Assessment of Right Heart Structures Using Echocardiography

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			Nature of Relevant Financial Relationship		
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Speaker: The conflict was resolved by Dr. Sivaram agreeing to not include discussion of products or services or make clinical recommendations on which the conflict exists. As a planner he has recused himself from planning content in the conflicted area. Moderator: The conflict was resolved by Dr. Sivaram agreeing to limit his role to the introduction of presenters, fielding questions and moderating the flow of discussion between participants and presenters.

Learning Objectives

Upon completion of this session, participants will improve their competence and performance by being able to:

- Review the latest guidelines for right heart evaluation by echocardiography
- Describe the potential errors to watch for in the measurement techniques

ASSESSMENT OF RV BY ECHOCARDIOGRAPHY

Right Ventricle

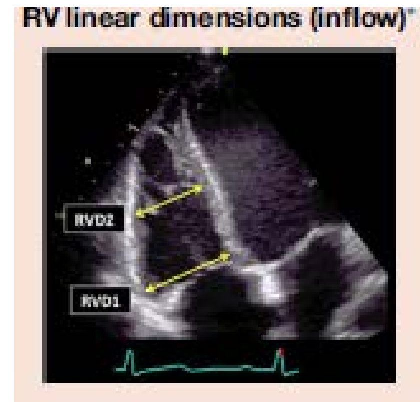
- Crescentic shape, non-geometric, does not lend to traditional formulae for volume measurements
- RV function has very important prognostic implications

Right Heart Imaging Windows

- Apical 4-chamber view
  - Focused apical RV view
- Parasternal long axis view
- Right ventricular inflow view
- Parasternal short axis view
- Subcostal view

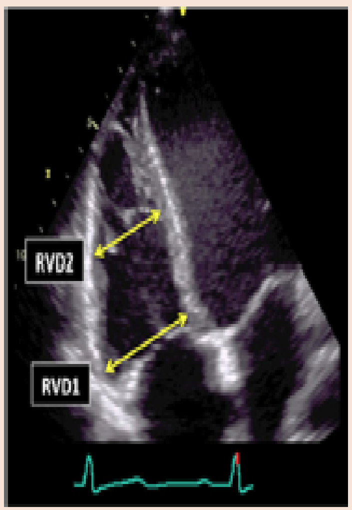
Measurement of Right Heart Dimensions

- Maximum diameter or diameter at end-diastole
- RV dilatation=
  - Diameter at base > 4.2 cm
  - Diameter at mid-level > 3.5 cm
  - Length > 8.6 cm
- Obtain focused apical 4 chamber view for RV
- Crux and apex of RV needs to be shown without foreshortening



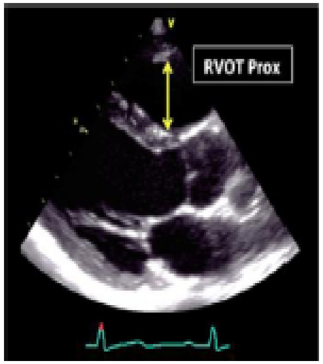
RV Size

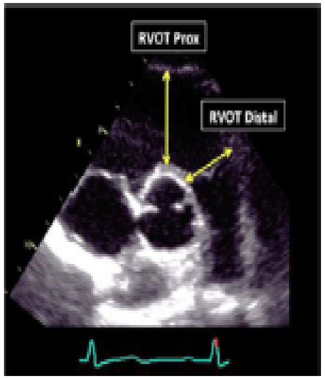
Table 7 Recommendations for the echocardiographic assessment of RV size

Echocardiographic imaging	Recommended methods	Advantages	Limitations
RV linear dimensions (inflow)* 	• Basal RV linear dimension (RVD1) = maximal transversal dimension in the basal one third of RV inflow at end-diastole in the *RV-focused view* • Mid-cavity RV linear dimension (RVD2) = transversal RV diameter in the middle third of RV inflow, approximately halfway between the maximal basal diameter and the apex, at the level of papillary muscles at end-diastole.	• Easily obtainable • Simple • Fast • Wealth of published data	• RV size may be underestimated due to the crescent RV shape • RV linear dimensions are dependent on probe rotation and different RV views; in order to permit inter-study comparison, the echocardiography report should state the window from which the measurement was performed.

RV Dimensions (outflow)

RV linear dimensions (outflow)*





- Proximal RV outflow diameter (RVOT prox) = linear dimension measured from the anterior RV wall to the interventricular septal-aortic junction (in parasternal long-axis view) or to the aortic valve (in parasternal short-axis) at end-diastole
- Distal RV outflow diameter (RVOT distal) = linear transversal dimension measured just proximal to the pulmonary valve at end-diastole

- Easily obtainable
- Simple
- Fast

- RVOT prox is dependent on imaging plane position and less reproducible than RVOT distal
- Risk of underestimation or overestimation if the RV view is obliquely oriented with respect to RV outflow tract
- RV outflow dimensions can be inaccurate in case of chest and spine deformities
- Endocardial definition of the RV anterior wall is often suboptimal
- Limited normative data is available
- Regional measure; may not reflect global RV size (underestimation or overestimation)

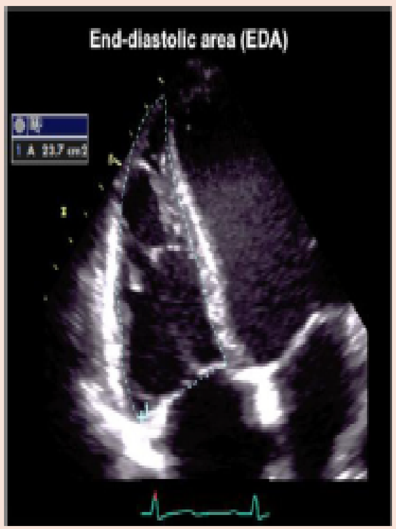
2.0 to 3.0 cm PLAX
2.1 to 3.5 cm Short Axis Proximal
1.7 to 2.7 cm Distal

RVOT Dimensions

Table 8 Normal values for RV chamber size

Parameter	Mean ± SD	Normal range
RV basal diameter (mm)	33 ± 4	25-41
RV mid diameter (mm)	27 ± 4	19-35
RV longitudinal diameter (mm)	71 ± 6	59-83
RVOT PLAX diameter (mm)	25 ± 2.5	20-30
RVOT proximal diameter (mm)	28 ± 3.5	21-35
RVOT distal diameter (mm)	22 ± 2.5	17-27
RV wall thickness (mm)	3 ± 1	1-5

RV Inflow area

RV areas (inflow)  	• Manual tracing of RV endocardial border from the lateral tricuspid annulus along the free wall to the apex and back to medial tricuspid annulus, along the interventricular septum at end-diastole and at end-systole • Trabeculations, papillary muscles and moderator band are included in the cavity area	• Relatively easy to measure	• Challenging in case of suboptimal image quality of RV free wall • Challenging in the presence of trabeculation • RV size underestimation if RV cavity is foreshortened • Due to the LV twisting motion and the crescent RV shape, the end-diastolic RV image may not be in the same tomographic plane as the end-systolic one • May not accurately reflect global RV size (underestimation or overestimation)

