The WASHVU Echocardiography Guide

FIRST EDITION

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Preface

In November, 2017, Dr. Shayibu Harruna called me and asked me if I would be interested in establishing a cardiac and vascular ultrasound school in Tamale, Ghana. I said yes and in April, 2018, the West Africa School of Heart and Vascular Ultrasound (WASHVU) enrolled our first three students – Samson Aweligiba, Godwin Asare and Saeed Ibrahim.

This echocardiography guide represents the first publication for the school and its students. It is meant to provide support for our students as they begin to scan in the “real world” where anything is possible. We hope that others in the field of echocardiography may find this guide useful as well.

First, I would like to express appreciation to Dr. Harruna for his total dedication to the idea of establishing WASHVU. I would like to thank Dr. Moro Salifu who, through the Association of Ghana/Turkish Trained Ghana Professionals of North America, has supported the school since the beginning. Dr. Jacques Kpodonu continues to provide additional guidance. Thank you Dr. Rohit Malhol;ra for your echocardiography laboratory support at Avondale Medical Center. I would like to recognize Hyehyun Reynolds technical assistance and expertise. I would like to thank our secretary, Peace Dellor and her husband Joseph, for their efforts and patience. Jeff Campbell and his staff at Vesuvius Press who steered this guide to the finish line.

Most important, to our first three students, I deeply appreciate and respect your commitment and dedication to believing each patient you serve requires your very best.

Terry Reynolds, BS, RDCS
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Table of Contents

Table of Contents

Table of Contents

Table of Contents

Valvular Heart Disease

Mitral Stenosis

Definition

A narrowing of the mitral valve area impeding the diastolic flow of blood from the left atrium into the left ventricle. The most common etiology of mitral stenosis in adults is rheumatic fever (99%).

M-Mode

Thickened mitral valve leaflets

Decreased E-F slope of the anterior mitral valve leaflet

Anterior motion of the posterior mitral valve leaflet

2-D

Thickened mitral valve leaflets, especially at the leaflet tips and chordae tendineae

Diastolic "doming" of the anterior mitral valve leaflet ("hockey-stick" appearance)

Left atrial enlargement (Normal LA volume: ≤ 34 mL/m^2)

Left atrial thrombus (commonly located in the left atrial appendage)

"Small"/ "protected" left ventricle

Right ventricular enlargement (Abnormal RVIDd: > 41 mm apical four chamber view at the cardiac base)

Pulmonary hypertension

Determine the anatomic mitral valve area by planimetry (tracing) of the mitral valve orifice in the parasternal short-axis view of the mitral valve

Evaluate mitral valve leaflet morphology for acceptability of mitral balloon valvuloplasty

Determine the presence of Lutembacher's syndrome (mitral stenosis with ostium secundum atrial septal defect)

Determine the presence of aortic stenosis, tricuspid stenosis and/or pulmonary stenosis

PW and CW Doppler

CW Doppler recommended

Atrial fibrillation – average 5 cycles with the least variation of R-R intervals and as close to as possible to a normal heart rate

Turbulent flow

Increased mitral valve peak E velocity (> 1.3 m/sec)

Decreased E-F slope (deceleration time) of the mitral inflow Doppler tracing (indicates increased pressure half-time)

Determine the pressure half-time

Determine mitral valve area by the pressure half-time method

Determine the mitral valve area by the continuity equation

Determine the mean pressure gradient

Determine the pulmonary artery pressures (e.g.; SPAP/MPAP/PAEDP/PVR)

Determine the presence of aortic stenosis, tricuspid stenosis and/or pulmonary stenosis

Determine the presence and severity of co-existing valvular regurgitation

Color Flow Doppler

"Flame-shaped" turbulent jet at the mitral valve orifice which extends into the left ventricle during ventricular diastole

Determine the mitral valve area using the PISA method

Mitral Stenosis Severity Scales

Specific Findings	Normal	Mild	Moderate	Severe
Valve area (cm^2)	4 to 5	> 1.5	1.0 to 1.5	< 1.0
Supportive Findings				
Mean pressure gradient (mm Hg)[a]		< 5	5 to 10	> 10
Systolic pulmonary artery pressure (mm Hg)		< 30	30 to 50	> 50

[a]*At heart rates between 60 and 80 bpm and in normal sinus rhythm*

Mitral Regurgitation

Definition

The backward flow of blood from the left ventricle through the mitral valve into the left atrium during ventricular systole; may be acute, chronic or intermittent.

M-Mode/2-D

Determines the anatomic basis for the presence of mitral regurgitation (e.g.; flail mitral valve leaflet, mitral annular calcification, mitral valve prolapse, left ventricular enlargement)

Left atrial enlargement (Normal LA volume: ≤ 34 mL/m^2)

Left ventricular enlargement (Normal LVIDd: M: 4.2-5.8 cm; W: 3.8-5.2 cm)

Left ventricular volume overload pattern (left ventricular enlargement with ventricular wall hyperkinesis)

Rapid sideways expansion of the left atrium during ventricular systole

Abnormal systolic bowing of the interatrial septum

Increased LA/RA ratio (Normal is 1:1)

Evidence of pulmonary hypertension

PW Doppler

Increased mitral valve peak E velocity (> 1.2 m/sec) (most accurate in patients > 50 years old with an ejection fraction of > 40%)

Systolic blunting or reversed S wave of the pulmonary vein with increased D wave (influenced by other factors including left ventricular diastolic dysfunction, atrial fibrillation, left atrial pressure)

Determine regurgitant volume (Mild: < 30 mL; Severe: ≥ 60 mL), regurgitant fraction (Mild: < 30%; Severe: ≥ 50%), effective regurgitant orifice area (Mild: < 0.20 cm^2; Severe: ≥ 0.40 cm^2)

CW Doppler

Jet density (spectral strength) indicates severity (Mild: faint/partial/parabolic; Severe: holosystolic/dense/triangular)

Color Flow Doppler

Color flow Doppler jet area indicates severity (Mild: small, central, narrow, often brief; Severe: large central jet (> 50% of LA area) or eccentric wall impinging jet of variable size)

Flow convergence (PISA) (Mild: Not visible, transient or small; Severe: large throughout systole)

Determine vena contracta width (Mild: ≤ 0.3 cm; Severe: ≥ 0.7 cm)

Determine PISA regurgitant volume (Mild: < 30 mL; Severe: ≥ 60 mL) and PISA effective regurgitant orifice area (Mild: < 0.20 cm^2; Severe: ≥ 0.40 cm^2)

Classification of Mitral Regurgitation Severity

MILD

Structural

Normal mitral valve or mild leaflet abnormality (e.g.; mild thickening, calcifications, prolapse, mild tenting)

LA and LV size usually normal

Qualitative Doppler

Color flow jet area: small, central, narrow, often brief

Flow convergence (PISA): not visible, transient or small

CW Doppler spectral strength: faint/partial/parabolic

Semiquantitative

Vena contracta width: ≤ 0.3 cm

Pulmonary vein flow: systolic dominance

Mitral inflow: A-wave dominant

Quantitative

Effective regurgitant orifice area (2-D or PISA): < 0.20 cm^2

Regurgitant volume: < 30 mL

Regurgitant fraction: < 30%

MODERATE

Structural

Moderate leaflet abnormality or moderate leaflet tenting

LA and LV: Normal or mildly dilated

Qualitative Doppler

Color flow jet area: variable

Flow convergence (PISA): intermediate in size and duration

CW Doppler spectral strength: dense but partial or parabolic

Semiquantative

Vena contracta width: intermediate

Pulmonary vein flow: systolic blunting

Mitral inflow: variable

Quantitative

Effective regurgitant orifice area (2-D and/or PISA): 0.20 to 0.29 cm^2; 0.30 to 0.39 cm^2

Regurgitant volume: 30 to 44 mL; 45 to 59 mL

Regurgitant fraction: 30 to 39%; 40 to 49%

Mitral Regurgitation

SEVERE

Structural

Severe valve lesions (e.g,; Primary: flail leaflet, ruptured papillary muscle, severe retraction, large perforation, Secondary: severe tenting, poor leaflet coaptation)

LA and LV: dilated

Qualitative Doppler

Color flow jet area: large central jet (> 50% of left atrial area) or eccentric wall impinging jet of variable size

Flow convergence (PISA): large throughout systole

CW Doppler spectral strength: holosystolic/dense/triangular

Semiquantitative

Vena contracta width: ≥ 0.7 cm

Pulmonary vein flow: minimal to no systolic flow /systolic flow reversal

Mitral inflow: E wave dominant (> 1.2 m/sec)

Quantitative

Effective regurgitant orifice (2-D and/or PISA): ≥ 0.40 cm^2

Regurgitant volume: ≥ 60 mL (may be lower in secondary mitral regurgitation due to elliptical regurgitant orifice area

Regurgitant fraction: ≥ 50% (may be lower in low flow conditions)

Classification of Mitral Regurgitation Severity at a Glance

Mild Mitral Regurgitation	Severe Mitral Regurgitation
Small, central, narrow, often brief color flow jet	Flail leaflet
Vena contracta ≤ 0.3 cm	Vena contracta width ≥ 0.7 cm
PISA radius absent or ≤ 0.3 cm at Nyquist limit of 30 to 40 cm/sec	PISA radius ≥ 1.0 cm at Nyquist limit 30 to 40 cm/sec
Mitral A wave dominant flow	Central large jet > 50% of LA area
Soft or incomplete jet by CW Doppler	Pulmonary vein systolic flow reversal
Normal LA and LV size	Enlarged LV with normal function
≥ 4 criteria definitely mild	**≥4 criteria definitely severe**

Mitral Valve Prolapse

Definition

Posterior displacement of the anterior, posterior or both mitral valve leaflets greater than 2 mm beyond the mitral annular plane in the parasternal long axis view.

M-Mode

Primarily used to differentiate mid-systolic mitral valve prolapse from holosystolic (pansystolic) mitral valve prolapse

2-D

Using the parasternal long axis view as the gold standard, mitral valve prolapse is present when any portion of the anterior, posterior or both mitral valve leaflets prolapse beyond an imaginary line drawn from the origin of the posterior aortic root to the atrioventrioventricular groove (where atrial muscle meets ventricular muscle) greater than 2 mm

Determine if classic mitral valve prolapse (thick (diastolic thickness ≥ 5 mm in parasternal long axis view), redundant, myxomatous leaflet(s) versus non-classic mitral valve prolapse (thin leaflet(s) is present

Doppler

Mitral regurgitation (may be holosystolic (pansystolic) or mid-to-late systolic)

Aortic Stenosis

Definition

The narrowing of the aortic valve area during ventricular systole. The most common causes of aortic stenosis are calcific stenosis of a tri-leaflet aortic valve (most common in the elderly > 75 years of age), a bicuspid aortic valve with superimposed calcific changes (common in younger patients < 65 years of age) and rheumatic valve disease.

Bicuspid Aortic Valve

Definition

The most common acyanotic congenital heart defect in the adult population (up to 3% of the adult population).

M-Mode/2-D

Thickened aortic valve leaflets

Systolic "doming" ("pear-shaped" systolic opening versus normal leaflets which should be parallel to the aortic wall when fully open) (e.g.; best seen in parasternal long axis view)

Diastolic "doming" (e.g.; aortic valve prolapse)

Elliptical ("football-shaped") ("fish-mouth") systolic opening of the aortic valve (best seen in the parasternal short axis of the aortic valve) (normal tri-leaflet aortic valve has a triangular shaped opening in parasternal short axis of aortic valve)

Eccentric closure line

Dilatation of the ascending aorta ("bicuspid aortic valve syndrome")

Evaluate for aortic coarctation (bicuspid aortic valve present in 50 to 80% of patients with aortic coarctation)

Degenerative/Inflammatory

M-Mode/2-D

Thickened aortic valve leaflets with reduced systolic excursion (< 15 mm)

Post-stenotic dilatation of the aorta

Left ventricular hypertrophy (Normal IVSd and LVPWd: M: 0.6 cm-1.0 cm; W: 0.6-0.9 cm)

Left atrial enlargement (Normal LA volume: ≤ 34 mL/m^2)

Decreased global left ventricular systolic function (late in course)

Doppler

Determine aortic valve peak velocity (Mild: 2.6 to 2.9 m/sec; Severe: ≥ 4.0 m/sec)

Determine mean pressure gradient (Mild: < 20 mm Hg; Severe: ≥ 40 mm Hg)

Determine aortic valve area using the continuity equation (Mild: > 1.5 cm^2; Severe: < 1.0 cm^2)

Determine aortic valve area index (AVA cm^2/BSA) Mild: > 0.85 cm^2/m^2; Severe: < 0.60 cm^2/m^2)

Determine velocity ratio ($LVOT_{VTI}/AoV_{VTI}$) (Mild: > 0.50; Severe: < 0.25)

Determine the presence and severity of co-existing valvular regurgitation

Aortic Stenosis Severity Scales

	Aortic sclerosis	Mild	Moderate	Severe
Peak velocity (m/sec)	≤ 2.5	2.6-2.9	3.0-4.0	≥ 4.0
Mean pressure gradient (mm Hg)		< 20	20-40	≥ 40
Aortic valve area (cm^2)		> 1.5	1.0-1.5	< 1.0
Aortic valve area index (cm^2/m^2)		> 0.85	0.60-0.85	< 0.60
Velocity ratio		> 0.50	0.25-0.50	< 0.25

Aortic Regurgitation

Definition

The backflow of blood from the aorta through the aortic valve into the left ventricle during ventricular diastole; may be acute or chronic.

M-Mode/2-D

Anatomic basis for the presence of aortic regurgitation (e.g.; aortic valve vegetation, ascending aortic aneurysm, thickened aortic valve leaflets)

Diastolic flutter of the anterior mitral valve, posterior mitral valve, chordae tendineae, papillary muscle(s), and/or the interventricular septum

Left ventricular enlargement (Normal LVIDd: M: 4.2-5.8 cm; W: 3.8-5.2 cm)

Left ventricular volume overload (left ventricular enlargement with ventricular wall hyperkinesis)

PW Doppler

Diastolic flow reversal in descending thoracic aorta (PW Doppler) (Mild: brief, early diastolic reversal; Severe: prominent holodiastolic reversal)

Determine regurgitant volume (mL) (Mild: < 30 mL; Severe: ≥ 60 mL)

Determine regurgitant fraction (%) (Mild: < 30%; Severe: ≥ 50%)

Determine effective regurgitant orifice (cm^2) (Mild: < 0.10; Severe: ≥ .30 cm^2)

CW Doppler

Jet density (CW Doppler) (Mild: incomplete or faint; Severe: dense)

Jet deceleration (Pressure half-time (msec): (Mild: > 500 msec; Severe: < 200 msec)

Color Flow Doppler

Jet width in LVOT (Parasternal long axis) (Mild: small in central jets; Severe: large in central jets; variable in eccentric jets)

Jet width/LVOT width, central jets (parasternal long axis) (Mild: < 25%; Severe: ≥ 65%)

Vena contracta (parasternal long axis) (Mild: < 0.3 cm; Severe: > 0.6 cm)

Flow convergence (PISA) (parasternal long axis) (Mild: none or very small; Severe: large)

Jet CSA/LVOT CSA (parasternal short axis of aortic valve) (Mild: < 5%; Severe: ≥ 60%)

Classification of Aortic Regurgitation Severity

	Mild	Moderate	Severe
Structural parameters			
Aortic leaflets	Normal or abnormal	Normal or abnormal	**Abnormal/flail, or wide coapatation defect**
LV size	Normal	Normal or dilated	Usually dilated
Qualitative Doppler			
Jet width in LVOT, color flow	Small in central jets	Intermediate	**Large in central jets; variable in eccentric jets**
Flow convergence (PISA) color flow	None or very small	Intermediate	**Large**
Jet density (CW)	Incomplete or faint	Dense	Dense
Jet deceleration rate, (CW) (PHT, msec)	Slow, > 500	Medium, 200-500	**Steep, < 200**
Diastolic flow reversal in descending thoracic aorta	Brief, early diastolic	Intermediate	**Prominent, holodiastolic reversal**
Semiquantitative parameters			
Vena contracta width (cm)	< 0.3	0.3-0.6	> 0.6
Jet width/LVOT width, central jets (%)	< 25	25 to 45 / 46 to 64	≥ 65
Jet CSA/LVOT CSA central jets (%)	< 5	5-20 / 21-59	≥ 60
Quantitative parameters			
RV (mL)	< 30	30 to 44 / 45 to 59	≥ 60
RF (%)	< 30	30 to 39 / 40 to 49	≥ 50
EROA (cm^2)	< 0.10	0.10 to 0.19 / 0.20 to 0.29	≥ 0.30

Classification of Aortic Regurgitation Severity at a Glance

Mild Aortic Regurgitation

Central Jet, width < 25% of LVOT

Small or no flow convergence (PISA)

Vena contracta width < 0.3 cm

Soft or incomplete jet by CW

CW PHT > 500 msec

Normal LV size

≥ 4 criteria definitely mild (quantitation not needed)

Severe Aortic Regurgitation

Flail valve

Central Jet, width ≥ 65%

Vena contracta > 0.6 cm

Large flow convergence (PISA)

PHT < 200 msec

Prominent holodiastolic flow reversal in descending thoracic aorta

Enlarged LV with normal function

≥4 criteria definitely severe (may still need to quantitate)

Tricuspid Stenosis

Definition

A narrowing of the tricuspid valve area during ventricular diastole. Most commonly associated with rheumatic mitral stenosis and aortic stenosis.

M-Mode

Thickened tricuspid valve leaflets

Decreased E-F slope of the anterior tricuspid valve leaflet

Anterior motion of the posterior tricuspid valve leaflet

2-D

Thickened tricuspid valve leaflets, especially at the leaflet tips and chordae tendineae

Diastolic "doming" of the anterior tricuspid valve leaflet ("hockey-stick" appearance)

Right atrial enlargement (Normal RA volume: M: 25 ± 7 mL/m^2; W: 21 ± 6 mL/m^2)

Dilated inferior vena cava (Normal: ≤ 2.1 cm), hepatic veins (Normal: 0.5 to 1.1 cm)

PW and CW Doppler

CW Doppler recommended

Atrial fibrillation – average 5 cycles with the least variation of R-R intervals and as close to as possible to a normal heart rate

Turbulent flow

Increased tricuspid valve peak E velocity (> 1.0 m/sec)

Decreased E-F slope (deceleration time) of the tricuspid valve inflow Doppler tracing (indicates increased pressure half-time)

Determine the tricuspid valve area using the continuity equation

Determine the mean pressure gradient

Determine the pressure half-time

Determine tricuspid valve area by the pressure half-time method (190 ÷ PHT (msec)

Determine the pulmonary artery pressures (SPAP/MPAP/PAEDP/PVR)

Determine the presence of mitral stenosis, aortic stenosis and/or pulmonary stenosis

Determine the presence and severity of co-existing valvular regurgitation

Color Flow Doppler

"Flame-shaped" turbulent jet at the tricuspid valve orifice which extends into the right ventricle during ventricular diastole

May demonstrate flow convergence (PISA) proximal to the tricuspid valve leaflets in the right atrium

Significant Tricuspid Stenosis

Specific Findings

Mean pressure gradient	≥ 5 mm Hg
Inflow velocity time integral (VTI)	> 60 cm
Pressure half time	≥ 190 msec
Tricuspid valve area (TVA) (cm^2) (continuity equation)	≤ 1.0 cm^2

Supportive Findings

Dilated right atrium	≥ moderate
Inferior vena cava	dilated (> 2.1 cm)

Tricuspid Regurgitation

Definition

The backward flow of blood from the right ventricle into the right atrium during ventricular systole; may be acute, chronic or intermittent.

M-Mode/2-D

Determines the anatomic basis for the presence of tricuspid regurgitation (e.g.; tricuspid valve vegetation, flail leaflet, right ventricular enlargement)

Right atrial enlargement (Normal RA volume: M: 25 ± 7 mL/m^2; W: 21 ± 6 mL/m^2)

Right ventricular enlargement (Abnormal RVIDd: > 41 mm apical four chamber at the cardiac base)

Right ventricular volume overload pattern (right ventricular enlargement with paradoxical interventricular septal motion)

Dilated tricuspid valve annulus (Significant tricuspid annular dilatation end-diastole: ≥ 40 mm or < 21 mm/m^2)

Dilated inferior vena cava (Normal: ≤ 2.1 cm and hepatic veins: Normal: 0.5 to 1.1 cm)

Rapid sideways expansion of the right atrium during ventricular systole

Abnormal systolic bowing of the interatrial septum toward the left atrium

PW Doppler

Increased tricuspid valve peak E velocity (> 1.0 m/sec)

Systolic flow reversal flow reversal in the hepatic veins suggests severe tricuspid regurgitation

Laminar tricuspid regurgitation flow suggests significant tricuspid regurgitation

CW Doppler

Jet density (spectral strength) indicates severity (Mild: faint/partial/parabolic;
Severe: holosystolic/dense/triangular)

Color Flow Doppler

70 to 90% of normal patients appear to have tricuspid regurgitation

Color flow jet area (Mild: small, narrow, central; Severe: large central jet (> 10 cm^2) or eccentric wall impinging jet of variable size

Determine vena contracta (Mild: < 0.3 cm; Severe: ≥ 0.7 cm)

Determine flow convergence (PISA) (Mild: not visible, transient or small, radius ≤ 0.5 cm; Severe: large throughout systole, radius > 0.9 cm)

Classification of Tricuspid Regurgitation Severity

Parameters	Mild	Moderate	Severe
Structural			
TV morphology	**Normal or mildly abnormal leaflets**	Moderately abnormal leaflets	**Severe valve lesions (e.g.; flail leaflet, severe retraction, large perforation)**
RV and RA size	Usually normal	Normal or mild dilatation	Usually dilated
Inferior vena cava diameter	Normal ≤ 2.1 cm	Normal or mildly dilated ≥ 2.2 to 2.5 cm	Dilated > 2.5 cm
Qualitative Doppler			
Color flow jet area	**Small, narrow, central**	Moderate central	**Large central jet** or eccentric impinging jet of variable size
Flow convergence	**Not visible, transient or small**	Intermediate in size and duration	**Large throughout systole**
CW jet	Faint/partial/parabolic	Dense, parabolic triangular	Dense, often triangular
Semiquantitative			
Color flow jet area (cm^2)	Not defined	Not defined	**> 10**
Vena contracta width (cm)	< 0.3	0.3 to 0.69	**≥ 0.7**
PISA radius (cm)	≤ 0.5	0.6 to 0.9	**> 0.9**
Hepatic vein flow	Systolic dominance	Systolic blunting	**Systolic flow reversal**
Tricuspid inflow	**A-wave dominant**	Variable	E-wave > 1.0 m/sec
Quantitative			
EROA (cm^2)	< 0.20	0.20 to 0.39	**≥ 0.40**
RV (2-D or PISA) (mL)	< 30	30 to 44	≥ 45

Bolded signs are considered specific for their tricuspid regurgitation grade

Classification of Tricuspid Regurgitation Severity at a Glance

Mild Tricuspid Regurgitation	Severe Tricuspid Regurgitation
Thin, small, central color jet	Dilated annulus with no valve coaptation or flail leaflet
Vena contracta width < 0.3 cm	Vena contracta width ≥ 0.7 cm
PISA radius ≤ 0.5 cm at Nyquist 30 to 40 cm/sec	Large central jet > 50% of RA
Systolic dominant hepatic vein flow	PISA radius > 0.9 cm at Nyquist at 30 to 40 cm/sec
Tricuspid A-wave dominant inflow	Systolic flow reversal of hepatic vein flow
Normal RA and RV	Dilated RV with preserved function

Tricuspid Valve Prolapse

Definition

Posterior displacement of the anterior, septal, posterior or all tricuspid valve leaflets beyond the tricuspid annular plane in the parasternal long axis view of the right ventricle (RA-RV view) and/or the apical four chamber view.

M-Mode

Mid to late systolic hammocking of the tricuspid valve leaflet(s)

Holosystolic (pansystolic) hammocking of the tricuspid valve leaflet(s)

2-D

Prolapse of the anterior, septal, posterior tricuspid valve leaflets, individually or together, superior to the tricuspid annulus during ventricular systole

Recommended views are the parasternal long axis of the right ventricle (RA-RV view: anterior and posterior tricuspid valve leaflets visualized) and/or the apical four chamber view (anterior and septal tricuspid valve leaflets visualized)

Doppler

Tricuspid regurgitation (often predominantly late systolic)

Pulmonary Regurgitation

Definition

The backflow of blood through the pulmonary valve into the right ventricle during ventricular diastole; may be acute or chronic

M-Mode/2-D

Anatomic basis for the presence of pulmonary regurgitation (e.g.; valvular pulmonary stenosis, pulmonary hypertension)

Right ventricular enlargement (Abnormal RVIDd: > 41 mm apical four chamber view at the cardiac base)

Right ventricular volume overload (right ventricular enlargement with paradoxical interventricular septal motion)

PW Doppler

Diastolic flow reversal in the main pulmonary artery or branches (Severe)

Pulmonic systolic flow (VTI) compared to systemic flow (LVOT VTI)
(Mild: slightly increased; Severe: greatly increased)

Regurgitation fraction (Mild: < 20%; Severe: > 40%)

CW Doppler

Jet density and contour (Mild: soft; Severe: dense; early termination of diastolic flow)

Deceleration time of the spectral Doppler signal (Severe: < 260 msec)

Pulmonary regurgitation pressure half time (Severe: < 100 msec)

Pulmonary regurgitation jet index (Total PR flow duration ÷ Total duration of ventricular diastole) (Moderate and/or severe: < 0.77)

Color Flow Doppler

Up to 87% of normal patients appear to have pulmonary regurgitation

Jet size (Mild: thin (usually < 10 mm in length) with a narrow origin;
Severe: broad origin; variable depth of penetration)

Jet width/Pulmonary valve annulus width ratio (Severe: > 0.7)

Classification of Pulmonary Regurgitation Severity

Parameter	Mild	Moderate	Severe
Pulmonic valve	Normal	Normal or dilated	Abnormal and may not be visible
RV size	Normal	Normal or dilated	Dilated
Jet size color			
Doppler	Thin (usually < 10 mm in length)	Intermediate	Broad origin; variable depth of penetration
Ratio of PR jet width/ pulmonary annulus			> 0.7
Jet density and contour (CW)	Soft	Dense	Dense; early termination of diastolic flow
Deceleration time of PR of the PR spectral signal			Short, < 260 msec
Pressure half time of PR jet			< 100 msec
PR index		< 0.77	< 0.77
Diastolic flow reversal In the main or branch PA's (PW)			Prominent
Pulmonic systolic flow (VTI)	Slightly increased	Intermediate	Greatly increased
Compared to systemic flow VTI by PW			
Regurgitant fraction	< 20%	20 to 40%	> 40%

Pulmonary Regurgitation Severity Classification at a Glance

Mild PR	Severe PR
Small jet, narrow in width	Jet width/Annulus > 70%
Soft or faint CW jet	Dense jet, PHT < 100 msec
Slow deceleration time	Early termination of PR flow
Normal RV size	Diastolic flow reversal in PA branches
	Dilated RV with normal function

Valvular Pulmonary Stenosis

Definition

A narrowing of the pulmonary valve area during ventricular systole.

