Doppler Evaluation of Valvular Regurgitation: Principles and Pitfalls

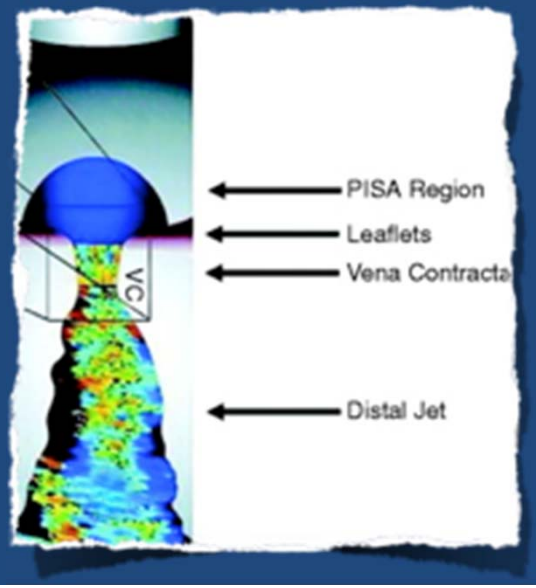
Catholic University of Korea
Chan Seok Park

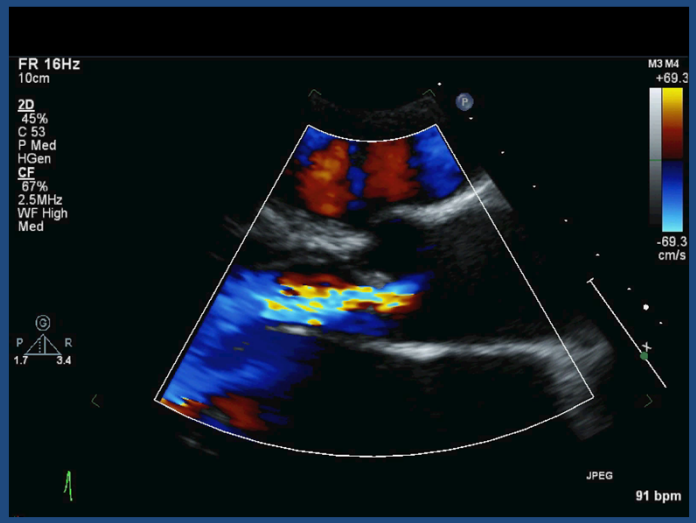
Doppler Use for Evaluation of Regurgitation

- Color Doppler
- Pulsed-Wave Doppler
- Continuous-Wave Doppler

Color Doppler

- Flow Convergence Zone
  - Vena Contracta
  - Jet Turbulence

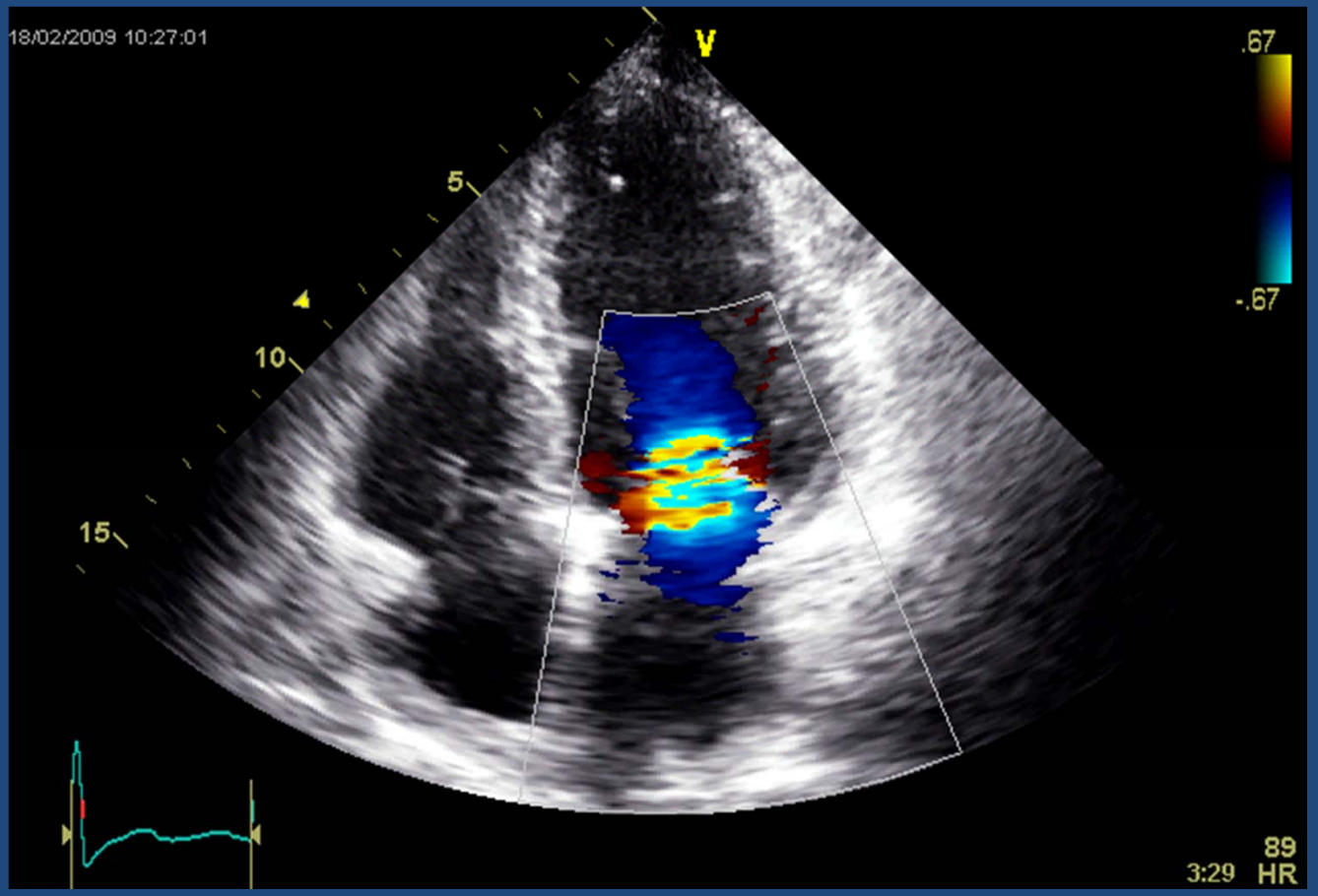




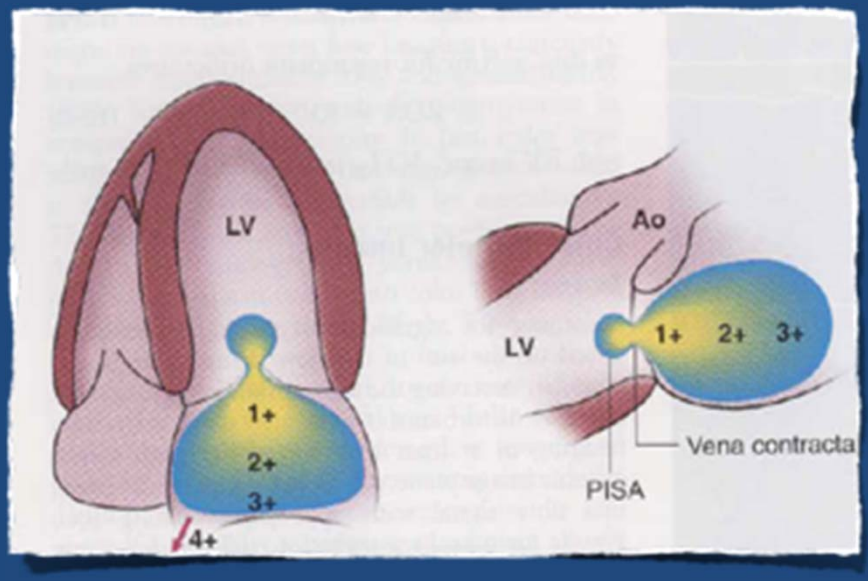
Color Flow Doppler

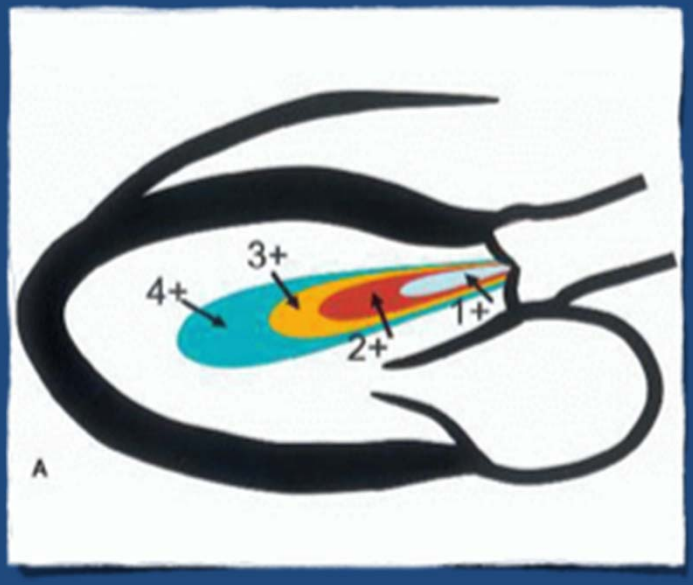
- Color Jet Area Method
- Vena Contracta Width
- Proximal Isovelocity Surface Area (PISA) or Flow Convergence Method

