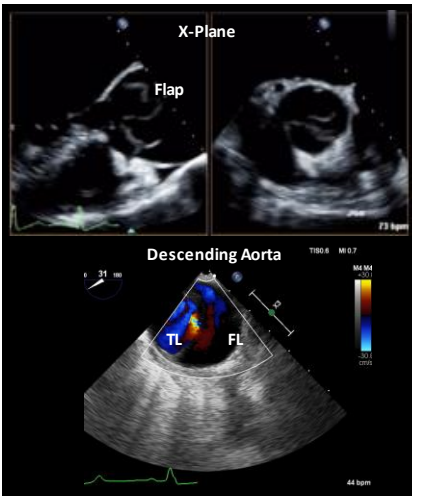
- Ventricular dysfunction (RV, LV)
  - Biventricular (?rejection)
  - RV due to PHTN
- Anastomoses stenosis: Cava, LA
- Pulmonary vein distortion
- Effusions: Pleural, Pericardial

PostCPB Assessment

- ❑ **Deairing**
- ❑ **LV Function**
  - Global
  - Regional
- ❑ **RV Dysfunction**
  - Dilated
  - Regional wall motion
  - IVS septal bowing
  - Reduced TAPSE
  - RV strain
- ❑ **Tricuspid Regurgitation**
  - Estimate PASP
- ❑ **Mitral Regurgitation**
- ❑ **PFO**
- ❑ **Anastomosis**
  - LA (tissue)
  - Pulmonary vein (CFD, PW)
  - SVC, IVC (size, CFD)
  - Aorta
  - Pulmonary artery

18 Aortic Dissection Procedure

- **ME AV LAX** 2D
  - Dissection flap
    - Location
    - Intimal tears
  - AV structure
  - Aortic Root dimensions
  - CFD (50-60cm/s)
    - AV: AI
    - Coronary perfusion (R)
- **ME Ascend Aorta LAX/SAX** 2D
- **UE Arch SAX/LAX** 2D
  - Intimal flap, tear
  - True and false lumens
- **Descending Aorta SAX/LAX** 2D
  - L pleural effusion
- **ME AV SAX** 2D
  - AV structure, CFD: AI
  - Right coronary perfusion
- **ME 4C and TG SAX** 2D
  - RV, LV size and function
  - Pericardial effusion



PreCPB Assessment

- ❑ **Intimal Flap**
  - Identify flap origin
  - Identify extent of flap
    - Arch
    - Descending aorta
  - 2D and Mmode
- ❑ **Intimal Tear**
  - Location(s), 90% near AV
  - CFD flow between lumens
- ❑ **True lumen**
- ❑ **False lumen**
- ❑ **Aortic dilatation/aneurysm**
- ❑ **Complications**
  - Ventricular dysfunction
    - Global
    - Regional
  - Coronary dissection
  - Aortic insufficiency
    - Mechanism
    - Severity
  - Pericardial effusion
  - Pleural effusion

Peri/PostCPB Assessment

- ❑ **Arterial Cannulation**
  - Femoral, axillary, LV apex
- ❑ **Aortic Repair Type**
  - Aortic root, Ascending aorta
  - Arch or hemi-arch
- ❑ **Aortic Valve**
  - Sparing, residual AI
  - Replacement
- ❑ **Ventricular function**
  - Regional, global

True Lumen (TL)	False Lumen (FL)
• Smaller lumen	• Larger lumen
• Circular	• Crescent shape
• Expands in systole	• Expands in diastole
• CFD prominent	• CFD less prominent
• No smoke or clot	• Smoke or clot present
Intimal Flap	**AI Mechanism**
• Discrete edge	• Flap disrupts STJ
• Oscillating	• Flap prolapse AV
• Interrupts CFD	• Aortic dilatation
• Not outside aorta	• Intrinsic AV path

Left Ventricle Anatomy and Views [Ref 2]

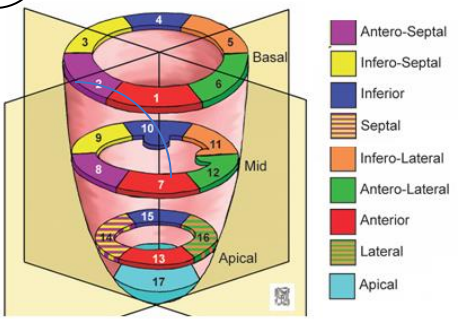
- **LV Function**
  - Systolic: Global, Regional
  - Diastolic
- **LV Dimensions**
  - EDD, ESD
  - Wall thickness
- **Associated**
  - MV annulus size
  - MR
  - LA size
  - AV/LVOT cardiac output

LV Systolic Function	Abnormal
Ejection Fraction	< 55%
Mild	40-49%
Moderate	30-39%
Severe	<30%
GL strain	< -20%

No longer recommended:
Fractional Shortening (<25%)
Fractional Area Change (<40%)
S' velocity MV Annulus < 5cm/s

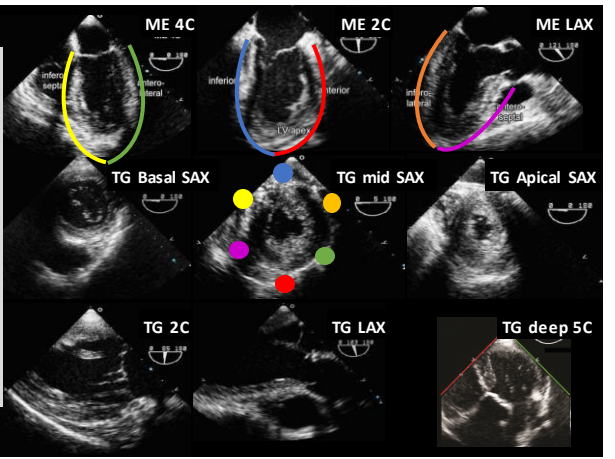
LV Anatomy Normal

- Geometric shape ellipse
- Inlet, apex, outlet portions
- 17 segment model (shown)
- 16 and 18 models exist
- TG and ME views
- TG views to measure size
- Examine regional wall motion and thickening
- Systolic/diastolic function