M-Mode

An increased “a” dip (≥ 8 mm) of the pulmonary valve

Right ventricular hypertrophy (Normal: < 5 mm)

2-D

Thickened pulmonary valve leaflets (parasternal short axis view of the aortic valve, parasternal long axis view of the right ventricular outflow tract and/or subcostal short axis view of the aortic valve)

Post-stenotic dilatation of the main pulmonary artery

Right ventricular hypertrophy (Normal < 5 mm) (may result in asymmetric septal hypertrophy - ASH)

Right atrial enlargement (Normal RA volume: M: 25 ± mL/m^2; W: 21 ± 6 mL/m^2)

Doppler

CW Doppler recommended

Multiple views recommended (e.g. parasternal short axis view of the aortic valve, parasternal long axis view of the right ventricular outflow tract, modified apical five chamber view, subcostal short axis view of the aortic valve)

Determine the peak velocity (Mild: < 3.0 m/sec; Severe: > 4.0 m/sec)

Determine the peak pressure gradient (Mild: < 36 mm Hg; Severe: > 64 mm Hg)

Determine if subinfundibular, infundibular, main pulmonary artery and/or pulmonary branch stenosis is/are present (may be a part of valvular pulmonary stenosis)

Presence of infundibular obstruction may appear on CW Doppler as dagger-shaped, late peaking systolic gradient

Color flow Doppler may aid in determining the direction of the stenotic jet, which aids in the CW Doppler interrogation of the stenotic valve

Determine the presence and severity of pulmonary regurgitation

Valvular Pulmonary Stenosis Severity Scales

	Normal	Mild	Moderate	Severe
Peak velocity (m/sec)		< 3	3 to 4	> 4
Peak gradient (mm Hg)		< 36	36 to 64	> 64
Pulmonary valve area (cm^2)	3.5 to 4.5	> 2.0 cm	1.0 to 2.0	< 1.0 cm

Infective Endocarditis

Definition

An infection of the endocardial surface of the heart which may include one or more cardiac valves, the mural endocardium or septal defect.

M-Mode/2-D

Evaluate for:

- Vegetation (oscillating mass with independent motion), usually found on the atrial side of the mitral valve/tricuspid valve or on the ventricular surface of the aortic valve/pulmonary valve (most common finding)
- Valve ring abscess
- Valve perforation
- Valve aneurysm
- Flail leaflet
- Chamber enlargement due to valve regurgitation/intracardiac shunt
- Premature closure of the mitral valve (M-mode)
- Prosthetic heart valve dehiscence
- Pericardial effusion
- Heart failure

Doppler

Evaluate for:

- Valve regurgitation (most common Doppler finding)
- Valve stenosis (rare) (most likely involving prosthetic heart valve)
- Valve perforation (flow through the cardiac valve leaflet instead of through coaptation of the leaflets)
- Intracardiac shunt (e.g.; fistula)
- Restrictive mitral valve inflow pattern (suggests increased left ventricular end-diastolic pressure)

Prosthetic Heart Valves

Types of prosthetic heart valves: mechanical (metal), bioprosthetic (tissue), homograft, transcatheter.

All prosthetic heart valves are inherently stenotic (except homografts).

Prosthetic valves have regurgitation: closing volume plus leakage volume. The regurgitation is usually trace to mild in severity.

Perivavular leaks are considered abnormal.

M-Mode/2-D/Doppler

Acquire a baseline study within 30 days of surgery

Evaluate for stenosis, regurgitation, perivalvular leak, thrombus (especially mechanical valves), thickness (bioprosthetic valves),vegetation, dehiscence, pannus, ventricular systolic and diastolic function

Doppler Parameters of Prosthetic Mitral Valve Function

	Normal	**Possible stenosis**	**Suggests significant stenosis**
Peak velocity (m/sec)	< 1.9	1.9 – 2.5	≥ 2.5
Mean gradient (mm Hg)	≤ 5	6 – 10	> 10
VTI_{PrM}/VTI_{LVOT}	< 2.2	2.2 – 2.5	> 2.5
EOA (cm^2)	≥ 2.0	1 – 2	< 1
PHT	< 130	130 to 200	> 200

Doppler Parameters of Prosthetic Aortic Valve Function

Parameter	**Normal**	**Possible Stenosis**	**Suggests significant stenosis**
Peak velocity (m/sec)*	< 3	3 – 4	> 4
Mean gradient (mm Hg)*	< 20	20 – 35	> 35
Velocity ratio	≥ 0.30	0.29 – 0.25	< 0.25
EOA (cm^2)	> 1.2	1.2 – 0.8	< 0.8
Contour of the jet velocity	Triangular, early peaking	Triangular to intermediate	Rounded, symmetrical
Acceleration time (msec)	< 80	80 – 100	> 100

**Assumes normal left ventricular systolic function, may be affected by significant aortic regurgitation.*

Doppler Parameters of Prosthetic Tricuspid Valve Function

	Consider valve stenosis*
Peak velocity**	> 1.7 m/sec
Mean gradient**	≥ 6 mm Hg
Pressure half-time	≥ 230 msec
EOA and VTI_{PrTV}/VTI_{LVOT}	No data yet available for tricuspid prostheses

**Because ofrespiratory variation, average ≥ 5 cycles*
***May be increased also with valvular regurgitation*

Findings Suspicious for Prosthetic Pulmonary Valve Stenosis

- Peak velocity through the prosthesis > 3 m/sec or > 2 m/sec through a homograft*
- Increase in peak velocity on serial studies†
- Impaired RV systolic function or elevated RV systolic pressure
- Cusp or leaflet thickening or immobility
- Narrowing of forward color map

** suspicious but not diagnostic of stenosis † More reliable parameter*

Transcatheter Aortic Valve Replacement (TAVR)

Definition

TAVR is a minimally invasive delivery of an aortic valve through a catheter to treat patients with severe aortic stenosis.

TAVR prostheses include the Edwards SAPIEN and Medtronic CoreValve

M-Mode/2-D/Doppler

Post-Implantation

Determine TAVR hemodynamnics:

Peak velocity (Normal: 2.0 ± 0.4 m/sec)

Peak pressure gradient (Normal: 17.1 ± 7.4 mm Hg)

Mean pressure gradient (Normal: 9.3 ± 4.5 mm Hg)

Effective orifice area (Normal: 1.82 ± 0.43 cm^2)

Effective orifice area indexed (Normal: 1.0 ± 0.27 cm^2/m^2)

Presence and severity of aortic regurgitation (central, perivalvular)

Evaluate

- Left ventricular global and segmental systolic function
- Left ventricular volumes and ejection fraction
- Systolic pulmonary artery pressures
- Other cardiac pathologies (e.g. mitral regurgitation)

Transcatheter Repair for Mitral Regurgitation (MitraClip)

Definition

MitraClip is a transcatheter repair for significant mitral regurgitation.

M-Mode/2-D/Doppler

Post-Implantation

Evaluate

- Presence and severity of residual mitral regurgitation
- Double orifices of the mitral valve and planimeter for valve area
- Left ventricular systolic global and segmental function
- Left ventricular volumes and ejection fraction
- Evaluate right ventricular systolic function (e.g.; TAPSE)
- Acquire peak velocity, peak pressure gradient, mean pressure gradient, pressure and mitral valve effective orifice area
- Determine the systolic pulmonary artery pressures
- Evaluate iatrogenic atrial septal defect

Pericardial Disease

Pericarditis/Pericardial Effusion

Definition

Pericarditis is an inflammation of the pericardium which may result in the visceral pericardium secreting fluid (pericardial effusion).

M-Mode/2-D

Echo-free space located between the visceral pericardium (epicardium) and parietal (fibrous) pericardium anterior to the descending thoracic descending aorta which persists throughout the cardiac cycle (ventricular diastole and ventricular systole)

Attenuated pericardial motion

Doppler

Evaluate for cardiac tamponade

Pericardial Effusion Severity Scales

Physiologic	A clear space is seen only during ventricular systole
Small:	(< 100 mL): clear space is detectable during ventricular diastole and ventricular systole posterior only and is < 1 cm in width
Moderate:	(100 to 500 mL): Clear space is detectable during ventricular diastole and ventricular systole anteriorly and posteriorly and is 1 to 2 cm in width
Large:	(> 500 mL): Clear space is detectable during ventricular diastole and ventricular systole, surrounds the entire heart and is > 2 cm in width (may result in swinging heart)
Pleural effusion	Clear space located posterior to the descending thoracic aorta

Cardiac Tamponade

Definition

An increase in intra-pericardial pressures due to the accumulation of pericardial effusion leading to impaired diastolic filling and decreased cardiac output.

M-Mode/2-D

Pericardial effusion (usually moderate to large and/or rapid accumulation)

Right ventricular early diastolic collapse/compression

Right atrial diastolic collapse/inversion (late ventricular diastole/early ventricular systole lasting at least one-third the cardiac cycle

Inferior vena cava plethora (Normal dimension: ≤ 2.1 cm)

"Swinging heart" due to moderate to large pericardial effusion

Doppler

Marked (> 25%) respiratory variation of the tricuspid valve inflow velocities and time velocity integrals (increase with inspiration; decrease with expiration) (PW Doppler preferred and reduce sweep speed to 25 mm/sec)

Marked (> 25%) respiratory variation of the mitral valve inflow velocities and time velocity integrals (decrease with inspiration; increase with expiration) (PW Doppler preferred and reduce sweep speed to 25 mm/sec)

Echocardiographic Findings for Cardiac Tamponade

Pericardial effusion (usually moderate to large or rapidly accumulating)

Respiratory variation of the atrioventricular valves (tricuspid first followed by mitral)

Pre-systolic collapse/inversion of the right atrium

Right ventricular diastolic collapse/compression in early ventricular diastole

Inferior vena cava plethora

Abnormal hepatic vein flow with reduced/reversed diastolic flow during expiration

Constrictive Pericarditis

A thickened, fibrotic and adherent pericardium restricting the diastolic filling of the heart.

M-Mode/2-D

Bright, thick pericardium (normal thickness: 1.2 ± 0.8 mm (> 3 mm suggests constrictive pericarditis)

"Septal bounce" ("septal shudder") (interventricular septal leftward movement with inspiration; rightward movement with expiration)

"Bound-down" appearance with lack of "pericardial slide" of the lateral walls of the ventricles (parasternal long axis, apical four chamber; subcostal four chamber)

Normal sized ventricles with dilated atria

Inferior vena cava plethora (Normal dimension: ≤ 2.1 cm)

Doppler

Marked (> 25%) respiratory variation of the tricuspid valve inflow velocities and time velocity integrals (increase with inspiration; decrease with expiration) (PW Doppler preferred and reduce sweep speed to 25 mm/sec)

Marked (> 25%) respiratory variation the mitral valve inflow velocities and time velocity integrals (decrease with inspiration; increase with expiration) (PW Doppler preferred and reduce sweep speed to 25 mm/sec)

Marked reduction or reversal of hepatic vein forward diastolic flow (important finding)

Higher TDI mitral valve annulus peak E' septal velocity versus lateral wall E' peak velocity ("annulus reversus")

Preserved TDI mitral valve E' (> 8 cm/sec) in a patient with heart failure ("annulus paradoxus") (sampling of mitral septal annulus recommended)

Preserved TDI mitral valve annulus E/E' ratio (< 15) in a patient with heart failure ("annulus paradoxus") (sampling of septal mitral annulus recommended)

Echocardiographic Findings for Constrictive Pericarditis

Thickened pericardium

Interventricular/Interatrial septal bounce

"Bound-down" appearance of the ventricular walls with lack of pericardial slide

Inferior vena cava/hepatic vein dilatation

Normal atrial/ventricular dimensions

Restrictive filling pattern with respiratory variation (MV, TV)

Hepatic vein diastolic flow reversal with expiration

Higher mitral annular septal E' peak velocity as compared to the lateral E' peak velocity ("annulus reversus")

Normal mitral annulus TDI E/E' (< 15 in patients with heart failure ("annulus paradoxus")

Constrictive Pericarditis

Separation of Constrictive Pericarditis from Restrictive Cardiomyopathy

	Constriction	**Restriction**
Atrial size	Normal	Dilated
Septal motion	Abnormal	Normal
Annular E'	Normal-elevated	Reduced (≤ 10 cm/sec)
Respiratory variation of Mitral E velocity	Exaggerated (≥ 25%)	Normal

Systemic and Pulmonary Hypertensive Heart Disease

Systemic Hypertension

Definition

Blood pressure categories: (based on the mean of two or more readings on two separate office visits)

Normal: Less than 120/80 mm Hg

Elevated: Systolic blood pressure between 120 to 129 mm Hg and diastolic less than 80 mm Hg

Stage 1: Systolic blood pressure between 130 to 139 mm Hg or diastolic between 80 to 89 mm Hg

Stage 2: Systolic blood pressure at least 140 mm Hg or diastolic at least 90 mm Hg

Hypertensive crisis: Systolic blood pressure over 180 mm Hg and/or diastolic 120 mm Hg

M-Mode/2-D

Left ventricular hypertrophy: (Normal IVSd and LVPWd: M: 0.6 to 1.0 cm; W: 0.6 to 0.9 cm)

Left ventricular dilatation (late in course) (Normal LVIDd: M: 4.2 to 5.8 cm; W: 3.8 to 5.2 cm)

Increased left ventricular mass index (linear method) (Normal: M: 49 to 115 g/m^2; W: 43 to 95 g/m^2)

Left atrial enlargement (Normal LA volume: ≤ 34 mL/m^2)

Aortic root dilatation/aortic aneurysm

Mitral annular calcification

Doppler

Aortic regurgitation

Diastolic dysfunction

Left Ventricular Hypertrophy Severity Scales

Men	Normal	Mild	Moderate	Severe
Septal wall thickness (cm)	0.6 to 1.0	1.1 to 1.3	1.4 to 1.6	> 1.6
Posterior wall thickness (cm)	0.6 to 1.0	1.1 to 1.3	1.4 to 1.6	> 1.6
LV mass* (g)	88 to 224	225 to 258	259 to 292	> 292
LV mass index* (g/m^2)	49 to 115	116 to 131	132 to 148	> 148
LV mass+ (g)	96 to 200	201 to 227	228 to 254	≥ 255
LV mass index+ (g/m^2)	50 to 102	103 to 116	117 to 130	≥ 131
Women				
Septal wall thickness(cm)	0.6 to 0.9	1.0 to 1.2	1.3 to 1.5	> 1.5
Posterior wall thickness(cm)	0.6 to 0.9	1.0 to 1.2	1.3 to 1.5	> 1.5
LV mass* (g)	67 to 162	163 to 186	187 to 210	> 210
LV mass index* (g/m^2)	43 to 95	96 to 108	109 to 121	> 121
LV mass+ (g)	66 to 150	51 to 171	172 to 182	> 183
LV mass index+ (g/m^2)	44 to 88	89 to 100	101 to 112	≥ 113

***LV mass by linear method**
+ LV mass by 2-D method

Pulmonary Hypertension

Definition

Increased pulmonary artery pressure (mean pulmonary artery pressure ≥ 25 mm Hg at rest) due to abnormalities in the precapillary pulmonary arterioles or abnormalities which increase left atrial pressure.

M-Mode/2-D

Right ventricular hypertrophy (Normal: < 0.5 cm)

Right ventricular dilatation (Abnormal RVIDd: > 41 mm apical four chamber view at the cardiac base)

D-shaped left ventricle throughout the cardiac cycle

Dilatation of the inferior vena cava (Normal ≤ 2.1 cm) and hepatic veins (Normal: 0.5 to 1.1 cm)

Right atrial enlargement (Normal RA volume: M: 25 ± 7 mL; W: 21 ± 6 mL)

Determine tricuspid annular plane systolic excursion (TAPSE) (Abnormal: < 17 mm)

Doppler

Tricuspid regurgitation

Pulmonary regurgitation

Shortened RVOT acceleration time (PW Doppler) (normal: > 120 msec)

Determine the pulmonary artery pressures (e.g. SPAP/MPAP/PAEDP/PVR)

Pulmonary Hypertension Severity Scales

Systolic Pulmonary Artery Pressure (SPAP)

Normal: 18 to 25 mm Hg

Mild pulmonary hypertension: 35 to 45 mm Hg

Moderate pulmonary hypertension: 45 to 60 mm Hg

Severe pulmonary hypertension: > 60 mm Hg

Right Ventricular Outflow Tract (RVOT) Acceleration Time (AcT)

Normal: > 120 msec

Mild pulmonary hypertension: 80 to 100 msec

Moderate pulmonary hypertension: 60 to 80 msec

Severe pulmonary hypertension: < 60 msec

Mean Pulmonary Artery Pressure (MPAP)

Normal: 9 to 18 mm Hg

Pulmonary Artery End-diastolic Pressure (PAEDP)

Normal: 4 to 12 mm Hg

Recently new guidelines have been proposed:

Echocardiographic probability of pulmonary hypertension in symptomatic patients with a suspicion of pulmonary hypertension

Peak Tricuspid Regurgitation velocity (m/sec)	Presence of other "PH" signs	Echocardiographic probability of pulmonary hypertension
≤ 2.8 or not measureable	No	Low
≤ 2.8 or not measurable	Yes	Intermediate
2.9 to 3.4	No	Intermediate
2.9 to 3.4	Yes	High
> 3.4	Not required	High

Echocardiographic signs used to assess the probability of pulmonary hypertension in addition to the tricuspid regurgitation peak velocity (Echocardiographic signs from at least two different categories should be present to alter the echocardiographic probability of pulmonary hypertension

The Ventricles	Pulmonary Artery	Inferior Vena Cava and Right Atrium
Right ventricle/Left ventricle Basal diameter ratio > 1.0	Right ventricular outflow tract PW Doppler acceleration time < 105 msec and/or Mid-systolic notching	Inferior vena cava diameter > 2.1 cm with decreased inspiratory collapse < 50% with a sniff) or < 20% with quiet inspiration
Flattening of the interventricular septum Eccentricity index > 1.2 in systole and/or diastole	Peak pulmonary regurgitation velocity > 2.2 m/sec	Right atrial area > 18 cm^2
	MPA diameter > 2.5 cm	

Cardiomyopathies

Dilated Cardiomyopathy

Definition

Dilated cardiomyopathy is dilatation and impaired contraction of the left ventricle, right ventricle or both ventricles.

M-Mode/2-D

Four chamber enlargement (Normal LVIDd: M: 4.2 to 5.8 cm; W: 3.8 to 5.2)
(Normal LVIDs: M: 2.5 to 4.0 cm; W: 2.2 to 3.5 cm)

Reduced global ventricular systolic function (e.g.; global hypokinesia)
(e.g.; ejection fraction < 40%)

Increased mitral valve E-point to septal separation (EPSS) (> 7 mm suggests reduced ejection fraction; > 20 mm suggests an ejection fraction < 30%) (best measured with M-Mode)

Evaluate for ventricular thrombus (especially at the cardiac apex)

Pericardial effusion

Pleural effusion

Doppler

Mitral regurgitation (nearly 100%)

Tricuspid regurgitation (nearly 90%)

Pulmonary regurgitation (approximately 50%)

Aortic regurgitation (approximately 20%)

Diastolic dysfunction

Determine pulmonary artery pressures (e.g.; SPAP/MPAP/PAEDP/PVR)

Hypertrophic Cardiomyopathy

Definition

Hypertrophic cardiomyopathy is a genetic disorder that is characterized by left ventricular hypertrophy unexplained by secondary causes and a non-dilated left ventricle with preserved or increased ejection fraction. The hypertrophy is commonly asymmetrical involving the basal interventricular septum.

M-Mode/2-D

Asymmetrical septal hypertrophy (ASH) (IVSd/LVPWd ratio ≥ 1.3 suggests ASH)

Systolic anterior motion of the mitral valve (SAM)

Mid-systolic notching of the aortic valve (M-mode)

'Small", hypercontractile left ventricle

Left atrial enlargement (Normal LA volume: ≤ 34 mL/m^2)

Doppler

Left ventricular outflow tract CW Doppler "dagger-shaped" (sharp and triangular) spectral tracing

Determine peak left ventricular outflow tract obstruction pressure gradient (> 50 mm Hg indicates significant obstruction)

Determine the presence and severity of mitral regurgitation

Diastolic dysfunction

Restrictive/Infiltrative Cardiomyopathies

Definition

A disease of the myocardium characterized by restrictive diastolic filling and reduced diastolic volume of either or both ventricles, with normal or near-normal global systolic function, may be classified as primary (e.g.; endomyocardial fibrosis, Loffler's endocarditis, idiopathic restrictive) or secondary (infiltrative – amyloidosis, sarcoidosis, hemochromatosis)

Endomyocardial Fibrosis/Loeffler's Endocarditis

Definition

Endomyocardial fibrosis is a progressive disease of unkown origin. It is most commonly found in the tropical and sub-tropical regions of the world. The cardiac feature is fibrosis of the endocardium involving the ventricles and cardiac valves. Loeffler's endocarditis is similar to endomyocardial fibrosis with an increasing number of white blood cells (eosinophilia) resulting in fibrosis of the endocardium (hypereosinophilia).

M-Mode/2-D

Apical thrombus/obliteration (may extend to basal inflow portion of ventricular wall) with normal global/segmental systolic function

Dilated atria

Doppler

Mitral regurgitation

Tricuspid regurgitation

Diastolic dysfunction

Cardiac Amyloidosis

Definition

A multisystem disease in which there is extracellular deposition of the amyloid protein in the kidney, liver, heart, nerve, skin and tongue.

M-Mode/2-D

Thickened right ventricle, left ventricle or both ventricular walls with "ground-glass" speckled appearance of the myocardium

Atrial enlargement

Pericardial effusion

Pleural effusion

Doppler

Valvular regurgitation (may involve all four cardiac valves)

Diastolic dysfunction

Sarcoidosis

Definition

A systemic disease resulting in the formation of noncaseating granulomas which can infiltrate the myocardium.

M-Mode/2-D

Increased ventricular wall thickness (early in course)

Segmental wall thinning (classic finding) (late in course)

Left ventricular enlargement with reduced ejection fraction (late in course)

Ventricular aneurysm (late in course)

Doppler

Mitral regurgitation

Diastolic dysfunction

Hemochromatosis

Definition

A disease which results in iron overload and deposition of iron in the sarcoplasmic reticulum of many organs, including the heart.

M-Mode/2-D

Dilated cardiomyopathy

Doppler

Valvular regurgitation

Separation of Restrictive Cardiomyopathy from Constrictive Pericarditis

	Restriction	Constriction
Atrial size	Dilated	Normal
Septal motion	Normal	Abnormal
Annular E’	Reduced (≤ 10 cm/sec)	Normal-elevated
Respiratory variation of mitral E velocity	Normal	Exaggerated (≥ 25%)

Ischemic Heart Disease

Ischemic Heart Disease

Definition

A narrowing of the coronary artery(s) sufficiently to prevent adequate blood supply to the myocardium (myocardial ischemia). A complete blockage may result in death of tissue (myocardial infarction).

M-Mode/2-D

Segmental wall motion abnormality (e.g.; abnormal systolic wall thickening) (multiple views should be used)

Thin, bright and akinetic suggests “old” (chronic) myocardial infarction

Normal thickness with segmental wall motion abnormality(s) suggests acute myocardial infarction

Determine wall motion score index

Wall Motion Score Index (WMSI)

Systolic Wall Motion	Score	Definition
Normal/Hyperkinesis	1	Systolic wall thickening > 40%
Hypokinetic	2	Systolic wall thickening < 40 %
Akinetic	3	Systolic wall thickening < 10%
Dyskinetic	4	Systolic wall thinning with myocardial scarring moving outward during ventricular systole

WMSI = Sum of wall motion scores ÷ Number of segments visualized

Note

In normal subjects, the percent of systolic thickening of the interventricular septum is less than the free wall of the left ventricle

A normal contracting left ventricle has a wall motion score index of 1

Patients with a wall motion score index of > 1.7 are abnormal

Doppler

Mitral regurgitation

Complications of Myocardial Infarction

Pericardial Effusion

A common acute response to acute myocardial effusion (usually small).

Dressler's Syndrome

Delayed form of pericarditis; a post-myocardial infarction illness which manifests with fever, pericarditis and pleuritis; may occur one week to several weeks after myocardial infarction.

Evaluate for pericardial effusion

Left Ventricular True Aneurysm

Definition

A thin, dyskinetic area of myocardium composed of muscle fibers and scar tissue recognized as a bulge distorting the normal counter of the left ventricle during ventricular systole and ventricular diastole.

Left ventricular aneurysm is the final result of infarct expansion and ventricular remodeling.

M-Mode/2-D

Thin walls with distorted shape of the ventricle that demonstrates akinesis/dyskinesis (commonly located at the cardiac apex)

"Hinge" point where "good" left ventricular myocardium meets "bad"

Thrombus within the aneurysm possible

Doppler

Mitral regurgitation

Pseudoaneurysm

Definition

The free wall of the left ventricle ruptures and a hemopericardium is confined by the pericardium.