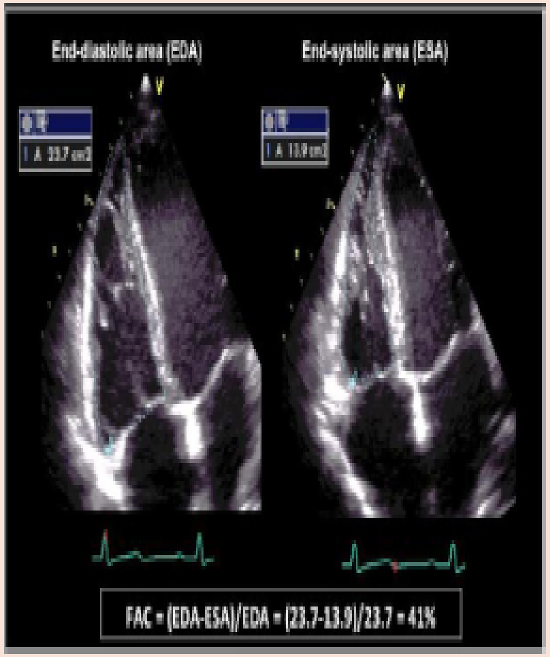
2D RV Fractional Area Change

- Provides an estimate of RV systolic function
- Obtain an adequate view of entire RV
- Trace the free wall beneath RV trabeculations
- (RVED area – RVES area)/ RVED area X 100
- **RV systolic dysfunction= FAC < 35%**

Fractional Area of Change

RV global systolic function

FAC



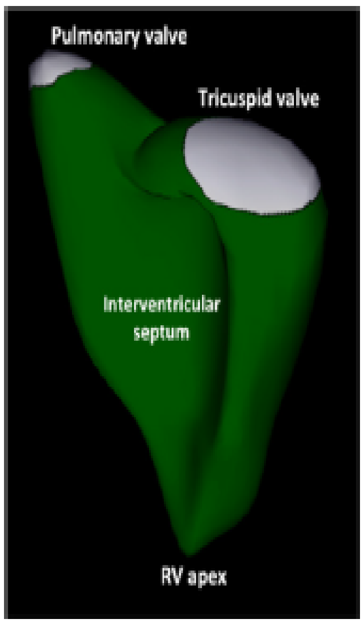
RV FAC in RV-focused apical four-chamber view:
RV FAC (%) = 100 × (EDA – ESA)/EDA

- Established prognostic value
- Reflects both longitudinal and radial components of RV contraction
- Correlates with RV EF by CMR

- Neglects the contribution of RV outflow tract to overall systolic function
- Only fair inter-observer reproducibility

3DE RV Volumes

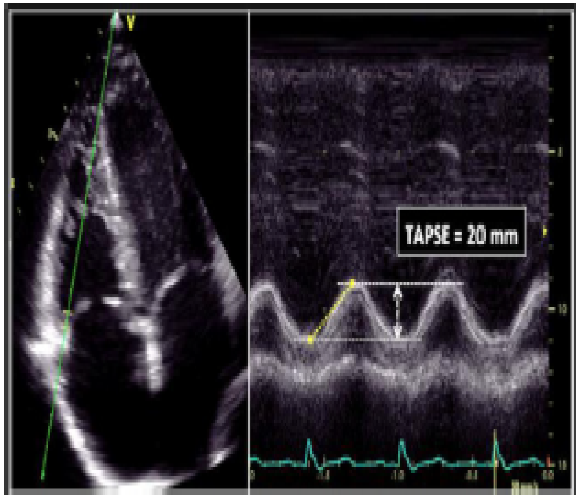
Table 7 (*Continued*)

Echocardiographic imaging	Recommended methods	Advantages	Limitations
3DE RV volumes 	• Dedicated multibeat 3D acquisition, with minimal depth and sector angle (for a temporal resolution > 20–25 volumes/sec) that encompasses entire RV cavity • Automatically identified timing of end-diastole and end-systole should be verified • Myocardial trabeculae and moderator band should be included in the cavity	• Unique measures of RV global size that includes inflow, outflow and apical regions • Independent of geometric assumptions • Validated against cardiac magnetic resonance	• Dependent on image quality, regular rhythm, patient cooperation • Needs specific 3D echocardiographic equipment and training • Reference values established in few publications

Tricuspid Annulus Plane Systolic Excursion (TAPSE)

- Measures RV longitudinal function
- Obtained from apical 4 chamber view
- M-mode through lateral tricuspid annulus, while being perpendicular to tricuspid annulus
- Measures the longitudinal motion of annulus towards apex during peak systole
- TAPSE **< 16 mm** suggests RV systolic dysfunction

TAPSE

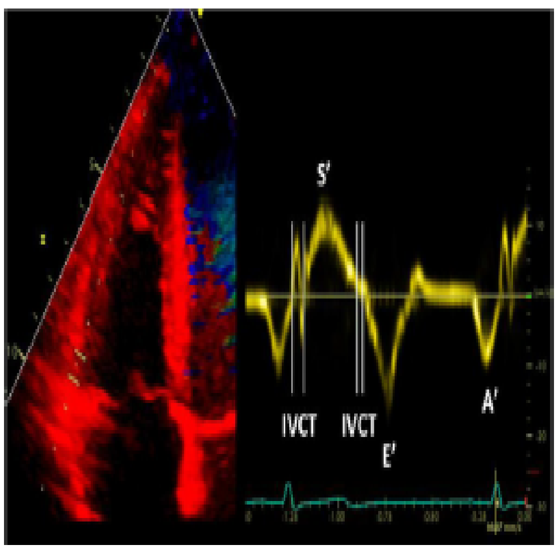
Echocardiographic imaging	Recommended methods	Advantages	Limitations
RV longitudinal systolic function			
TAPSE 	• Tricuspid annular longitudinal excursion by M-mode (mm), measured between end-diastole and peak systole • Proper alignment of M-mode cursor with the direction of RV longitudinal excursion should be achieved from the apical approach.	• Established prognostic value • Validated against radionuclide EF	• Angle dependency • Partially representative of RV global function*

S’

- Easy, reliable and reproducible measurement
- Proper alignment of Doppler cursor important
- S’ < 10 cm/s suggest RV systolic dysfunction

S’

Pulsed tissue Doppler S wave



- Peak systolic velocity of tricuspid annulus by pulsed-wave DTI (cm/sec), obtained from the apical approach, in the view that achieves parallel alignment of Doppler beam with RV free wall longitudinal excursion

- Easy to perform
- Reproducible
- Validated against radionuclide EF
- Established prognostic value