LV Views

- ME 4C
- ME 2C
- ME LAX
- TG Basal SAX
- TG Mid SAX
- TG Apical SAX
- TG 2C
- TG LAX
- TG deep 5C



20 Left Ventricle Size and Systolic Function

LV Size [Ref 2]	Female				Male			
Diameter Index (diameter/BSA)	Refer. range	Mild	Moderate	Severe	Refer. range	Mild	Mod	Severe
Diastole, cm	3.8-5.2	5.3-5.6	5.7-6.1	**> 6.2**	4.2-5.8	5.9-6.3	6.4-6.8	**> 6.8**
Diastole index, cm/m²	2.2-3.1	3.2-3.4	3.5-3.7	**> 3.7**	2.2-3.0	3.1-3.3	3.4-3.6	**> 3.6**
Systole, cm	2.2-3.5	3.6-3.8	3.9-4.1	**> 4.1**	2.5-4.0	4.1-4.3	4.4-4.5	**> 4.5**
Systole index, cm/m²	1.3-2.1	2.2-2.3	2.4-2.6	**> 2.6**	1.3-2.1	2.2-2.3	2.4-2.5	**> 2.5**
LV volume								
Diastolic, mL	46-106	107-120	121-130	**> 130**	62-150	151-174	175-200	**> 200**
Diastolic index, mL/m²	29-61	62-70	71-80	**> 80**	34-74	75-89	90-100	**> 100**
Systolic, mL	14-42	43-55	56-67	**> 67**	21-61	62-73	74-85	**> 85**
Systolic index, mL/m²	8-24	25-32	33-40	**> 40**	11-31	32-38	39-45	**> 45**

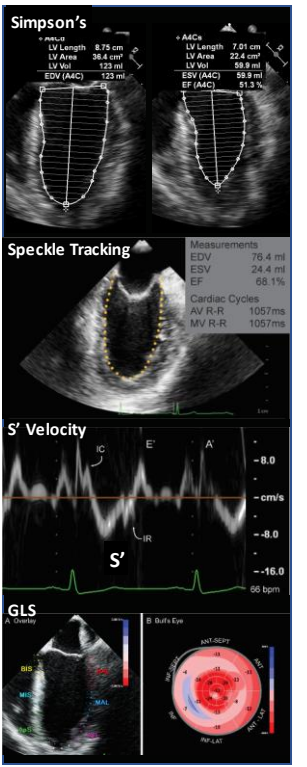
Simpson's (EF)
- Acquire 2D ME 4C + 2C
  - Increase gain to highlight endocardial border
- Use software to trace endocardial border in S and D
  - Identify LV apex
  - Exclude papillary muscles
- Obtain EDV, ESV, stroke volume, EF

Speckle Tracking (EF)
- Acquire 2D ME 4C + 2C, FR > 50Hz, similar HR
  - Increase gain to highlight endocardial border
- Use software (2DQ)
  - Identify MV annular and LV apex points
- Software automatically tracks, edit if needed
- Obtain EDV, ESV, stroke volume, EF

3D EF
- Acquire Full volume 3D dataset ME 4C + 2C
  - Increase 2D gain to highlight endocardial border
  - Multi-beat (4-6) to increase FR
  - Avoid stitch artifact
- Use software 3DQ (basic) or A3DQ (advanced) models
  - Identify MV annular and LV apex points
  - Software automatically tracks, edit if needed
- Obtain EDV, ESV, stroke volume, EF

S' velocity MV lateral annulus
- ME 4C use TDI pre-set
- Narrow sector, TDI color to identify myocardium
- PW Doppler on myocardium below annulus
- Obtain spectral trace and measure S' velocity

Global Longitudinal Strain (GLS)
- Acquire 2D ME views (4C, 2C, LAX)
- Open CMQ software
- Position points at mitral annulus + LV apex
- Software automatically tracks, edit if needed
- Display bull's eye for regional and GLS

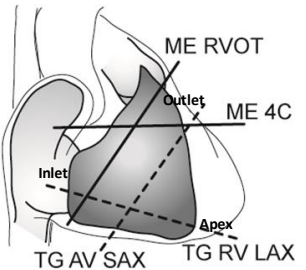


Right Ventricle Anatomy and Views [Ref 2]

- ❑ **RV Function**
- ❑ **RV Dimensions**
  - EDD
  - RV apex
  - Wall thickness
- ❑ **Associated**
  - TV annulus size
  - TR
  - RVSP
  - RA size

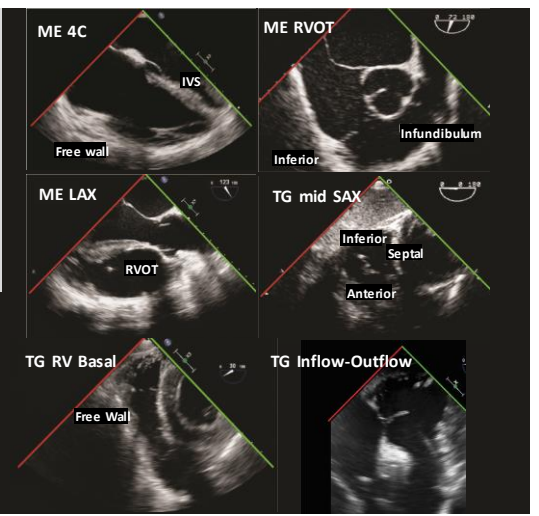
RV Anatomy Normal

- Nongeometric shape
- Inlet, apex, outlet portions
- TG and ME views
- ME views for size measurement
- Examine regional wall motion