Color Jet Area Method



Color Jet Area Method





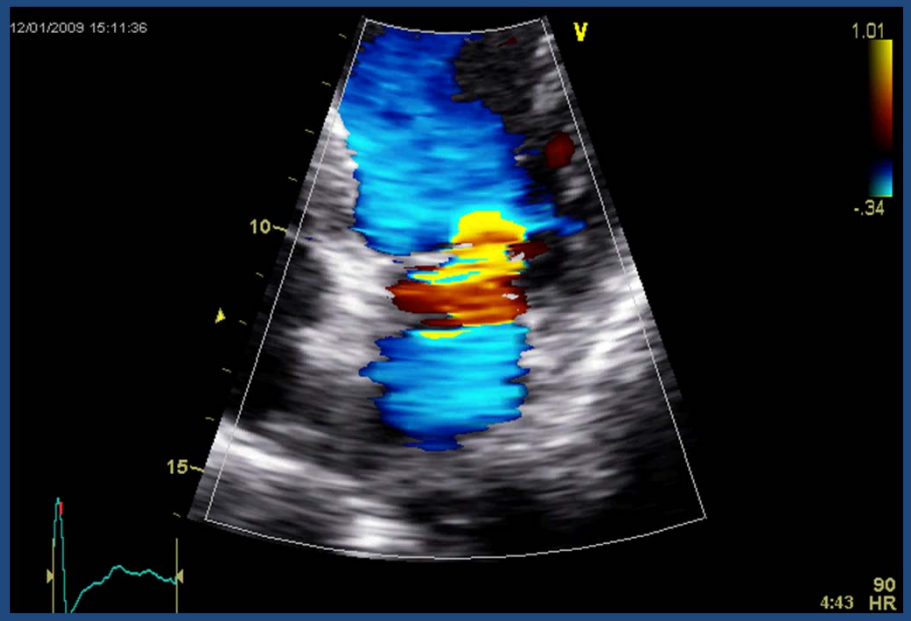
Color Jet Area Method

- Nyquist limit at the maximum for the imaging depth (60-80 cm/s)

- Color gain setting just below the appearance of color noise artifacts

Color Jet Area Method

- Maximum frame rate
- (e.g., narrow sector, decrease depth)



Color Jet Area Method

- **Standardization of the instrument set-up within a given laboratory**

Color Jet Area Method : Benefits

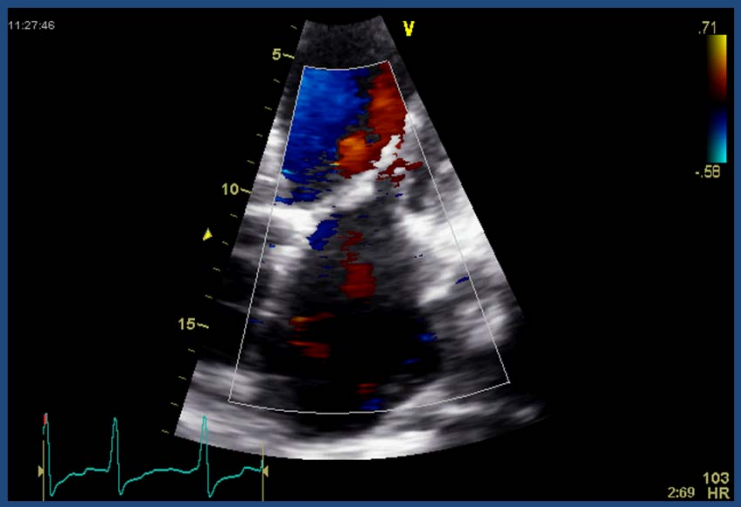
- Simple
- Quick Screen

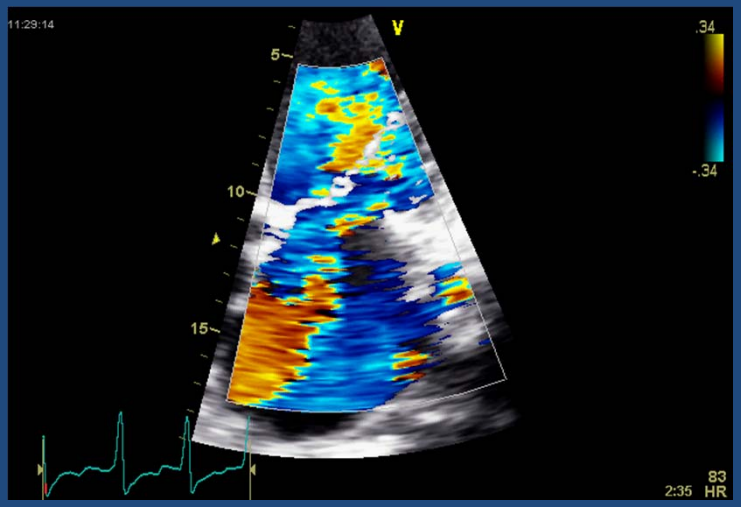
Color Jet Area Method

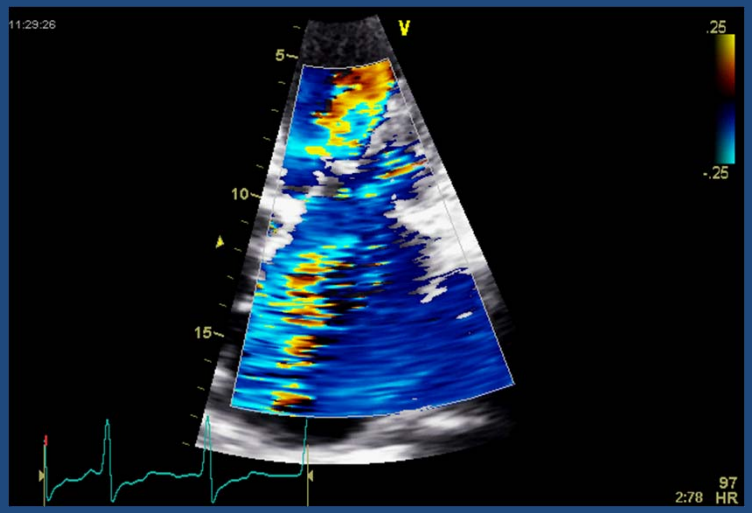
- Factors that affect regurgitant jet size and shape

Physiologic	Technical
Regurgitant volume	Ultrasound system gain
Driving pressure	Pulse repetition frequency
Size and shape of regurgitant orifice	Transducer frequency
Receiving chamber constant	Frame rate
Wall impingement	Image plane
Timing relative to the cardiac cycle	Depth
Influence on coexisting jets or flow streams	Signal strength

Color Jet Area Method







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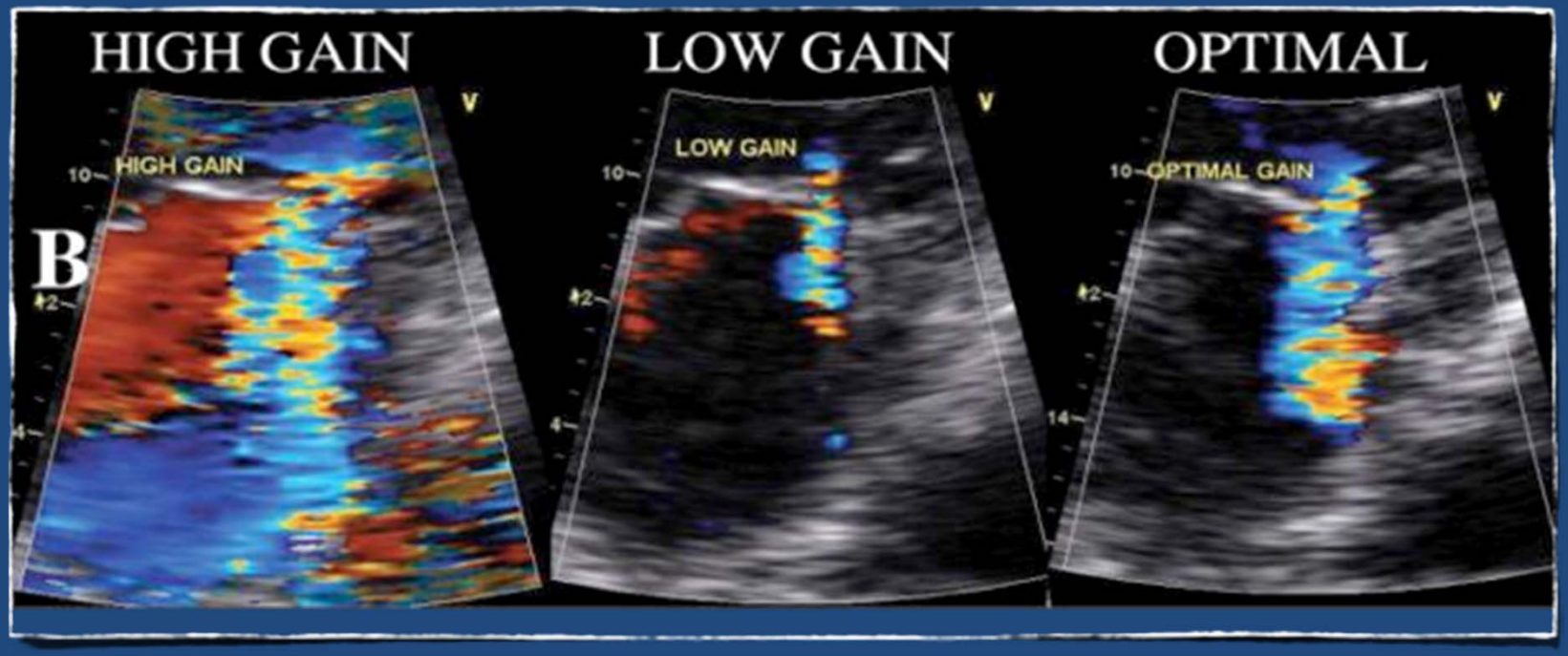
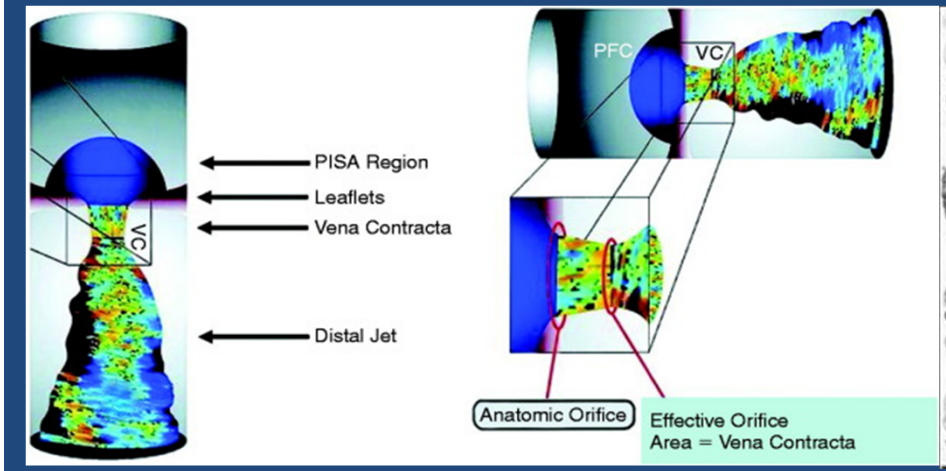
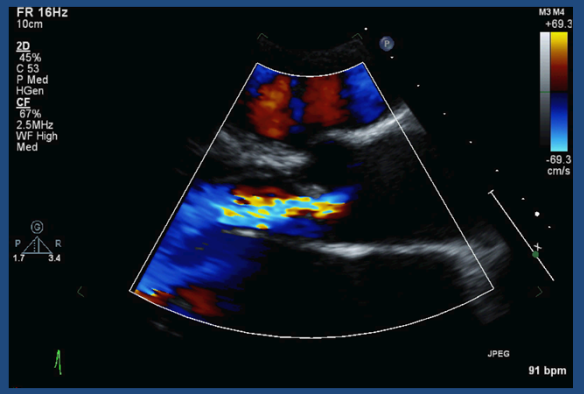
Color Jet Area Method