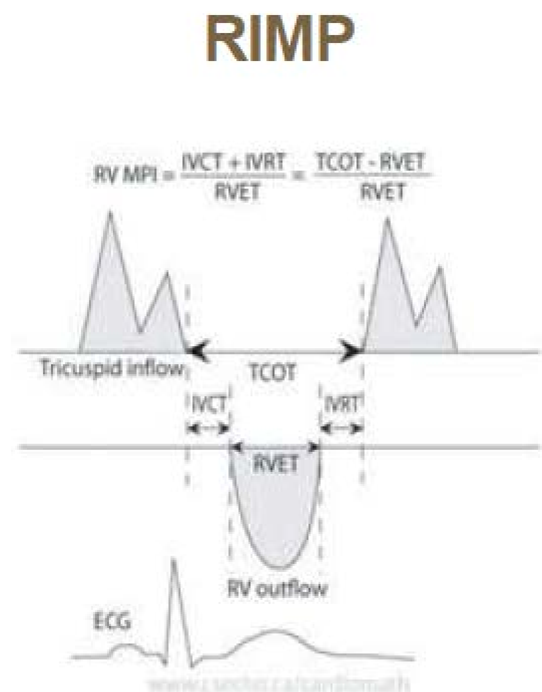
- Angle dependent
- Not fully representative of RV global function, particularly after thoracotomy, pulmonary thromboendarterectomy or heart transplantation

< 10 mm/sec indicates RV dysfunction

RIMP

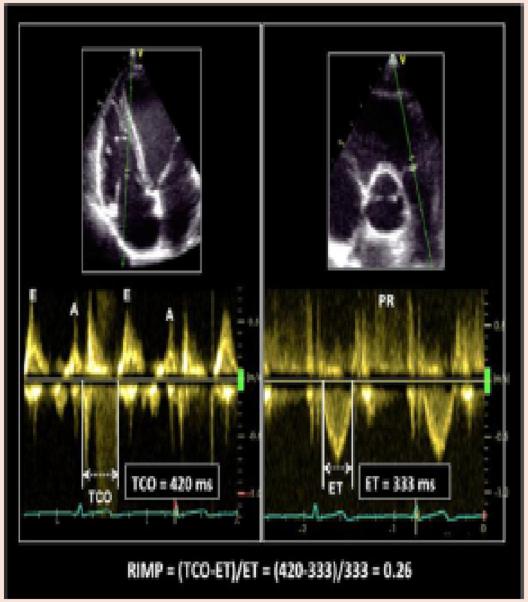
- Right sided Index of Myocardial Performance
- Index of global RV function
- RV Dysfunction= RIMP > 0.40

$$\frac{IVCT + IVRT}{RVET}$$



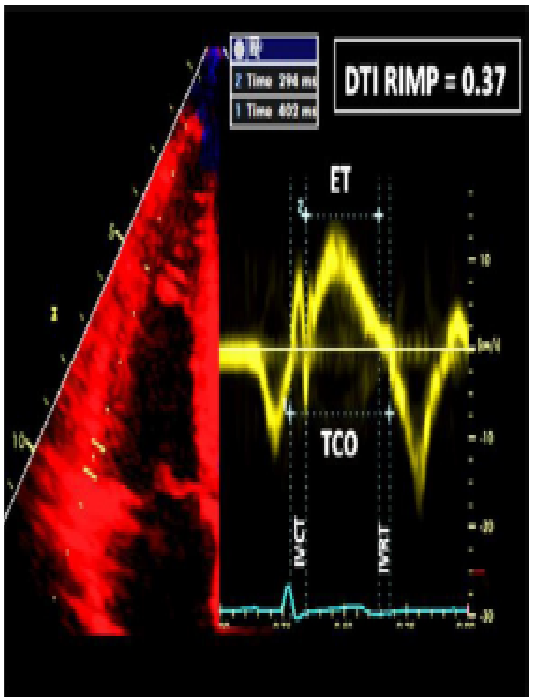
R-IMP by Doppler

Table 9 Recommendations for the echocardiographic assessment of RV function

Echocardiographic imaging	Recommended methods	Advantages	Limitations
RV global function Pulsed Doppler RIMP  	RIMP (Tei index) by pulsed Doppler: RIMP = (TCO – ET)/ET	• Prognostic value • Less affected by heart rate	• Requires matching for R-R intervals when measurements are performed on separate recordings • Unreliable when RA pressure is elevated

R-IMP using Tissue Doppler

Tissue Doppler RIMP



RIMP by tissue Doppler: RIMP = (IVRT + IVCT)/ET = (TCO – ET)/ET

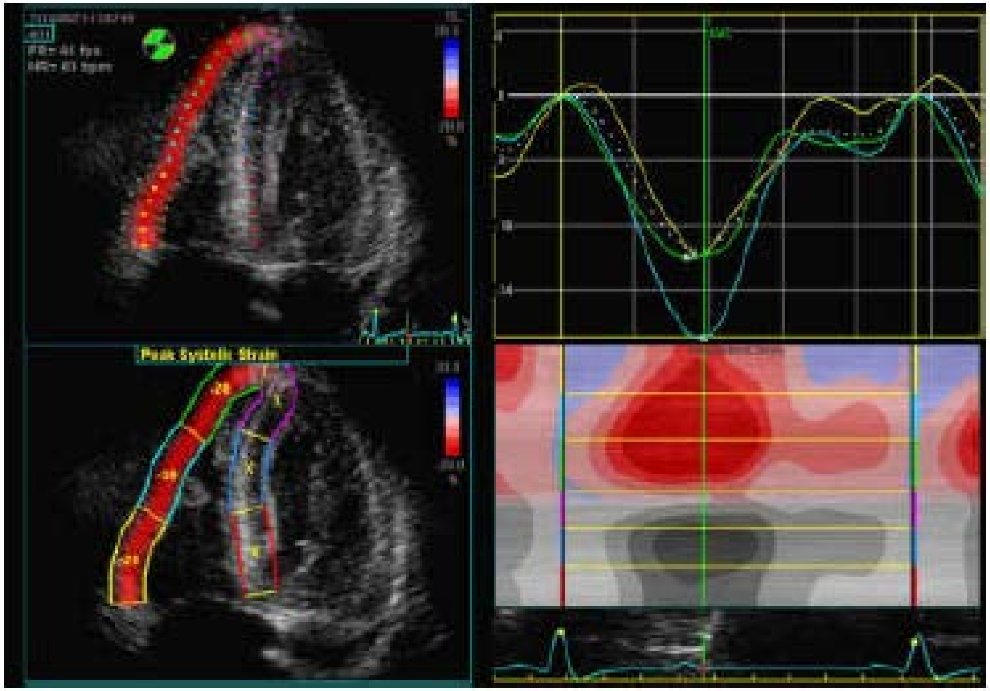
- Less affected by heart rate
- Single-beat recording with no need for R-R interval matching