M-Mode/2-D

A narrow perforation of the ventricular free wall with a saccular globular contour of the false chamber

Thrombus may line the aneurysm

Doppler

A to-and-fro turbulent flow noted at the orifice of the pseudoaneurysm

Left Ventricular Thrombus

Definition

The diagnosis is based on the detection of an echodense mass with defined margins, clearly identifiable throughout the cardiac cycle, adjacent to asynergic myocardium, visible in at least two orthogonal views and distinguished from other cardiac structures and artifacts.

M-Mode/2-D

Thrombus (located most often at the cardiac apex) with underlying segmental wall motion abnormality visualized in two orthogonal two-dimensional views

Color Flow Doppler

May demonstrate “filling defect” in the area of the thrombus (decrease color velocity scale and wall filter)

Ventricular Septal Rupture

Definition

A rupture of the interventricular septum post-myocardial infarction.

M-Mode/2-D/

Allows direct visualization of the defect (disrupted, “spliced” interventricular septum) (off-axis and unconventional views may be required)

Inferolateral, inferoapical, anteroapical most common locations most common

Doppler

A high velocity jet with turbulent flow with left-to-right shunting

Determine systolic pulmonary artery pressure (e.g.; SPAP/MPAP/PAEDP/PVR)

Determine the shunt ratio

Papillary Muscle Dysfunction

Definition

Papillary muscle dysfunction may occur as a result of (1) ventricular dilatation, (2) ischemia or infarction of a papillary muscle,(including ventricular aneurysm), (3) fibrosis/calcification/inflammatory disease of a papillary muscle (4) rupture of a papillary muscle, (5) interventricular conduction disturbances

M-Mode/2-D

Incomplete closure of the mitral valve leaflets where they fail to meet the level of the mitral annulus ("tenting") implies papillary muscle dysfunction (parasternal long axis, apical four chamber)

Left ventricular dilatation interrupts the spatial orientation of the papillary muscles to the rest of the mitral valve apparatus, which induces papillary muscle dysfunction

An area of segmental wall motion abnormality around either papillary muscle suggests papillary muscle dysfunction

Fibrosis/calcification of the papillary muscle implies papillary muscle dysfunction (anterolateral papillary muscle more commonly fibrocalcific)

The most severe form of papillary muscle dysfunction is the rupture of a papillary muscle head or muscle itself which results in flail mitral valve leaflet (medical emergency)

Mass representing the ruptured papillary muscle may be visualized moving between the left and left atrium during ventricular systole

Doppler

Mitral regurgitation

Right Ventricular Infarction

Definition

Associated most often with inferior infarction

M-Mode/2-D

Segmental wall motion abnormality – look for associated segmental wall motion abnormality of the inferior interventricular septum (W-shaped infarction)

Right ventricular dilatation (Abnormal RVIDd: > 41 mm apical four chamber view at the base)

Use multiple views (the right ventricle may be visualized in almost every standard 2-D echocardiographic view)

Doppler

Tricuspid regurgitation (pulmonary artery pressures may be unexpectedly low)

Right-to-left shunting through a patent foramen ovale

Cardiac Tumors

Cardiac Tumors

Primary Benign (Intracardiac)

Myxoma (most common primary benign intracardiac tumor in the adult population) (30%)

Papilloma (papillary fibroelastoma) (most common primary benign cardiac valve tumor in the adult)

Lipoma

Fibroma

Rhabdomyoma most common primary benign intracardiac tumor found in children; occurs most often in the right ventricle; associated with tuberous sclerosis

Myxoma

Definition

A primary benign intracardiac tumor that is usually attached to a stalk to the interatrial septum in the area of the fossa ovalis.

M-Mode/2-D

Dramatic motion of the myxoma prolapsing from the left atrium into the left ventricle during ventricular diastole

Doppler

Mimics findings of valvular mitral stenosis

Mitral regurgitation

Papilloma (Papillary Fibroelastoma)

Found on the endocardial surface of the cardiac valves or ventricular endocardium (most common primary benign cardiac valve tumor in the adult)

Lipoma (Lipomatous Hypertrophy of the Interatrial Septum)

Thickened interatrial septum

"Dumb-bell" appearance with sparing of the fossa ovalis

Best views to use are parasternal short axis of the aortic valve, subcostal four chamber

Fibroma

Frequently embedded in the myocardial wall

Rhabdomyoma

Most common primary benign intracardiac tumor found in children

Associated with tuberous sclerosis

Found in the ventricular walls (more common in right ventricle)

Primary Malignant (Intracardiac)

Angiosarcoma

Found in the atrial walls and pericardium; may compromise the inflow portions of the ventricles

Associated with pericardial effusion, cardiac tamponade

Secondary Tumors (Metastatic)

More common than primary tumors

Pericardial more often than myocardial involvement

Melanoma (most common), malignancy of breast or lung, lymphoma can invade myocardium

Renal, liver, Wilm's tumors extend from the inferior vena cava to the right atrium and right ventricle

Extracardiac Tumors

Mediastinal cysts, hematoma, thymoma, diaphragmatic hernia, pancreatic cyst may involve pericardium

Carcinoid Heart Disease

Definition

The result of a metastasizing carcinoid tumor, usually in the appendix or ileum.

The carcinoid tumor secretes a substance known as serotonin; if the tumor metastasizes to the liver, the serotonin may be deposited on the endocardial linings of the right heart. The serotonin is inactivated by the lungs so left heart involvement is rare.

M-Mode/2-D/Doppler

Thickened, retracted, whitish in appearance tricuspid valve (more common) and/or pulmonary valve

Tricuspid regurgitation (usually moderate to severe)

Tricuspid stenosis (functional tricuspid stenosis due to retracted tricuspid valve leaflets)

Pulmonary regurgitation

Pulmonary stenosis (valvular)

Evaluate right ventricular global systolic function

Evaluation of the Atria

Evaluation of the Left Atrium

Common Causes of Left Atrial Enlargement

Mitral valve disease (e.g.; mitral stenosis, significant chronic mitral regurgitation)

Left ventricular diastolic dysfunction

Left ventricular pressure overload (e.g.; systemic hypertension, aortic stenosis)

Congenital heart disease (e.g.; ventricular septal defect, patent ductus arteriosus)

Cardiac transplantation

Atrial arrhythmias (e.g.; atrial fibrillation)

M-Mode/2-D

Two-dimensional left atrial volume preferred (Simpson's biplane (apical four view with apical two chamber view) method of discs at end-systole) (Normal: LA volume: ≤ 34 mL/m^2)

Left atrial linear dimension (measured in the parasternal long axis view perpendicular to the aortic root at the level of the sinuses of Valsalva, leading edge to leading edge at end-systole) (Normal: M: 3.0 to 4.0 cm; W: 2.7 to 3.8 cm)

Left Atrium Severity Scales

Men	Normal	Mildly abnormal	Moderately abnormal	Severely abnormal
LA diameter (cm)	3.0 to 4.0	4.1 to 4.6	4.7 to 5.2	> 5.2
LA diameter/BSA (cm/m^2)	1.5 to 2.3	2.4 to 2.6	2.7 to 2.9	≥ 3.0
LA area (cm^2)	20	20 to 30	30 to 40	> 40
LA volume (mL)	18 to 58	59 to 68	69 to 78	≥ 79
LA volume/BSA (mL/m^2)	16 to 34	35 to 41	42 to 48	> 48
Women				
LA diameter (cm)	2.7 to 3.8	3.9 to 4.2	4.3 to 4.6	≥ 4.7
LA diameter/BSA (cm/m^2)	1.5 to 2.3	2.4 to 2.6	2.7 to 2.9	≥ 3.0
LA area (cm^2)	20	20 to 30	30 to 40	> 40
LA volume (mL)	22 to 52	53 to 62	63 to 72	≥ 73
LA volume/BSA (mL/m^2)	16 to 34	35 to 41	42 to 48	> 48

Evaluation of the Right Atrium

Common Causes of Right Atrial Enlargement

Tricuspid valve disease (e.g.; tricuspid stenosis, significant chronic tricuspid regurgitation)

Right ventricular diastolic dysfunction

Right ventricular pressure overload (e.g.; pulmonary hypertension, valvular pulmonary stenosis)

Congenital heart disease (e.g.; atrial septal defect, partial anomalous pulmonary venous return)

Cardiac transplantation

Atrial arrhythmias (e.g.; atrial fibrillation)

2-D

Right atrial volume preferred (Simpson's method of discs apical four chamber view at end-systole) (Normal RA volume: M: 25 ± mL/m^2; W: 21 ± 6 mL/m^2)

Right Atrial Pressure

Estimated by evaluating the inferior vena cava and the presence of inspiratory collapse (normal: ≤ 2.1 cm with greater than 50% inspiratory collapse measured 1 to 2 cm from entrance into the right atrium using the subcostal window suggests right atrial pressure of 3 mm Hg)

Normal Right Atrial Dimensions

	Men	Women
RA volume (mL/m^2)	25 ± 7	21 ± 6
Right atrial area (cm^2)	≤ 18	≤ 18
Right atrial major axis (cm)	≤ 5.3	≤ 5.3
Right atrial major axis/BSA(cm^2)	2.4 ± 0.3	2.5 ± 0.3
Right atrial minor axis (cm)	≤ 4.4	≤ 4.4
Right atrial minor axis BSA (cm/m^2)	1.9 ± 0.3	1.9 ± 0.3

Right Atrial Pressure

Variable	Normal (0 to 5 {3}mm Hg)	Intermediate (5 to 10 {8} mm Hg)		High (15 mm Hg)
IVC diameter	≤ 2.1 cm	≤ 2.1	> 2.1	> 2.1
Collapse sniff	> 50^%	< 50	> 50%	< 50%
Secondary indices				Restrictive filling pattern Tricuspid E/E' > 6 Diastolic prominence in hepatic veins (systolic filling fraction < 55%)

Evaluation of the Ventricles

Evaluation of Left Ventricular Systolic Function

M-Mode/2-D

Determine left ventricular global systolic function (e.g.; ejection fraction) with qualitative visualization of the left ventricle utilizing multiple views (e.g.; parasternal long axis, parasternal short axis of the left ventricle at the level of the papillary muscles, apical four chamber, apical two chamber)

Determine segmental wall motion abnormalities and wall motion score index

Determine quantitative ejection fraction (Simpson's method of disc biplane recommended)

Determine descent of the cardiac base (> 10 mm predicts a normal ejection fraction)

Doppler

Determine left ventricular outflow tract velocity time integral, stroke volume, cardiac output, cardiac index

Left Ventricle Normal Values

	Men	Women
Left ventricle end-diastolic dimension (cm)	4.2 to 5.8	3.8 to 5.2
Left ventricle end-systolic dimension (cm)	2.5 to 4.0	2.2 to 3.5
Interventricular septal thickness end-diastole (cm)	0.6 to 1.0	0.6 to 0.9
Left ventricular posterior wall thickness end-diastole (cm)	0.6 to 1.0	0.6 to 0.9
Left ventricular mass index (g/m^2) (2-D)	50 to 102	44 to 88
End-diastolic volume (mL)	62 to 150	46 to 106
End-systolic volume (mL)	21 to 61	14 to 42
Ejection Fraction (%)	52 to 72	54 to 74
LVOT velocity time integral (cm)	18 to 24	8 to 24
Stroke volume (mL)	70 to 100	70 to 100
Cardiac output (lpm)	4 to 8	4 to 8
Cardiac index (lpm/m^2)	2.4 to 4.2	2.4 to 4.2

Ejection Fraction (%) Severity Scales

	Men	Women
Normal	52 to 72	54 to 74
Mildly reduced	41 to 51	41 to 53
Moderately reduced	30 to 40	30 to 40
Severely reduced	< 30	< 30

Abnormal Ranges and Severity of Left Ventricular Dimension

Men	**Normal**	**Mildly Abnormal**	**Moderately Abnormal**	**Severely Abnormal**
LV end-diastolic dimension (cm)	4.2 to 5.8	5.9 to 6.3	6.4 to 6.8	> 6.8
LV end-systolic dimension (cm)	2.4 to 4.0	4.1 to 4.3	4.4 to 4.5	> 4.5
Women				
LV end-diastolic dimension (cm)	3.8 to 5.2	5.3 to 5.6	5.7 to 6.1	> 6.1
LV end-systolic dimension (cm)	2.2 to 3.5	3.6 to 3.8	3.9 to 4.1	> 4.1

Left Ventricular Hypertrophy Severity Scales

Men	**Normal**	**Mild**	**Moderate**	**Severe**
Septal wall thickness (cm)	0.6 to 1.0	1.1 to 1.3	1.4 to 1.6	> 1.6
Posterior wall thickness (cm)	0.6 to 1.0	1.1 to 1.3	1.4 to 1.6	> 1.6
LV mass* (g)	88 to 224	225 to 258	259 to 292	> 292
LV mass index* (g/m^2)	49 to 115	116 to 131	132 to 148	> 148
LV mass+ (g)	96 to 200	201 to 227	228 to 254	≥ 255
LV mass index+ (g/m^2)	50 to 102	103 to 116	117 to 130	≥ 131
Women				
Septal wall thickness(cm)	0.6 to 0.9	1.0 to 1.2	1.3 to 1.5	> 1.5
Posterior wall thickness(cm)	0.6 to 0.9	1.0 to 1.2	1.3 to 1.5	> 1.5
LV mass* (g)	67 to 162	163 to 186	187 to 210	> 210
LV mass index* (g/m^2)	43 to 95	96 to 108	109 to 121	> 121
LV mass+ (g)	6 to 150	151 to 171	172 to 182	> 183
LV mass index+ (g/m^2)	44 to 88	89 to 100	101 to 112	≥ 113

***LV mass by linear method**
+ LV mass by 2-D method

Left Ventricular Diastolic Function

Definition

Diastolic dysfunction is the inability of the heart to fill with normal pressures. There are five diastolic grades: Normal, Grade 1, Grade 2, Grade 3, Indeterminate

The minimum diastolic function examination should include:

Patient history and physical examination (e.g.; history of systemic hypertension, coronary artery disease)

Evaluation of 2-D findings (e.g.; left ventricular dimensions, wall thickness, volumes, ejection fraction, valvular disease)

Mitral valve PW Doppler E/A ratio

TDI E' peak velocities (septal and lateral)

Mitral valve E/E' ratio

Tricuspid regurgitation peak velocity

LA volume

Diastolic Function Parameters for Normal Ejection Fraction (Ejection Fraction > 50%)

Average E/E' > 14

E' velocity < 7 cm/sec septal or < 10 cm/sec lateral

Tricuspid regurgitation peak velocity > 2.8 m/sec

LA volume ≥ 34 mL/m^2

Diastolic Grading Guide for Normal Ejection Fraction (Ejection Fraction > 50%)

Normal diastolic function: < 2 positive parameters

Indeterminate diastolic function: 2 parameters

Diastolic dysfunction: > 2 parameters (refer to reduced ejection fraction guide for diastolic grade) (see below)

Diastolic Function Parameters for Reduced Ejection Fraction (< 50%)

E/E' average: > 14

Tricuspid regurgitation peak velocity > 2.8 m/sec

LA volume: > 34 mL/m^2

Diastolic Grading for Reduced Ejection Fraction or Normal Ejection Fraction with Greater Than Two Positive Parameters

Grade 1:

E/A ratio: ≤ 0.8 + E velocity ≤ 50 cm/sec plus two negative parameters

E/A ratio > 0.8 to 2.0 plus ≤ 1 positive parameters

Grade 2:

E/A ratio: ≤ 0.8 + E velocity > 50 cm/sec plus two or more positive parameters

E/A ratio > 0.8 cm/sec to < 2.0 and two or more positive parameters

Note:

If only two parameters available:

Both positive: Grade 2

Both negative: Grade 1

One positive and one negative: Indeterminate diastolic function

Grade 3:

E/A ratio: ≥ 2.0

Additional Measurements

Mitral valve deceleration time

Pulmonary vein AR wave peak velocity

Pulmonary vein AR duration as compared to the mitral valve A wave duration

Isovolumic relaxation time

Left Ventricular Relaxation, Filling Pressures and 2D and Doppler Findings According to Left Ventricular Diastolic Function

	Normal	Grade 1	Grade 2	Grade 3
LV relaxation	Normal	Impaired	Impaired	Impaired
Left atrial pressure	Normal	Impaired or low	Elevated	Elevated
Mitral E/A ratio	≥ 0.8	≤ 0.8	> 0 .8 to < 2	> 2
E/E'(average)	< 10	< 10	10 to 14	> 14
Peak TR velocity (m/sec)	< 2.8	< 2.8	> 2.8	> 2.8
LA volume index (mL/m^2)	Normal	Normal or Increased	Increased	Increased

Right Ventricular Systolic Function

M-Mode/2-D/Doppler

Determine global and segmental right ventricular systolic function with qualitative visualization of the right ventricle utilizing multiple views.

Geometry (shape) of the right ventricle (e.g.; D-shaped left ventricle due to right ventricular volume overload or pressure overload)

The echocardiogram report should include:

- Right ventricular dimension
- Right atrial dimension
- Right ventricular systolic function (one of the following parameters):
  - Tricuspid annular plane systolic excursion (TAPSE)
  - TDI S' peak velocity
  - Systolic pulmonary artery pressure using the tricuspid regurgitation peak velocity with an estimate of right atrial pressure using the inferior vena cava and the degree of inspiratory collapse
  - Fractional area change (FAC)
  - Right ventricular index of myocardial performance (RIMP)

Evaluation of Global and Segmental Right Ventricular Systolic Function at a Glance

Examine the right heart using multiple acoustic windows

Report should include qualitative (e.g.; evaluation of global/segmental function) and quantitative parameters

Report should include:

- A measure of right ventricular dimension at end-diastole (Abnormal RVIDd: > 41 mm apical four chamber at the cardiac base)
- Right atrial dimension at end-systole (Normal RA volume: M: 25 ± 7 mL/m^2; W: 21 ± 6 mL/m^2)
- Right ventricular systolic function (at least one of the following):
  - TAPSE (abnormal < 17 mm)
  - TDI S' (abnormal < 9.5 cm/sec)
  - SPAP using tricuspid regurgitation method (SPAP (mm Hg) = 4 x TR^2 + RAP)
  - Fractional area change (FAC) (abnormal < 35%)
  - RV index of myocardial performance (RIMP) (PW Doppler abnormal: > 0.43) (TDI abnormal > 0.54)

Additional parameters when clinically indicated:

- Pulmonary artery end-diastolic pressure using the pulmonary regurgitation method
- Assessment of right ventricular diastolic function

Right Ventricular Diastolic Function

The evaluation of right ventricular diastolic function may be included when clinically indicated. (e.g.; right ventricular systolic dysfunction, pulmonary hypertension, congenital heart disease)

M-Mode/2-D

Evaluate right ventricular global systolic function (e.g.; TAPSE)

Evaluate right atrial dimension (Normal RA volume: M: 25 ± 7 mL/m^2; W: 21 ± 6 mL/m^2)

Doppler

To evaluate right ventricular diastolic function use PW Doppler and acquire tricuspid valve peak E velocity, A velocity, deceleration time using the parasternal right ventricular long axis (RA-RV), parasternal short axis of the aortic valve or apical four chamber or modified apical four chamber view (e.g.; RV focused view)

Acquire TDI using the apical four chamber view and sample the tricuspid valve lateral annulus to measure E' peak velocity (S' for global systolic function)

Determine the SPAP/MPAP/PAEDP/PVR

Evaluation of Right Ventricular Diastolic Function

	E/A	E/E'	Deceleration Time	Additional Findings
Normal	0.8 to 2.0	< 6	> 119 to 242 msec	
Impaired relaxation	< 0.8	< 6	> 242 msec	
Pseudonormal	0.8 to 2.0	> 6	> 119 to 242 msec	Diastolic flow predominance in hepatic vein
Restrictive	> 2.0	> 6	< 119 msec	Late diastolic antegrade flow in main pulmonary artery

Congenital Heart Disease

Atrial Septal Defect

Definition

An abnormal opening (defect) in the interatrial septum.

Types

Ostium secundum (70%); defect located in the mid-portion of the interatrial septum

Ostium primum (20%); defect located at the inferior portion of the interatrial septum (associated with cleft mitral valve)

Sinus venosus (10%) defect located in the superior portion of the interatrial septum (associated with partial anomalous pulmonary venous return)

M-Mode/2-D

Subcostal approach is recommended to best visualize the interatrial septum (parasternal short axis of the aortic valve may also be useful)

Right atrial enlargement (Normal RA volume: M: 25 ± 7 mL/m^2; W: 21 ± 6 mL/m^2)

Right ventricular volume overload (right ventricular enlargement with paradoxical interventricular septal motion)

Flattened interventricular septum (“pancaking”) during ventricular diastole with restoration of circular left ventricle due to right ventricular volume overload

Pulmonary artery enlargement

T-artifact (increased echogenicity at the edge of the interatrial septum) as seen from the apical four chamber view

Cleft mitral valve (associated with ostium primum atrial defect defect)
Mitral valve prolapse

Evidence of right heart pressure overload (e.g.; right ventricular hypertrophy/enlargement, D-shaped left ventricle due to right ventricular pressure overload, right atrial enlargement, increased pulmonary artery pressures (Eisenmenger’s syndrome)

Doppler

Subcostal approach is recommended to best visualize the interatrial septum (parasternal short axis of the aortic valve may be useful)

PW and color flow Doppler demonstrates shunt flow (decrease color flow Doppler velocity scale and wall filter)

Tricuspid regurgitation

Mitral regurgitation (e.g.; cleft mitral valve)

Determine Qp/Qs

Agitated Saline Contrast

An injection of agitated saline contrast may be used to determine the presence of an atrial septal defect

Look for contrast crossing the defect into the left atrium or the negative contrast effect due to left-to-right shunting (apical four chamber recommended)

Atrial Septal Defect

Patent Foramen Ovale

Approximately 30% of normal adults have a patent foramen ovale, which may be a site for a shunt or embolic event

Perform an agitated saline contrast examination using the apical four chamber view. Instruct the patient to cough or release after a Valsalva to see if shunt exists.

Atrial Septal Aneurysm

An abnormal bulging (> 1.5 cm in length and excursion) from the midline of the interatrial septum

The aneurysm may be a potential site for either (1) a shunt and/or (2) a source of embolism

Agitated saline contrast examination may be indicated to determine the presence of a shunt

Ventricular Septal Defect

An abnormal opening (defect) in the interventricular septum.

Types

Membranous (perimembranous) (most common) (located beneath the aortic valve)

Trabecular (may be multiple)

Inlet (located beneath the atrioventricular valves)

Outlet (located beneath pulmonary valve)

M-Mode/2-D

Parasternal long axis and parasternal short axis of the aortic valve are best for membranous and outlet ventricular septal defects

Parasternal long axis and parasternal short axis views of the left ventricle and cardiac apex are best for trabecular ventricular septal defects

Apical four chamber view with a posterior tilt is best to visualize inlet ventricular septal defect

Left ventricular enlargement

Left atrial enlargement

Left ventricular volume overload pattern (left ventricular dilatation with hyperkinetic wall motion)

Evidence of right heart pressure overload (e.g.; right ventricular hypertrophy/enlargement, D-shaped left ventricle due to right ventricular pressure overload, right atrial enlargement, increased pulmonary artery pressures (Eisenmenger's syndrome)

Doppler

Color flow Doppler is extremely useful to determine presence, location and size of ventricular septal defect

Determine Qp/Qs

Determine systolic pulmonary artery pressure

(SPAP (mm Hg) = Systolic blood pressure - 4 x Peak velocity of ventricular septal defect^2)

Aortic regurgitation (e;g.; membranous ventricular septal defect, outlet ventricular septal defect)

Atrioventricular Septal Defect

Types

Partial: ostium primum atrial septal defect, cleft mitral valve (partial endocardial cushion defect)

Complete: ostium primum atrial septal defect, inlet ventricular septal defect, common atrioventricular valve (complete endocardial cushion defect)

Incomplete: two separate atrioventricular valve orifices, left ventricle to right atrial shunt, three leaflets with cleft atrioventricular valve (incomplete endocardial cushion defect)

M-Mode/2-D

Apical four chamber view demonstrates ostium primum atrial septal defect, inlet ventricular septal defect, both atrioventricular valves are inserted at the same level

Posterior angulation in the apical four chamber view may improve visualization of inlet ventricular septal defect

Parasternal short axis view of mitral valve demonstrates cleft mitral valve

Evidence of right heart pressure overload (e.g.; right ventricular hypertrophy/enlargement, D-shaped left ventricle due to right ventricular pressure overload, right atrial enlargement, increased pulmonary artery pressures (Eisenmenger's syndrome)

Associated with Trisomy 21 (Down's syndrome)

Doppler

Identify shunts (color flow Doppler most useful – decrease color flow Doppler velocity scale and wall filter) (e.g.; ostium primum atrial septal defect, inlet ventricular septal defect)

Determine the presence and severity of atrioventricular regurgitation

Patent Ductus Arteriosus

Definition

Persistent patentcy of the fetal vessel which connects the pulmonary artery with the aorta.

M-Mode/2-D

Parasternal short axis view of the aortic valve with visualization of the pulmonary artery bifurcation, high parasternal short-axis view at the cardiac base (ductal view), suprasternal long axis views may permit direct visualization

Left atrial enlargement

Left ventricular enlargement

Left ventricular volume overload (left ventricular enlargement with ventricular wall hyperkinesis)

Evidence of right heart pressure overload (e.g.; right ventricular hypertrophy/enlargement, D-shaped left ventricle due to right ventricular pressure overload, right atrial enlargement, increased pulmonary artery pressures (Eisenmenger's syndrome)

Doppler

Parasternal short axis view of the aortic valve with visualization of the pulmonary artery branches is the best view

Color flow Doppler useful in demonstrating shunt flow

Determine Qp/Qs

Determine systolic pulmonary artery pressure

(SPAP (mm Hg) = Systolic blood pressure - 4 x patent ductus arteriosus peak velocity^2)

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Coarctation of the Aorta

Definition

Narrowing of the distal segment of the aortic arch in the area of the aortic isthmus. May be discrete (focal) or involve a long segment of the descending thoracic aorta (tubular hypoplasia).