Vena Contracta Width

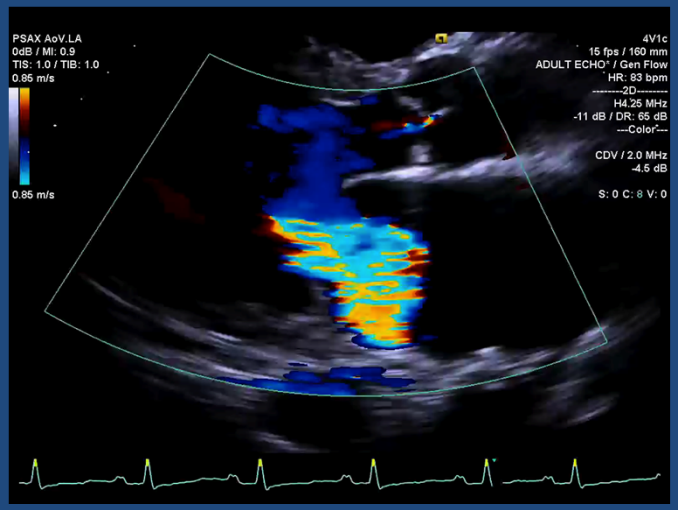
- Narrowest portion of the regurgitant jet downstream from the regurgitant orifice

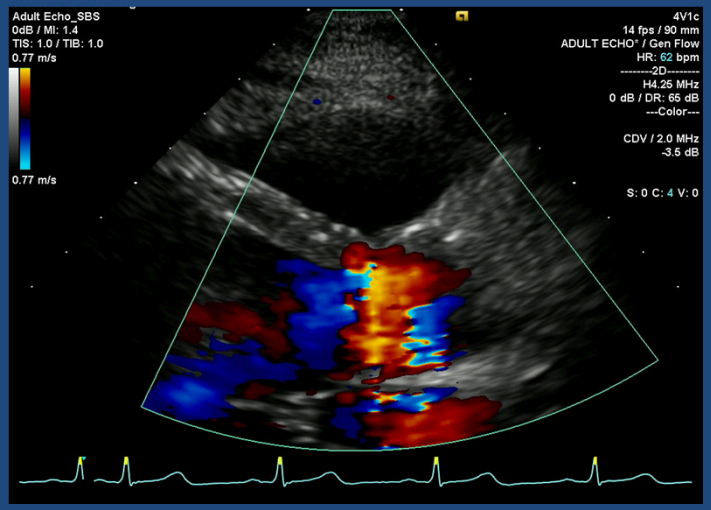




Vena Contracta Width

- In zoom mode
- Perpendicular to jet width
- Narrow sector
- Minimum depth





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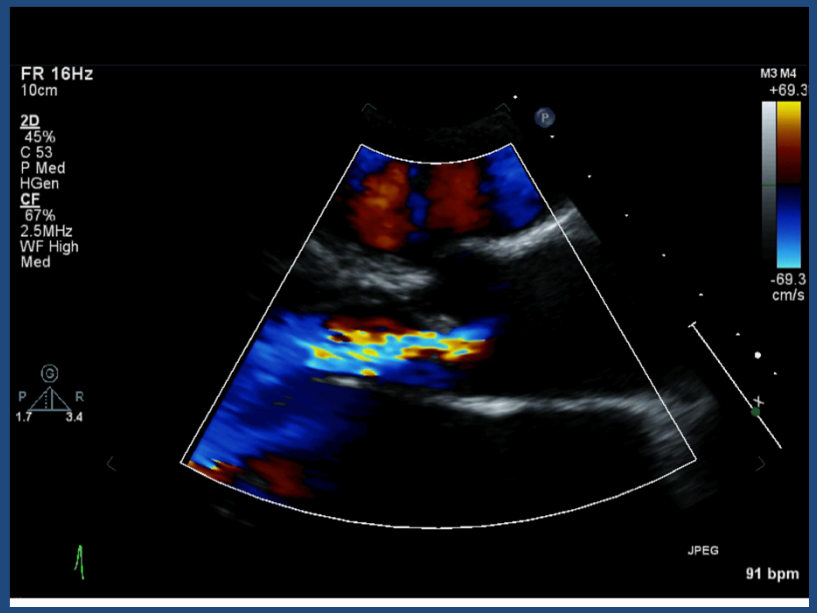
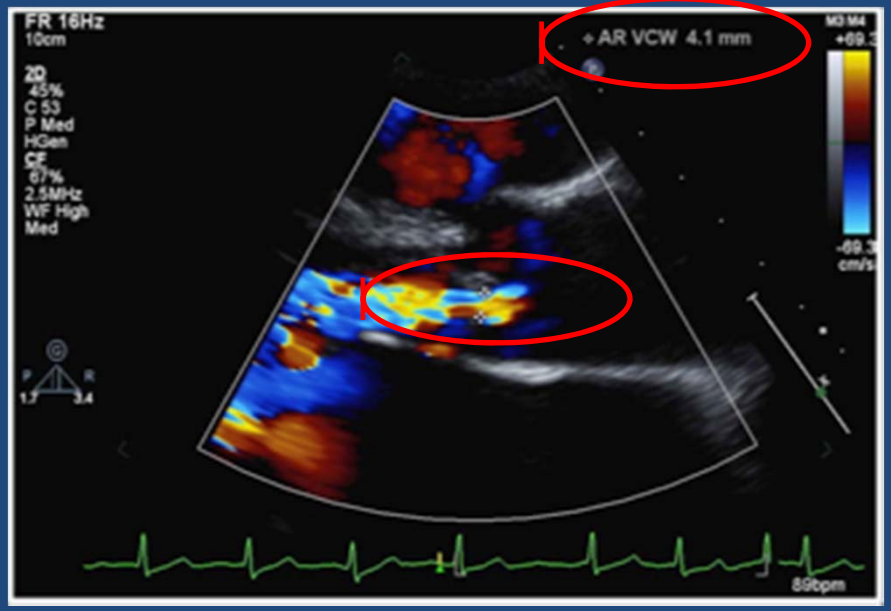
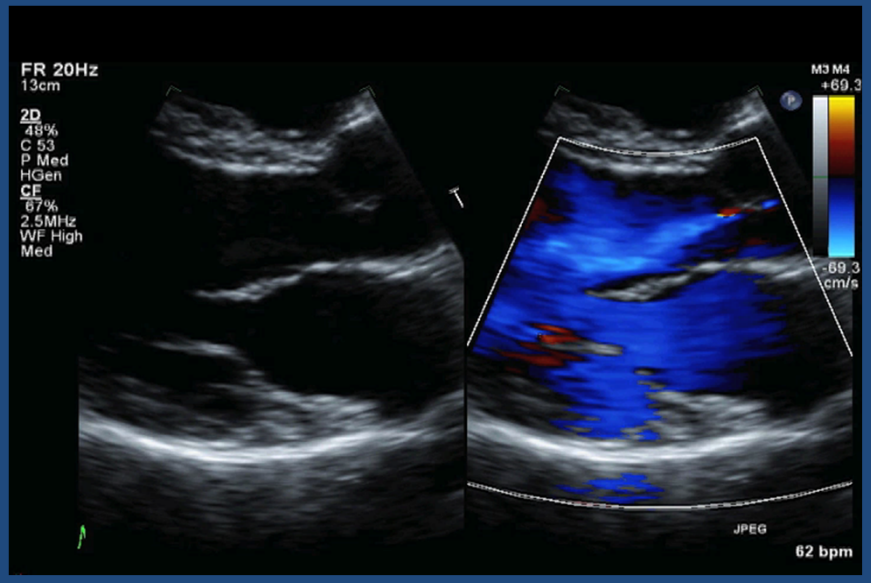
VCW: Benefits