RV Views

- ME 4C
- ME RVOT
- ME LAX
- TG mid SAX
- TG RV Inflow
- TG RV Basal
- TG Inflow Outflow



22 Right Ventricle Function and Size [Ref 2]

Parameter [Ref 2]	Abnormal
FAC	< 35%
TAPSE	< 17 mm
S' Velocity TV annulus	< 9.5 cm/s
GLS Free Wall	< -20

Measures (mm)	Abnormal
EDD Basal (ME 4C)	> 42
EDD Mid (ME 4C)	> 35
Wall Thickness (TG)	> 5

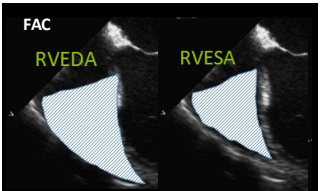
Fractional Area Change (FAC)
- Acquire 2D ME 4C rotate to show RV
  - Increase gain (endocardium)
  - Retroflex (RV apex)
- Trace endocardial border to TV annulus in S + D
  - Exclude papillary muscles
  - Obtain ED and ES areas
- Calculate **FAC = EDA – ESA / EDA**

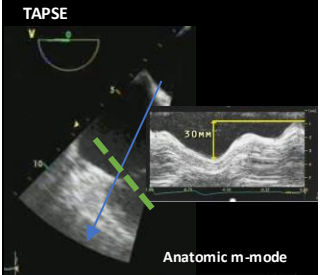
Speckle Tracking FAC
- Acquire 2D ME 4C view of RV as above
- Use software (2DQ)
  - Change to area from volume measurement
  - Mark points TV annulus + RV apex
- Software tracks RV area, display FAC
  - Edit if needed to track endocardium

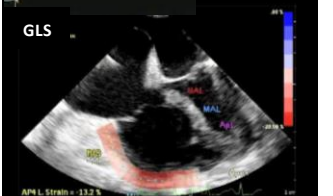
Tricuspid Annular Plane Systolic Excursion (TAPSE)
- Acquire 2D ME 4C view of RV
  - Narrow sector size to TV lateral annulus
- Activate m-mode sample line
  - Align parallel to annular movement
  - Use anatomic m-mode (if available)
- Measure TAPSE
  - Identify similar lower + upper portions

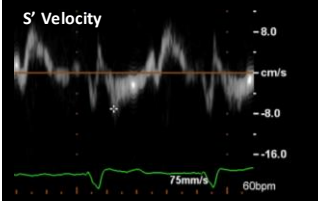
Global Longitudinal Strain (GLS) Free Wall
- Acquire ME 4C 2D view of RV
- Activate CMQ preset
  - Mark points TV annulus + RV apex
- Software automatically tracks, edit if needed
  - Obtain GLS that includes IVS
  - Edit to eliminate the IVS for GLS free wall

S' Velocity TV lateral annulus
- TG RV LAX as difficult alignment in ME 4C
- Activate TDI
  - Use TDI color to identify myocardium
- PW Doppler
  - Sample volume on myocardium parallel to motion
- Obtain spectral trace
- Measure S' velocity









PreCPB

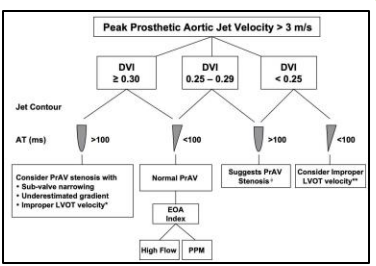
- **Mechanism/Level**
  - Subvalvular/Valvular/Supravalvular
- **Etiology**
  - Calcific, rheumatic, bicuspid
- **Severity**
  - Pressure Gradient mean
  - Aortic Valve Area
  - Velocity Ratio
- **Associated**
  - LV size, function, LVH
  - LVOTO, IVS hypertrophy
  - Aorta aneurysm or coarctation
  - Mitral Valve pathology
  - TV/TR/RVSP
- **Root Dimensions**

AS Views

- **ME AV SAX**
- **ME AV LAX**
- **Deep TG 5C**
- **TG LAX**
- **TG mid SAX**
- **ME Asc Ao LAX**
- **± ③D AV**

PostCPB

- **Prosthetic Valve**
  - Valve function
  - Pressure gradient
  - Valvular regurgitation
  - Paravalvular leak
- **LV Function**
- **Complications**
  - LVOT obstruction/SAM
  - VSD



Use TG views to best assess prosthetic valve function, measure PG and evaluate for paravalvular leaks

24 Aortic Stenosis Assessment

- ❑ **Mechanism** (2D, CFD: LAX/SAX)
  - Sub/valve/supra
  - Etiology: calcific, rheumatic
- ❑ **Severity**
  - Velocity peak
  - PG mean
  - AV Area
  - Velocity Ratio or DVI
- ❑ **Associated**
  - LV: LVH, function, LVOTO
  - MV: calcium, SAM
  - Aorta aneurysm
  - TV annulus, TR, RVSP
- ❑ **Root Dimensions**