M-Mode/2-D

Suprasternal long axis view is the best view

Narrowing may be visualized ("shelf" of tissue)

Increased pulsation of the aorta may be seen proximal to the lesion

Increased diameter of the left subclavian artery

Post-stenotic dilatation may be present

Left ventricular hypertrophy (Normal IVSd and LVPWd: M: 0.6 to 1.0 cm; W: 0.6 to 0.9 cm)

Left atrial enlargement (Normal LA volume: ≤ 34 mL/m^2)

Evaluate for bicuspid aortic valve (associated with aortic coarctation – 50 to 80%)

Evaluate left ventricular global/segmental systolic function

Doppler

Suprasternal view is best approach

PW and color flow Doppler may detect turbulence and increased velocity at the site of obstruction

CW Doppler may demonstrate characteristic flow pattern of increased systolic and diastolic velocities ("saw-tooth" appearance)

CW Doppler determines peak velocity, peak pressure gradient and mean pressure gradient across the aortic coarctation

Ebstein's Anomaly

Definition

A congenital malformation of the tricuspid valve in which attachment of one, two or all three tricuspid valve leaflets are displaced downward from the tricuspid valve annulus to the right ventricular wall.

The portion of the right ventricle above the displaced leaflet(s) is composed of atrial tissue; referred to as the atrialized portion of the right ventricle (right ventricular dysplasia).

M-Mode/2-D

The apical four chamber view reveals the extent of the tricuspid valve displacement; Ebstein's is diagnosed when the level of the mitral valve annulus to the displaced tricuspid valve leaflet(s) measures > 20 mm or ≥ 8 mm/m^2

Doppler

Tricuspid regurgitation

Tricuspid stenosis

Patent foramen ovale (shunt may be predominantly right-to-left)

Atrial septal defect (shunt may be predominantly right-to-left shunt)

Valvular pulmonary stenosis/atresia

Congenitally Corrected Transposition of the Great Arteries

Definition

Characterized by inverted ventricles (right ventricle positioned to the left; left ventricle located to the right) and transposition of the great arteries (pulmonary valve/artery posterior and rightward; aortic valve/aorta anterior and leftward) which results in the normal circulation of blood. Also referred to as l-transposition.

M-Mode/2-D

Parasternal long axis view demonstrates abnormal appearing lack of continuity between the aorta and tricuspid valve

Parasternal short axis view at the cardiac base demonstrates the aortic valve/aorta positioned anterior and leftward superior to the pulmonary valve; the pulmonary valve/artery are positioned posterior and rightward

Apical four chamber view confirms the diagnosis by demonstrating the abnormally displaced left atrioventricular valve (tricuspid valve) in the left-sided morphologic right ventricle (presence of moderator band helps in identifying the right ventricle)

Abnormalities of the left-sided tricuspid valve (90%) (e.g.; Ebstein's anomaly)

Evaluate left sided right ventricular global systolic function

Doppler

Evaluate:

Atrioventricular valve regurgitation (90% especially left sided a tricuspid valve)

- Ventricular septal defect shunt (70%)
- Left ventricular outflow tract obstruction (40%)
- Right ventricular outflow tract obstruction (10%)

Tetralogy of Fallot

Definition

The combination of four defects: (1) large, overriding aorta, (2) perimembranous ventricular septal defect, (3) right ventricular outflow tract obstruction (e.g.; pulmonary stenosis) and (4) right ventricular hypertrophy. Tetralogy of Fallot is the most common cyanotic congenital heart defect in adults.

M-Mode/2-D

Parasternal long axis view demonstrates overriding aorta, ventricular septal defect and right ventricular hypertrophy

Parasternal short axis view of the aortic valve demonstrates right ventricular outflow tract obstruction (e.g.; subvalvular, valvular and/or supravalvular)

Doppler

Demonstrates ventricular septal defect shunt flow

Determine the peak velocity, peak pressure gradient and mean pressure gradient across the right ventricular outflow tract obstruction

Determine peak velocity, peak pressure gradient, mean pressure gradient of residual right ventricular outflow tract obstruction (CW Doppler), severity of pulmonary regurgitation, evaluate ventricular septal defect repair, evaluate ventricular global and segmental systolic function (post-op)

Eisenmenger's Syndrome

Definition

Reversal of a congenital shunt (e.g.; atrial septal defect, ventricular septal defect, patent ductus arteriosus) from left-to-right to right-to-left or bidirectional secondary to severe pulmonary hypertension.

M-Mode/2-D/Doppler

Identifies congenital heart defect (e.g.; perimembranous ventricular septal defect)

Right ventricular hypertrophy (Normal: < 0.5 cm)

D-shaped left ventricle due to flattening ("pancaking") of the interventricular septum throughout the cardiac cycle indicating right ventricular pressure overload

Right ventricular enlargement (Abnormal RVIDd: > 41 mm apical four chamber at the cardiac base)

Right atrial enlargement (Normal RA volume: M: 25 ± 7 mL; W: 21 ± 6 mL)

Tricuspid regurgitation

Color flow Doppler demonstrates direction of shunt (bidirectional; right-to-left)

Determine systolic pulmonary artery pressure using the tricuspid regurgitation method

Diseases of the Aorta

Aortic Aneurysm

Definition

Localized dilatation of the aorta greater than 1.5 times the normal diameter.

M-Mode/2-D

Dilatation of the aorta (utilize multiple acoustic windows including suprasternal long axis)

Loss of tapering at the sino-tubular junction (aortic effacement)

Measure the aorta at the level of the aortic annulus, sinuses of Valsalva, sino-tubular junction, ascending aorta

Compression of the left atrium

Doppler

Aortic regurgitation (ascending aortic dilatation/aneurysm, aortic effacment)

Normal Diameters of the Aorta

	Absolute Values (cm)		Index Values (cm/m²)	
Aortic Root	**Men**	**Women**	**Men**	**Women**
Annulus	2.6 ± 0.3	2.3 ± 0.2	1.3 ± 0.1	1.3 ± 0.1
Sinuses of Valsalva	3.4 ± 0.3	3.0 ± 0.3	1.7 ± 0.2	1.8 ± 0.2
Sino-tubular junction	2.9 ± 0.3	2.6 ± 0.3	1.5 ± 0.2	1.5 ± 0.2
Proximal ascending aorta	3.0 ± 0.4	2.7 ± 0.4	1.5 ± 0.2	1.6 ± 0.3

Aortic Dissection

Definition

A tear in the aortic intima through which a column of blood enters the aortic wall, destroying the media and stripping the intima from the adventitia.

Types

DeBakey Classification

Type 2: Dissection confined to the ascending aorta

Type 3: Dissection confined to the descending thoracic aorta

Type 1: Dissection throughout the aorta (in other words types 2 plus 3)
(associated with highest mortality)

(Remember 2 + 3 = 1)

Stanford Classification

Type A: All dissections which involve the ascending aorta (DeBakey's types 1 and 2)

Type B: All dissections that do not include the ascending aorta (DeBakey's type 3)

M-Mode/2-D

Dilatation of the aorta

The presence of an intimal flap which is seen as a thin, linear structure in two orthogonal views

Demonstration of a true lumen and a false lumen (e.g.; parasternal short axis of the aortic valve – type 1 and 2)

Pericardial effusion (a potentially serious finding that may indicate rupture of the dissection)

Pleural effusion (a potentially serious finding that may indicate rupture of the dissection)

Doppler

Aortic regurgitation (DeBakey type 1 and type 2)

Sinus of Valsalva Aneurysm

Definition

Dilatation of the aortic sinuses of Valsalva, a rare cardiac anomaly; may be acquired or congenital; may present as ruptured or unruptured.

M-Mode/2-D

Parasternal short axis view of the aortic valve is an excellent view to use to visualize the aneurysm

Abnormal dilatation of one or more of the sinuses of Valsalva; the right sinus is most common

Aneurysm, especially if ruptured, may appear as a finger-like projection (“windsock” appearance)

Right coronary sinus – 69% (protrudes into right ventricle and/or right atrium)

Non-coronary sinus – 26% (protrudes into right atrium)

Left coronary sinus – 5%

Doppler

High-velocity systolic and diastolic flow pattern (ruptured sinus of Valsalva aneurysm) (most common type ruptures into the right atrium)

Aortic regurgitation

Supravalvular Aortic Stenosis

Definition

A narrowing of the ascending aorta.

Types

Hourglass: an abnormal thickening of the medial layer of the aorta located above the aortic valve (associated with Williams syndrome)

Membranous: a thin membrane located just above the aortic valve with one or multiple openings causing obstruction to flow

Strand: an under-developed aorta, usually associated with hypoplastic left heart syndrome

M-Mode/2-D/Doppler

Parasternal long axis with movement of the transducer one intercostal space upward is useful

Hourglass appearance of the of the supravalvular area of the aorta (hourglass type)

Membrane located in the supravalvular area of the aorta apical five chamber and apical long axis may be useful)

Left ventricular hypertrophy

Determine peak velocity, peak pressure gradient and mean pressure gradient across the obstruction (CW Doppler)

Cardiac Transplantation

Cardiac Transplantation

Indications

Dilated cardiomyopathy with global left ventricular systolic dysfunction.

"Normal" M-Mode/2-D/Doppler

The following echocardiographic findings, which would be considered abnormal in the general population, are characteristic of transplant recipients:

Biatrial dilatation due to surgical procedure

Pericardial effusion

Paradoxical or flat interventricular septal motion ("post-op" septum)

Increased left ventricular interventricular septal and posterior wall thickness

Increased right ventricular dimension

Early right ventricular dysfunction with improvement

Tricuspid regurgitation

M-Mode/2-D/Doppler Echocardiographic Indicators of Rejection

Two or more of the following parameters may indicate rejection:

New or increasing pericardial effusion

A > 10% decrease in ejection faction

Increasing wall thickness > 4 mm (interventricular septal thickness plus left ventricular posterior wall thickness)

Increased left ventricular mass

Increased myocardial echogencity

A > 20% decrease in pressure half time

Restrictive diastolic filling pattern

E/E' (average) ratio > 8

TDI S' > 11 cm/sec may exclude transplant vasculopathy

Increase in the amount of mitral regurgitation and/or tricuspid regurgitation

Miscellaneous

Acquired Immune Deficiency Syndrome (AIDS)

Definition

A disease of the immune system due to infection with human immunodeficiency virus (HIV). HIV destroys the CD4 T lymphocytes (CD4 cells) of the immune system, leaving the body vulnerable to life-threatening infections and cancers.

M-Mode/2-D/Doppler

Pericardial effusion (most common (82%)/cardiac tamponade/constrictive pericarditis

Myocarditis (52%)

Dilated cardiomyopathy (2 to 41%)

Malignant infiltration (Karposi's sarcoma) (39%)

Infective endocarditis (10%)

Valvular regurgitation (e.g.; mitral, tricuspid)

The Aging Heart

Definition

Normal changes in cardiac structure due to aging. The expected cardiac changes include:

M-Mode/2-D/Doppler

Mitral annular calcification (hallmark finding)

Aortic valve sclerosis/calcification (common)

Increased aortic root dimension with rightward shift

Sigmoid ("septal knuckle") interventricular septum

Left ventricular hypertrophy

Increased left atrial dimension

Atrioventricular regurgitation

Increased pulmonary artery pressures

Hypertensive hypertrophic cardiomyopathy

Progressive increase in mitral valve peak A velocity with a decrease in the mitral valve E/A ratio

Decrease in TDI E' annular peak velocity with an increase in the E/E' ratio

Aortic Valve Prolapse

Definition

Aortic valve prolapse is defined as the downward displacement of one or more aortic valve leaflets below a line joining the points of attachment on the aortic valve leaflets.

M-Mode/2-D/Doppler

Best visualized in the parasternal long axis view

The leaflets may be thick, redundant with preserved systolic excursion

Aortic regurgitation

Associated with bicuspid aortic valve (most common association), peimembranous ventricular septal defect, outlet ventricular septal defect, infective endocarditis, aortic root dilatation, severe mitral regurgitation

Aortic Valve Sclerosis

Definition

Aortic valve sclerosis represents a degenerative process which occurs primarily in the elderly (up to 29% greater than 65 years of age).

M-Mode/2-D/Doppler

Thickened aortic valve leaflets with preserved systolic excursion

Valve thickening may be localized, nodular or diffuse

Can be categorized:

Mild: valve thickness < 4 mm

Moderate: 4 to 6 mm

Severe: > 6 mm

Peak velocity across aortic valve is ≤ 2.5 m/sec

Arrhythmogenic Right Ventricular Cardiomyopathy

Definition

A right ventricular cardiomyopathy characterized by the fibrofatty sporadic/familial replacement of the myocardium of the right ventricle.

Affects young males (< 50 years of age), associated with left bundle branch block, ventricular tachycardia, syncope, thrombolic events, heart failue, sudden death.

M-Mode/2-D/Doppler

Right ventricular dilatation, aneurysm, focal wall thinning, trabecular derangement/prominence, hyper-reflective moderator band

Right ventricular outflow tract dilatation (> 30 mm) (most common)

Tricuspid regurgitation (may be < 2.0 m/sec due to reduced right ventricular systolic function)

Transpulmonary agents may be useful (e.g.; Definity, Optison)

Aortic Atherosclerotic Plaques

Definition

Atheroma located in the thoracic aorta which may represent a source of embolism.

M-Mode/2-D/Doppler

May present as atherosclerotic changes such as aortic wall calcification, thickening, ulceration, mural thrombi or atheromatous debris

A plaque > 4 mm in ascending aorta/aortic arch; > 5 mm in descending thoracic aorta may indicate an increased risk for embolism

Pedunculated (protruding, mobile debris) may represent an increased risk for embolism

Athletes Heart

Definition

The differentiation of physiologic and pathologic changes in the athlete's heart is difficult.

M-Mode/2-D/Doppler

Dynamic exercise (e.g.; running, skiing, soccer) generally will have a large LV diastolic cavity dimension and increased wall thickness (eccentric hypertrophy), increased RV dimensions, increased IVC dimension

Isometric (static) sports (e.g.; weight lifting, wrestling, gymnasts) have higher values for wall thickness relative to cavity dimension (concentric hypertrophy)

Track sprinting, diving, field weight training events are at the lower end of the spectrum for cardiac adaptions to athletic training

Female athletes have a smaller LV diastolic cavity dimension and wall thickness than male athletes training in the same sports

It is believed that LV wall thickness seldom exceeds > 1.3 cm no matter the sport

Evaluate for:

Hypertrophic cardiomyopathy, dilated cardiomyopathy, RV dysplasia (e.g.; arrythmogenic RV dysplasia, Uhl's anomaly), coronary artery abnormalities, anabolic steroids (significant ventricular hypertrophy), premature coronary artery disease

Cessation of the exercise (for 6 to 8 weeks) causes a 2 to 5 mm regression in wall thickness in athletic left ventricular hypertrophy but not in hypertrophic cardiomyopathy (reliable finding)

Proposed Abnormal Findings in Athletes Heart

Left ventricle end-diastolic dimension > 6.0 cm

Left ventricle end-diastolic wall thickness > 1.3 cm (rarely > 1.7 cm)

IVSd/LVPWd ratio > 1.5

Concentric/Eccentric remodeling (defined as LVPWd × 2 ÷ LVIDd) ≥ 0.45 represents concentric remodeling; <0.30 represents eccentric remodeling

Left atrial enlargement

Abnormal transmitral flow velocity (abnormal diastolic function)
(e.g.; mitral valve E/A ratio < 1.0 in a young athlete)

Mitral septal annular TDI E' < 7 cm/sec

Strain/Strain rate may be abnormal/paradoxical

Atrial Fibrillation

Definition

Atrial fibrillation is caused by multiple atrial ectopic foci. There is no well defined P wave, the QRS complex is normal although the ventricular rate is usually irregular.

M-Mode/2-D/Doppler

Evaluate for etiology (e.g.; mitral valve disease, cardiomyopathy, congenital heart disease)

Left atrial enlargement (Normal LA volume: $\leq$ 34 mL/m^2)

Left atrial thrombus (usually located in left atrial appendage)

Measure PW Doppler mitral valve peak E velocity and mitral valve deceleration time for evaluation of diastolic function

E/E' mitral septal annulus > 11 suggests increased filling pressure

Left atrial appendage peak velocity (normal: 46 ± 18 cm/sec) reduced in atrial fibrillation (26.5 ± 19.6 cm/sec) (usually acquired with TEE)

Pulmonary venous flow will demonstrate absent pulmonary vein A wave and blunted S wave

Chagas Disease ('kissing bug" disease)

Definition

The initial infection with trypanosoma occurs when bit, usually around the mouth or eye, by the reduviid bug. Approximately 1% develop acute myocarditis and pericarditis. The major cardiac manifestations of Chagas disease occur approximately 20 years after the initial infection and is present in approximately 20% to 30% of infected subjects. Cardiomegaly, heart failure, arrhythmias, thromboembolism, right bundle branch block and sudden death may occur.

M-Mode/2-D/Doppler

Dilated cardiomyopathy

Left ventricular apical aneurysm with thrombus

Pericardial effusion

Atrioventricular regurgitation

Cocaine

Definition

Cocaine is associated with negative cardiovascular effects.

M-Mode/2-D/Doppler

Acute myocardial infarction (most common clinical presentation)

Coronary artery aneurysm (30%)

Aortic dissection

Dilated cardiomyopathy (acute; chronic)

Infective endocarditis

Marked elevation in blood pressure

Cardiac arrhythmias (e.g.; bundle branch block) ventricular fibrillation

Cor Pulmonale

Definition

Right heart failure due to intrinsic pulmonary disease. Echo/Doppler findings are similar to pulmonary hypertension.

M-Mode/2-D/Doppler

Right ventricular dilatation (Abnormal RVIDd: > 41 mm apical four chamber view at the cardiac base)

Right ventricular hypertrophy (Normal: < 0.5 cm)

Right ventricular global systolic function (e.g.; reduced TAPSE < 17 mm)

D-shaped left ventricle throughout the cardiac cycle

Right atrial enlargement (Normal RA volume: M: 25 ± 7 mL/m^2; W: 21 ± 6 mL/m^2)

Dilated inferior vena cava (Normal ≤ 2.1 cm); hepatic veins (Normal: 0.5 to 1.1 cm)

Tricuspid regurgitation

Pulmonary regurgitation

Reduced right ventricular out tract acceleration time (Normal: > 120 msec)

Abnormal right ventricular/left ventricular diastolic function

Determine pulmonary artery pressure (SPAP/MPAP/PAEDP/PVR)

Cor Triatriatum

Definition

A membrane which divides the left atrium.

M-Mode/2-D/Doppler

Best views include parasternal long axis and apical long axis, apical four chamber and subcostal four chamber

Upper left atrial chamber receives the pulmonary veins and the lower left atrial chamber contains the left atrial appendage and the foramen ovale

Doppler may demonstrate turbulent flow, increased velocities and pressure gradients across the membrane

Associated defects include atrial septal defect (70 to 80%), persistent left superior vena cava, atrioventricular septal defect, aortic coarctation and anomalous pulmonary venous return

Diabetes

A disorder of carbohydrate metabolism which is characterized by hyperglycemia and glycosuria and resulting in inadequate production or utilization of insulin.

M-Mode/2-D/Doppler

Premature coronary artery disease

Left ventricular global systolic dysfunction (diabetic cardiomyopathy with left ventricular dilatation)

Left ventricular hypertrophy

Abnormal diastolic function

Abnormal strain/strain rate

Discrete Subaortic Stenosis

Definition

A thin membrane attached to the left side of the interventricular septum to the anterior mitral valve leaflet. May progress to a thick fibromuscular collar or form a tunnel (tunnel subaortic stenosis).

M-Mode/2-D/Doppler

Thin membrane visualized in parasternal long axis, apical long axis, apical five chamber views

Doppler

Increased systolic velocity across the membrane; determine peak velocity, peak pressure gradient, mean pressure gradient using CW Doppler

Aortic regurgitation

Double Orifice Mitral Valve

Definition

A condition in which an accessory mitral valve orifice is present; may be congenital or iatrogenic (e.g.; MitraClip).

M-Mode/2-D/Doppler

Parasternal short axis of the mitral valve preferred view to identify the two mitral valve orifices

Doppler may demonstrate normal flow, stenosis and/or regurgitation

Determine peak velocity, peak pressure gradient, mean pressure gradient using CW Doppler from the apical four chamber view

Associated defects include atrioventricular septal defect, ventricular septal defect, Ebstein's anomaly, tetralogy of Fallot, aortic coarctation

Ectopic Chordae/False Tendon/Chordal Web/ Aberrant Bands

Definition

Fibrous/muscular chords joining the papillary muscle to papillary muscle, papillary muscle to the ventricular free wall, or ventricular septum to free wall of the ventricle. May be single or multiple and located in either/both ventricles. May cause a systolic murmur, be confused as a ventricular thrombus or be a potential cause of catheter entrapment during an invasive procedure.

M-Mode/2-D/Doppler

String-like structure(s) with free cavity course unrelated to the atrioventricular valve(s)

Color flow Doppler may be used to differentiate an ectopic chordae from thrombus, color flow Doppler (decrease color velocity scale and wall filter) will be displayed on either side of the chord(s) while if a thrombus, there will be a filling defect

Ehlers-Danlos Syndrome

Definition

A heterogeneous group of connective tissue disorders with simple mendelian inheritance. The cardinal manifestations are hyperextensibility, ("stretchy") skin, hypermobile joints and easy bruising.

M-Mode/2-D/Doppler

Aortic root dilatation/aneurysm (annuloaortic ectasia)

Sinus of Valsalva aneurysm

Valvular prolapse

Ventricular septal defect

Atrial septal defect

Tetralogy of Fallot

Aortic coarctation

Bicuspid aortic valve

Dextrocardia

Fabry's Disease

Definition

An X-linked recessive inborn error of glycosphingolipid metabolism.

M-Mode/2-D/Doppler

Classic mitral valve prolapse (thick, redundant, myxomatous mitral valve leaflets)

Increased ventricular wall thickness/ventricular mass most likely due progressive glycosphingolipid deposition in the myocardium (may mimic findings of hypertrophic cardiomyopathy)

Myocardial infarction

Aortic root dilatation

Mitral regurgitation (usually mild)

Diastolic dysfunction

Flail Mitral Valve

Definition

Ruptured chordae tendineae/papillary muscle will result in the abnormal coaptation of the mitral valve leaflets.

M-Mode/2-D/Doppler

Systolic inversion of the flail mitral valve leaflet tip toward the left atrium (flail leaflet tip points towards the left atrium; in mitral valve prolapse the leaflet tip points towards the left ventricle)

Lack of valve leaflet coaptation (mitral valve prolapse coaptation is maintained)

Presence of floating ruptured chordae tendineae/papillary muscle

Doppler findings include mitral regurgitation, left atrial systolic antegrade flow, vertical striations superimposed on the typical valve regurgitant flow pattern

Color flow Doppler may underestimate the severity of mitral regurgitation due to the coanda effect (jet hugging wall or valve leaflet which reduces the area of the color flow Doppler jet area)

Friedreich's Ataxia

Definition

Cardiac abnormalities are a characteristic feature of the autosomal recessively inherited spinocerebellar degeneration known as Friedreich's ataxia, which is the most common hereditary ataxia.

M-Mode/2-D/Doppler

Increase in left ventricular wall thickness (most common) (may resemble hypertrophic cardiomyopathy) (68%)

Globally reduced left ventricular systolic function (7%)

Increased left atrial dimension

Dilated cardiomyopathy

Heart Failure

Definition

The inability of the heart to meet the metabolic demands of the body.

M-Mode/2-D/Doppler

Determine:

- Etiology (e.g.; systolic global ventricular systolic dysfunction, pressure overload - e.g.; systemic hypertension, aortic stenosis, volume overload e.g.; - significant valvular regurgitation; diastolic dysfunction)
- Evaluate global left ventricular systolic function (e.g.; chamber dimensions, wall thickness, volumes, geometry, ejection fraction)
- Determine the presence and severity of valvular regurgitation
- Determine the diastolic function grade
- Determine pulmonary artery pressures (SPAP/MPAP/PAEDP/PVR)

Holt-Oram (Heart-Hand) Syndrome

Definition

An autosomal dominant syndrome characterized by skeletal abnormalities and congenital cardiac defects.

M-Mode/2-D/Doppler

Atrial septal defect (ostium secundum atrial septal defect)

Right heart volume overload (e.g.; right atrial dilatation, right ventricular dilatation, paradoxical interventricular septal motion, D-shaped left ventricle during ventricular diastole)

Ventricular septal defect

May present with complex congenital heart disease/vascular malformations

Mitral valve prolapse (10 to 20%)

Hyperthyroidism

Definition

A condition caused by excessive secretion of the thyroid glands which increases the metabolic rate causing an increased demand for food to support the metabolic activity.

M-Mode/2-D/Doppler

Enhanced global left ventricular systolic function

Hyperthyroid cardiomyopathy (“high-output” failure)

Myocardial ischemia

Pulmonary hypertension (> 75 mm Hg possible)

Diastolic dysfunction

Global left ventricular systolic dysfunction (long term)

Hypothyroidism

Definition

A thyroid secretion deficiency resulting in a lowered basal metabolism.

M-Mode/2-D/Doppler

Reduced global left ventricular systolic function

Pericardial effusion/cardiac tamponade/constrictive pericarditis

Left ventricular hypertrophy with abnormal myocardial texture (“ground-glass” appearance)

Asymmetrical septal hypertrophy

Mitral valve prolapse

Diastolic dysfunction

Non-communicating Intramural Hematoma (IMH)

Definition

May represent rupture of the vasa vasorum into the media and subadventitial regions (spontaneous intramural hemorrhage without an intimal tear) (10 to 15% of aortic dissections).

An aortic dissection without an intimal tear.