- Unreliable when RA pressure is elevated

RV Strain

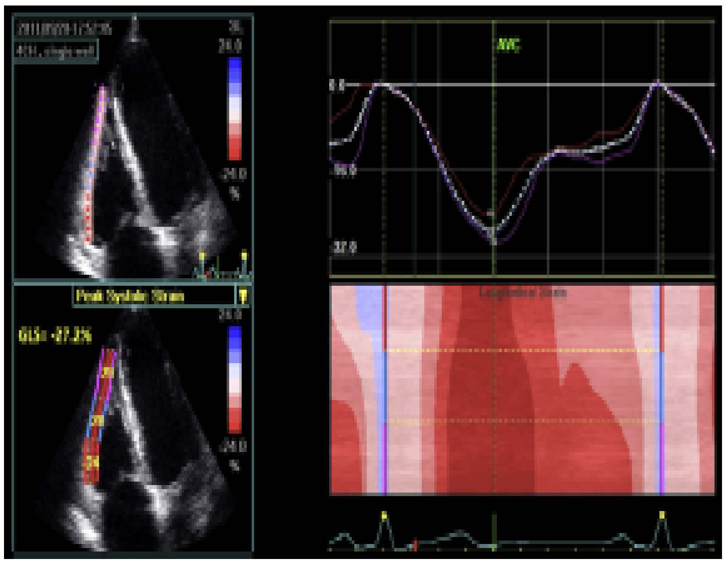
- Obtain apical 4 chamber, RV focused view
- Need at least 40 frames per second
- Obtain 3 cardiac cycles
- Place cursors at basal RV free wall, IVS and then apex
- Block IVS segments

Normal RV Strain



Speckle Tracking/Strain

GLS

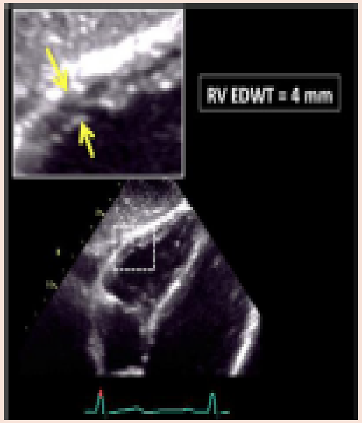


- Peak value of 2D longitudinal speckle tracking derived strain, averaged over the three segments of the RV free wall in RV-focused apical four-chamber view (%)
- Angle independent
- Established prognostic value

Measurement of RV wall thickness

- Measure from subcostal or parasternal long axis views
- During diastole
- Using m-mode or 2D
- Thickness > 5 mm suggests RV hypertrophy

RV Wall Thickness

RV wall thickness  	• Linear measurement of RV free wall thickness (either by M-mode or 2DE) performed at end-diastole, below the tricuspid annulus at a distance approximating the length of anterior tricuspid leaflet, when it is fully open and parallel to the RV free wall. • Trabeculae, papillary muscles and epicardial fat should be excluded • Zoomed imaging with focus on the RV mid-wall and respiratory maneuvers may improve endocardial border definition	• Easy to perform	• Single-site measurement • Harmonic imaging and oblique M-mode sampling may overestimate RV wall thickness • Challenging in case of thickening of visceral pericardium • There is no criterion for defining an abnormally thin RV wall

IVC Measurements

- From subcostal view
- At the level of hepatic veins
- IVC < 2.1 cm, collapsing to < 50% during inspiration indicates RA pressure of 3 mm Hg (normal)
- IVC > 2.1 cm with < 50% collapse indicates RA pressure of 15 mm Hg (elevated)
- **3-8-15 mm Hg (filling pressure estimates using IVC)**

Right Atrial Area Measurement

- Apical 4 chamber view
- Trace from medial to lateral tricuspid annulus at end systolic
- RA enlargement= **> 18 cm^2**
- RA enlargement= length > 53 mm
- RA enlargement= diameter > 44 mm

Assessment of RV Systolic Function

- TAPSE
- Systolic tricuspid annulus velocity (tissue Doppler, tricuspid annulus, S’)
- 2D RV Fractional Area Change
- R Index of Myocardial Performance
- Longitudinal strain

PA/RV Systolic Pressure estimation

Pulmonary Artery Systolic Pressure

- Obtain peak TR velocity with CW Doppler
- TR Velocity reflects gradient RV/RA
- RVSP = $4(V_{maxTR})^2$ + RAP
- The RVSP = PASP unless pulmonic stenosis.
- Normal RVSP = 18-30 mm HG

ASSESSMENT OF DIASTOLIC DYSFUNCTION

Pathophysiology of Diastolic Heart Failure

- In spite of normal LV systolic function and normal LV volumes, left sided filling pressures are elevated; with exercise there is even further disproportionate rise in filling pressures, resulting in dyspnea on exertion

LV Filling Pressures

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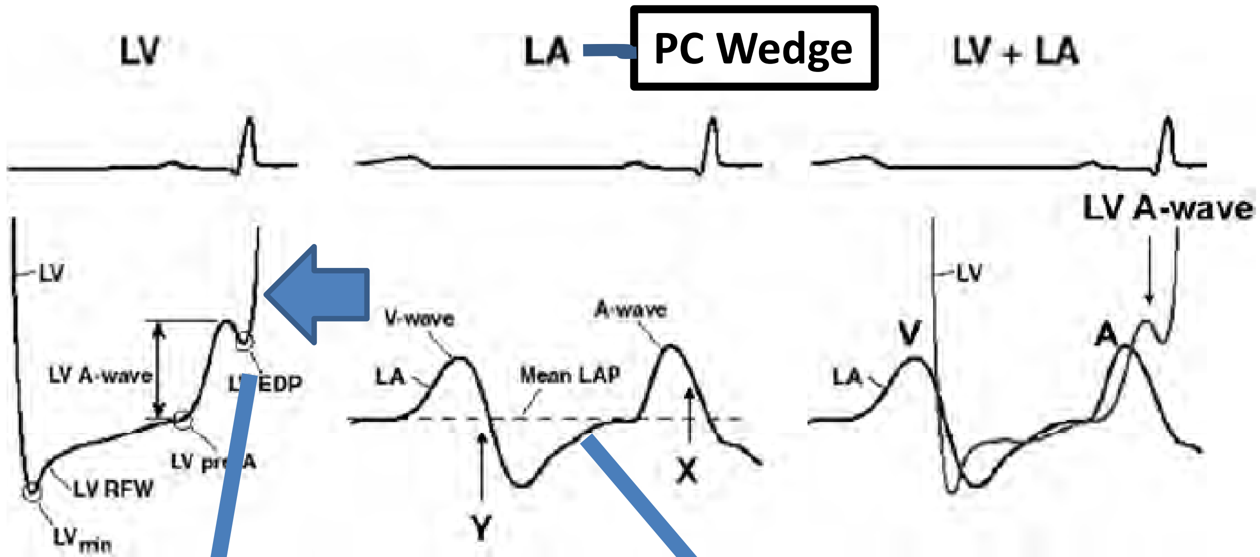

Figure 1 (*Left*) LV diastolic pressures recording. *Arrows* point to LV minimal pressure (min), LV rapid filling wave (RFW), LV pre-A pressure (pre-A), A wave rise with atrial contraction and end-diastolic pressure (EDP). (*Middle*) LAP recording showing "V" and "A" waves marked along with Y and X descent (*Right*) Simultaneous LV and LAP recording showing early and late transmitral pressure gradients. Notice that LA "A wave" pressure precedes the late diastolic rise (LV A wave) in LV pressure.