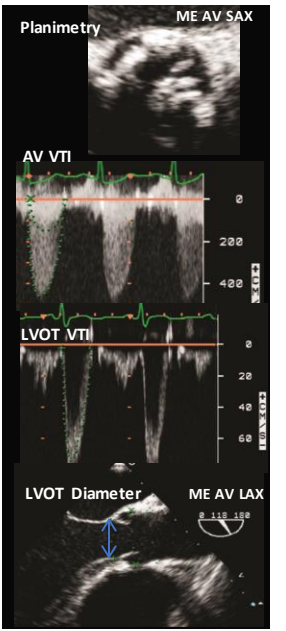
AS Severity [Ref 3]	Mild	Mod	Severe
Velocity peak (m/s)	2.6-2.9	3.0-4.0	>4.0
PG mean (mmHg)	<20	20-40	>40
AVA (cm^2)	1.5-2.0	1.0-1.5	<1.0
AVA indexed (cm^2/m^2)	>0.85	0.6-0.85	<0.6
Velocity Ratio or DVI	>0.50	0.25-0.50	<0.25

Pressure Gradient (PG)
- Acquire CWD of AV, from TG views
  - CWD: shape -> mid-peaking more severe
- PG is dynamic and flow dependent
  - Less flow -> underestimate PG
    - ↑SVR, ↓CO, shunt, severe MR/MS
  - More flow -> overestimate PG
    - ↓SVR, ↑CO, severe AI
- Use AVA measure if PG unreliable

AVA (Planimetry 2D, ③D)
- ME SAX view trace narrowest orifice
- Often difficult due to calcium shadowing

AVA (Continuity)
- Calculate flow through AV and LVOT
- Measure LVOT diameter (ME AV LAX view)
- Obtain VTI: CWD through AV and PWD of LVOT
  - $\text{AVA} = \frac{\text{VTI}_{lvot} \times 0.785 \text{D}^2_{lvot}}{\text{VTI}_{AV}}$
- Can use double envelope technique if inner envelope is well seen
- Simplified continuity uses peak velocity instead of VTI if similar shape of LVOT and AV Doppler traces

Velocity Ratio (VR) or Dimensionless Velocity Index (DVI)
- Measure flow through the LVOT and AV
- Eliminates need for LVOT area measurements
- Useful if poor LV function
- Calculate: $\text{VR} = \frac{\text{Vmax}_{lvot}}{\text{Vmax}_{AV}}$ or $\text{DVI} = \frac{\text{VTI}_{lvot}}{\text{VTI}_{AV}}$



Low Velocity/Low Gradient AS

AVA ≤1cm^2, Vel <4m/s, PG < 40mmHg may occur with normal or low EF
- Low flow (low EF) → consider Dobutamine Stress Echo (DSE)
- Low gradient (normal EF) measure Stroke volume index (SVI) if <35cc/m^2 then result of a small hypertrophied LV, underfilled LV

Aortic Insufficiency Procedure

PreCPB

- **Mechanism**
- **Etiology**
  - Aortic valve
  - Aorta
- **Jet**
  - Single, multiple
  - Central, eccentric
- **Severity**
  - Pressure Half Time
  - Vena Contracta width, area
  - EROA
  - Regurgitant Volume
- **Associated**
  - LV size, function
  - Mitral Valve pathology
- **Root Dimensions**

El Khoury Functional Classification

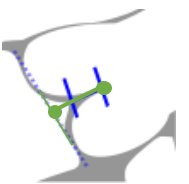
Cusp motion related to annulus
Type I normal: root dilated, fenestration
Type II excessive: prolapse, flail
Type III restrictive: calcium

AV Sparing Procedure PreCPB

- Root/aorta measurements
- AV cusp coaptation
- Non calcified valve
- Tri/bi-cuspid AV
- Independent of AI severity

PostCPB

- **Valve Sparing Root**
  - Valve morphology
    - **Coaptation length** (> 8mm)
    - **Effective AV height** (> 9mm)
    - No residual cusp prolapse
  - Residual AI severity
  - AV pressure gradient
- **Prosthetic Valve**
  - Valve function
  - Pressure gradient
  - Valvular regurgitation
  - Paravalvular leak
- **LV Function**
- **Complications**



Use TG views to best assess prosthetic valve function, measure PG and evaluate for paravalvular leaks

26 Aortic Insufficiency Assessment

- ❑ **Etiology** (2D SAX/LAX)
  - ○ Valve
  - ○ Aorta
- ❑ **Severity**
  - ○ Jet width/LVOT
  - ○ Jet CSA/LVOT CSA
  - ○ Vena Contracta: 2D, ③D
  - ○ Desc Ao flow reversal
  - ○ PHT CWD
  - ○ Reg Volume/Fraction
  - ○ EROA: 2D, ③D
- ❑ **Associated**
  - ○ LV: size, function
  - ○ MV flutter, early closure

AI Severity Ref 4	Mild	Mod	Severe
Jet/LVOT Width (%)*	<25	25-64	≥65
Jet/LVOT CSA (%)*	<5	5-59	≥60
Vena Contracta (mm)**	3	3-6	>6
Aorta flow reversal	early		holo
PHT (ms)	>500	200-500	<200
Reg Volume (cc/beat)	<30	30-59	≥60
Reg Fraction (%)	<30	30-49	≥50
EROA (cm^2)	<0.10	0.10-0.29	≥0.30
* Central jet, ** Nyquist 50-60cm/s			