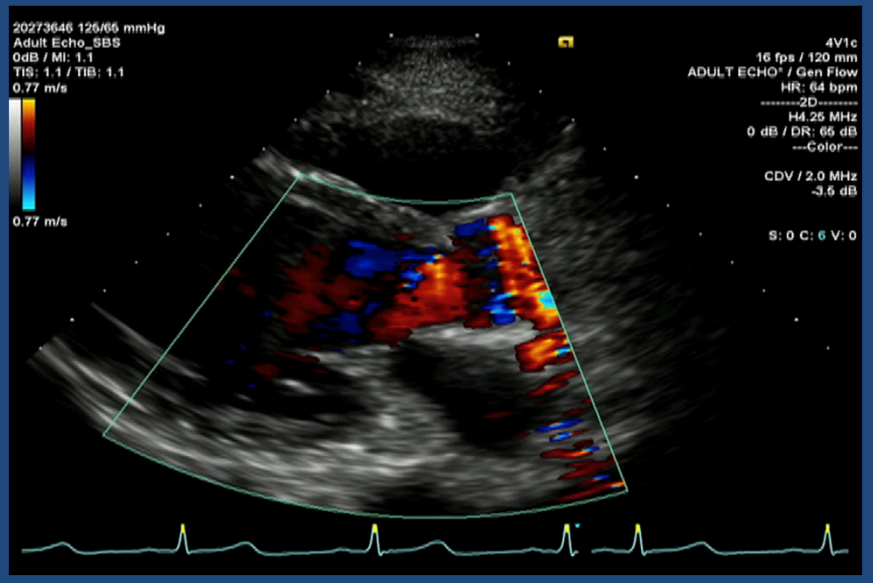
- Simple, quantitative





VCW: Benefits

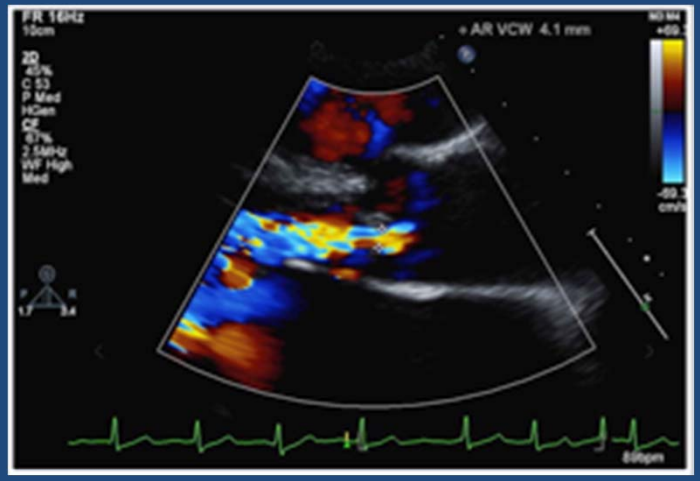




- Good at identifying mild or severe regurgitation

VCW: Benefits

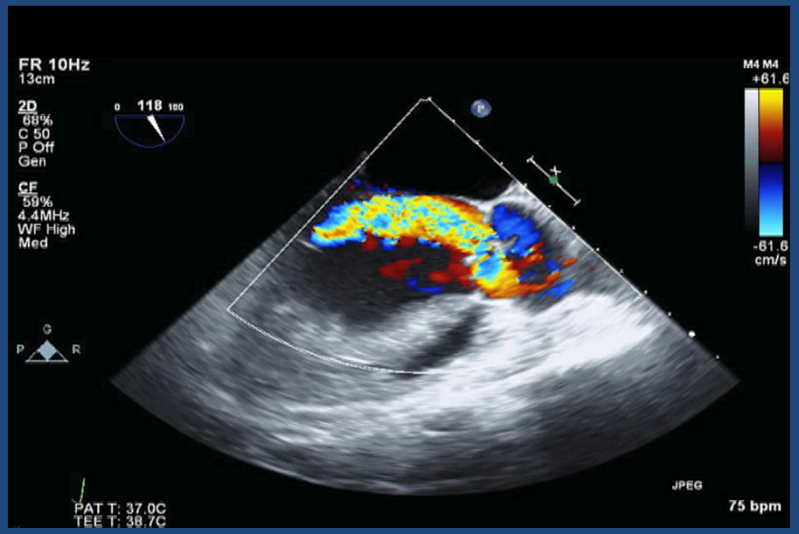
Technical factors

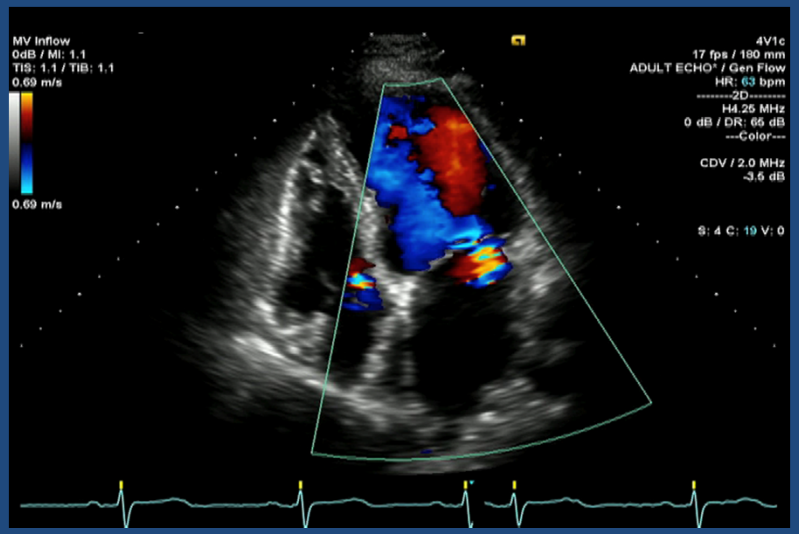


Flow rate

Other valve leak

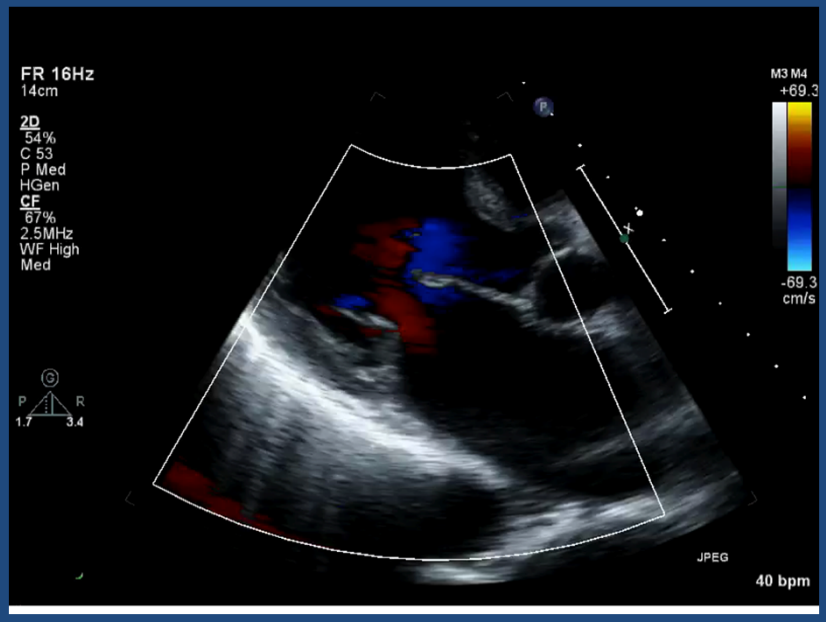
VCW: Benefits

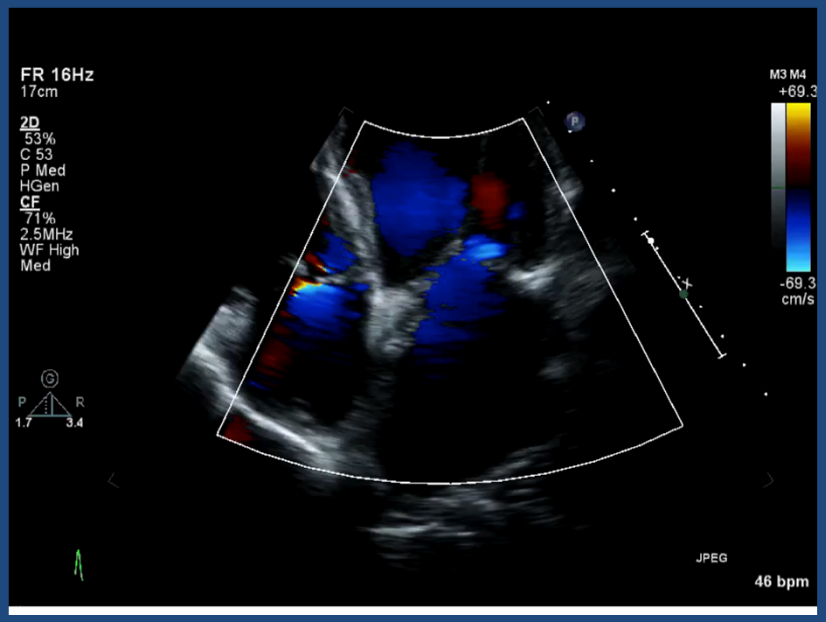




- Can be used in eccentric jet

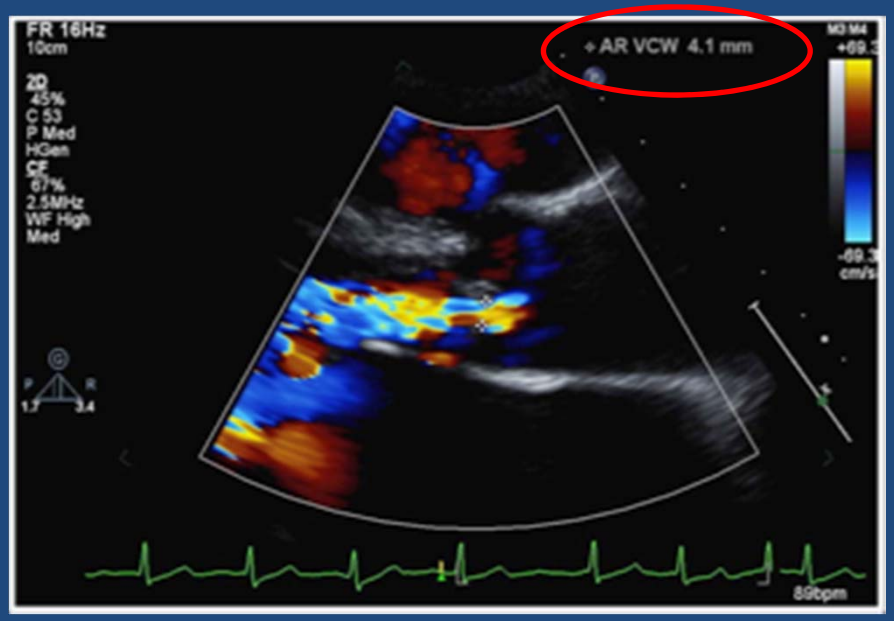
VCW: Limitations





- Not valid for multiple jets

VCW: Limitations



VCW: Limitations

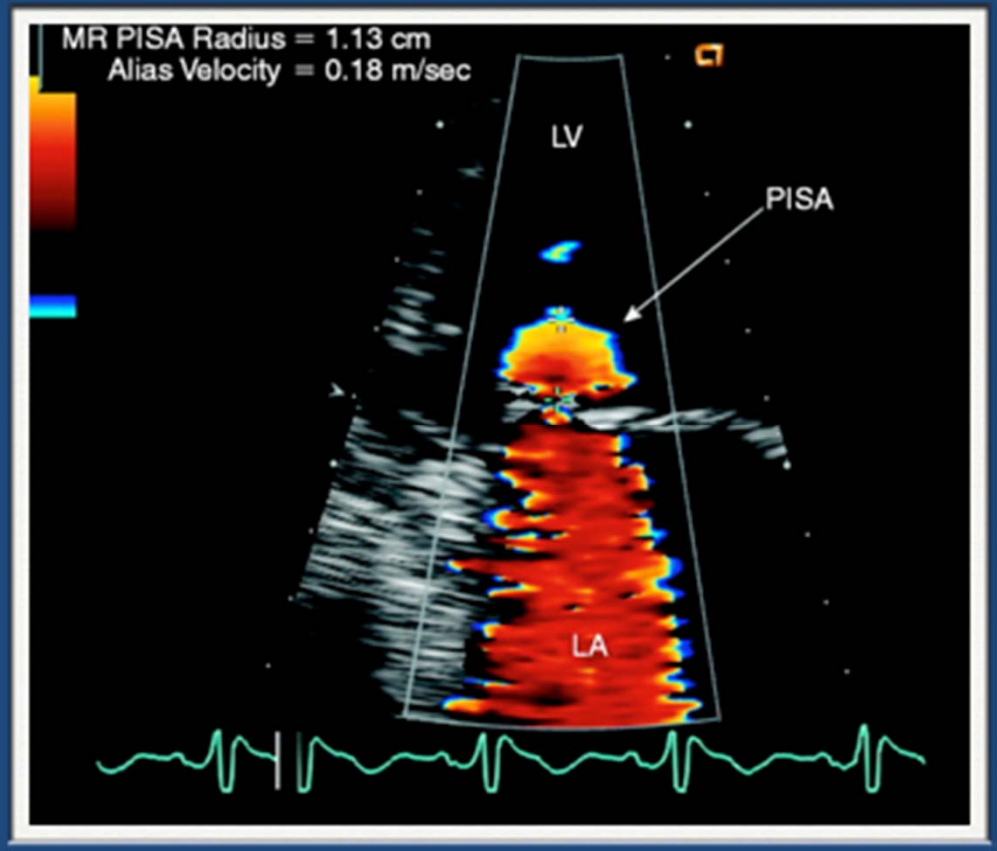
- Small measurement errors lead to large % error

	Mild	Moderate	Severe
Aortic Regurgitation	< 3 mm	Intermediate	> 6 mm