M-Mode/2-D/Doppler

Best visualized using transesophageal echocardiography

Hemorrhage with crescentic/circular thickening of the aortic wall (> 0.5 cm)

Central displacement of intimal calcification

Layered appearance

Length from 1 to 20 cm

Preserved aortic lumen without intimal flap

Kawasaki Disease

Definition

Febrile illness of unknown etiology resulting in vasculitis; also referred to as mucocutaneous lymph node syndrome.

M-Mode/2-D/Doppler

Coronary artery aneurysm (usually proximal) (may be filled with thrombus)

Left ventricular global and segmental systolic dysfunction

Myocardial infarction

Pericardial effusion (30%)

Mitral regurgitation (30%)

Left Bundle Branch Block

Definition

Delay or blockage of conduction in the main left bundle branch with the initial activation of the ventricles greatly changed. Left bundle branch is almost always an indicator of organic heart disease.

M-Mode/2-D/Doppler

Abnormal (paradoxical) interventricular septal motion – brief downward motion (“beaking”) within 0.04 seconds of the onset of the QRS complex followed by rapid anterior motion of the interventricular septum lasting throughout ventricular ejection.

Determine the presence and severity of cardiac abnormality(s) (e.g.; evidence of coronary artery disease)

Loeys-Dietz Syndrome (Aortic Aneurysm Syndrome)

Definition

Autosomal dominant aortic aneurysm syndrome characterized by the triad of arterial tortuosity and aneurysms, hypotolerism and cleft palate caused by heterozygous mutations in the genes encoding transforming growth factor beta receptors.

M-Mode/2-D/Doppler

Aggressive arterial aneurysms (mean age of death 26 years of age)

Vascular disease may be widespread

Increased pregnancy related complications

Lyme Disease

Definition

Caused by the tick-borne spirochete, Borrelia burgdorferi, initial infection marked by rash, followed by weeks to months by involvement of other organ systems, including the heart, neurologic system and joints.

M-Mode/2-D/Doppler

Severe atrioventricular node block associated with syncope

Dilated cardiomyopathy

Mitral Annular Calcification

Definition

Idiopathic calcification of the mitral valve annulus is a common finding in the elderly. Mitral annular calcification may be accelerated by systemic hypertension, aortic valve stenosis, hypertrophic cardiomyopathy, diabetes, mitral valve prolapse, obesity, disorders of calcium/phosphorous metabolism, Marfan's syndrome, Hurlers syndrome and chronic renal failure. Also referred to submitral calcification and/or fibrosis.

M-Mode/2-D/Doppler

Echodense structure anterior to the left ventricular inferolateral (posterior) wall at the atrioventricular junction; may be visualized in parasternal long axis, parasternal short axis of the mitral valve, apical and subcostal views.

May appear as a semicircular linear band beneath the base of the posterior mitral valve leaflet in the parasternal short-axis of the mitral valve

Usually involves the posterior mitral valve annulus but may extend to the entire mitral valve annulus, ventricular wall, mitral valve posterior leaflet, left atrium, posterior aortic root

May become infected (e.g; abscess)

May be a source of embolism

Mitral regurgitation (usually mild)

Functional mitral stenosis is possible (especially if there is anterior combined with the posterior annular calcification) (determine mitral valve peak velocity, peak pressure gradient, mean pressure gradient, mitral valve area by the pressure half-time method using CW Doppler)

Determine the severity by measuring the maximal thickness in the parasternal short axis of the mitral valve

Mild: < 5 mm

Moderate: 6 to 10 mm

Severe: > 10 cm

Marfan's Syndrome

Definition

A hereditary condition of connective tissue, bones, muscles, ligaments and skeletal structures.

M-Mode/2-D/Doppler

Proximal aortic dilatation (e.g. aortic annulus, sinuses of Valsalva, ascending aorta)

Multivalvular prolapse (especially mitral valve prolapse)

Mitral annular calcification

Left atrial compression

Left ventricular volume overload (left ventricular enlargement with left ventricular wall hyperkinesis)

Aortic regurgitation

Mitral regurgitation

Aortic dissection (most common cause of death)

Coronary artery dissection

Prophylactic repair of ascending aorta has been recommended when the aortic diameter reaches 5.0 cm

Noncompaction of Ventricular Myocardium (NVM)

Definition

Noncompaction of the myocardium without associated cardiac anomaly is a rare congenital disorder.

M-Mode/2-D/Doppler

Multiple prominent ventricular trabeculations and deep intratrabecular recesses (especially mid-lateral, mid-inferior, apical) of the ventricle ("spongy" appearance of myocardium)

Dilated ventricle(s)

Depressed global ventricular systolic function

Diastolic dysfunction

Deep intratrabecular recesses may be visualized using color flow Doppler (decrease color velocity scale and wall filter)

Transpulmonary contrast agents may be useful (e.g.; Definity, Optison)

Noonan's Syndrome

Definition

Noonan syndrome is inherited in an autosomal dominant manner and is characterized by congenital heart disease, short stature, abnormal facies, and the somatic features of Turner's syndrome.

M-Mode/2-D/Doppler

Valvular pulmonary stenosis (40%) with thickened, dysplastic pulmonary valve leaflets

Secundum atrial septal defect (33%)

Ventricular septal defect (10%)

Patent ductus arteriosus (10%)

Localized anterior interventricular septal hypertrophy

Diffuse right ventricular hypertrophy

Left ventricular hypertrophy

Partial atrioventricular canal defect with left ventricular outflow tract obstruction

Dilatation of the ascending aorta

Constrictive pericarditis

Obesity

Definition

A person whose bodyweight is at least 20% higher than it should be; a body mass index (BMI) ≥ 30 kg/m^2 (BMI = weight (kg) $\div$ height (m^2))

M-Mode/2-D/Doppler

Cardiac hypertrophy (e.g.; left ventricular concentric hypertrophy)

Cardiac chamber enlargement (e.g.; increased left atrial and left ventricular dimensions)

Reduced global left ventricular systolic function

Diastolic dysfunction

Strain/Strain rate may demonstrate abnormal systolic function

Parachute Mitral Valve

Definition

A congenital abnormality in which there is only one papillary muscle in the left ventricle and the chordae tendineae of the two mitral valve leaflets insert into this single papillary muscle.

M-Mode/2-D/Doppler

Single left ventricular papillary muscle (usually posteromedial papillary muscle) (best seen in the parasternal short-axis of the left ventricle at the level of the papillary muscles)

Additional papillary muscle (usually small) may be present but receive no chordae tendineae

Diastolic "doming" of the mitral valve leaflets may be present

Mitral valve leaflets and chordae tendineae are normal

Doppler findings similar to mitral stenosis – determine peak velocity, peak pressure gradient, mean pressure gradient, mitral valve area by the pressure half time method

Mitral regurgitation

Patent Foramen Ovale (PFO)

Definition

Patent foramen ovale is failure of the primum and secundum atrial septa to fuse. This lack of fusion allows bidirectional blood flow between the atria.

PFO is common (up to 30% of the adult population)

Associated complications include cryptogenic stroke (cerebral ischemia of unknown origin), paradoxical emboli, hypoxia with significant right-to-left shunt in COPD, complication in pulmonary embolism, decompression illness in divers, migraines

M-Mode/2-D/Doppler

Color flow Doppler may detect (use subcostal four chamber view, parasternal short axis of the aortic valve view) (decrease color flow Doppler velocity scale and wall filter)

Intact atrial septum with shunting (may require transesophageal with agitated saline contrast)

Valsalva maneuver/cough may enhance detection during an agitated saline contrast exam

Patent foramen ovale is suggested if one microbubble appears in the left atrium within three cardiac cycles (if agitated saline contrast appears after three cardiac cycles, pulmonary arteriovenous fistula may be present)

Three or more agitated saline contrast injections may be required (e.g.; rest, Valsalva, cough)

Recent study recommended 5 agitated saline contrast injections: rest, Valsalva (2), cough, bed tilt with early Valsalva (10 degrees feet down to decrease preload)

Causes of false negative agitated saline contrast exams include failure of the Valsalva maneuver or cough to transiently increase right atrial pressure, increased left atrial pressure, use of antecubital venous contrast injection when a prominent eustachian valve is present

Cause of false positive agitated saline contrast exam include sinus venosus atrial septal defect, pseudo-contrast caused by Valsalva maneuver, pulmonary arteriovenous fistula

Transcranial Doppler may be indicated

Penetrating Aortic Ulcer (PAU)

Definition

A type of aortic dissection where a penetrating ulcer burrows deeply through the intima into the aortic media, precipitating a localized intramedial dissection and hematoma. PAU occur throughout the aorta.

M-Mode/2-D/Doppler

Transesophageal echocardiography demonstrates plaque that is a “crater-like” (“dished out”) ulcer with jagged edges, usually in the presence of extensive atheroma. There is an absence of an intimal flap and false lumen.

Transpulmonary contrast agents may be useful (e.g.; Definity, Optison)

Persistent Left Superior Vena Cava (PLSVC)

Definition

The left horn of the sinus venosus persists and may drain to the coronary sinus, left atrium or left pulmonary vein.

M-Mode/2-D/Doppler

The persistent left superior vena cava may be imaged from the suprasternal long axis view with a leftward tilt

Dilated coronary sinus best seen in the parasternal long axis view and apical four chamber view with a posterior tilt

PW Doppler/color flow Doppler will demonstrate a low velocity, biphasic flow pattern away from the transducer when persistent left superior vena cava is imaged in the suprasternal long axis view (decrease color flow Doppler velocity scale and wall filter)

Agitated saline contrast injected into the left arm demonstrates contrast in the coronary sinus before arriving into the right atrium

Pheochromocytoma

Definition

A tumor of chromaffin cells which secrete catecholamines and cause systemic hypertension.

M-Mode/2-D/Doppler

Concentric left ventricular hypertrophy (20%)

Asymmetric septal hypertrophy with or without obstruction

Myocarditis (acute) with catecholamine crisis

Dilated cardiomyopathy

Reversible ventricular dilatation

Segmental wall motion abnormality(s)

Tumor located in atrioventricular groove

Pregnancy

Definition

There are normal anatomic changes with pregnancy. They include:

M-Mode/2-D/Doppler

Increase in heart rate

Increase in cardiac arrhythmias

Increase in stroke volume, cardiac output

Slight increase in ventricular dimensions (5 to 10%)

Slight increase in ventricular wall thickness

Slight increase in atrial dimensions (10 to 15% increase)

Small pericardial effusion (20%)

Valvular regurgitation (usually mild)

Diastolic dysfunction (usually Grade 1; E/A ratio ≤ 0.8) (late in pregnancy)

Anatomic/hemodynamic return to baseline (6 to 12 weeks)

Peripartum (acute) dilated cardiomyopathy

Peripartum coronary artery dissection (rare)

Normal Echocardiographic Parameters During Pregnancy at Term or Third Trimester

Parameter	Mean ± SD
LVIDd (mm)	47 ± 4
LV wall thickness (mm)	10 ± 1
LV mass (gm)	186 ± 39
EF (%)	60 ± 4
LA (mm)	38 ± 4
RV (mm)	20 ± 1
Mitral annulus (mm)	24 ± 5
Tricuspid annulus (mm)	27 ± 3
Aortic root (mm)	30 ± 12

Pulmonary Embolism

Definition

Embolus (e.g.; blood, tissue, air bubbles) in the pulmonary artery or one of its branches.

M-Mode/2-D/Doppler

Actual visualization of the thrombus within the right heart/pulmonary artery

McConnells sign (akinesia of the mid-free wall of the right ventricle with normal/ hyperdynamic motion of the cardiac apex)

60/60 sign (SPAP < 60 mm Hg and RVOT acceleration time < 60 msec)

Right ventricular dilatation

Right ventricular global and segmental systolic dysfunction

Pulmonary artery dilatation

Right atrial dilatation

D-shaped left ventricle maintained throughout the cardiac cycle (right ventricular pressure overload)

Abnormal interventricular septal motion (e.g.; flat, paradoxical)

Respiratory variation of mitral and tricuspid valve inflow (similar to cardiac tamponade)

Tricuspid regurgitation

Pulmonary regurgitation

Determine pulmonary artery pressures

Pulmonary Vein Stenosis

Definition

Discrete narrowing of one or more pf the pulmonary veins at or near the junction of the left atrium.

M-Mode/2-D/Doppler

Difficult to identify using two-dimensional echocardiography

Right ventricular hypertrophy

Right ventricular dilatation

Right atrial dilatation

Color flow Doppler may demonstrate mosaic (turbulent) flow pattern

PW Doppler may demonstrate increased peak systolic velocity (> 1.5 m/sec) with a continuous flow pattern and phasic variation

Renal Failure

Definition

Failure of the kidneys to perform their essential functions.

M-Mode/2-D/Doppler

Pericardial effusion /cardiac tamponade/constrictive pericarditis

Left ventricular hypertrophy

Left ventricular dilatation with global systolic dysfunction (dilated cardiomyopathy)

'Ground-glass" speckled appearance of the myocardium

Mitral annular calcification

Mitral stenosis (functional due to significant mitral annular calcification)

Aortic valve sclerosis/stenosis

Mitral regurgitation

Aortic regurgitation

Diastolic dysfunction

Improvement of systolic function post-renal transplant

Rheumatoid Arthritis

Definition

A chronic autoimmune disease characterized by systemic arthritis.

M-Mode/2-D/Doppler

Pericardial effusion/cardiac tamponade/constrictive pericarditis

Left ventricular global systolic dysfunction (e.g.; myocarditis, coronary artery disease)

Leaflet fibrosis/nodules

Myocardial nodules

Aortic aneurysm, wall thickening secondary to aortitis (rare)

Secondary amyloidosis

Pulmonary hypertension

Valvular regurgitation

Diastolic dysfunction

Scimitar Syndrome

Definition

Partial or total anomalous pulmonary venous connection of the right lung into the inferior vena cava.

'Scimitar" refers to the appearance of the anomalous right pulmonary vein on chest radiography, it produces a silhouette likened to the Arabic or Turkish sword (the scimitar) along the right border of the heart.

M-Mode/2-D/Doppler

Partial or total anomalous pulmonary venous connection of the right lung into the inferior vena cava

Sinus venosus atrial septal defect

Dextrocardia

Scleroderma

Definition

Excessive connective tissue accumulation in the blood vessels, skin, joints, skeletal muscle and multiple organs.

M-Mode/2-D/Doppler

Left ventricular global systolic dysfunction

Segmental wall motion abnormality(s)

Left ventricular hypertrophy

Valvular sclerosis

Pericardial effusion/cardiac tamponade/constrictive pericarditis

Mitral valve prolapse

Pulmonary hypertension

Diastolic dysfunction

Shone's Syndrome

Definition

A combination of left ventricular inflow tract and left ventricular outflow tract obstructions.

M-Mode/2-D/Doppler

Supravalvular mitral valve ring

Parachute mitral valve

Subaortic stenosis (membranous or muscular)

Aortic coarctation

Bicuspid aortic valve

Supravalvular Mitral Valve Ring

Definition

A membrane located at the level of the mitral valve annulus.

M-mode/2-D/Doppler

A thin band located just above the mitral valve or within the funnel of the mitral valve leaflets

Doppler may demonstrate turbulent flow, increased velocities and pressure gradients similar to mitral valve stenosis

Determine peak velocity, peak pressure gradient and mean pressure gradient

Associated with atrial septal defect, persistent left superior vena cava, aortic coarctation, ventricular septal defect and Shone's syndrome

Syncope

Definition

A transient loss of consciousness due to inadequate blood to the brain.

M-Mode/2-D/Doppler

Hypertrophic obstructive cardiomyopathy

Aortic stenosis

Hypovolemia (small left ventricle with hypercontractile systolic function)

Mitral stenosis

Myxomatous mitral valve prolapse

Left ventricular systolic dysfunction

Pulmonary hypertension

Pulmonary embolism

Myocardial infarction

Intracardiac mass

Aortic dissection

Pericardial effusion/cardiac tamponade

Systemic Lupus Erythematosus

Definition

Chronic inflammatory disease which affects the musculoskeletal and mucocutaneous systems causing fatigue, arthalgias, arthritis, photosensitivity and serositis.

M-Mode/2-D/Doppler

Libman Sacks vegetation (noninfected valve mass) usually involving the mitral valve or aortic valve with the vegetation small in size, with irregular borders and no independent motion

Pericardial effusion (10 to 15%)/Cardiac tamponade (< 1%)/Constrictive pericarditis

Mitral valve prolapse (5 to 10%)

Pulmonary hypertension (5%)

Left ventricular global/segmental systolic dysfunction (accelerated atherosclerosis, coronary artery embolism)

Coronary artery aneurysm

Valvular regurgitation

Valvular stenosis (rare)

Aortitis (rare)

Vascular thrombosis

Takayasu's Disease

Definition

An aortic arteritis with marked proliferation and fibrosis and fibrous scarring and degeneration of the elastic fibers of the media which leads to localized aneurysm, post-stenotic dilatation and calcification of the aorta and its major branches.

M-Mode/2-D/Doppler

Dilatation of the aortic root/aorta

Increased echogenicity of the aortic root/aorta (similar in appearance to atherosclerosis)

Left ventricular systolic dysfunction (myocarditis, coronary artery vasculitis)

Aortic regurgitation

Stenosis/occlusion of large vessels

Takotsubo Cardiomyopathy

Definition

Acute heart failure precipitated by sudden, intense emotional or physical stress (e.g.; death of a spouse, surgery, severe pain).

Also referred to as stress cardiomyopathy, transient apical ballooning syndrome, "broken heart" syndrome.

Typical findings include: chest pain in a woman (mean age 58 to 77), after an acute stressor, ST segment elevation/T wave inversion, angiogram will demonstrate normal coronary arteries

M-Mode/2-D/Doppler

Classic findings include apical regional systolic wall motion abnormality with preserved basilar systolic function (apical ballooning)

Segmental wall motion abnormalities may include mid-ventricular region, basal left ventricle, right ventricle

Reduced ejection fraction

Apical thrombus may be present

Traumatic Heart Disease

Definition

Penetrating and non-penetrating chest trauma can damage the myocardium, pericardium, cardiac valves and great vessels.

M Mode/2-D/Doppler

Pericardial effusion/Cardiac tamponade

Myocardial contusion seen as a thick, bright signal with segmental wall motion abnormality(s)

Thinning of the ventricular wall, true aneurysm, pseudoaneurysm, intramural thrombosis (especially the right ventricle)

Laceration/tear of the myocardium, great vessels, ventricular septal defect, atrial septal defect

Papillary muscle rupture

Flail tricuspid/mitral valve leaflet

Aortic valve trauma

Aortic hematoma, aneurysm, dissection (especially in the area of the aortic isthmus)

Fistula (e.g.; aorta to right atrium)

Comet tail artifact may indicate bullet

Valvular regurgitation

Uhl’s Anomaly

Definition

Dysplasia of the right ventricle with the tricuspid valve inserted at the normal level.

M-Mode/2-D/Doppler

Thin, hypokinetic right ventricular myocardium (may be biventricular)

Right ventricular dilatation with poor global systolic function

Right ventricular trabeculation may be absent

Tricuspid regurgitation

Tricuspid located in the correct position (versus Ebstein’s anomaly where the tricuspid valve is abnormally displaced downward)

Valsalva Maneuver

Definition

The Valsalva maneuver is performed by attempting to forcibly exhale while keeping the mouth and nose closed. May be useful in the echocardiography laboratory to evaluate patent foramen ovale, atrial septal defect, hypertrophic cardiomyopathy, diastolic function.

The four phases of the Valsalva maneuver are:

Phase1: Onset of straining with increased intrathoracic pressure. The heart rate does not change, blood pressure increases.

Phase 2: Marked by a significant decrease in venous return with a reduction in stroke volume and pulse pressure as straining continues. The heart rate increases, blood pressure decreases, intrathoracic pressure is maintained (useful in the evaluation of hypertrophic cardiomyopathy, diastolic function)

Phase 3: Release of straining which results in a sudden decrease in intrathoracic pressure with an increase in preload (useful in the evaluation of patent foramen ovale and atrial septal defect)

Phase 4: Sudden increase in cardiac output, aortic pressure (blood pressure overshoot) with return of heart rate to baseline

Proper technique for evaluation of patent foramen ovale during an agitated saline contrast exam:

While imaging, practice with patient straining for 5 to 10 seconds and releasing, adjust imaging if necessary

Valsalva should be started 3 to 5 seconds before the injection of saline contrast and should be held for at least 8 to 10 seconds

Once contrast is seen in the right atrium, Valsalva may be released

If the interatrial septum does not shift towards the left atrium, then the Valsalva may not be being performed properly or the left atrial pressure is increased

Valvular Strands/Lambl's Excrscences

Definition

Thin, mobile filamentous projections attached to the valvular leaflets (Lambl's excrescences) or prosthetic valves and may be multiple. May represent small, endothelial covered fibrinous protuberances resulting from mechanical trauma.

M-Mode/2-D/Doppler

Thin, linear echo attached to the valve leaflet - best visualized by transesophageal echocardiography

May be considered an embolic source when visualized on a prosthetic heart valve

Ventricular Assist Device (VAD)

Definition

A bridge to transplant and a blood pump that can augment or replace the function of a failing ventricle.

M-Mode/2-D/Doppler

Evaluate the surgical results of the ventricular assist device

Evaluate overall structure, size, function of the cardiac chambers

Determine the presence and severity of mitral regurgitation; with normal VAD, mitral regurgitation should decrease

Determine the frequency of aortic valve opening and presence and severity of aortic regurgitation

Evaluate the apical inflow cannula position and inflow with color flow and PW Doppler:

Cannula should be aligned with the left ventricular outflow tract

PW Doppler assessment of the inflow cannula should be done in the apical 4 and 2 chamber views - laminar flow should be present

High velocity and/or turbulent flow suggests obstruction of the inflow cannula secondary to thrombus or intermittent ventricular obstruction

Evaluate the outflow cannula with color flow Doppler and PW Doppler, use a high left parasternal long axis view to show the end-to-side anastomosis to the mid-ascending aorta

Position of the interventricular septum: a leftward shift suggests an under-filled left ventricle; a rightward shift suggests poor left ventricular remodeling

Evaluate right ventricular dimension and systolic function

Weight Reduction

Definition

Weight loss.

M-Mode/2-D/Doppler

Improved global left ventricular global systolic function

Reduced ventricular dimensions, wall thickness, left ventricular mass

Stress Echocardiography

Exercise Stress Echocardiography

Definition

A noninvasive diagnostic method which combines a baseline echocardiogram with a peak/post exercise echocardiogram in order to detect and assess known or suspected coronary artery disease.

Types

Two-phase: compares ventricular wall segments before the stress test and after the stress test with pre and post images; usually using a treadmill

Three-phase: compares ventricular wall segments before, during and after the stress test; usually using as a supine bicycle

Four-phase: compares ventricular wall segments before, during and after stress using a pharmacologic agent (e.g.; Dobutamine four-phase: rest, low dose, peak dose, recovery)

Protocol

Two-Phase

Patient should be NPO (nil per os – nothing through the mouth) for three hours before the examination

Patient should be informed of the procedure and a patient consent form should be signed

Position EKG electrodes to ensure echo windows are unobstructed

Instruct patient that time is important when the exercise ends and the need to control their breathing post-exercise may be required

Obtain resting images (e.g.; parasternal long axis, parasternal short axis of the left ventricle at the level of the papillary muscle, apical four chamber view, apical 2 chamber view) (note: other views may be added)

Exercise patient

Prepare ultrasound transducer and ultrasound system for immediate post-exercise images

Obtain and record (digital capture) post-exercise images within 60 seconds or less (scan for at least 2 to 3 minutes post exercise)

Select post-exercise images, shuffle, and review pre and post-exercise images

Interpretation

Normal Response

All walls become hyperdynamic with symmetric systolic wall thickening and equal excursion in all segments

Ejection fraction increases (minimum increase of 5%)

Left ventricular end-systolic dimension decreases

Abnormal Response

New segmental wall motion abnormality

Resting hypokinetic segment worsens with exercise (may represent hibernating myocardium)

Global systolic dysfunction (reduced or no change in ejection fraction as compared to pre-exercise)

Shape change of left ventricle

Increased right ventricular dimensions

Increased atrial dimensions

New/increased mitral regurgitation

Significant increase in pulmonary artery pressures

Interpretation by Segmental Wall Motion

Rest	Stress	Interpretation
Normal wall motion	Hyperdynamic	Normal
Normal wall motion	New wall motion abnormality	Ischemia
Wall motion abnormality	Worsens	Ischemia/Infarction
Wall motion abnormality	Unchanged	Infarct
Hypokinetic/Akinetic wall motion	Improved to normal wall motion (biphasic response)	Viable

Dobutamine Stress Echocardiography

Definition

Dobutamine stress echocardiography has become an alternative to exercise echocardiography.

Dobutamine augments myocardial contractility, increases heart rate and increases blood pressure.

Dobutamine Stress Echo Protocol

Patient should be NPO (nil per os – nothing through the mouth) for three hours before the examination

Patient should be informed of the procedure and a patient consent form should be signed

Position EKG electrodes to ensure echo windows are unobstructed

Explain the test to the patient

Connect 12 lead EKG and blood pressure monitor

Begin IV

Obtain resting echo digital images

Begin Dobutamine infusion at 5 or 10 mcg/kg/min

Monitor EKG and blood pressure

Obtain low dose images

Increase Dobutamine infusion by 10 mcg/kg/min every three minutes up to a maximum dose of 40 mcg/kg/min or until achieving 85% of the age-predicted maximal heart rate (atropine may be added)

Obtain peak-dose images

Obtain recovery images 4 to 6 minutes post-infusion

Monitor patient until he/she returns to baseline

Review acquired images

Interpretation

Normal Response

All walls become hyperdynamic with symmetric systolic wall thickening and equal excursion in all segments

Ejection fraction increases (minimum increase of 5%)

Left ventricular end-systolic dimension decreases

Improvement of a hypokinetic, akinetic or dyskinetic segment during administration of low dose Dobutamine (5 or 10 mcg/kg/min) suggests the presence of viable myocardium

Improvement of a hypokinetic, akinetic or dyskinetic segment that improves with low dose Dobutamine but worsens with a higher dose of Dobutamine is called a biphasic response and may indicate hibernating myocardium

Dobutamine Stress Echocardiography

Abnormal Response

New segmental wall motion abnormality (e.g.; hypokinesia, akinesia, dyskinesia)

Global systolic dysfunction (reduced or no change in ejection fraction as compared to pre-exercise)

Shape change of left ventricle

Increased right ventricular dimensions

Increased atrial dimensions

New/increased mitral regurgitation

Significant increase in pulmonary artery pressures

Transesophageal Echocardiography

Transeosphageal Echocardiography (TEE)

Definition

A specialized type of cardiac ultrasound which allows for real time imaging of the heart by means of a transducer mounted on a flexible gastroscope and positioned behind the heart via the esophagus. There are two types: multiplane and 3-D.