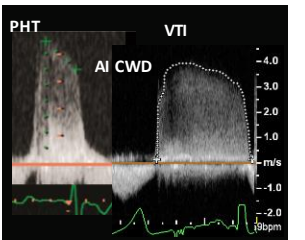
Pressure Half Time (PHT)
- ○ Acquire CWD, TG LAX or deep TG 5C views
  - ▪ Peak velocity > 3m/s, full spectral trace
  - ▪ Measure peak velocity slope to baseline
  - ▪ Machine automatically displays PHT
- ○ Flow dependent
  - ▪ Steep slope (short PHT): severe AI, ↓SVR, ↑LVEDP
  - ▪ Low slope (high PHT): mild AI, ↑ SVR, dilated aorta

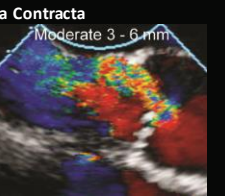
Jet/LVOT Width (%) or Jet/LVOT CSA (%) in SAX
- ○ Acquire zoom CFD ME AV LAX (Nyquist 50-60cm/s)
  - ▪ Measure LVOT diam + AI jet height within 1 cm AV
- ○ Acquire zoom CFD ME AV SAX (Nyquist 50-60cm/s)
  - ▪ Trace AI jet and LVOT circumferences
- ○ Valid for central AI, not eccentric jet

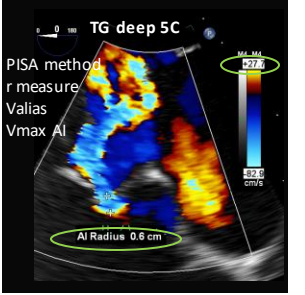
Vena Contracta
- ○ Acquire zoom CFD ME AV LAX (Nyquist 50-60cm/s)
  - ▪ Focus on AI jet through the AV
  - ▪ Preferably show all 3 jet components
- ○ Measure maximum width of AI jet at AV level
  - ▪ Align parallel to jet direction
- ○ Measure ③D Vena contract area (VCA)
  - ▪ Obtain ③D dataset of AI jet
  - ▪ Use MPR software to analyze AI jet

EROA
- ○ Calculate using Volume or PISA methods
  - ▪ **EROA = Reg Volume / VTI AI**
  - ▪ **EROA = $2\pi r^2$ x α angle/180° x Valias / Vpeak AI**
- ○ Measure directly from ③D dataset

Regurgitant Volume, Regurgitant Fraction
- ○ Calculate **Reg Volume = LV SV – MV SV (or RV SV)**
  - ▪ Measure LV SV (STE, Simpson's, ③D, CSA_{LVOT} x VTI_{LVOT})
  - ▪ Measure MV SV = CSA_{MV} x VTI_{MV} or use RV SV
- ○ Calculate **Reg Fraction = Reg Volume/LV SV**







Mitral Stenosis Procedure

PreCPB

- **Etiology**
  - Rheumatic
    - Commissure fusion
    - Chordal shortening
    - Leaflet thickening
    - Diastolic doming
  - Calcific, MAC
  - Radiation induced
- **Severity**
  - Pressure gradient mean
  - MV area
- **Associated**
  - LAA thrombus
  - RVSP
  - TR
- **Mitral Annulus Dimensions**

MS Views
- ME 4C
- ME MC
- ME 2C
- ME AV LAX
- TG Basal SAX
- TG mid SAX
- ME Bicaval
- ± ③D MV

PostCPB

- **Prosthetic Valve**
  - Valve function
  - Pressure gradient (mean)
  - Peak velocity
  - Valvular regurgitation
  - Paravalvular leak
- **LV Function**
  - Global
  - Regional
- **Complications**
  - LVOT obstruction (strut)
  - RWMA (Circumflex injury)
- **Cannulation sites**
  - IVC + hepatic vein flow
  - Aorta

Use ME views or ③D to best assess prosthetic valve function and evaluate for paravalvular leaks, measure PG

28 Mitral Stenosis Assessment

- **Mechanism** (2D)
  - Rheumatic, calcific
  - Subvalvular (TG views)
- **Severity**
  - PG mean
  - MVA:
    - Planimetry (③D)
    - PISA
    - PHT
  - PAP (RVSP)
- **Associated**
  - LA size, SEC, thrombus
  - PHTN, TR, RV dilated
  - MR

MS Severity	Mild	Mod	Severe
MVA (cm^2)*	>1.5	1.0-1.5	< 1.0
PG mean (mmHg)**	<5	5-10	>10
PAP (mmHg)***	<30	30-50	>50

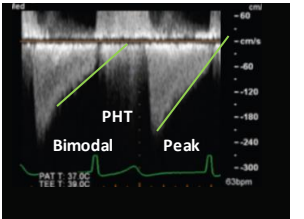
*ESC guidelines MVA < 1.5 severe MS
**HR dependent, faster HR → higher PG
high PG → ↑HR, ↑CO, MR
***estimate from TR jet

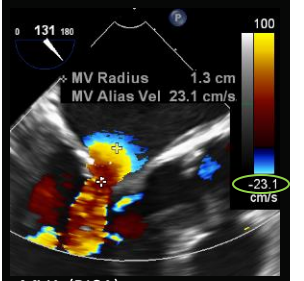
Pressure Gradients
- Acquire CWD of MV inflow, from ME MV views
  - Mean PG better than peak PG for severity
  - MR increases Peak E velocity, mean PG <10mmHg
- Flow dependent (see below)

MVA (PHT)
- Acquire CWD trace of MV inflow
- Activate MV PHT
  - Place point at peak velocity to baseline
  - Machine automatically displays **MVA =220/PHT**
  - Bimodal trace use flatter mid portion
- Flow dependent measure so same limitations as PG
  - Steep/short PHT: ↑LVEDP (AI, ↓CO), ↓LAP (ASD)
  - Low slope/high PHT: ↓LVEDP (↓ SVR, ↑CO), ↑LAP