Pulmonary regurgitation	Not defined	Not defined	Not defined
Mitral Regurgitation	< 3 mm	Intermediate	≥ 7 mm
Tricuspid Regurgitation	Not defined	< 7 mm	≥ 7 mm

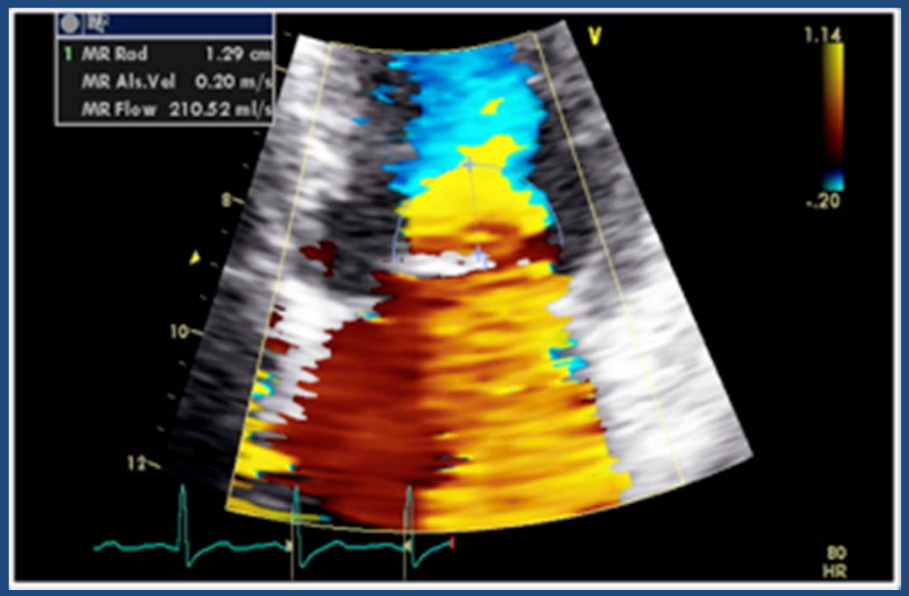
VCW: Limitations

- Intermediate values need confirmation
- Affected by systolic changes in regurgitant flow

Proximal isovelocity surface area (PISA) or flow convergence method

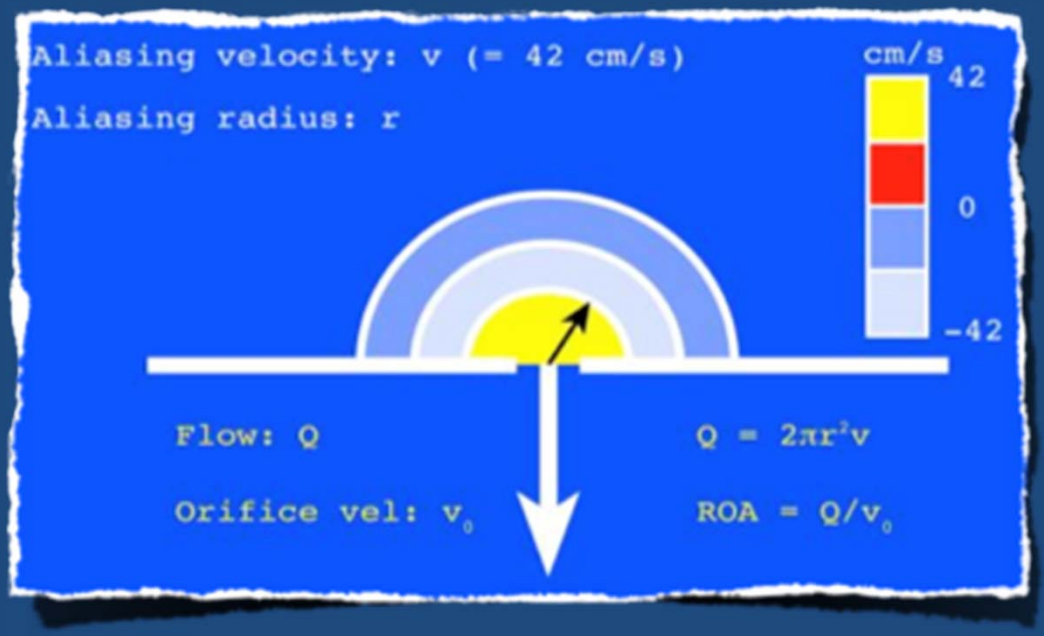


PISA method



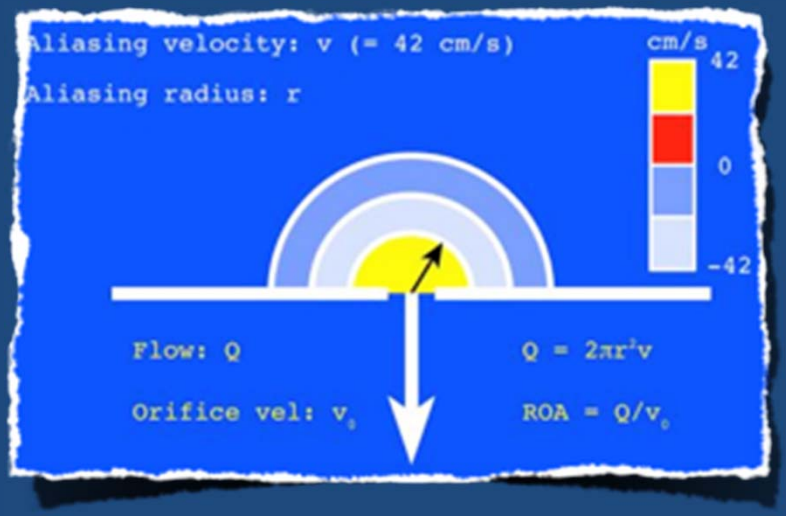
- Based on the principle of conservation of mass
  - Concentric isovelocity shells
  - Decreasing surface area and increasing velocity

PISA method



- Regurgitant flow rate = PISA x aliasing velocity
- ERO x peak MR velocity = PISA x aliasing velocity
- PISA = $2\pi r^2$