Mitral A velocity, DT of A
A duration
PV Ar velocity, duration
PV.Ar-Mitral .A duration, Mitral A' Velocity

Mitral E vel, E/A ratio, DT of E, E/E' ratio
PV systolic to diastolic velocity ratio, TR velocity

Variables in the Measurement of Diastolic Dysfunction

- 4 recommended variables:
  - 1. Annular e’ velocity
    - Septal e’ < 7 cm/sec
    - Lateral e’ < 10 cm/sec
  - 2. Average E/e’ ratio > 14
  - 3. LA volume index > 34 ml/m^2
  - 4. Peak TR velocity > 2.8 m/sec
- LV diastolic function:
  - Normal: if more than half of parameters do not reach cut off values
  - Diastolic dysfunction present: if more than half the variables are above cut off values
  - Inconclusive: if half of the parameters do not reach cut off values

<u>Need:</u>
Annular velocities- septal & lateral
Transmitral PW
LA volume
TR jet velocity (when present)

Grading of Diastolic Dysfunction

- First step: establish the presence or absence of LV filling pressures
- Flow propagation velocities (Vp) and time intervals ($T_{E\text{-}e'}$) not emphasized in the new guidelines due to low rates of feasibility and reproducibility
- Algorithms do not apply to pediatric patients and post-op situation
- Age should be taken into consideration when interpreting data
- No single parameter should be viewed in isolation

Technical Tips (Quality)

Table 1 Two-dimensional and Doppler methods for assessment of LV diastolic function

Variable	Acquisition	Analysis
Peak E-wave velocity (cm/sec)	1. Apical four-chamber with color flow imaging for optimal alignment of PW Doppler with blood flow. 2. PW Doppler sample volume (1–3 mm axial size) between mitral leaflet tips. 3. Use low wall filter setting (100–200 MHz) and low signal gain. 4. Optimal spectral waveforms should not display spikes or feathering.	Peak modal velocity in early diastole (after ECG T wave) at the leading edge of spectral waveform

Also applies to peak A velocity, A duration, E/A ratio and DT

Technical Tips (Quality)

Pulsed-wave TDI e′ velocity (cm/sec)	1. Apical four-chamber view: PW Doppler sample volume (usually 5–10 mm axial size) at lateral and septal basal regions so average e′ velocity can be computed. 2. Use ultrasound system presets for wall filter and lowest signal gain. 3. Optimal spectral waveforms should be sharp and not display signal spikes, feathering or ghosting.

Technical Tips

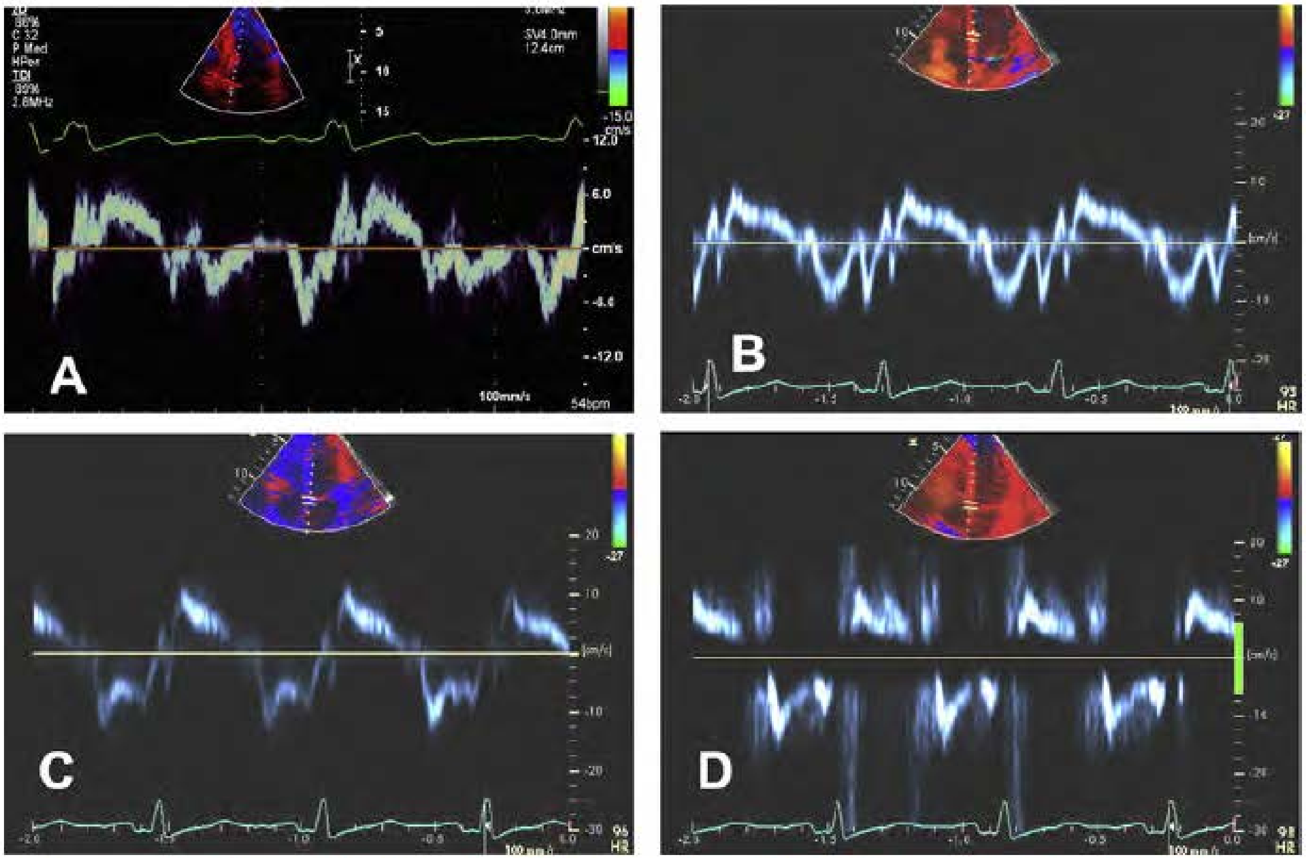

Figure 2 Tissue Doppler recordings of septal mitral annular velocities. In **(A)**, Doppler settings and sample volume location are optimal, whereas in **(B)** the sample volume is placed in the ventricular septum (not annulus). Doppler setting are suboptimal in **(C)** with low gain and in **(D)** with high filter.