MVA (PISA)
- Acquire zoom CFD ME MV (Nyquist 50-60cm/s)
- Shift velocity baseline down for larger hemisphere or reduce velocity scale
  - Choose smooth hemisphere, measure r
  - Angle correction if < 180°
- Obtain MV inflow
  - Measure peak velocity
- Calculate: **MVA PISA = $\frac{2\pi r^2 \times \alpha \text{ angle}/180° \times \text{Valias}}{\text{Vpeak MS}}$**

MVA (Continuity)
- Measure flow through the LVOT or AV
- Calculate: **MVA = LVOT VTI x LVOT area / MV VTI**





MVA (PISA)
- Measure r
- α correction (if < 180°)
- V alias (lower #)
- Measure Vpeak MV inflow

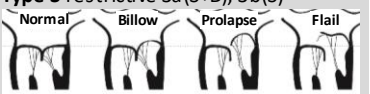
MVA	Avoid in	Use in
Planimetry	Heavily calcified	----
PHT	> Mod AI, LV/diastolic dysfunction, ASD, MV replace/repair	MR, AF
PISA	-----	AI, MR, AF, prosthetic
Continuity	AI, LVOT obstruct, MR, AF, intracardiac shunt	----

Mitral Regurgitation Procedure

PreCPB

- ❑ **Mechanism**
- ❑ **Etiology**
  - ○ Organic (1°)
  - ○ Functional (2°)
- ❑ **Severity**
  - ○ Vena Contracta
  - ○ Flow Convergence (PISA)
  - ○ Pulmonary Vein Doppler
  - ○ Reg Volume/Fraction
  - ○ EROA
- ❑ **Associated**
  - ○ LV size, function
  - ○ TV annulus (diastole, 4C)
  - ○ TR severity, RVSP

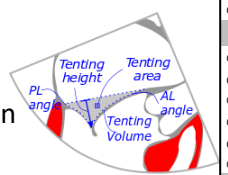
Carpentier Functional Classification
Leaflet motion related to annulus
Type 1 normal
Type 2 excessive: billow, prolapse, flail
Type 3 restrictive 3a(S+D), 3b(S)

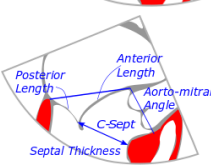


- **Use multiple 2D views**
  - **TG 2C for subvalvular**
- **③D Enface MV**
  - **Clefts**
- **Construct 3D model**
- **Record hemodynamics**

PostCPB

- ❑ **Valve Repair**
  - ○ Valve morphology (2D, 3D)
    - ▪ Coaptation point, length
  - ○ No residual prolapse
  - ○ Residual MR (severity)
  - ○ MV PG PWD/CWD
- ❑ **Prosthetic Valve**
  - ○ Valve function
  - ○ Pressure gradient
  - ○ Paravalvular leak
  - ○ Valve regurgitation
- ❑ **LV function**
- ❑ **Complications**
  - ○ RWMA (Cx artery)
  - ○ SAM, LVOTO
  - ○ New AI
- ❑ **Cannulation sites**
  - ○ IVC/HV flow (CFD)
  - ○ Aorta 2D





Risk Factors For Failed Repair
Prolapse
○ MV annulus > 5.0cm
○ MAC
○ ≥ 3 prolapsing scallops
○ Anterior leaflet disease
○ Bileaflet disease
○ Central MR jet
Ischemic MR
○ Tenting height > 1cm
○ Tenting area > 2.5cm^2
○ Tenting volume
○ Ant leaflet angle > 25°
○ Post leaflet angle > 45°
○ Basal aneurysm
Risk of SAM
○ LVEDD < 4.5cm
○ Septal thickness > 1.5cm
○ Posterior leaflet > 1.5cm
○ Anterior leaflet > 2.5cm
○ Ant:Post leaflet ≤ 1:3
○ Septal contact < 2.5cm
○ Aorto-mitral angle <120°

30 Mitral Regurgitation Assessment

- ❑ **Mechanism** (2D LAX)
  - Carpentier classification
- ❑ **Etiology** (2D SAX/LAX, ③D)
  - Valve (1°)
  - Functional (2°)
- ❑ **Severity**
  - Vena Contracta: 2D, ③D
  - Flow convergence (PISA)
  - Pulmonary vein Doppler
  - Reg Volume, Fraction
  - EROA
  - CWD: signal strength
- ❑ **Associated**
  - LV: size, function
  - LA dilated
  - TV annulus
  - RVSP

MR Measures[Ref 3]	Mild	Mod	Severe
Vena Contracta (mm)*	<3*	Inter	≥7*
Pulmonary Vein*	normal	blunt	reverse*
Mitral Inflow (cm/s)**	A wave	variable	E ≥12
Reg Volume (cc/beat)***	<30	30-59	≥60
Reg Fraction (%)***	<30	30-49	≥50
EROA (cm²)***	<0.20	0.20-0.39	≥0.40

Use appropriate BP during severity assessment

***Specific**: jet area, flow convergence (Nyquist 40cm/s)
****Supportive:** CWD signal strength, LV size
*****Quantitative:** differentiate severity

Vena Contracta
- Valid for central and eccentric jets, not multiple
- Acquire zoom CFD ME AV LAX (Nyquist 50-60cm/s)
  - Visualize all 3 components of MR jet
  - Measure MR jet width above flow convergence
  - Perpendicular to coaptation line (ME4C, LAX)
- Measure ③D Vena Contracta area (VCA)
  - Severe ≥ 0.4cm²