PISA method



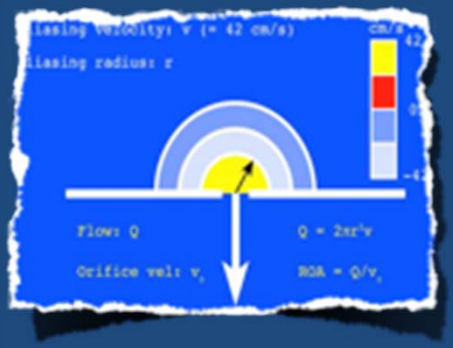
Regurgitant flow rate = PISA x aliasing velocity

ERO x peak MR velocity = PISA x aliasing velocity

$PISA = 2\pi r^2$

- ERO = $2\pi r^2$ x aliasing velocity/ peak MR velocity

PISA method



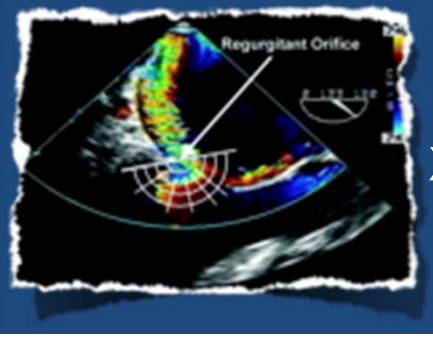
Regurgitant flow rate = PISA x aliasing velocity

ERO x peak MR velocity = PISA x aliasing velocity

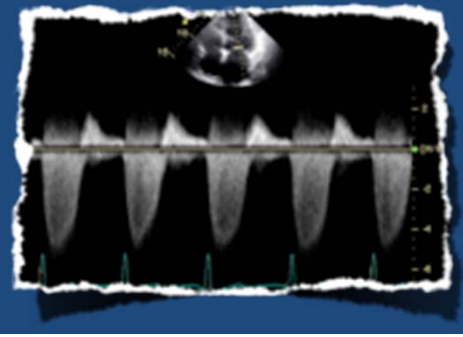
PISA = $2\pi r^2$

- ERO = $2\pi r^2$ x aliasing velocity/ peak MR velocity

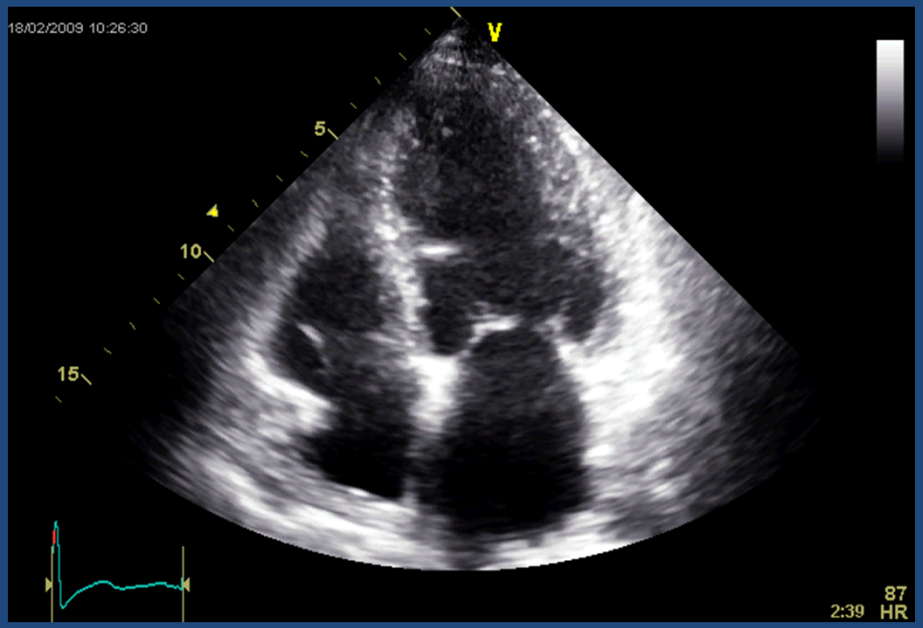
Regurgitant volume = ERO x MR VTI

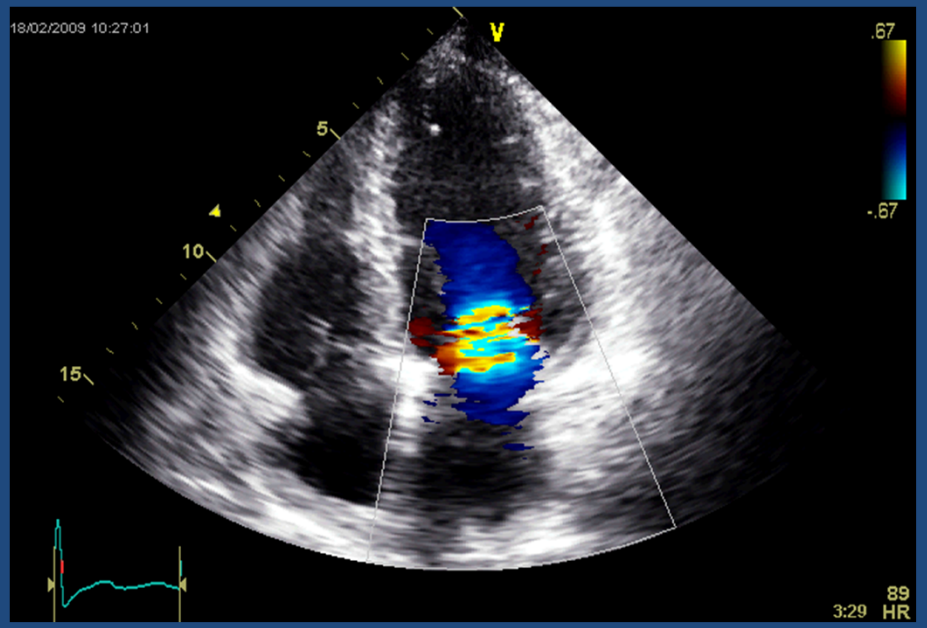


x



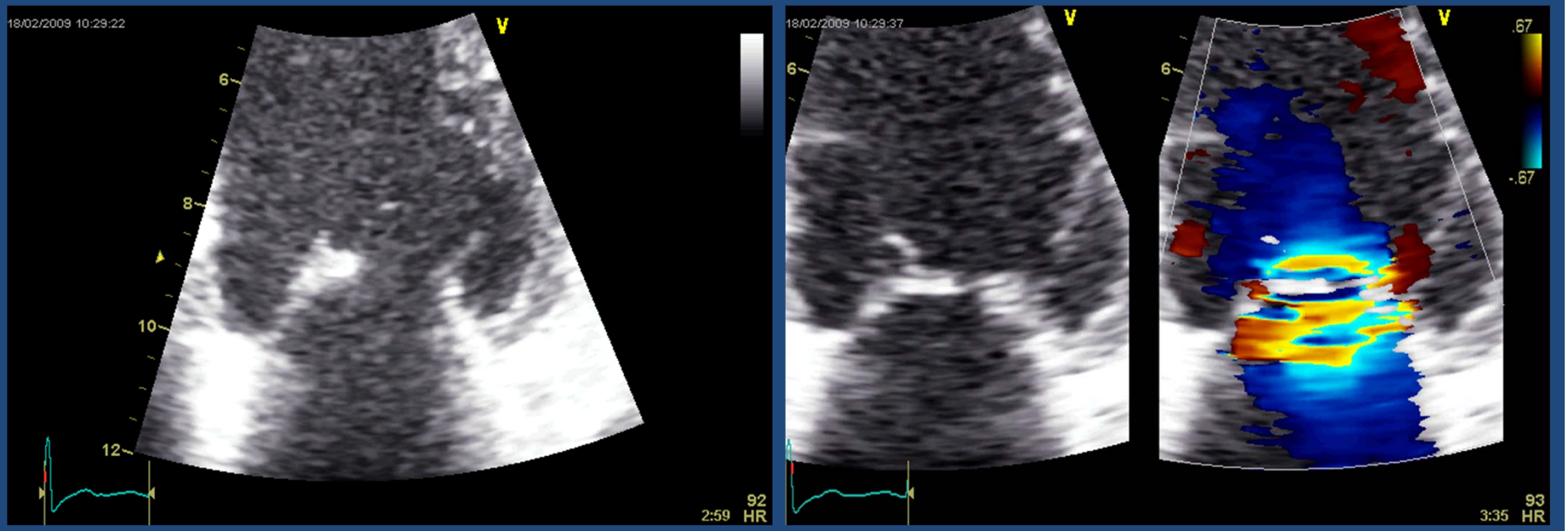
PISA method: Calculation Step (I)





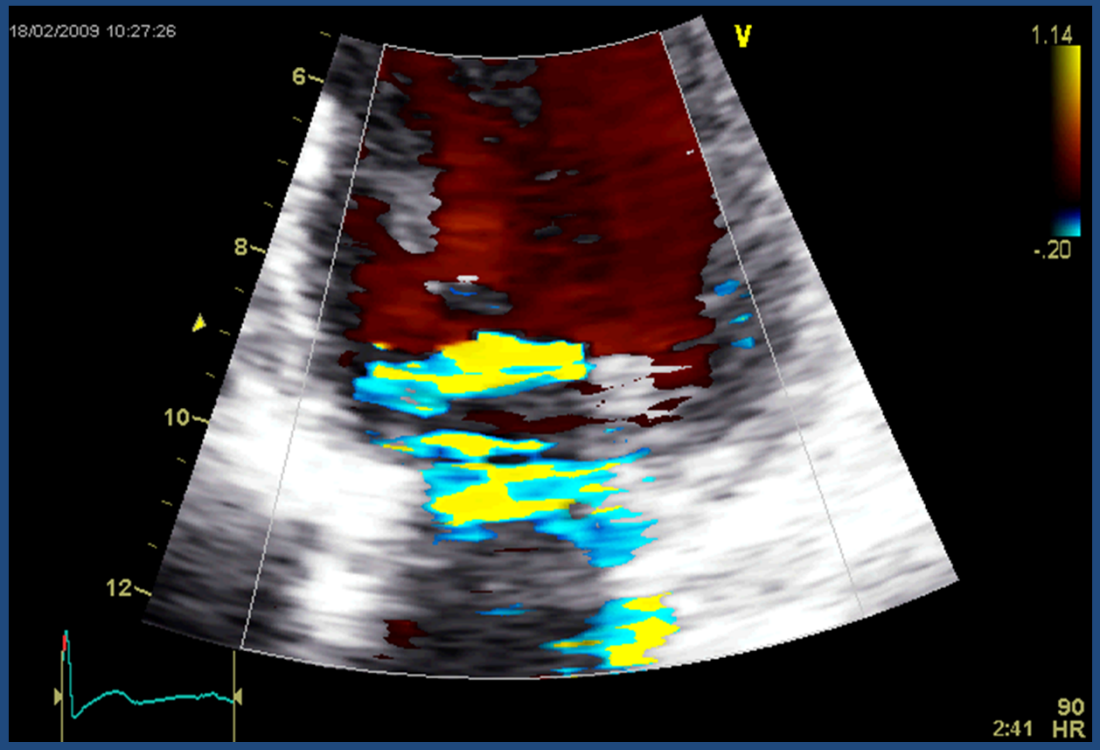
- Regurgitation?