Indications

Cardiac source of embolism (e.g.; thrombus)

Infective endocarditis

Prosthetic heart valve dysfunction

Diseases of the aorta (e.g.; aortic dissection)

Pre-cardioversion in patients with atrial fibrillation (screen for left atrial/left atrial appendage thrombus)

Intracardiac masses

Congenital heart disease (e.g.; sinus venosus atrial septal defect)

Complications of myocardial infarction (e.g.; ventricular septal rupture, papillary muscle rupture)

Intraoperative studies (e.g.; TAVR)

Evaluation of the critically ill/injured

Technically difficult transthoracic exam

Pre-Procedure

Verify order and time

Patient should fast for 4 to 6 hours prior to the examination

Obtain patient history

Explain the procedure to the patient and obtain a signed consent form

Remove patient dentures

Check CPR equipment

Insert IV line

Administer prophylactic antibiotics

Anesthetize pharynx with Cetacaine or Xylocaine spray to suppress gag reflex

Deliver IV sedation (e.g.; Demerol, Diazepam)

Select appropriate TEE probe (make sure probe is without cracks and tears and is working properly)

Flex the patient's neck with patient in left lateral decubitus position, place a bite guard in the patient's mouth, apply gel to the tip of the slightly flexed probe and insert probe through the bite guard while asking the patient to swallow. The index finger may be used to guide the probe. Advance probe 30 to 35 cm.

Post-Procedure

Check probe for evidence of bleeding

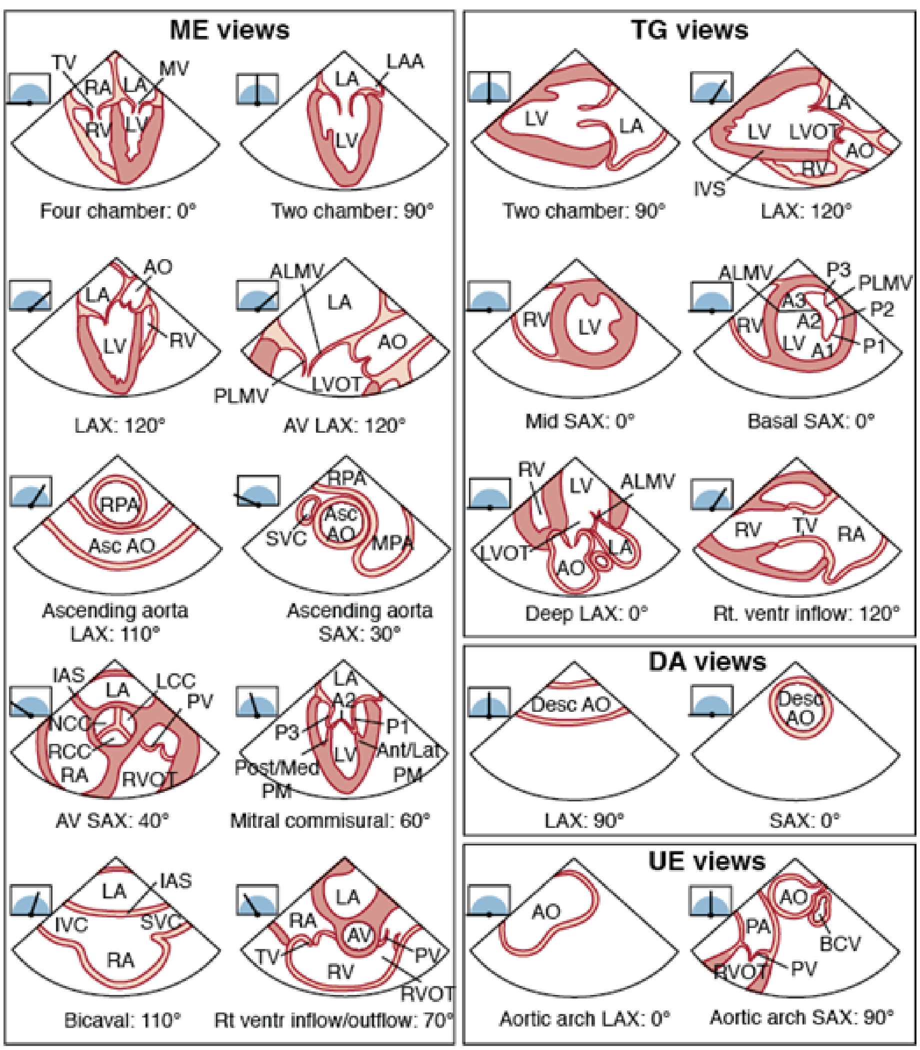
Check mouthpiece/pharynx

Monitor vital signs for 20 to 30 minutes

Patient should remain NPO until gag reflex returns (1 to 2 hours), be informed that performing tasks such as driving or operating moving equipment should not be done for 12 to 14 hours, report a sore throat if it persists more than 2 days, contact a physician immediately if bleeding from the mouth occurs, IV site is painful or if fever develops.

The TEE probe should be examined for cracks and tears, rinsed with soap or enzymatic solution and then soaked in a disinfecting solution for at least 20 minutes, rinse under running water, dry and hang on TEE rack.

Twenty Cross-Sectional Views for a Comprehensive Transesophageal Examination



Contrast Echocardiography

Contrast Echocardiography

Definition

New ultrasonographic (ultrasound) contrast agents and new imaging technologies to detect the transpulmonary contrast have recently become available to the echocardiography laboratory.

Indications

Two or more contiguous wall segments are poorly visualized in any of the three apical views

To improve endocardial border detection (e.g. evaluation of ejection fraction)

To document or exclude left ventricular structural abnormalities such as thrombus, apical hypertrophy, noncompaction, LV apical ballooning (e..g; Takotsubo), LV aneurysm, LV pseudoaneurysm, myocardial rupture

To identify and characterize intracardiac masses

Improve the detection of Doppler assessment of blood flow (e.g.; peak velocity of tricuspid regurgitation in determining systolic pulmonary artery pressure)

To improve the accuracy of stress echocardiography

Improve the triage of patients presenting with chest pain

Provide better assessment in technically difficult patients (e.g.; ICU patients)

Improve the detection of vascular pathology (e.g.; atherosclerotic plaque, aortic dissection)

Safety

The present FDA document for both Definity and Optison state that these products are not to be administered to patients in whom the following conditions are known or suspected:

Right-to-left shunt, bidirectional shunt or transient right-to-left shunt

Hypersensitivity to perflutren

Hypersensitivity to blood product, or albumin (applies to Optison)

Intra-arterial injection of ultrasound contrast is contraindicated

Serious cardiopulmonary reactions, including fatalities, have uncommonly occurred with the most serious reactions occurring within 30 minutes of administration. Assess all patients for the presence of any condition that precludes the administration and always have resuscitation personnel readily available. In patients with pulmonary hypertension or unstable cardiopulmonary conditions, monitor vital signs during and at least 30 minutes after administration.

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Practical Guideline and Ways to Avoid Common Pitfalls When Using Transpulmonary Contrast Agents

Start at the apical window and have the patient in a bed with a cutout

To improve image quality and decrease shadowing

- Use respiratory maneuvers
- Move transducer to change its position (more laterally)
- If shadowing cannot be eliminated, attempt to direct shadow to the center of the ventricle

If apex is under-filled

- Reduce the mechanical index (MI)
- Inject more contrast
- Use a higher volume and more rapid saline flush
- Adjust transmit focus to apex

If attenuation occurs

- Wait a few seconds
- Increase mechanical index (MI)
- Use high-power impulse ultrasound

Three-Dimensional Echocardiography

Three-Dimensional Echocardiography (3-D)

Definition

Three-dimensional echocardiography refers to the acquisition and display of cardiac anatomy and blood flow in three-dimensional space width, height and depth).

Clinical Applications of Three-Dimensional Echocardiography

Improved volume calculations (e.g.; ejection fraction)

Positioning of the standard two-dimensional echocardiographic views

Measurement of cardiac dimensions (e.g.; wall thickness, ventricular mass)

Stress echocardiography

Efficiency/accuracy of the sonographer and physician

Catheter device guidance (e.g. MitraClip, TAVR)

Evaluation of:

Ventricular shape

Segmental wall motion abnormalities

Myocardial infarction

Ventricular aneurysm

Cardiac valve anatomy and pathology

Presence and severity of valvular regurgitation

Hypertrophic cardiomyopathy

Pre and post cardiac resynchronization therapy

Aortic aneurysm/dissection

Guidance in valve repair

Myocardial Strain and Strain Rate Imaging

Myocardial Strain and Strain Rate Imaging

Definition

Strain is deformation of an object and is defined as the longitudinal lengthening and shortening of myocardial muscle. Tissue Doppler imaging (TDI) and speckle tracking echocardiography (STE) are able to determine the percent change in the length of cardiac muscle which appears to be useful in evaluating regional systolic function.

$$\textbf{Strain (\%)} = L_1 - Lo / Lo$$

where Lo is the original length and L_1 is the final length

Since during ventricular systole, the cardiac muscle length shortens, longitudinal strain and circumferential strain values are negative compared to radial strain systolic wall thickening whose normal values are positive.

Normal longitudinal systolic strain in most segments ranges from 17 to 25%

Normal circumferential strain range from 20 to 28%

Normal radial strain values range from 50 to 70%

Clinical Application

Ventricular systolic global and segmental function (especially in chemotherapy patients)

Subclinical disease (e.g.; amyloidosis, Friedreich ataxia, hypertrophic cardiomyopathy, left ventricular hypertrophy (e.g; systemic hypertension), ventricular noncompaction, arrythmogenic right ventricular cardiomyopathy)

Ventricular systolic function status-post congenital heart disease repair

Coronary artery disease

Postsystolic shortening

Echo-Doppler Measurements and Calculations: Step by Step

M-mode Measurements

M-mode of the Aortic Valve and Aortic Root

Acquire an M-mode of the aortic valve using the parasternal long axis view or the parasternal short axis view of the aortic valve.

1. Aortic Root End-Diastolic Diameter (AoRd)

Measure the vertical distance from the outer-edge of the anterior aortic root wall to the inner-edge of the posterior aortic root wall (leading edge-to-leading edge) at end-ventricular diastole. (Normal: M: 3.4 ± 0.3 cm; W: 3.0 ± 0.3 cm)

2. Left Atrial End-Systolic Dimension (LAes)

Measure the greatest vertical distance between the leading edge of the posterior aortic root wall and the anterior side of the posterior left atrial wall (leading edge-to-leading edge) at end-ventricular systole when the aorta is in its maximal anterior position. (Normal: M: 3.0 to 4.0 cm; W: 2.7 to 3.8 cm) (Note: Left atrial volume measurement preferred)

3. Aortic Valve Systolic Separation (ACS)

Measure the maximal opening of the aortic valve cusps during the initial part of ventricular systole, using the internal borders of the aortic cusp echoes (inner-edge-to-inner edge). The distance between the cusps may decrease slightly during ventricular systole. (Normal: 1.5 to 2.6 cm)

M-mode of the Mitral Valve

Acquire an M-mode of the mitral valve using the parasternal long axis view or the parasternal short axis view of the mitral valve.

1. E Point Septal Separation (EPSS)

Measure the vertical distance from the mitral valve E point to the lowest point of the interventricular septum. (Normal range 2 to 7 mm)

An increased EPSS suggests a reduced ejection fraction. An EPSS of greater than 20 mm suggests an ejection fraction of less than 30%.

M-mode of the Left Ventricle

Acquire an M-mode of the left ventricle using the parasternal long axis view or the parasternal short axis view of the left ventricle.

1. Right Ventricular Dimension (RVIDd)

Measure the vertical distance from the internal side of the anterior right ventricular wall to the right ventricular side of the septum at end-diastole. (Normal: 1.9 to 2.6 cm) (Note: RVIDd measured in the apical four-chamber view at the cardiac base preferred)

2. IVS Diastolic Thickness (IVSd)

Measure the vertical distance from the right ventricular side of the IVS to the left ventricular side of the IVS at end-diastole. (Normal: M: 0.6 to 1.0 cm; W: 0.6 to 0.9 cm)

3. LVID End-Diastole (LVIDd)

Measure the vertical distance from the endocardium of the IVS to the endocardium of the LVPW at end-diastole. (Normal: M: 4.2 to 5.8 cm; W: 3.8 to 5.2 cm)

4. LV Posterior Wall Diastolic Thickness (LVPWd)

Measure the vertical distance from the endocardium of the LVPW to the epicardium at end-diastole. (Normal: M: 0.6 to 1.0 cm; W: 0.6 to 0.9 cm)

5. LVID End-Systole (LVIDs)

Measure the vertical distance from the endocardium of the IVS at the lowest point of the septal motion to the endocardium of the LVPW. (Normal range: M: 2.5 to 4.0 cm; W: 2.2 to 3.5 cm)

End-diastole can be defined as the frame in the cardiac cycle in which the cardiac chamber dimension is largest, one frame after mitral valve closure or the onset of the QRS complex.

End-systole is defined as the time in the cardiac cycle in which the cardiac chamber dimension is smallest,one frame after aortic valve closure or the end of the T wave. (For the atria end-systolic dimension, end-systole is when the atrial chamber is largest in dimension).

2-D Measurements

Parasternal Long-Axis

1. **Right Ventricular Outflow Tract (Proximal) (RVIDd)**

   Measure from the anterior wall of the right ventricle to the interventricular septal-aortic junction at end-diastole. (Normal 2.0 to 3.0 cm) (Note: RVIDd measurement in apical four chamber view at the cardiac base is preferred).

2. **IVS Diastolic Thickness (IVSd)**

   Measure the vertical distance from the right ventricular side of the IVS to the left ventricular side of the IVS at end-diastole. (Normal: M: 0.6 to 1.0 cm; W: 0.6 to 0.9 cm).

3. **LV Minor Axis End-Diastole (LVIDd)**

   Measure the vertical distance from the endocardium of the IVS to the endocardium of the LVPW at end-diastole. (Normal LVIDd: M: 4.2 to 5.8 cm; W: 3.8 to 5.2 cm)

4. **LV Posterior Wall Diastolic Thickness (LVPWd)**

   Measure the vertical distance from the endocardium of the LVPW to the epicardium at end-diastole. (Normal M: 0.6 to 1.0 cm; W: 0.6 to 0.9 cm)

5. **LV Minor Axis End-Systole (LVIDs)**

   Measure the vertical distance from the endocardium of the IVS to the endocardium of the LVPW at end-systole. (Normal: M: 2.5 to 4.0 cm; W: 2.2 to 3.5 cm)

6. **Aorta (AoRd)**

   The aorta is measured at end-diastole perpendicular to the walls of the aortic root at the level of the sinuses of Valsalva. This is an outer-edge to inner-edge (leading edge-to-leading-edge) measurement. (Normal: M: 3.4 ± 0.3 cm; W: 3.0 ± 0.3 cm)

7. **Left Atrium End-Systole (LAs)**

   The left atrium is measured at the level of the sinuses of Valsalva perpendicular to the aortic root. This is an outer-edge to inner-edge (leading edge-to-leading-edge) measurement. (Normal: M: 3.0 to 4.0 cm; W: 2.7 to 3.8 cm) (Note: Left atrial volume measurement preferred)

End-diastole can be defined as the frame in the cardiac cycle in which the cardiac chamber dimension is largest, the frame after mitral valve closure or the onset of the QRS complex.

End-systole is defined as when the cardiac chamber dimension is smallest, one frame after the aortic valve closes or the end of the T wave. (For the atria end-systolic dimension, end-systole is when atrial chamber is largest in dimension).

Left Atrial Volume – Simpson's Biplane Method of Discs

1. Acquire the apical four chamber view and zoom the left atrium.
2. Trace the left atrial cavity area at end-systole (largest dimension) from the lateral aspect of the mitral valve annulus to the medial aspect of the mitral annulus excluding the mitral valve funnel, left atrial appendage and pulmonary vein inlets.
3. Measure the left atrial length from the center of the mitral annulus to the center of the superior wall of the left atrium.
4. Acquire apical two chamber and repeat steps 2 and 3.
5. The difference between the left atrium lengths between the apical four chamber view and the apical two chamber view should be less than 5 mm.

(Normal LA volume: ≤ 34 mL/m^2)

Left Ventricular Volume – Simpson's Biplane Method of Discs

1. Acquire the apical four chamber view and reduce the image depth to better visualize the left ventricular cavity.
2. The left ventricular cavity endocardial border is traced at the black-white interface between the compacted myocardium and the left ventricular cavity from the lateral aspect of the mitral annulus to the medial aspect of the mitral annulus excluding the mitral valve funnel and papillary muscles and end-diastole (largest dimension) and end-systole (smallest dimension).
3. The left ventricular length is measured from the center of the mitral annulus to the left ventricular apex at end-diastole and end-systole.
4. Repeat steps 2 and 3 for the apical two chamber view.
5. The percentage difference between the two lengths measured in the apical four chamber view and apical two chamber view should be less than 10%.

   (Normal LV end-diastolic volume: M: 34 to 74 mL/m^2; W: 29 to 61 mL/m^2) (Normal LV end-systolic volume: M: 11 to 31 mL/m^2; W: 14 to 42 mL/m^2)

Left Ventricular Mass

1. Acquire the parasternal short axis view of the left ventricle at the level of the papillary muscles.
2. Trace the epicardial (outer-wall) border at end-diastole.
3. Trace the endocardial (inner-wall) border of the left ventricle at the level of the papillary muscles at end-diastole.
4. Acquire the apical four chamber view.
5. Measure the length of the left ventricle at end-diastole from the mid-mitral annulus to the cardiac apex.

The left ventricular mass is determined by subtracting the left ventricular volume enclosed by the endocardial surface (cavitary volume) from the volume enclosed by the epicardial surface (total volume). The specific weight of the myocardium is also considered.

Left ventricular mass divided by body surface area will determine left ventricular mass index. (Normal: M: 50 to 102 mL/m^2; W: 44 to 88 mL/m^2)

Right Atrial Measurements

The primary transthoracic window for the evaluation of right atrial dimensions is the apical four chamber view.

Right Atrial Volume – Simpson's Single Plane Method of Discs

1. Acquire the apical four chamber and zoom the right atrium.
2. Trace the right atrial cavity at end-systole (largest dimension) from the lateral aspect of the tricuspid annulus to the medial aspect of the tricuspid annulus following the right atrial endocardium excluding the tricuspid valve funnel, inferior vena cava and right atrial appendage.
3. The right atrial length is measured from the center of the tricuspid annulus to the center of the superior wall of the right atrium. (Normal: M: 25 mL/m^2 ± 7 mL; W: 21 mL/m^2 ± 6 mL)

Right Atrial Area

1. Acquire the apical four chamber view and zoom the right atrium.
2. Trace the right atrial cavity at end-systole (largest dimension) from the lateral aspect of the tricuspid annulus to the medial aspect of the tricuspid annulus following the right atrial endocardium, excluding the tricuspid valve funnel, inferior vena cava and right atrial appendage. (Abnormal: > 18 cm^2)

Superior-Inferior (Major dimension)

1. Acquire the apical four chamber view and zoom the right atrium.
2. Measure the maximal superior-inferior measurement of the right atrium from the center of the tricuspid valve annulus to the center of the superior right atrial wall parallel to the interatrial septum at end-systole (largest dimension). (Abnormal: > 5.3 cm)

Medial-Lateral (Minor dimension)

1. Acquire the apical four chamber view and zoom the right atrium.
2. Measure the mid-minor distance at end-ventricular systole (largest dimension) from the mid-level of the right atrial free wall to the mid-interatrial septum perpendicular to the long axis of the right atrium. (Abnormal: > 4.4 cm)

Right Atrial Pressure

Estimation of Right Atrial Pressure on the Basis of IVC Diameter and Collapse

1. Acquire the subcostal long axis view of the inferior vena cava (IVC).
2. Measure the IVC at end-expiration 1 to 2 cm from the junction where the IVC meets the right atrium.(Normal: ≤ 2.1 cm)
3. Evaluate the change in the IVC diameter during quiet respiration and with a sniff. (Normal: ≥ 50% change in diameter with a sniff)

Note

The inferior vena cava may be dilated in normal young athletes.

Positive pressure ventilation using the inferior vena cava dimension and collapsibility is not useful although an inferior vena cava dimension of ≤ 12 mm in these patients suggests a right atrial pressure of < 10 mm Hg.

Additional Indications of Increased Right Atrial Pressure

A dilated right atrium and/or interatrial septal bulge towards the left atrium throughout the cardiac cycle suggests increased right atrial pressure.

Hepatic Veins and the Estimation of Right Atrial Pressure

- With normal right atrial pressures, the hepatic vein S wave is dominant with the S wave peak velocity greater than the D wave peak velocity.
- With increased right atrial pressure, the S wave dominance is lost and the Vs/Vd is < 1.0.
- With increased right atrial pressure, the hepatic vein systolic filling fraction (Vs/Vs + Vd) < 55% is the most sensitive and specific sign of increased right atrial pressure.

Right Ventricle Measurements

Wall Thickness

1. Acquire the subcostal four chamber view.
2. Measure the RV free wall thickness at end-diastole with M-mode or 2-D at the level of the tip of the anterior tricuspid valve leaflet. (Normal: < 0.5 cm)

Linear Dimensions

The right ventricle can be measured from a RV focused apical four chamber view at end-diastole (largest dimension) (RV focused view: apical four chamber view with transducer moved lateral from apical four position).

1. Basal diameter: Measure the maximal short axis dimension in the basal one third of the right ventricle. (Abnormal: > 4.1 cm)
2. Mid-cavity dimension: Measure in the middle third of the right ventricle at the level of the left ventricular papillary muscles at end-diastole. (Abnormal: > 3.5 cm)
3. Longitudinal dimension: Measure from the mid-plane of the tricuspid annulus to the right ventricular apex. (Abnormal: > 8.3 cm)

Right Ventricular Outflow Tract (RVOT)

RVOT outflow tract proximal

1. Acquire the parasternal long axis view.
2. Measure inner edge-to-inner edge from the anterior wall of the right ventricle to the interventricular septal-aortic junction at end-diastole (largest dimension). (Normal 2.0 to 3.0 cm)

RVOT distal:

1. Acquire the parasternal short axis view of the aortic valve,
2. Measure the distal RVOT diameter just proximal to the pulmonary valve annulus at end-diastole (largest dimension). (Abnormal: > 2.7 cm).

Right Ventricular Area and Right Ventricular Fractional Area Change

1. Acquire the apical four chamber view.
2. Trace the right ventricle from the tricuspid annulus along the free wall to the apex back to the annulus along the interventricular septum at end-diastole (largest dimension) and end-systole (smallest dimension) and this will allow calculation of the right ventricular area change (Abnormal < 35%).

Right Ventricle Measurements

Right Ventricular Ejection Fraction

- The method of discs has been used to determine the right ventricular "body" volume using the apical four chamber view. RV volumes are underestimated because of exclusion of the right ventricular outflow tract. The lower reference value of the right ventricular ejection fraction is 44%.
- Two dimensional derived estimation of right ventricular ejection fraction is not recommended because of the heterogeneity of methods and the numerous geometric assumptions.
- Three dimensional right ventricular volumes and ejection fraction have been calculated. The upper reference limit for indexed right ventricular end diastolic volume is 89 mL/m^2 and for end systolic is 45 mL/m^2 (10% to 15% lower in women than men).

Tricuspid Annular Plane Systolic Excursion

(TAPSE) or Tricuspid Annular Motion (TAM)

TAPSE or TAM is a method to measure the distance of the systolic excursion of the RV annular segment along its longitudinal plane from the standard apical 4 chamber view.

It is inferred that that the greater the descent of the base during systole, the better the RV global systolic function. It assumes that it is representative of the entire right ventricle and may be invalid in many disease states or in the presence of RV segmental wall motion abnormalities.

TAPSE should be used routinely as a simple method of estimating RV global systolic function.

1. Acquire the apical four chamber view.
2. Place an M-mode cursor through the lateral tricuspid valve annulus.
3. Measure the amount of longitudinal motion of the tricuspid annulus at peak systole. (Normal: ≥ 17 mm)

Tissue Doppler Imaging (TDI)

RV S' (systolic excursion velocity)

1. Acquire an apical 4-chamber view.
2. Place the TDI sample volume on either the tricuspid annulus or the middle of the basal segment of the RV free wall.
3. Measure the S' peak velocity.(< 9.5 cm/sec is abnormal)

Mitral Valve Area (MVA) by 2-D Planimetry

1. Acquire the parasternal short-axis view of the mitral valve using the zoom mode.
2. Angle the short-axis scan plane in a superior-inferior arc until the smallest anatomic valve orifice is recorded during maximal initial diastolic leaflet distention.
3. Planimeter (trace) where the tissue meets the blood pool during mid-diastole on a frozen image. The instrument will determine the mitral valve area.

Note

This represents the true anatomic valve area and may be larger than the Doppler determined valve area.

Several measurements may be required in patients with atrial fibrillation.

Proper gain settings and care in measuring the true valve orifice is required.

Real time 3-D and 3-D guided biplane imaging may be useful in optimizing the position of the measurement plane improving reproducibility.

Aortic Valve Area (AVA) by 2-D Planimetry

Aortic valve area can be determined by planimetry using either 2-D, 3-D or TEE 3-D. Planimetry may be an acceptable alternative when Doppler estimation of the flow velocities are unreliable.