Pulmonary Vein Flow (PWD)
- S wave reversal is specific for severe MR
- Contralateral vein if eccentric MR

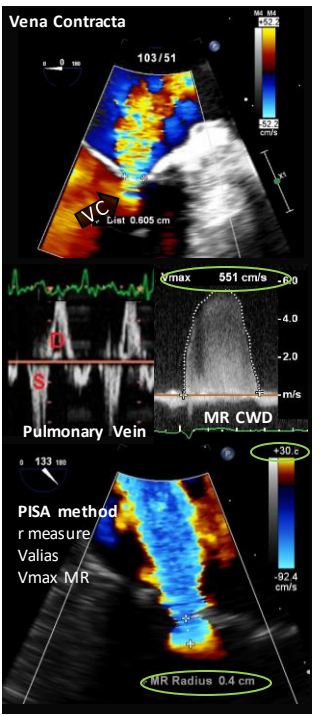
EROA
- Not valid in multiple, less valid in eccentric jets
- Calculate using PISA or Volume methods

PISA method
- Zoom MR jet, shift baseline up, measure r, V_{alias}
- Obtain CWD MR, note Peak Velocity MR
- **EROA = $\frac{2\pi r^2 \times \alpha \text{ angle}/180° \times \text{Valias}}{\text{Peak V MR}}$**

Volumetric method
- Calculate Reg Volume (see below)
- **EROA = Reg Volume / VTI MR**

- Measure directly from ③D dataset

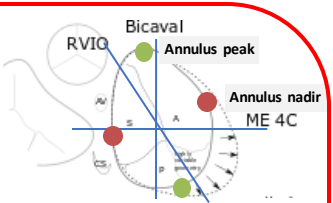
Regurgitant Volume/Fraction
- Valid multiple, eccentric jets
- Calculate **Reg Volume = LV SV – AV or LVOT SV**
  - Measure LV stroke volume (STE, Simpson's, ③D)
  - Measure AV or LVOT SV (VTI x area)
- Calculate using PISA
  - **Reg Vol = PISA EROA x VTI MR**
- Calculate **Reg Fraction = Reg Volume/LV SV**



Tricuspid Regurgitation Procedure

PreCPB

- **Etiology**
  - Primary (15%)
  - Functional (85%)
  - TV annulus diameter
    - 2D use ME 4C (diastole)
    - ③D MPR
- **Severity**
  - Vena Contracta
  - Flow convergence (PISA)
  - Hepatic vein Doppler
  - Reg Volume, Reg Fraction
  - EROA
- **Associated**
  - RV size, function
  - RVSP
  - RA/IVC size
  - Valvulopathy
    - Left heart: MS,MR,AS
    - Right heart: PI, PS



Functional TR

- TV annulus peaks + nadirs
- Dilates right lateral direction
- Annulus > 40mm → repair

TV Views

- **ME 4C**
- **ME RV In/Outflow**
- **ME Modified Bicaval TV**
- **TG Basal SAX**
- **TG RV Inflow**
- **± ③D TV**
- **TG IVC LAX**

PostCPB

- **Valve Repair**
  - Annular ring size
  - Residual prolapse
  - Residual TR
  - TV mean PG PWD
- **Prosthetic Valve**
  - Valve function
  - Pressure gradient
  - Valve regurgitation
  - Paravalvular leak
- **RV function**
  - Global
  - RWMA

Use ME views to best assess prosthetic valve function, measure PG and evaluate for paravalvular leaks

32 Tricuspid Regurgitation Assessment

- **Mechanism** (2D SAX/LAX)
  - Functional (2°):
    - TV annulus: 2D, ③D
  - Primary Valve (1°)
- **Severity**
  - CWD TR jet
  - Jet area CFD
  - Vena Contracta: 2D, ③D
  - PISA radius
  - EROA: 2D, ③D
  - Reg Volume
  - Hepatic Vein (PWD)
- **Associated**
  - RV: size, function
  - RA size
  - IVC dilated ≥2cm

TR Severity [Ref 4]	Mild	Mod	Severe
TV morphology	N	N/Abn	Abn
IVC diameter (cm)	<2	2.1-2.5	>2.5
RA size	N	mild	dilated
CWD TR	soft	dense	dense
Jet Area (cm^2)*	NA	NA	>10
Vena Contracta (mm)	<3	<3.0-6.9	≥7
PISA radius (mm)**	≤5	6-9	>9
EROA (cm^2)	<0.2	0.2-0.39	≥0.4
Reg Volume (cc/beat)	<30	30-44	≥45
Hepatic vein S wave	N	blunted	reverse

N, normal; Abn, abnormal; NA, not applicable
*Nyquist 50-60cm/s, **Baseline shift 28cm/s

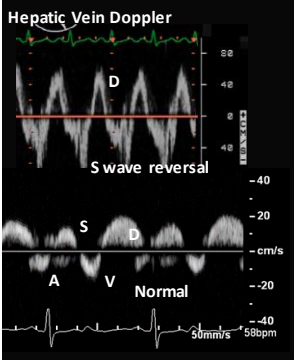
Jet Area
- ME views trace maximum jet area
- Load dependent
- Laminar flow with equal RA, RV pressures (severe TR)

Vena Contracta
- Acquire zoom CFD ME view TV (Nyquist 50-60cm/s)
  - Measure maximum width of TR jet at TV level
  - Align parallel to jet direction
- Measure ③D Vena contracta area (VCA)