Technical Errors

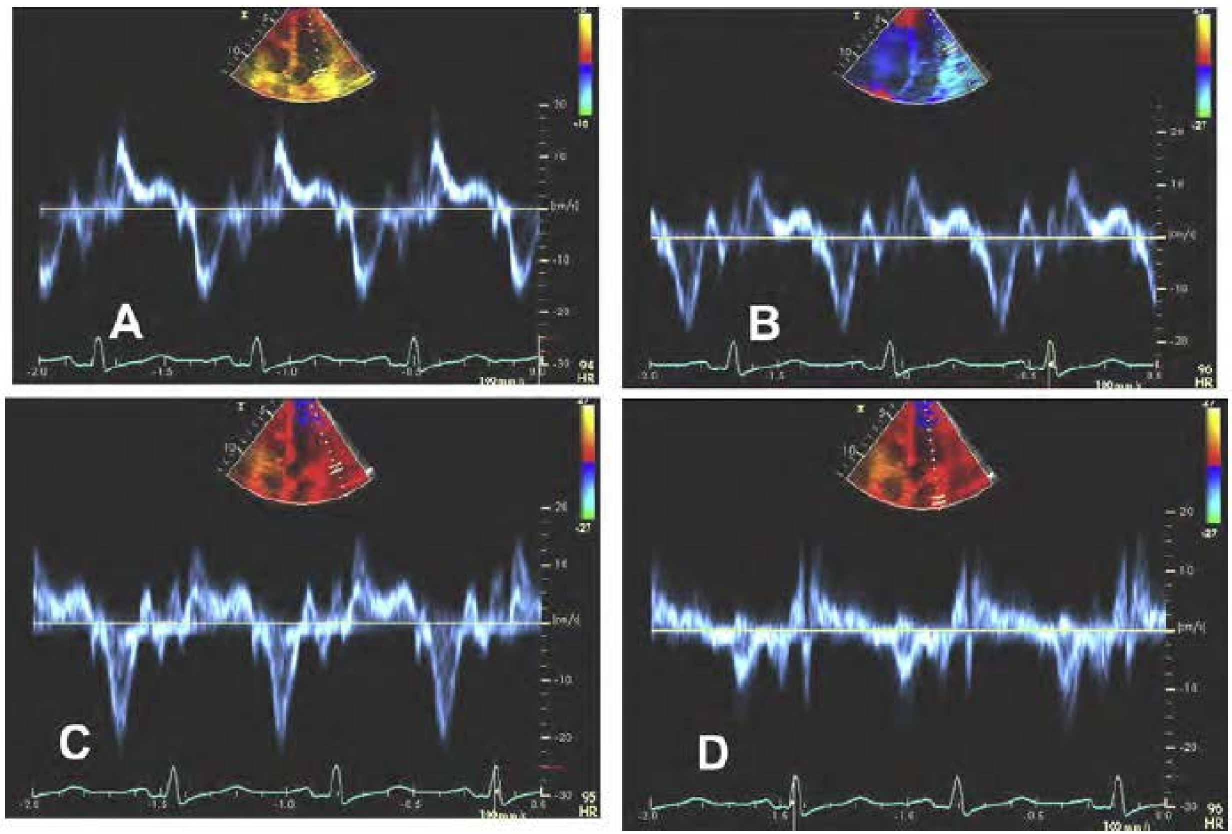

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Figure 3 Tissue Doppler recordings of lateral mitral annular velocities. In **(A)**, Doppler sample volume is located in part in LV cavity. In **(B)** the sample volume is in basal segment of lateral wall, in **(C)** the location is partly outside the heart altogether, and in **(D)** it is located in the left atrium above the mitral annulus.

Technical Tips (Quality)

LA maximum volume index (mL/BSA)	1. Apical four- and two-chamber: acquire freeze frames 1–2 frames before MV opening. 2. LA volume should be measured in dedicated views in which LA length and transverse diameters are maximized.