PISA method: Calculation Step (II)



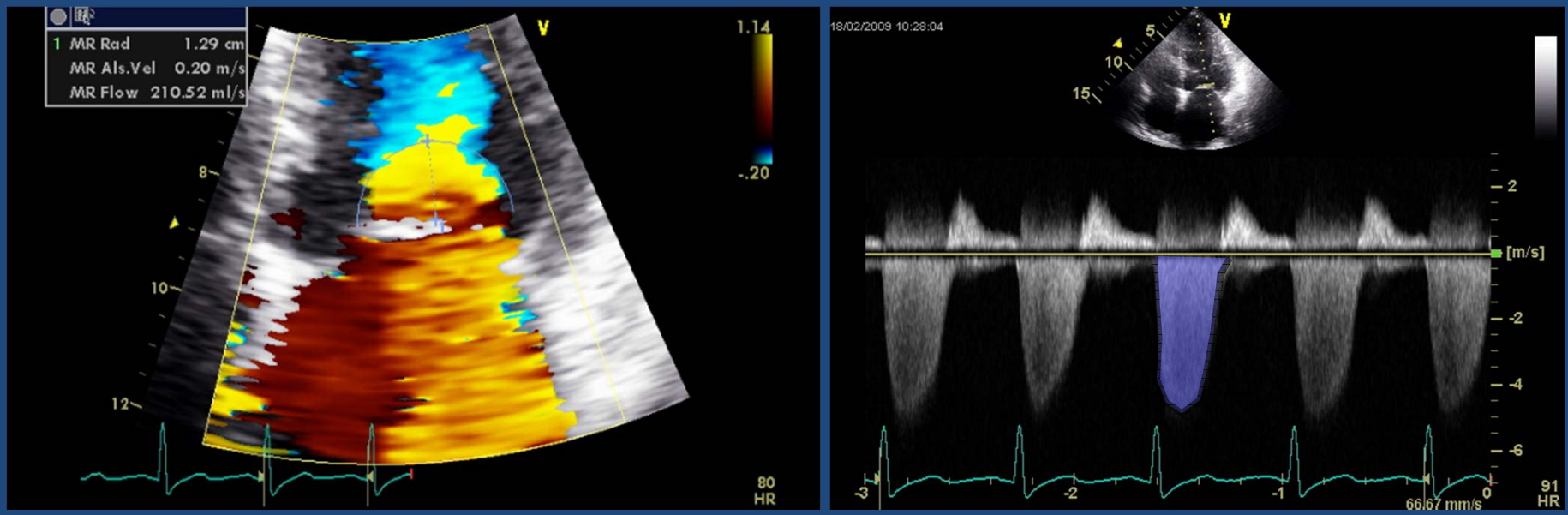
- Zoom and Color

PISA method: Calculation Step (III)



- Nyquist limit: 20-40 cm/s

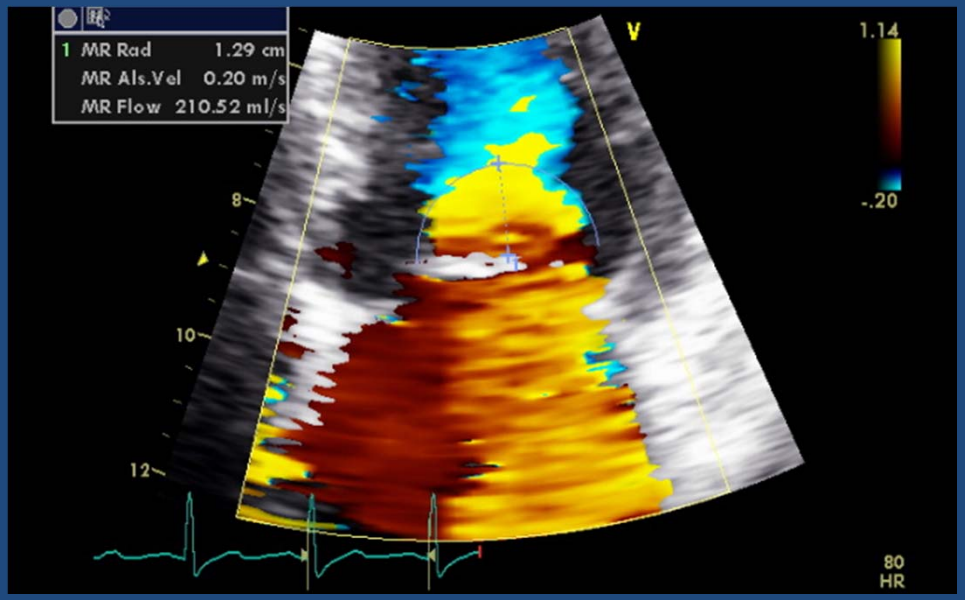
PISA method: Calculation Step (IV)

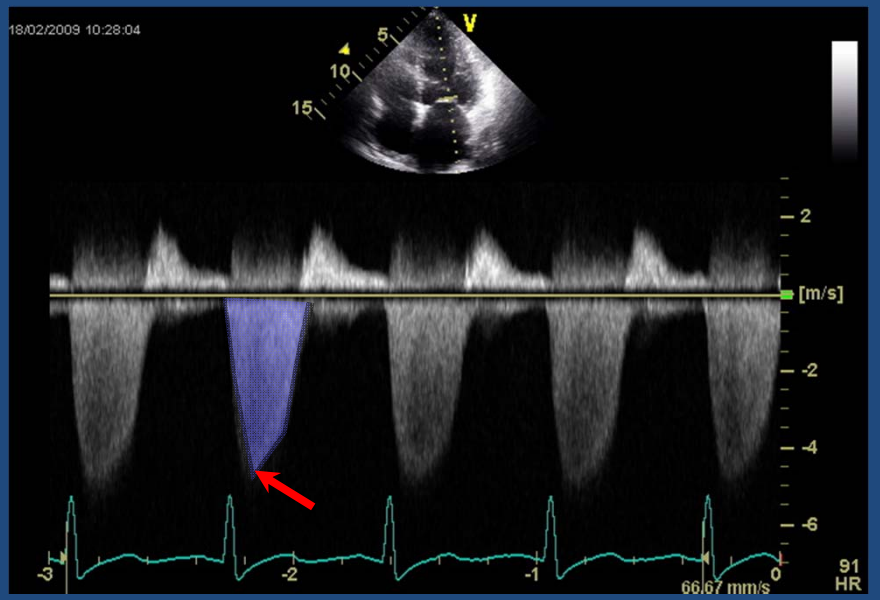


- ERO = $2\pi r^2$ x aliasing velocity/ peak MR velocity
- Regurgitant volume = ERO x MR VTI

PISA method: Benefits

- Quantitative

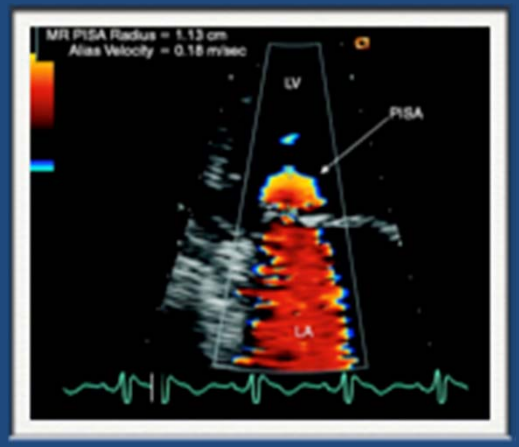




PISA method: Benefits

Instrumental factors

Hemodynamic Factors



Etiology

Concomitant Valve disease

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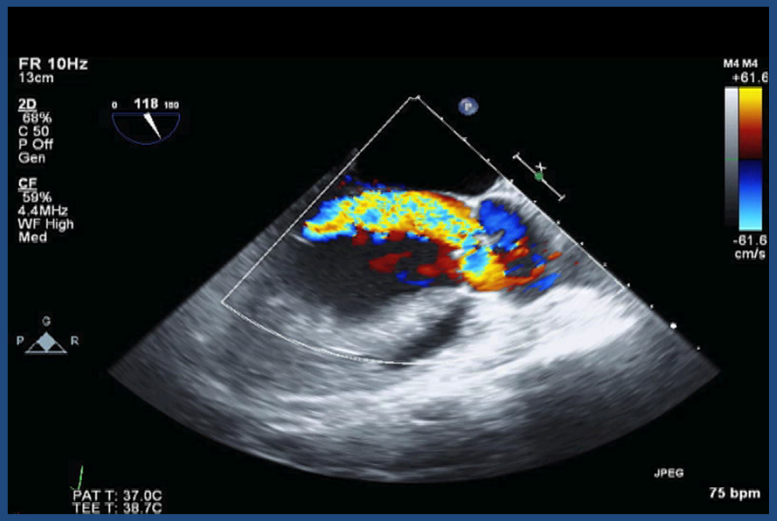
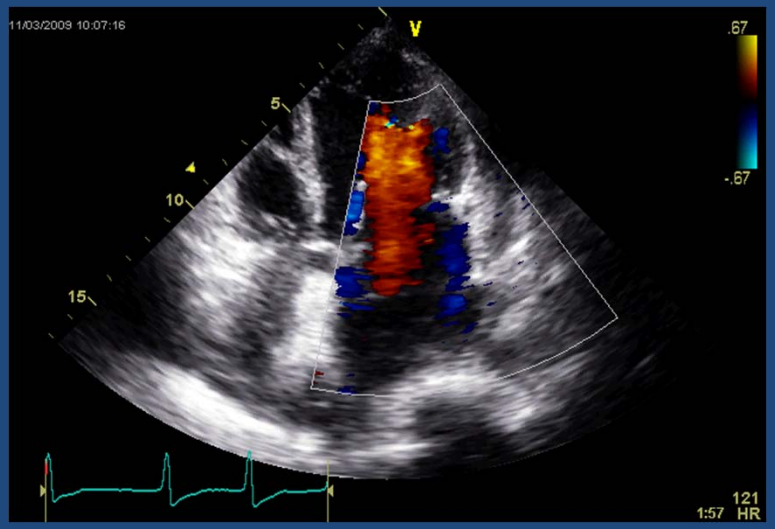
PISA method: Benefits