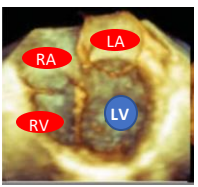
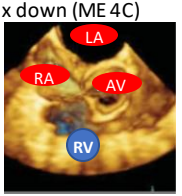
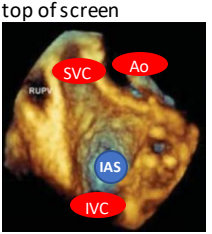
EROA
- Calculate using Volume or PISA methods
  PISA method (see card 27, MR)
  - Zoom TR jet, shift baseline up, measure r, Valias
  - Obtain CWD TR, note Peak Velocity TR
  - **EROA = $\frac{2\pi r^2 \times \alpha \text{ angle}/180° \times \text{Valias}}{\text{Peak V TR}}$**

  Volumetric method
  - Calculate **Reg Vol = TV VTI x TVA – RV (or LV) SV**
    - Measure TV diameter ($A = 0.785d^2$)
    - Measure RV or LV stroke volume
    - Measure TV VTI
  - **EROA = Reg Volume / VTI TR**
- Measure directly from ③D dataset

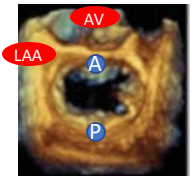
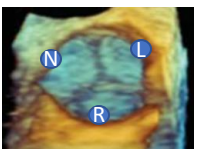
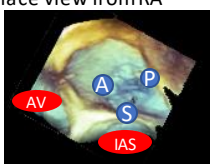
Hepatic Vein Doppler
- Obtain TG IVC view
- PWD hepatic vein
  - Look for systolic reversal
  - Lack of S wave reversal if AF or dilated RA
- Systolic blunting other causes: AF, ↑RAP



3D TEE Overview

Orientation	Technique	Assessment
• Display according to: ▪ Guidelines ▪ Surgical orientation ▪ Any orientation (add labels) • Use additional structures (AV, LAA) to help orientate • Crop out excess material	• Acquisition of a 3D dataset uses modes • Live, zoom, full volume (FV), Color (CFD) • Use smallest volume and gating to ↑ FR • Avoid stitch artifacts with gated acquisitions or use HVR (Philips) • CFD set Nyquist in 2D	• Rotate + crop 3D image to show pathology • Software analysis ▪ MPR: measure ○ dimensions ○ area ▪ Models: LV, MV ▪ CFD ○ vena contracta ○ EROA
LV: R side of display with apex down (ME 4C) 	• Gated (4-6 beats) FV ▪ FR > 10Hz • ME 4C, 2C, LAX: use biplane view to see ▪ LV apex ▪ Endocardial border	• Systolic function ▪ 2DQ: LVEF, EDV, ESV, SV ▪ a2DQ: regional ▪ i-slice: SAX views • Structures ▪ Thrombus/masses ○ Attachment ○ MPR: dimensions ▪ VSD ○ CFD ○ MPR: dimensions
RV: L side of display with apex down (ME 4C) 	• Gated (4-6 beats) FV ▪ FR > 10Hz • ME 4C, RVIO: use biplane view to see ▪ Entire RV + RVOT ▪ Endocardial border	• Systolic function ▪ Tomtec: RVEF, EDV, ESV, SV • Structures ▪ Thrombus/masses ○ Attachment ○ MPR: dimensions ▪ VSD ○ CFD ○ MPR: dimensions
IAS: view from RA with SVC at top of screen 	• Gated (4-6 beats) FV ▪ FR > 10Hz • ME 4C, Bicaval: use biplane view to see ▪ Entire IAS ▪ Include AV, SVC • 3D Live mode for catheter guidance	• Percutaneous procedure ▪ ASD closure ▪ Septal puncture • Structures ▪ ASD ○ MPR: dimensions ○ CFD ▪ Wires, catheters

3D TEE Overview

Orientation	Technique	Assessment
Mitral Valve Enface view from LA or LV 	• ME 4C, 2C, LAX: use biplane view to see ▪ Entire MV annulus ▪ Include AV, LAA • Use any mode: Live, zoom, FV, CFD • Gating (4-6 beats) improves FR > 10Hz • 3D Live mode for catheter guidance	• Structure ▪ Leaflet motion ▪ MPR: annulus ▪ Prolapse, tenting ▪ Planimetry • Model ▪ Static/dynamic ▪ Dimensions, area ▪ Prolapse, tenting ▪ Annular dynamics • CFD: MR, leaks ▪ VCA (MR)
Aortic valve SAX view from aorta 	• ME AV SAX or LAX: use biplane view to see ▪ Entire aortic root ▪ Include MV, IAS • Use any mode: Live, zoom, FV, CFD • Gating (4-6 beats) improves FR > 10Hz • 3D Live mode for catheter guidance	• Structure ▪ Leaflet motion (AI) ▪ Root pathology ▪ MPR: annulus (AS) ▪ Planimetry (AS) • Model (E-Sie Valve) ▪ Dynamic • CFD ▪ VCA (AI)
Tricuspid Valve Enface view from RA 	• ME 4C, RVIO: use biplane view to see ▪ Entire TV annulus ▪ Include AV, IAS • Use any mode: Live, zoom, FV, CFD • Gating (4-6 beats)	• Structure ▪ Leaflet motion ▪ MPR: annulus ▪ Planimetry • CFD ▪ VCA (TR)
Pulmonic Valve SAX view from PA 	• UE Ao Arch SAX: use biplane view to see ▪ Entire PV annulus ▪ Include RVOT • Use any mode: Live, zoom, FV, CFD • Gating (4-6 beats)	• Structure ▪ Leaflet motion ▪ MPR: annulus ▪ Planimetry • CFD