1. Acquire the parasternal short axis view of the aortic valve and the zoom the aortic valve.
2. Trace the inner margin (blood-tissue interface) of the aortic orifice in mid-systole.

Note

This represents the true anatomic valve area and may be larger than the Doppler determined aortic valve area.

Doppler Measurements and Calculations

Doppler Measurements and Calculations

Normal Doppler Peak Velocities (m/sec)

	Mean (Range)
Mitral inflow:	0.90 (0.6 to 1.3)
Tricuspid inflow	0.50 (0.3 to 0.7)
Pulmonary artery	0.75 (0.6 to 0.9)
Left ventricular outflow tract	0.90 (0.7 to 1.1)
Aortic valve	1.35 (1.0 to 1.7)

Mitral Valve Doppler Tracings

Normal Mitral Valve

- Utilize apical window
- Flow in diastole
- Biphasic (“M” configuration)
- Flow toward the transducer (above the baseline)
- Normal peak velocity range 0.6 to 1.3 m/sec; mean 0.9 m/sec
- Color flow Doppler will demonstrate red with yellow at mitral valve leaflet tips

Tricuspid Valve Doppler Tracings

Normal Tricuspid Valve

- Utilize apical window (slide transducer medially)
- Flow in diastole
- Biphasic (“M” configuration)
- Flow toward the transducer (above the baseline)
- Normal peak velocity range 0.3 to 0.7 m/sec; mean 0.5 m/sec
- Color flow Doppler will demonstrate red at tricuspid valve leaflet tips

LVOT/Aortic Valve Doppler Tracings

Normal LVOT and Aorta

- Utilize apical window
- Flow in systole
- Bullet (parabolic) shaped
- Flow away from the transducer (below the baseline)
- Normal LVOT peak velocity range 0.7 to 1.1 m/sec; mean 0.9 m/sec
- Normal aortic valve peak velocity range 1.0 to 1.7 m/sec; mean 1.35 m/sec
- Color flow Doppler will demonstrate blue with aliasing to yellow, orange and red

RVOT/Pulmonary Valve Doppler Tracings

Normal RVOT and Pulmonary Artery

- Utilize parasternal short-axis of the base or subcostal
- Flow in systole
- Dome-shaped
- Flow away from the transducer (below the baseline)
- Normal peak velocity range 0.6 to 0.9 m/sec; mean 0.75 m/sec
- Color flow Doppler will demonstrate blue with aliasing to yellow, orange and red

Bernoulli Equation (simplified)

The simplified Bernoulli equation may be applied to the peak velocity to calculate the peak pressure gradient (pressure difference, pressure drop) between two chambers ($P_1 - P_2$).

$$\mathbf{P_1 - P_2 = 4 \times V_2^2}$$

Bernoulli Equation Mean Pressure Gradient

The mean pressure gradient is calculated by measuring the velocity at equally spaced points, squaring each velocity, averaging the velocity values and multiplying the average by 4.

Using the ultrasound machine, the mean pressure gradient can be calculated by tracing the Doppler spectral waveform. Tracing the Doppler spectral waveform provides the peak velocity, peak pressure gradient, mean pressure gradient and velocity time integral.

RV Systolic Pressure (RVSP)

RVSP (mm Hg) = 4 x (TR peak velocity^2) + Right Atrial Pressure (RAP) (mm Hg)

1. Acquire and measure the tricuspid regurgitation CW Doppler spectral waveform peak velocity using the parasternal long axis view of the right ventricle (RA-RV view), parasternal short axis view of the aortic valve, RV focused apical four chamber view (RV focused view - move transducer medial from the apical four position) and/or the subcostal four chamber view.
2. Estimate the right atrial pressure (RAP) using the diameter and collapsibility of the inferior vena cava as visualized in the subcostal long axis view of the inferior vena cava.

RVSP (mm Hg) = 4 x (TR peak velocity^2) + RAP (mm Hg)

Note

- RVSP equals systolic pulmonary artery pressure (SPAP) in the absence of RVOT obstruction.
- To approximate the right atrial pressure (RAP), examine the inferior vena cava (IVC) by the 2D and substitute one of the following values for the actual RAP:

Right Atrial Pressure (RAP)

Variable	Normal (0 to 5 {3} mm Hg)	Intermediate (5 to 10 {8} mm Hg)		High (15 mm Hg)
IVC diameter	≤ 2.1 cm	≤ 2.1	> 2.1	> 2.1
Collapse sniff	> 50^%	< 50	> 50%	< 50%
Secondary indices				Restrictive filling pattern
				Tricuspid E/E’ > 6
				Diastolic prominence in hepatic veins (systolic filling fraction < 55%)

Ranges are provided for low and intermediate categories, but for simplicity, midrange values of 3 mm Hg for normal and 8 mm Hg for intermediate are suggested. Intermediate (8 mm Hg) RA pressures may be downgraded to normal (3 mm Hg) if no secondary indices of elevated RA pressure are present, upgraded to high if minimal collapse with sniff (< 35%) and secondary indices of elevated RA pressures are present, or left at 8 mm Hg if uncertain.

- A dilated IVC in a mechanically ventilated patient may not indicate an increased right atrial pressure.
- Athletes may have dilated IVC with normal collapsibility.

Right Ventricular Systolic Pressure (RVSP) in the Presence of a Ventricular Septal Defect (VSD)

1. Acquire and measure the ventricular septal defect peak velocity.

RVSP (mm Hg) = Systolic blood pressure (mm Hg) - 4 x VSD peak velocity^2

Note

RVSP equals the systolic pulmonary artery pressure (SPAP) in the absence of right ventricular outflow tract obstruction.

Systolic Pulmonary Artery Pressure (SPAP) in the Presence of a Patent Ductus Arteriosus (PDA)

1. Acquire and measure the patent ductus arteriosus peak velocity.

SPAP (mm Hg) = Systolic blood pressure (mm Hg) – 4 x (PDA peak velocity^2)

Note

SPAP equals the right ventricular systolic pressure (RVSP) in the absence of right ventricular outflow tract obstruction

Mean Pulmonary Artery Pressure (MPAP) Utilizing Right Ventricular Outflow Tract (RVOT) Acceleration Time

1. Acquire the parasternal short axis view of the aortic valve, parasternal long axis view of the right ventricular outflow tract and/or subcostal short axis of the aortic valve.
2. Place a PW Doppler sample volume at the level of the pulmonary valve annulus to acquire a RVOT Doppler spectral waveform.
3. Measure the time from the onset of flow to the peak velocity of flow.

MPAP (mm Hg) = 79 – 0.5 x acceleration time (msec)

Mean Pulmonary Artery Pressure (MPAP) Utilizing the Pulmonary Regurgitation

Peak Velocity

1. Acquire the parasternal short axis view of the aortic valve, parasternal long axis view of the right ventricular outflow tract and/or subcostal short axis view of the aortic valve.
2. Using PW Doppler or CW Doppler, acquire a pulmonary regurgitation Doppler spectral waveform.
3. Measure the pulmonary regurgitation peak velocity.

MPAP (mm Hg) = 4 x (Pulmonary regurgitation peak velocity^2)

Pulmonary Artery End-Diastolic Pressure (PAEDP) Utilizing Pulmonary Regurgitation End-Diastolic Velocity

1. Acquire the parasternal short axis view of the aortic valve, parasternal long axis view of the right ventricular outflow tract and/or subcostal short axis view of the aortic valve.
2. Using PW Doppler or CW Doppler, acquire a pulmonary regurgitation Doppler spectral waveform.
3. Measure the pulmonary regurgitation end-diastolic velocity.

PAEDP (mm Hg) =
4 x (Pulmonary regurgitation end-diastolic velocity^2) + Right Atrial Pressure (mm Hg)

Note

The PAEDP estimates the pulmonary wedge pressure.

Pulmonary Vascular Resistance (PVR) Utilizing the Tricuspid Regurgitation Peak Velocity and the Right Ventricular Outflow Tract (RVOT) Velocity Time Integral (VTI)

1. Acquire the tricuspid regurgitation CW Doppler spectral waveform using the parasternal long axis view of the right ventricle (RA-RV view), parasternal short axis view of the aortic valve, RV focused apical four chamber view (focused right ventricular view – move transducer medial from apical four chamber view position) and/or the subcostal four chamber view.
2. Measure the tricuspid regurgitation peak velocity.
3. Acquire the parasternal short axis view of the aortic valve, parasternal long axis view of the RVOT and/or subcostal short axis view of the aortic valve.
4. Acquire the RVOT PW Doppler waveform with the sample volume placed at the level of the pulmonary valve annulus and trace the RVOT Doppler spectral waveform to acquire the RVOT VTI.

PVR (WU) = Tricuspid Regurgitation peak velocity (TRV) ÷ RVOT VTI x 10 + 0.16

LV Stroke Volume (SV)/CardiacOutput (CO)/Cardiac Index (CI)

SV (mL) = CSA (cm^2) × VTI (cm)

1. Acquire a parasternal axis view and zoom the left ventricular outflow tract and aortic valve region.
2. Measure the left ventricular outflow tract (LVOT) diameter in mid-systole from the black-white interface of the septal endocardium to the anterior mitral valve leaflet (inner-edge to inner-edge) parallel to the aortic valve annulus to calculate the LVOT cross-sectional area (CSA).

$$\mathbf{CSA_{LVOT}\ (cm^2) = .785 \times LVOT\ diameter^2}$$

3. Acquire an apical five-chamber view or apical long axis view.
4. Place a PW Doppler sample volume just proximal to the aortic valve so that the location of the velocity recording matches the LVOT diameter measurement location.
5. Trace the LVOT Doppler spectral waveform dense modal velocity throughout ventricular systole to acquire the LVOT velocity time integral ($LVOT_{VTI}$).

$$\mathbf{SV_{LVOT}\ (mL) = CSA\ (cm^2) \times LVOT_{VTI}\ (cm)}$$

$$\mathbf{SV_{LVOT}\ (mL) = .785\ x\ LVOT\ diameter^2\ x\ LVOT_{VTI}}$$

6. Multiply stroke volume times heart rate to determine cardiac output.
7. Divide cardiac output by body surface area to determine cardiac index.

Note

For the LVOT diameter measurement, some experts prefer to measure the LVOT diameter within 0.3 cm to 1.0 cm of the aortic valve orifice while others prefer the measurement at the aortic valve annulus level.

When the sample volume is optimally positioned, the PW Doppler LVOT recording demonstrates a well-defined peak, narrow band of velocities throughout ventricular systole. This may not be the case in many patients due to flow convergence resulting in spectral dispersion. In these cases, the sample volume is slowly moved towards the cardiac apex until a smooth velocity curve is obtained.

Increasing the sweep speed to 100 mm/sec may aid in acquiring Doppler spectral waveform measurements.

An aortic valve closing click should be obtained when acquiring the PW Doppler spectral waveform to ensure accuracy.

Aortic Valve Area (AVA) by the Continuity Equation

$$AVA\ (cm^2) = CSA_{LVOT}\ (cm^2) \times LVOT_{VTI}\ (cm) \div AoV_{VTI}\ (cm)$$

$$AVA\ (cm^2) = .785 \times LVOT\ Diameter^2 \times LVOT_{VTI} \div AoV_{VTI}$$

1. Acquire a parasternal axis view and zoom the left ventricular outflow tract and aortic valve region.
2. Measure the left ventricular outflow tract (LVOT) diameter in mid-systole from the black-white interface of the septal endocardium to the anterior mitral valve leaflet (inner edge-to-inner edge) parallel to the aortic valve annulus to calculate the LVOT cross-sectional area (CSA_{LVOT}).

$$CSA_{LVOT}\ (cm^2) = .785 \times LVOT\ diameter^2$$

3. Acquire an apical five chamber view or apical long axis view.
4. Place a PW Doppler sample volume just proximal to the aortic valve so that the location of the velocity recording matches the LVOT diameter measurement location.
5. Trace the LVOT Doppler spectral waveform dense modal velocity throughout ventricular systole to acquire the LVOT velocity time integral ($LVOT_{VTI}$).

$$Stroke\ volume\ (mL) = CSA_{LVOT} \times LVOT_{VTI}$$

$$Stroke\ volume\ (mL) = .785 \times LVOT\ Diameter^2 \times LVOT_{VTI}$$

6. Utilizing CW Doppler from multiple windows (e.g., apical, right parasternal, suprasternal, subcostal) (including the dedicated CW Doppler probe) obtain the maximal aortic peak velocity and measure the aortic valve velocity time integral ($VTIAoV_{VTI}$) by tracing the outer edge of the Doppler spectral waveform dense modal velocity. Choose the highest peak velocity and note the window from which it was obtained.

$$Aortic\ valve\ area\ (AVA\ cm^2) = CSA_{LVOT} \times LVOT_{VTI} \div AoV_{VTI}$$

$$Aortic\ Valve\ Area\ (AVA\ cm^2) = .785 \times LVOT\ Diameter^2 \times LVOT_{VTI} \div AoV_{VTI}$$

The peak velocities of the left ventricular outflow tract and aortic valve may be substituted for the velocity time integrals:

$$AVA\ (cm^2) = .785 \times LVOT\ Diameter^2 \times LVOT_{peak\ velocity} \div Aortic\ Valve_{peak\ velocity}$$

Note

For the LVOT diameter measurement, some experts prefer to measure the LVOT diameter within 0.3 cm to 1.0 cm of the aortic valve orifice while others prefer the measurement at the aortic valve annulus level.

When the sample volume is optimally positioned, the PW Doppler LVOT recording demonstrates a well-defined peak, narrow band of velocities throughout ventricular systole. This may not be the case in many patients due to flow convergence resulting in spectral dispersion. In these cases, the sample volume is slowly moved towards the cardiac apex until a smooth velocity curve is obtained.

Increasing the sweep speed to 100 mm/sec may aid in acquiring Doppler spectral waveform measurements.

Pulmonary Valve Area (PVA)

Pulmonary valve area can be determined by the continuity equation by measuring the RVOT diameter at the pulmonary valve annulus in mid-systole, acquiring a PW Doppler tracing of the RVOT at the level of the pulmonary valve annulus and a CW Doppler tracing of the pulmonary valve using the parasternal short axis view of the aortic valve, parasternal long axis view of the right ventricular outflow tract and/or the subcostal short axis view of the aortic valve.

$$\textbf{PVA (cm}^2\textbf{) = .785} \times \textbf{RVOT Diameter}^2 \times \textbf{RVOT}_{\textbf{VTI}} \div \textbf{Pulmonary valve}_{\textbf{VTI}}$$

Mitral Valve Area (MVA) by the Continuity Equation

$$\textbf{MVA (cm}^2\textbf{) = CSA}_{\textbf{LVOT}}\textbf{ (cm}^2\textbf{) x LVOT}_{\textbf{VTI}} \div \textbf{MV}_{\textbf{VTI}}$$

$$\textbf{MVA (cm}^2\textbf{) = .785 x Left Ventricular Outflow Tract Diameter}^2 \div \textbf{MV}_{\textbf{VTI}}$$

Acquire a parasternal axis view and zoom the left ventricular outflow tract and aortic valve region.

Measure the left ventricular outflow tract (LVOT) diameter in mid-systole from the black-white interface of the septal endocardium to the anterior mitral valve leaflet (inner-edge to inner-edge) parallel to the aortic valve annulus to calculate the LVOT cross-sectional area (CSA_{LVOT}).

$$\textbf{CSA}_{\textbf{LVOT}}\textbf{ (cm}^2\textbf{) = .785} \times \textbf{LVOT diameter}^2$$

Acquire an apical five-chamber view or apical long axis view.

Place a PW Doppler sample volume just proximal to the aortic valve so that the location of the velocity recording matches the LVOT diameter measurement location.

Trace the LVOT Doppler spectral waveform dense modal velocity throughout ventricular systole to acquire the LVOT velocity time integral ($LVOT_{VTI}$).

$$\textbf{SV (mL) = CSA}_{\textbf{LVOT}} \times \textbf{LVOT}_{\textbf{VTI}}$$

$$\textbf{SV (mL) = .785} \times \textbf{LVOT Diameter}^2 \times \textbf{LVOT}_{\textbf{VTI}}$$

Acquire an apical four chamber view.

Acquire a CW Doppler spectral waveform of the mitral valve and trace the mitral valve inflow to determine the mitral valve velocity time integral (VTI_{MV}).

$$\textbf{MVA (cm}^2\textbf{) = CSA}_{\textbf{LVOT}}\textbf{ (cm}^2\textbf{) x LVOT}_{\textbf{VTI}} \div \textbf{MV}_{\textbf{VTI}}$$

$$\textbf{MVA (cm}^2\textbf{) = .785 x LVOT Diameter}^{\textbf{2}}\textbf{ x LVOT}_{\textbf{VTI}} \div \textbf{MV}_{\textbf{VTI}}$$

Doppler Measurements and Calculations

Note

For the LVOT diameter measurement, some experts prefer to measure the LVOT diameter within 0.3 cm to 1.0 cm of the aortic valve orifice while others prefer the measurement at the aortic valve annulus level.

When the sample volume is optimally positioned, the PW Doppler LVOT recording demonstrates a well-defined peak, narrow band of velocities throughout ventricular systole. This may not be the case in many patients due to flow convergence resulting in spectral dispersion. In these cases, the sample volume is slowly moved towards the cardiac apex until a smooth velocity curve is obtained.

Increasing the sweep speed to 100 mm/sec may aid in acquiring Doppler spectral waveform measurements.

An aortic valve closing click should be obtained when acquiring the PW Doppler spectral waveform to ensure accuracy.

Tricuspid Valve Area (TVA)

Tricuspid valve area can be determined by the continuity equation by measuring the RVOT diameter at the level of the pulmonary valve annulus in mid-systole, acquiring a PW Doppler tracing of the RVOT at the level of the pulmonary valve annulus and a CW Doppler tracing of the tricuspid valve spectral waveform in the parasternal long axis view of the right ventricle (RA-RV view) or RV focused apical four chamber view (RV focused view – move transducer medial from apical four camber view position).

$$\mathbf{TVA\ (cm^2) = .785\ x\ RVOT\ Diameter^2 \times RVOT_{VTI} \div TV_{VTI}}$$

Mitral Regurgitation

Regurgitant Jet Area (RJA)

1. Acquire a parasternal long axis view, parasternal short axis view of the aortic valve and apical four chamber view with color flow Doppler on.
2. Outline the RJA and the area will be measured by computerized planimetry.

Regurgitant Jet Area/Left Atrial Area (RJA/LAA)

1. Outline the LAA and the ultrasound machine computer software will calculate the area
2. Divide the RJA by the LAA.

Note

In general, the Regurgitant Jet Area and Regurgitant Jet Area / Left Atrial Area ratio is predicted by a qualitative ("eyeball") evaluation.

The systolic blood pressure, heart rate and duration of flow should be known.

The color flow Doppler gain should be set appropriately (increase color gain until speckling appears then decrease color gain until color speckling disappears).

• The color flow Doppler velocity scale should be set between 50 to 70 cm/sec.

• Choose the largest ratio.

Tricuspid Regurgitation (RJA/RAA)

The same approach used for mitral regurgitation may be used for tricuspid regurgitation when determining RJA and RJA/RAA using the parasternal long axis view of the right ventricle (RA-RV view), parasternal short axis view of the aortic valve, RV focused apical four chamber (RV focused view – move transducer medial from the apical four chamber view position) and subcostal four chamber. Choose the largest ratio.

Vena Contracta (VC)

1. Acquire the parasternal long axis view with color flow Doppler velocity scale set at between 50 to 70 cm/sec.
2. Zoom the mitral valve and the mitral regurgitation jet (narrowest sector width which allows visualization of the flow acceleration zone (PISA), vena contracta and a portion of the regurgitant jet should be chosen).
3. Angulate the transducer until the regurgitant flow proximal to, through and distal to the mitral valve is well visualized.
4. Freeze and scroll until the largest diameter of the vena contracta is found.
5. Measure the vena contracta of the regurgitant flow immediately downstream from the flow convergence zone (PISA). Three to five beats should be measured and averaged.

Note

The apical two chamber view, which is oriented parallel to the line of leaflet coaptation, generally demonstrates a wide vena contracta in mild mitral regurgitation and should not be utilized to measure th vena contracta.

Tricuspid Regurgitation

The same approach may be used for tricuspid regurgitation by using the parasternal long axis view of the right ventricle (RA-RV view), parasternal short axis view of the aortic valve, RV focused apical four chamber view (RV focused view – move transducer medial from the apical four chamber view) and/or subcostal four chamber view.

PISA (Proximal Isovelocity Surface Area) Method

1. Acquire the apical four chamber and optimize the color flow Doppler of the mitral regurgitation.
2. Zoom the regurgitant mitral valve.
3. Shift the color flow Doppler zero baseline downward (upward for TEE) to an aliasing velocity of between 20 to 40 cm/sec.
4. Freeze the image and cine loop to identify the optimal hemispheric ("golf ball on a tee") which should occur in mid-systole.
5. Measure the radius.
6. Obtain the peak velocity and velocity time integral (VTI) of the mitral regurgitation utilizing CW Doppler.
7. Calculate the effective regurgitant orifice (EROA) by the formula.

$$\textbf{EROA (cm}^2\textbf{) =}$$
$$\textbf{6.28 x r}^2\textbf{ (cm}^2\textbf{)} \times \textbf{ Aliasing Velocity (cm/sec)} \div \textbf{ Mitral Regurgitation Peak Velocity (cm/sec)}$$

8. Calculate the regurgitant volume (RV) by the formula.

$$\textbf{RV (mL) = EROA (cm}^2\textbf{) x Mitral Regurgitation Velocity Time Integral (VTI) (cm)}$$

Simplified PISA Methods

Method 1

Measure the radius of the PISA as previously described and utilize color M-mode of the PISA for duration and timing.

Grade (assumes holosystolic duration)

Mild < 4 mm

Moderate 5 to 7 mm

Moderately Severe 8 to 10 mm

Severe > 10 mm

Method 2

PISA radius $\geq$ 1 cm = EROA $\geq$ 35 mm^2

Method 3

EROA (cm^2) = r^2 (cm^2) ÷ 2

Method 4

RV (mL) = 2 x r^2 × alias velocity (cm/sec)

Method 5

RV (mL) = 6.28 x r^2 (cm^2)   x aliasing velocity (cm/sec) ÷ 3.25

Method 6

r2 (cm^2) x aliasing velocity (cm/sec)

< 10 cm^3/sec = mild MR

> 20 cm^3/s = significant MR

Method 7

Qualitatively evaluate the radius of the PISA with the color velocity scale set at between 50 to 70 cm/sec.

Note

A common error in calculations is to forget to convert the peak mitral regurgitation velocity from m/s to cm/sec.

Effective regurgitant orifice area (EROA) may be reported out in mm^2 instead of cm^2. Multiply cm^2 × 100 to obtain mm^2.

Tricuspid Regurgitation

For tricuspid regurgitation, the velocity scale should be set at approximately 30 cm/sec in order to determine the PISA radius. The parasternal long axis view of the right ventricle (RA-RV view), parasternal short axis view of the aortic valve, and/or RV focused apical four chamber view (RV focused view – move transducer medial from the apical four chamber view position) may be used to evaluate and measure.

Regurgitant Volume (RV)

Regurgitant Volume (RV)

Regurgitant Fraction (RF)

Effective Regurgitant Orifice (EROA)

1. Acquire the apical four chamber view.
2. Measure the mitral annulus diameter from inner edge-to-inner edge at the base of the mitral valve leaflets in mid-diastole using the zoom feature.

$$\mathbf{CSA_{MV}\ (cm^2) = .785 \times Mitral\ Valve\ Annulus\ Diameter^2}$$

3. Place a PW Doppler sample volume at the level of the mitral valve annulus and trace the mitral valve Doppler spectral waveform dense modal velocity throughout ventricular diastole to determine the velocity time integral (VTI_{MV}).
4. Calculate the mitral valve stroke volume.

$$\mathbf{SV_{MV}\ (mL) = CSA_{MV} \times MV_{VTI}}$$

$$\mathbf{SV_{MV} = .785 \times Mitral\ annulus\ diameter^2 \times MV_{VTI}}$$

5. Measure the left ventricular outflow tract (LVOT) diameter in mid-systole from the black-white interface of the septal endocardium to the anterior mitral valve leaflet (inner edge-to-inner edge) parallel to the aortic valve annulus to calculate the LVOT cross-sectional area (CSA_{LVOT}).

$$\mathbf{CSA_{LVOT}\ (cm^2) = .785 \times LVOT\ Diameter^2}$$

6. Acquire an apical five-chamber view or apical long axis view.
7. Place a PW Doppler sample volume just proximal to the aortic valve so that the location of the velocity recording matches the LVOT diameter measurement location.
8. Trace the LVOT Doppler spectral waveform dense modal velocity throughout ventricular systole to acquire the LVOT velocity time integral ($LVOT_{VTI}$).
9. Calculate the left ventricular outflow tract stroke volume.

$$\mathbf{SV_{LVOT}\ (mL) = CSA_{LVOT} \times LVOT_{VTI}}$$

$$\mathbf{SV_{LVOT}\ (mL) = .785 \times LVOT\ diameter^2 \times LVOT_{VTI}}$$

10. Calculate regurgitant volume (RV):

$$\mathbf{RV_{MR}\ (mL) = SV_{MV}\ (mL) - SV_{LVOT}\ (mL)}$$

11. Calculate regurgitant fraction (RF):

$$\mathbf{RF\ (\%) = RV_{MR}\ (mL) \div SV_{MV}\ (mL)}$$

12. Acquire a CW Doppler tracing of the mitral regurgitation and trace the mitral regurgitation Doppler spectral waveform dense modal velocity throughout ventricular systole to determine a velocity time integral (MR_{VTI}).
13. Calculate effective regurgitant orifice area (EROA):

$$\mathbf{EROA\ (cm^2) = RV_{MR} \div VTI_{MR}}$$

Note

For the LVOT diameter measurement, some experts prefer to measure within 0.3 cm to 1.0 cm of the aortic valve orifice while others prefer the measurement at the aortic annulus level.