Exclude pulmonary veins and LAA

Reversible Diastolic Dysfunction

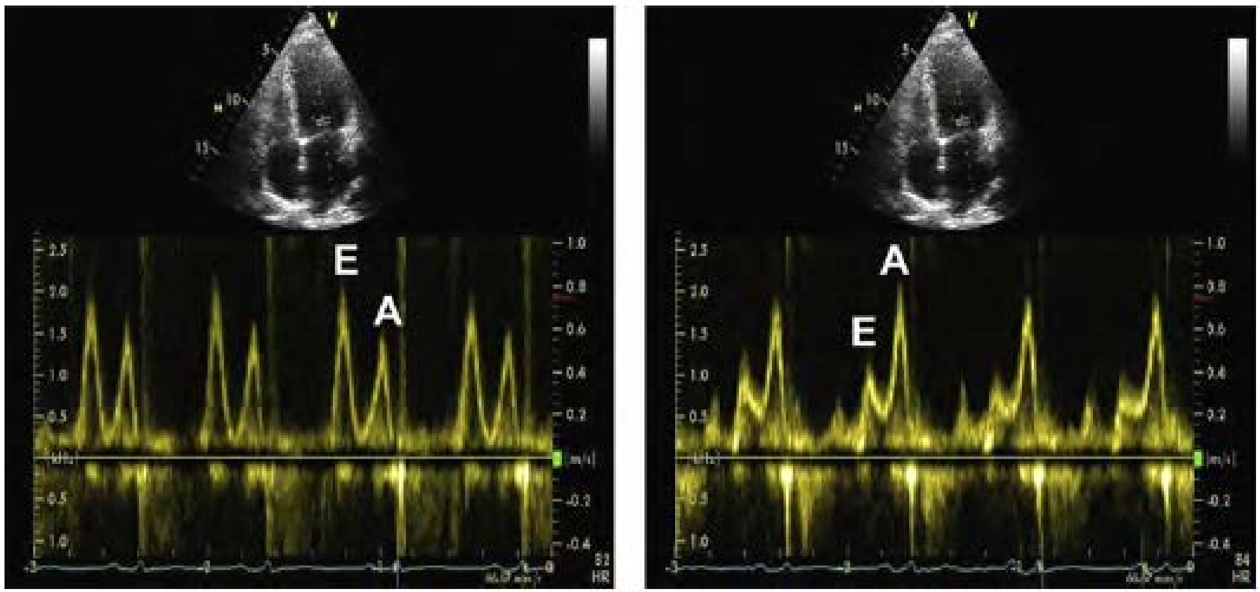
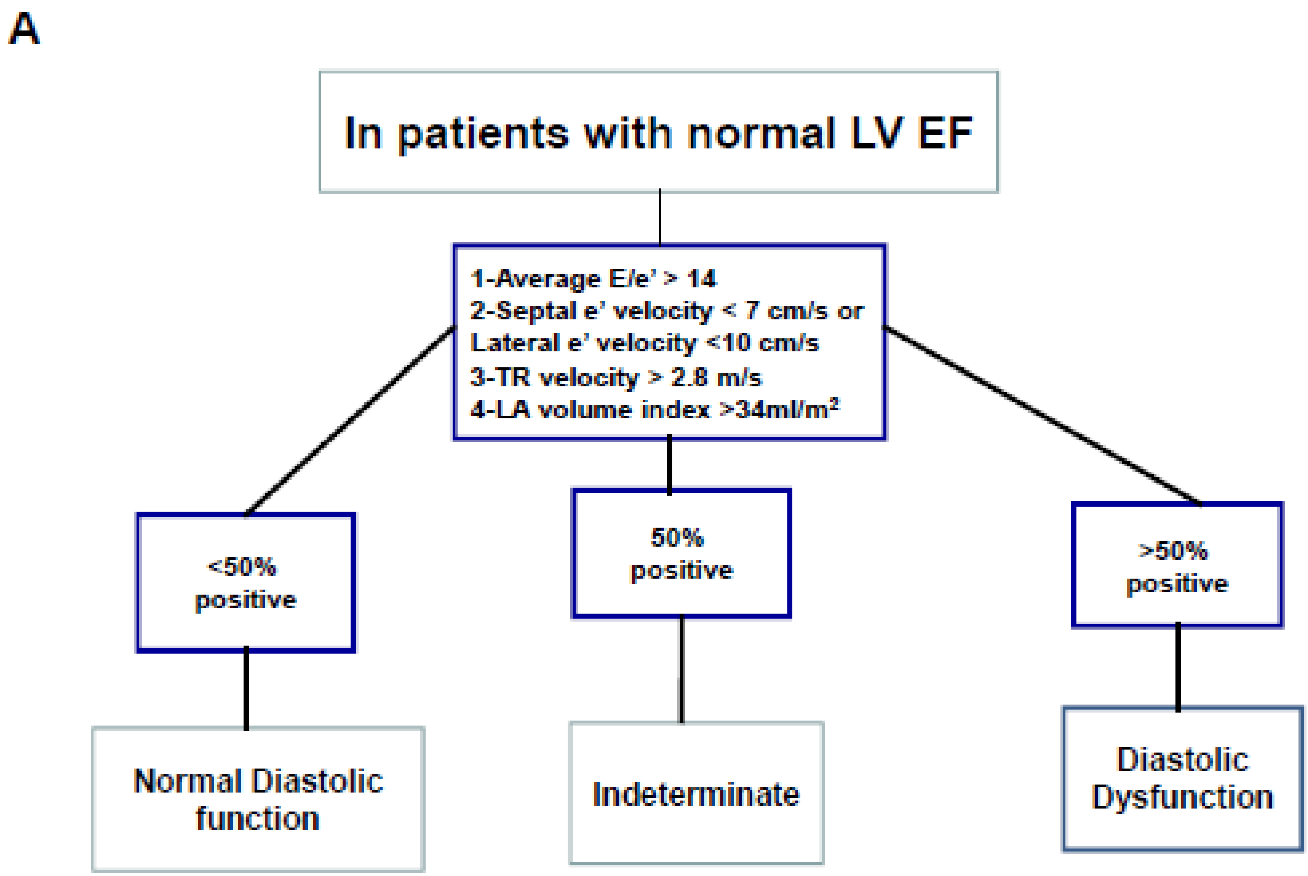


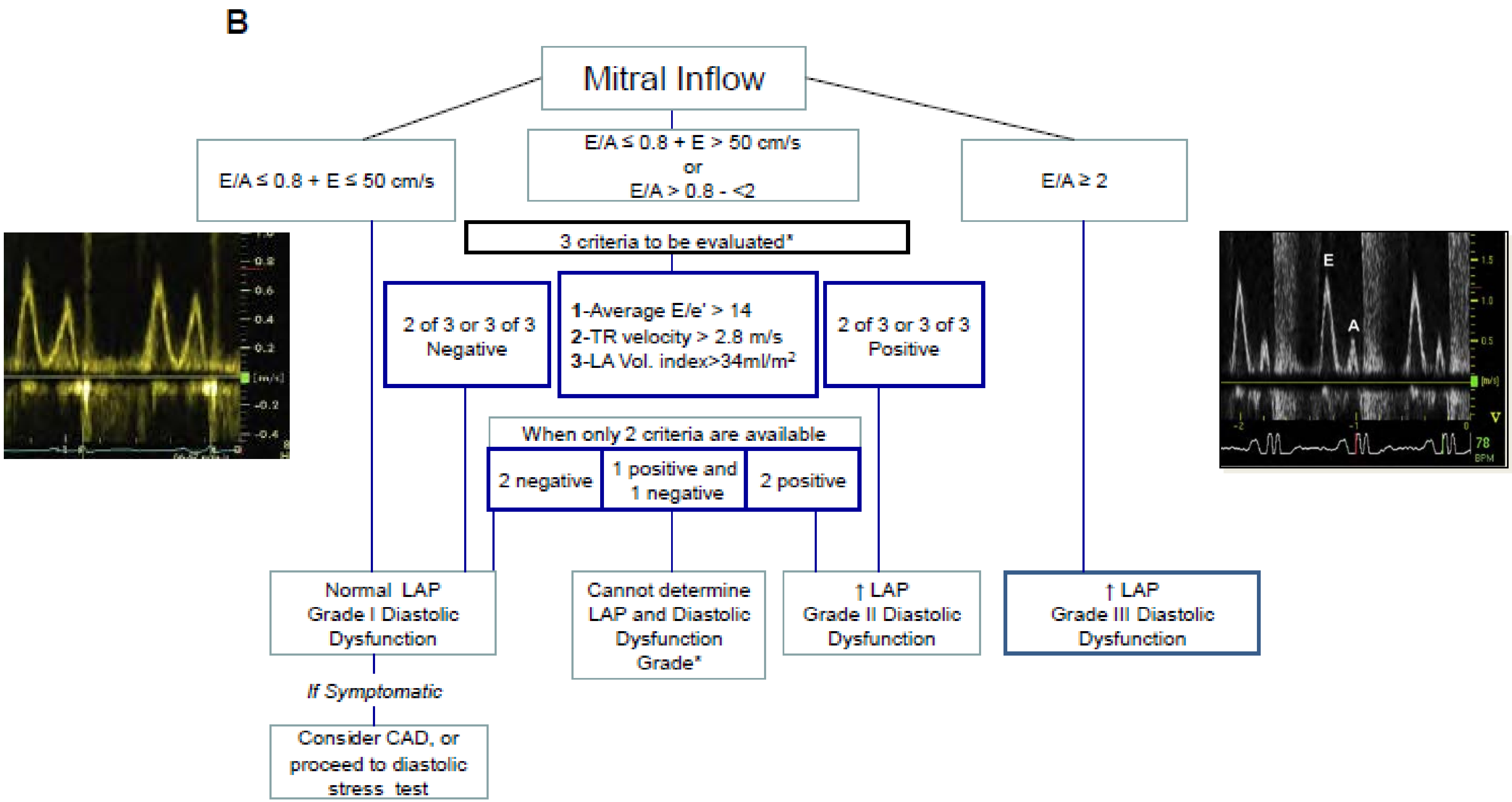
Figure 5 Valsalva maneuver in a patient with grade II diastolic dysfunction. At baseline, E/A ratio is 1.3 (*left*) and decreases to 0.6 (impaired relaxation pattern) with Valsalva.

Helpful in differentiating pseudo-normal from normal Doppler

Algorithm for Diagnosis of Diastolic Dysfunction when LVEF is normal



Algorithm when LVEF is reduced

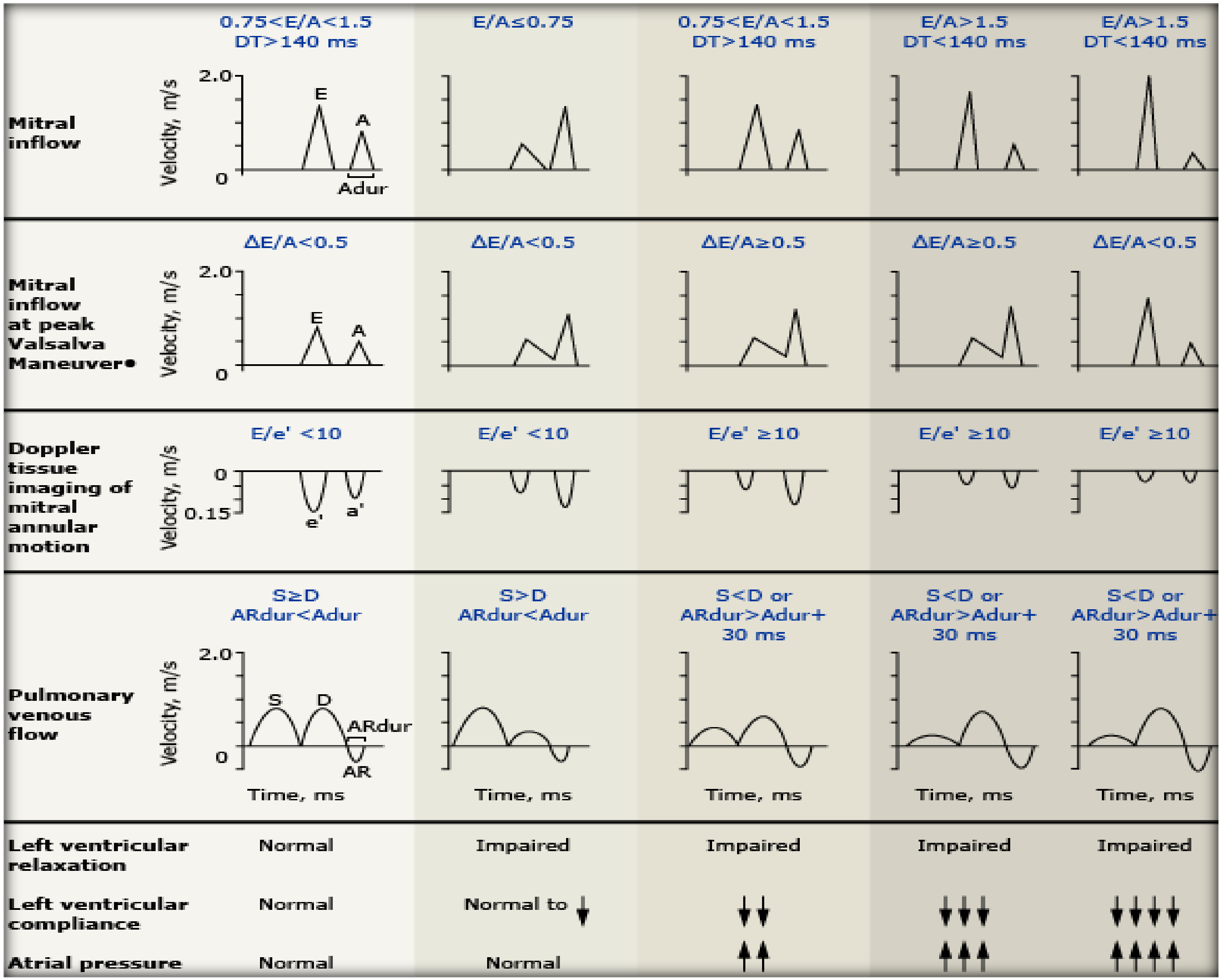


* : LAP indeterminate if only 1 of 3 parameters available. Pulmonary vein S/D ratio <1 applicable to conclude elevated LAP in atients with depressed LV EF)

Left heart filling pressures

Table 4 LV relaxation, filling pressures and 2D and Doppler findings according to LV diastolic function

	Normal	Grade I	Grade II	Grade III
LV relaxation	Normal	Impaired	Impaired	Impaired
LAP	Normal	Low or normal	Elevated	Elevated
Mitral E/A ratio	≥0.8	≤0.8	>0.8 to <2	>2
Average E/e′ ratio	<10	<10	10–14	>14
Peak TR velocity (m/sec)	<2.8	<2.8	>2.8	>2.8
LA volume index	Normal	Normal or increased	Increased	Increased



Mitral inflow
0.75<E/A<1.5 DT>140 ms
E/A≤0.75
0.75<E/A<1.5 DT>140 ms
E/A>1.5 DT<140 ms
E/A>1.5 DT<140 ms
Velocity, m/s
2.0
0
E
A
Adur
Mitral inflow at peak Valsalva Maneuver•
ΔE/A<0.5
ΔE/A<0.5
ΔE/A≥0.5
ΔE/A≥0.5
ΔE/A<0.5
Doppler tissue imaging of mitral annular motion
E/e' <10
E/e' <10
E/e' ≥10
E/e' ≥10
E/e' ≥10
0.15
e'
a'
Pulmonary venous flow
S≥D ARdur<Adur
S>D ARdur<Adur
S<D or ARdur>Adur+ 30 ms
S<D or ARdur>Adur+ 30 ms
S<D or ARdur>Adur+ 30 ms
S
D
ARdur
AR
Time, ms
Left ventricular relaxation
Normal
Impaired
Impaired
Impaired
Impaired
Left ventricular compliance
Normal
Normal to ↓
↓↓
↓↓↓
↓↓↓↓
Atrial pressure
Normal
Normal
↑↑
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References

- Rudski LG, Lai WW, Afilalo J, Gya, et al; Guidelines for the Echocardiographic Assessment of the Right Heart in Adults: A Report from the American Society of Echocardiography. J Am Soc Echocardiogr. 2010;23:685-713
- Recommendation for evaluation of diastolic function by echocardiography: An update from American Society of Echocardiography and the European Society for Cardiovascular Imaging. J Amer Soc Echocardiogr. 2016; 29: 277-314