When the sample volume is optimally positioned, the PW Doppler LVOT recording demonstrates a well-defined peak, narrow band of velocities throughout ventricular systole. This may not be the case in many patients due to flow convergence resulting in spectral dispersion. In these cases, the sample volume is slowly moved towards the cardiac apex until a smooth velocity curve is obtained.

An aortic valve closing click should be obtained when acquiring the PW Doppler spectral waveform to ensure accuracy.

Increasing the sweep speed to 100 mm/sec may aid in acquiring the Doppler spectral waveform measurements.

Left Ventricular Systolic Performance (dP/dt)

1. Acquire the apical four chamber view and optimize mitral regurgitation jet by CW Doppler.
2. On screen or paper, draw horizontal lines at 1 m/sec and 3 m/sec.
3. Draw a vertical line from intercept of mitral regurgitation jet at 1 m/sec and 3 m/sec.
4. Measure time (msec).
5. dP/dt = (32 mm Hg x 1000) ÷ change in time in msec.

dP/dt Values

- Normal > 1200 mm Hg/sec or < 27 msec
- Borderline 1000 to 1200 mm Hg/sec
- Abnormal < 1000 mm Hg/sec or ≥ 32 msec

Right Ventricular Systolic Performance (dP/dt)

Right ventricular dP/dt is calculated similar to left ventricular dP/dt by measuring the time required for the tricuspid regurgitation jet to increase in velocity from 1 to 2 m/sec. This represents a 12 mm Hg increase in pressure. The dP/dt is calculated as (12 mm Hg x 1000)/(the time in milliseconds) yielding a value in millimeters of mercury per second. An RV dP/dt of < 400 mm Hg/sec is abnormal.

Aortic Regurgitation

Jet Width/Left Ventricular Outflow Tract Width (JW/LVOTW)

1. Acquire the parasternal long axis view.
2. Measure the maximal anteroposterior diameter (width) of the regurgitant jet at the junction of the LVOT and aortic annulus within 1 cm of the aortic valve using the parasternal long-axis view (JW) (zoom with color flow Doppler velocity scale set at between 50 to 70 cm/sec).
3. Measure the maximal width of the LVOT at the same location (LVOTW).
4. Divide the jet width (JW) by the LVOT width (LVOTW) and the resultant ratio can be expressed as a percentage (JW/LVOTW).

Jet Cross-Sectional Area (CSA) / Left Ventricular Outflow Tract Cross Sectional Area (CSA) (Jet CSA/LVOT CSA)

1. Acquire parasternal short axis view of the aortic valve.
2. Planimeter the regurgitant jet area (Jet CSA) (zoom with color flow Doppler velocity scale set at between 50 to 70 cm/sec).
3. Planimeter the LVOT cross-sectional area (LVOT CSA).
4. The JCSA can then be divided by the LVOT CSA and the resultant ratio can be expressed as a percentage (Jet CSA/LVOT CSA).

Note

Similar to mitral regurgitation, tricuspid regurgitation and pulmonary regurgitation a qualitative ("eyeball") approach is used to determine Jet Width/LVOT Width and Jet CSA/LVOT CSA.

Vena Contracta (VC)

1. Acquire the parasternal long axis view with color flow Doppler velocity scale set at 50 to 70 cm/sec.
2. Zoom the aortic valve and the aortic regurgitation jet (narrowest sector width which allows visualization of the flow acceleration zone (PISA), vena contracta and a portion of the regurgitant jet should be chosen).
3. Angulate the transducer until the regurgitant flow proximal to, through and distal to the aortic valve is well visualized
4. Freeze and scroll until the largest diameter of the vena contracta is well visualized.
5. Measure the vena contracta of the regurgitant flow immediately downstream from the flow convergence region (PISA) (three to five beats should be measured and averaged).
6. The apical five chamber or apical long-axis may be substituted when the parasternal long axis is suboptimal.

Proximal Isovelocity Surface Area (PISA)

1. Optimize the color flow Doppler image of the aortic regurgitation utilizing the apical long axis view, apical five chamber view or parasternal long axis.
2. Zoom the aortic valve.
3. Shift the color flow Doppler baseline upward until the flow convergence region (PISA) is clearly visualized.
4. Freeze the image and cine loop to identify the optimal hemisphere which should occur in early diastole.
5. Measure the radius (between the first aliasing color (red-blue interface) and the regurgitant aortic orifice.
6. Obtain a peak velocity and velocity time integral (VTI) of the aortic regurgitation utilizing CW Doppler.
7. Calculate the effective regurgitant orifice area (EROA) by the formula.

$$\textbf{EROA cm}^2 = $$
$$\textbf{6.28 x r}^2\textbf{ (cm}^2\textbf{) x Aliasing Velocity (cm/sec)} \div \textbf{Aortic Regurgitation Peak Velocity (cm/sec)}$$

8. Calculate the regurgitant volume (RV) by the formula.

$$\textbf{RV (mL) = EROA (cm}^2\textbf{) x Aortic Regurgitation Velocity Time Integral (VTI) (cm)}$$

Regurgitant Volume (RV)

Regurgitant Fraction (RF)

Effective Regurgitant Orifice Area (EROA)

1. Acquire a parasternal axis view and zoom the left ventricular outflow tract and aortic valve region.
2. Measure the left ventricular outflow tract (LVOT) diameter in mid-systole from the black-white interface of the septal endocardium to the anterior mitral valve leaflet (inner-edge to inner-edge) parallel to the aortic valve annulus to calculate the LVOT cross-sectional area (CSA_{LVOT}).

$$\mathbf{CSA_{LVOT}\ (cm^2) = .785 \times LVOT\ diameter^2}$$

3. Acquire an apical five-chamber view or apical long axis view.
4. Place a PW Doppler sample volume just proximal to the aortic valve so that the location of the velocity recording matches the LVOT diameter measurement location.
5. Trace the LVOT Doppler spectral waveform dense modal velocity throughout ventricular systole to acquire the LVOT velocity time integral (VTI).

$$\mathbf{SV_{LVOT}\ (mL) = CSA_{LVOT}\ (cm^2) \times LVOT_{VTI}\ (cm)}$$

$$\mathbf{SV_{LVOT}\ (mL) = .785\ x\ LVOT\ diameter^2\ x\ LVOT_{VTI}}$$

6. Acquire the apical four chamber view.
7. Measure the mitral annulus diameter from inner-edge to inner-edge at the base of the mitral valve leaflets in mid-diastole with the zoom feature on.

$$\mathbf{CSA_{MV}\ (cm^2) = .785\ x\ Mitral\ Valve\ Annulus\ Diameter^2}$$

8. Place a PW Doppler sample volume at the level of the mitral valve annulus and trace the mitral valve Doppler spectral waveform dense modal velocity to determine the velocity time integral (MV_{VTI}).
9. Calculate the mitral valve stroke volume.

$$\mathbf{SV_{MV}\ (mL) = CSA_{MV}\ x\ MV_{VTI}}$$

$$\mathbf{SV_{MV}\ (mL)\ .785\ x\ Mitral\ valve\ annulus\ diameter^2\ x\ MV_{VTI}}$$

7. Calculate aortic regurgitant volume (RV).

$$\mathbf{RV_{AR} = SV_{LVOT}\ (mL) - SV_{MV}\ (mL)}$$

8. Calculate aortic regurgitant fraction (RF).

$$\mathbf{RF\% = RV_{AR}\ (mL) \div SV_{LVOT}\ (mL)}$$

9. From the apical window, obtain a CW Doppler tracing of the aortic regurgitation and determine a velocity time integral (VTI_{AR}) by tracing the aortic regurgitation signal.
10. Calculate effective regurgitant orifice area(EROA).

$$\mathbf{EROA\ (cm^2) = RV_{AR} \div VTI_{AR}}$$

Regurgitant Volume (RV)

Note

For the LVOT diameter measurement, some experts prefer to measure with 0.3 cm to 1.0 cm of the aortic valve orifice while others prefer the measurement at the aortic annulus level.

When the sample volume is optimally positioned acquiring the PW Doppler LVOT spectral waveform, the recording demonstrates a well-defined peak, narrow band of velocities throughout ventricular systole. This may not be the case in many patients due to flow convergence resulting in spectral dispersion. In these cases, the sample volume is slowly moved towards the cardiac apex until a smooth velocity curve is obtained.

Increasing the sweep speed to 100 mm/sec may aid in acquiring the Doppler spectral

An aortic valve closing click should be obtained when acquiring the PW Doppler spectral waveform to ensure accuracy.

Qp/Qs

1. Acquire the parasternal short axis view of the aortic valve, (parasternal long axis view of the right ventricular outflow tract or subcostal short axis view of the aortic valve may be used).

2. Measure the RVOT diameter inner edge-to-inner edge in mid-systole at the base of the pulmonary valve leaflets with zoom on to calculate the RVOT cross-sectional area (CSA_{RVOT}).

$$\mathbf{CSA_{RVOT}\ (cm^2) = .785 \times RVOT\ diameter^2}$$

3. Place a PW Doppler sample volume at the level of the pulmonary valve annulus and trace the RVOT Doppler spectral waveform dense modal velocity throughout ventricular systole to determine the RVOT velocity time integral($RVOT_{VTI}$).

$$\mathbf{SV_{RVOT}\ (mL) = CSA_{RVOT}\ (cm^2) \times RVOT_{VTI}\ (cm)}$$

$$\mathbf{SV_{RVOT}\ (mL) = .785 \times RVOT\ diameter^2 \times RVOT_{VTI}}$$

4. Measure the left ventricular outflow tract (LVOT) diameter in mid-systole from the black-white interface of the septal endocardium to the anterior mitral valve leaflet (inner-edge to inner-edge) parallel to the aortic valve annulus with zoom on to calculate the LVOT cross-sectional area (CSA_{LVOT}).

$$\mathbf{CSA_{LVOT}\ (cm^2) = .785 \times LVOT\ diameter^2}$$

5. Acquire an apical five-chamber view or apical long axis view.

6. Place a PW Doppler sample volume just proximal to the aortic valve so that the location of the velocity recording matches the LVOT diameter measurement location.

7. Trace the LVOT Doppler spectral waveform dense modal velocity throughout ventricular systole to acquire the LVOT velocity time integral (VTI).

8. Calculate the left ventricular stroke volume.

$$\mathbf{SV_{LVOT}\ (mL) = CSA_{LVOT}\ (cm^2) \times LVOT_{VTI}\ (cm)}$$

$$\mathbf{SV_{LVOT}\ (mL) = .785 \times LVOT\ diameter^2\ (cm^2) \times LVOT_{VTI}\ (cm)}$$

9. Calculate Qp/Qs: (ASD, VSD).

$$\mathbf{Q_p/Q_s = SV_{RVOT}\ (mL) \div SV_{LVOT}\ (mL)}$$

Note

For patent ductus arteriosus, the SVLVOT represents Qp and SVRVOT represents Qs.
For patent ductus arteriosus:

$$\mathbf{Q_p/Q_s = SV_{LVOT}\ (mL) \div SV_{RVOT}\ (mL)}$$

Mitral Valve Area (MVA)

Pressure Half-Time (PHT) Method

Mitral Valve Area (MVA) = 220 ÷ Pressure Half-Time (msec)

1. Acquire the apical four chamber view.
2. Optimize a CW Doppler tracing of the mitral valve inflow signal with a sweep speed of 100 mm/sec.
3. Place a caliper on the mitral valve E point and draw a line following the Doppler spectral waveform dense modal velocity to baseline to measure the mitral valve deceleration time.

Mitral valve PHT (msec) = 0.29 x Deceleration time (msec).

Tricuspid Stenosis

The same steps may be used to determine tricuspid valve pressure half-time and tricuspid valve area using a focused RV apical four chamber view (RV focused view – move the transducer media from the apical four chamber view position).

Tricuspid valve area (TVA) (cm^2) = 190 ÷ Pressure-half time (msec)

Mitral Valve Area - PISA (Proximal Isovelocity Surface Area) Method

1. Acquire the apical four chamber view with color flow Doppler on.
2. Zoom the area of the mitral valve.
3. Shift the color flow Doppler zero baseline upward (downward for TEE) to between 30 to 45 cm/sec aliasing velocity.
4. Freeze the image, cine loop to identify and measure the radius (r).
5. Utilizing CW Doppler, obtain the mitral valve inflow Doppler tracing and determine the mitral valve E wave velocity (Vmax).
   - Determine mitral valve area (MVA) by the formula:

$$\mathbf{MVA\ (cm^2) = 6.28 \times r^2\ (cm^2) \times Aliasing\ Velocity\ (cm/sec) \div Mitral\ Valve\ E\ Wave\ Velocity\ (V_{max})\ (cm/sec)}$$

Left Ventricular Diastolic Function

Mitral Inflow

1. From the apical four chamber view slide the transducer lateral and tilt posterior. This will assure the PW Doppler ultrasound beam is parallel to the mitral valve inflow.
2. Place the sample volume between the mitral valve leaflet tips during ventricular diastole (utilizing a small PW Doppler sample volume length (1 to 2 mm) to assure a clean Doppler spectral tracing is recommended)

The following are the routine measurements:

Mitral valve peak E wave velocity (E)

Mitral valve peak A wave velocity (A)

Mitral valve deceleration time (DT)

Additional measurements when clinically indicated:

Mitral valve E at A velocity

Mitral valve A wave duration (PW Doppler sample volume placed at level of mitral annulus)

Note

- Placing the sample volume too close to the mitral valve annulus or in the body of the mitral valve leaflets will result in lower mitral valve peak velocities and shorter mitral valve deceleration times (Numbers 1, 2, 3). The E wave will decrease more than the A wave as the sample volume is moved closer to the mitral valve annulus.
- Placing the sample volume below the mitral valve leaflet tips towards the left ventricle will result in lower mitral valve peak velocities and longer deceleration times and longer A wave durations.
- CW Doppler may be utilized to confirm the E/A ratio.

Isovolumic Relaxation Time (IVRT)

Method 1

1. Acquire the apical five chamber view.
2. Aim the CW Doppler beam between the aortic valve and the mitral valve with fine angulation record the closing click of the aortic valve and the opening click of the mitral valve.
3. Measure the time interval between these two valve clicks.(Normal: 76 ± 13 msec)

Method 2

1. Acquire the apical five chamber view.
2. Place the PW Doppler sample volume in the LVOT, increase the sample volume size and record the closing click of the aortic valve and the opening click of the mitral valve.
3. Measure the time interval between these two valve clicks.

Method 3

1. Acquire the apical four chamber.
2. Obtain a TDI of the mitral annulus.
3. Measure from the end of the S' wave to the onset of the E' wave.

Note

An IVRT of less than 60 msec suggests increased left atrial pressure. An IVRT of greater than 100 msec suggests left ventricular impaired relaxation.

Isovolumic Contraction Time (IVCT)

The isovolumic contraction time (IVCT) can be measured by obtaining a TDI of the mitral annulus and measuring from the end of the mitral valve A' wave to onset of the S' wave

Pulmonary Vein Flow

1. Utilizing a large (2 to 3 mm) PW Doppler sample volume length from the apical four-chamber view, tilt the transducer slightly anterior (almost to an apical five-chamber view) and place the sample volume > 0.5 cm into the right upper pulmonary vein.
2. Measure the following:
   - PVs1
   - PVs2 (if present)
   - PVd
   - PVa (pulmonary vein peak velocity of the atrial reversal flow)
   - PV ARdur (pulmonary vein atrial reversal duration)

Note

- A diagnostic pulmonary vein tracing may be difficult to obtain on every patient. Having the patient hold their breath at end expiration, moving the transducer up the chest wall (“closer” to the pulmonary vein), changing the Doppler wall filter settings, setting the sweep speed to 50 to 100 mm/sec and/or increasing the PW Doppler sample volume may be useful. An average of three or more consecutive cycles should be measured.
- In atrial fibrillation, there is no “a” wave and the systolic wave is blunted.
- Sinus tachycardia and first-degree AV block may make the measurement of the pulmonary vein ARdur difficult.
- A pulmonary vein ARdur - mitral valve Adur of > 30 msec indicates an elevated LVEDP (≥ 15 mm Hg) and remains accurate in patients with a normal ejection fraction, mitral valve disease and hypertrophic cardiomyopathy. It is age independent and may be the first or earliest indication of diastolic dysfunction.
- In patients with reduced ejection fraction, a pulmonary vein systolic filling fraction (S wave$_{VTI}$/S wave$_{VTI}$ + D wave$_{VTI}$) of < 40% suggests an increased mean left atrial pressure.

Hepatic Vein Flow

The hepatic vein provides important diastolic information such as in restrictive cardiomyopathy, constrictive pericarditis and cardiac tamponade.

1. Acquire a subcostal long axis of the inferior vena cava and optimize to visualize the hepatic veins.
2. Place the PW Doppler sample volume in the hepatic vein 2 to 3 cm from the junction of the inferior vena cava using a 1 to 3 mm sample volume length with the PW Doppler wall filter set between 200 to 400 Hz.

Superior Vena Cava

The superior vena cava flow pattern is similar to the hepatic vein pattern.

1. Place the transducer in the right supraclavicular fossa region with the transducer index mark pointed towards the patient’s neck..
2. The PW Doppler sample volume is positioned 5 to 8 cm from the transducer into the superior vena cava with a sample volume length set at 1 to 3 mm and the Doppler wall filter is set between 200 to 400 Hz.

Tissue Doppler Imaging (TDI)

The following method is recommended for obtaining a high quality tissue Doppler imaging (TDI) of the mitral annulus:

1. Review the ultrasound manufacturer's tissue Doppler imaging presets
2. Acquire an apical four chamber and optimize the frame rate by decreasing the image depth and sector width
3. Align the tissue Doppler cursor as parallel as possible (< 20 degrees) to the mitral annulus (lateral annulus and medial (septal) annulus)
4. The sample volume should be positioned at or 1 cm within the septal and lateral insertion sites of the mitral leaflets and the sample volume size should be adjusted as necessary (approximately 5 mm for the lateral annulus and 3 mm for the septal annulus) to cover the longitudinal excursion of the mitral annulus in both systole and diastole.
5. Decrease the tissue Doppler velocity scale to less than 25 cm/sec
6. Set the sweep speed to 50 to 100 mm/sec
7. Have patient hold their breath at end-expiration and measurements should reflect the average of ≥ 3 consecutive cardiac cycles 8. Measurements include the S' wave, E' wave, A' wave, E'/A' ratio, mitral PW Doppler E/E', $T_{E-E'}$(onset of QRS complex to onset of PW Doppler mitral E velocity — onset of QRS complex to the onset of TDI E' wave)
9. The average of the septal and lateral E' velocities should be used when calculating the E/E' ratio
10. The E/E' is not accurate as an index of filling pressures in normal subjects or in patients with heavy annular calcification, mitral valve disease, mitral valve replacement and constrictive pericarditis.
11. The above optimization techniques can be used for the apical two chamber view and right ventricle

Color M-mode (CMM)

Mitral E-wave Flow Velocity Propagation (V_p cm/s)

Technique

- Transducer Location — Apical four chamber using color flow Doppler
- Modality — Color M-mode
- Alignment — M-mode scan line is placed through the center of the LV inflow blood column from the mitral valve to the cardiac apex
- Velocity scale — Color flow baseline is shifted to lower the velocity scale (Nyquist limit) so that the central velocity jet is blue
- Sweep speed — 50 or 100 mm/sec
- Flow propagation velocity is measured as the slope of the first aliasing velocity (approximately set at 45 cm/sec) from the mitral annulus in early diastole to 4 cm distally into the left ventricular cavity (preferred measurement)
- In patients with a low peak E velocity (lower than aliasing velocity) measure the slope of the transition no color/to color (black/red)
- In patients with a low peak E wave velocity (< 45 cm/sec), where no aliasing may be seen, baseline shift is adjusted to alias at approximately 75% of the peak E wave velocity
- Vp > 50 cm/sec is considered normal.
- A E/Vp of ≥ 2.5 predicts a PCWP > 15 mm Hg.
- Patients with normal volumes and EF but increased filling pressures can have misleading normal Vp

Index of Myocardial Performance (IMP)

Basics of Calculating Index of Myocardial Performance

Step 1) Optimize the pulsed wave (PW) Doppler of the atrioventricular inflow signal. May use continuous wave (CW) atrioventricular regurgitant signal

Step 2) Measure interval between atrioventricular valve (AV) closure and AV valve opening (AVCO)

Step 3) Optimize pulsed wave semilunar outflow signal. May use semilunar valve CW signal

Step 4) Measure the ejection time (ET)

Step 5) Calculate the IMP:

$$\mathbf{IMP = (AVCO - ET) \div ET}$$

Calculation of IMP of Left Ventricle (LIMP):

Step 1) Optimize PW Doppler mitral inflow signal. May use CW mitral regurgitant signal

Step 2) Measure interval between mitral valve closure (MVC) and mitral valve opening (MVO)

Step 3) Optimize pulsed wave Doppler of the left ventricular outflow tract (LVOT) signal

Step 4) Measure the LVOT ejection time (ETLVOT)

Step 5) Calculate the Index of Myocardial Performance (IMPLV)

$$\mathbf{IMPLV = (MVC\ to\ MVO) – ETLVOT}$$

Calculation of IMP of Right Ventricle (RIMP)

Step 1) Optimize PW tricuspid inflow signal. May use CW tricuspid regurgitant signal

Step 2) Measure interval between tricuspid valve closure (TVC) and TV opening (TVO)

Step 3) Optimize pulsed wave right ventricular outflow tract (RVOT) signal

Step 4) Measure the RVOT ejection time (ET)

Step 5) Calculate the Index of Myocardial Performance (IMPRV)

$$\mathbf{IMPRV = (TVC\ to\ TVO) – ETRVOT}$$

Index of Myocardial Performance (IMP)

Values:

LIMP 0.39 ± 0.05 (normal)

0.59 ± 0.10 (moderately abnormal)

1.06 ± 0.24 (severely abnormal)

RIMP > 0.43 adults (abnormal) (PW Doppler)

> 0.54 (abnormal) (Tissue Doppler)

0.32 ± 0.03 children (normal)

Important to Note

- Myocardial contractility and relaxation are energy dependent (related to SV, CO, EF).
- Myocardial dysfunction results in prolongation of isovolumic intervals.
- Increased IMP consistent with LV dysfunction.
  — Increase in IVCT and IVRT.
  — Decrease in ejection time.
- Tissue Doppler imaging may be utilized to determine IMP.

Vascular Ultrasound

Carotid Artery Ultrasound Examination

Definition

Real-time imaging and a combination of pulsed-wave Doppler and color flow Doppler to evaluate the extracranial vessels to determine the presence and severity of carotid plaque due to atherosclerosis.

Carotid Artery Examination Protocol

Scan transverse (short axis) with gray scale and color flow Doppler

Proximal common carotid artery (CCA)

Mid-CCA

Distal CCA

Carotid bifurcation

Proximal external carotid artery (ECA)

Proximal internal carotid artery (ICA)

Mid ICA

Distal ICA

Scan longitudinal (long axis) with gray scale, color flow Doppler and PW Doppler

- Proximal CCA
- Mid-CCA
- Distal CCA
- Carotid bifurcation
- Proximal ECA
- Proximal ICA
- Mid ICA
- Distal ICA
- Vertebral
- Subclavian artery (when clinically indicated)

Determine plaque location, plaque surface characteristics, plaque texture

Measure highest peak systolic velocity (PSV) and end-diastolic velocity (EDV)

Determine classification of internal carotid artery disease

Classification of Internal Carotid Artery Stenosis

	Primary Parameters		Additional Parameters	
Degree of Stenosis (%)	**ICA/PSV (cm/sec)**	**Plaque estimate (%)**	**ICA EDV (cm/sec)**	**ICA/CCA ratio**
Normal	< 125	None	< 40	< 2.0
< 50	< 125	< 50	< 40	< 2.0
50 to 69	125 to 230	> 50	40 to 100	2.0 to 4.0
>70	> 230	> 50	> 100	> 4.0
Subtotal occlusion	Variable Narrow lumen	> 50	> 0	Variable
Total occlusion	0	> 50	0	< 1

Abdominal Aorto-Iliac Ultrasound Examination

Definition

Real-time imaging combined with color flow Doppler and pulsed-wave Doppler to examine the abdominal aorta and common iliac arteries for aneurysm and atherosclerotic plaque.

Abdominal Aorto-Iliac Ultrasound Examination

Transverse (Short Axis)

Transducer is moved slowly from the xyphoid process to the umbilicas with intermittent color flow Doppler

Measure the anterior-posterior diameter and medial-lateral diameter of the abdominal aorta at the following levels:

- Suprarenal at or above the celiac artery
- Juxtarenal just above or below the renal arteries
- Infrarenal aorta below the level of the renal arteries but above the common iliac bifurcation
- Right common iliac and left common iliac

Longitudinal (Long axis) Scan

Transducer moved slowly from the xyphoid process to the umbilicas with intermittent color flow Doppler and PW Doppler

Determine the peak systolic velocity and end-diastolic velocity with PW Doppler at the following levels:

- Suprarenal aorta at or above the celiac artery
- Juxtarenal aorta just below the renal arteries
- Infrarenal aorta below the level of the renal arteries, but above the common iliac bifurcation
- Right common iliac and left common iliac arteries

Abdominal Aorta Normal Dimensions

Site	Average	Range
Suprarenal at or above the celiac artery	23 mm	20 to 26 mm
Mid-aorta just above the renal arteries	20 mm	16 to 24 mm
Infrarenal aorta at the bifurcation	15 mm	11 to 20 mm
Common iliac arteries	10 mm	6 to 14 mm

Abdominal Aorta Normal Peak Systolic Velocities

Arterial Vessel	Peak Systolic Velocity (m/sec)
Aorta	0.80 ± 0.25
Celiac artery	1.60 ± 0.90
Superior mesenteric artery	1.60 ± 0.60
Renal artery	0.80 ±0.20
Common iliac arteries	1.0

Diagnostic Criteria for Abdominal Aortic Aneurysm

Aneurysm diameter > 3.0 cm