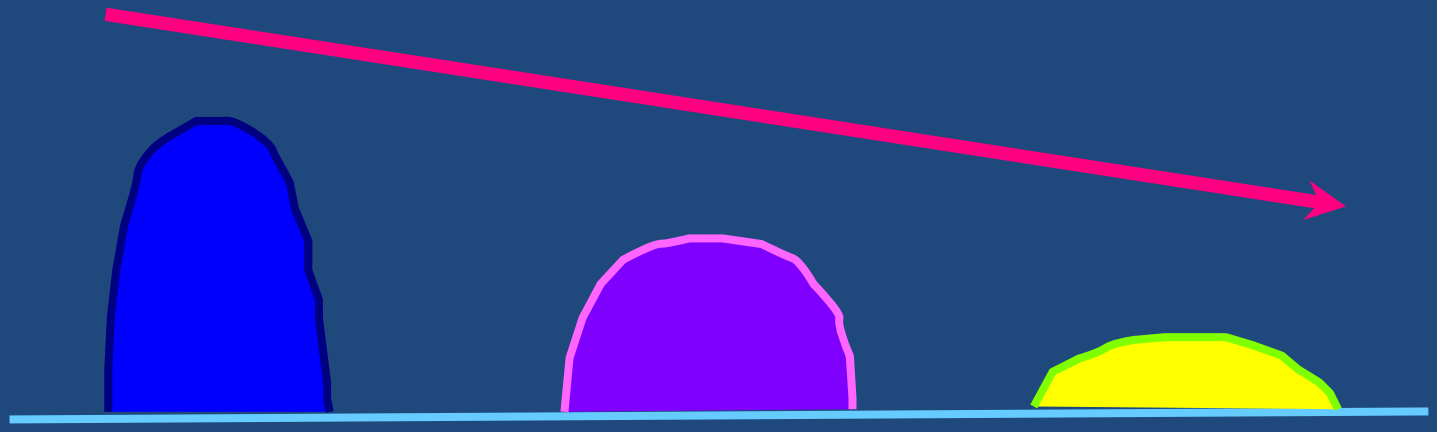




Although less accurate, this method can be used in eccentric jet

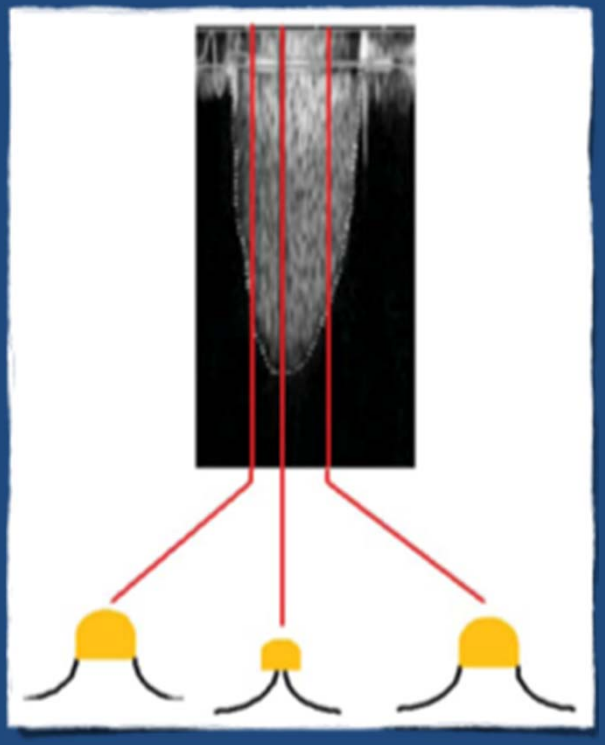
PISA method: Limitations

Aliasing velocity



Configuration of PISA

PISA method: Limitations



- Variation in the regurgitant orifice during the cardiac cycle

PISA method: Limitations

- The distortion of the isovelocity contours by encroachment of proximal structures on the flow

Doppler Volumetric Method

Doppler Volumetric Method

- Total forward volume across a regurgitant orifice
- = Systemic SV + Regurgitant Volume

Doppler Volumetric Method

- Total forward volume across a regurgitant orifice
- = Systemic SV + Regurgitant Volume

Regurgitant Volume

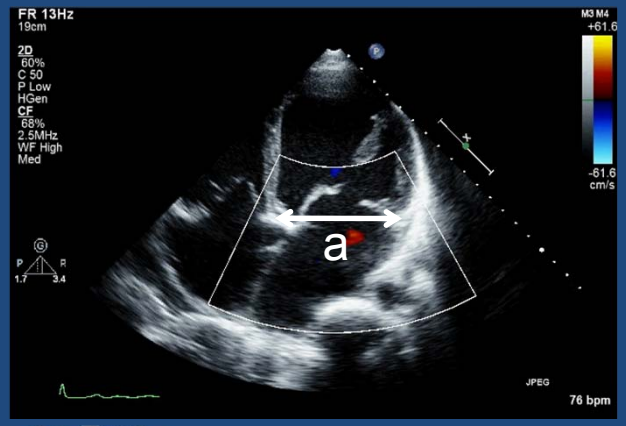
= SV Regurgitant Valve – SV Competent Valve

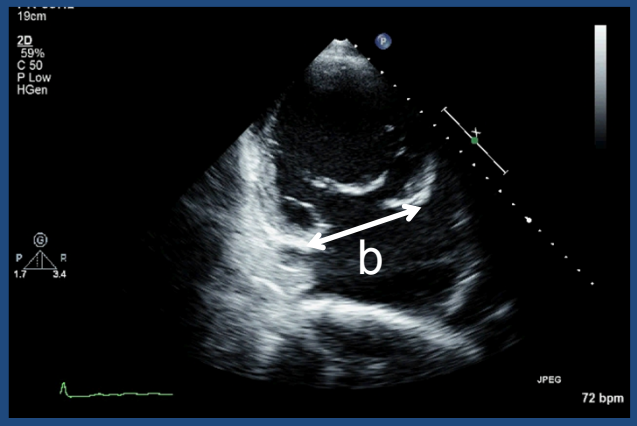
Doppler Volumetric Method

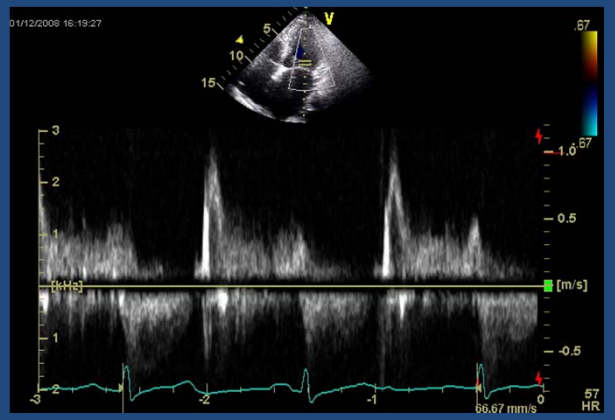
- **In MR**
- Total SV

–= Mitral annulus area X mitral inflow TVI

–= π X a/2 X b/2 X TVI_{mitral}





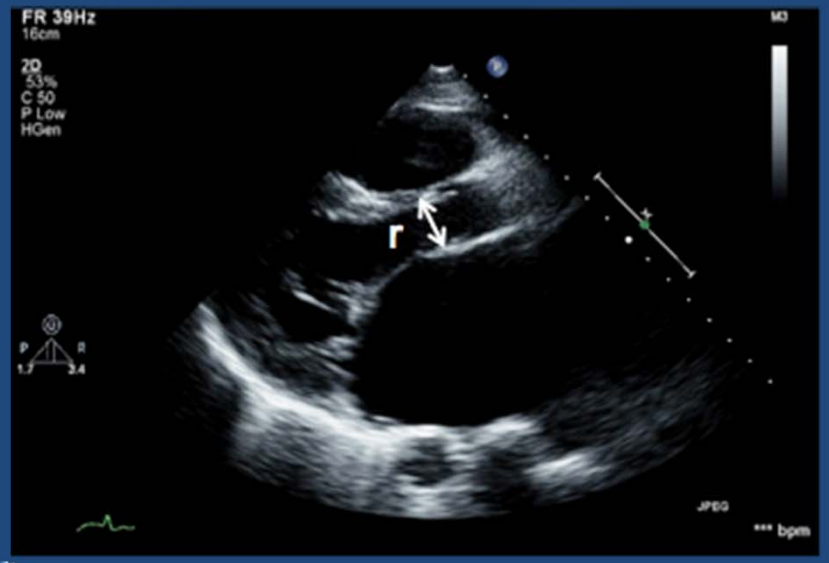


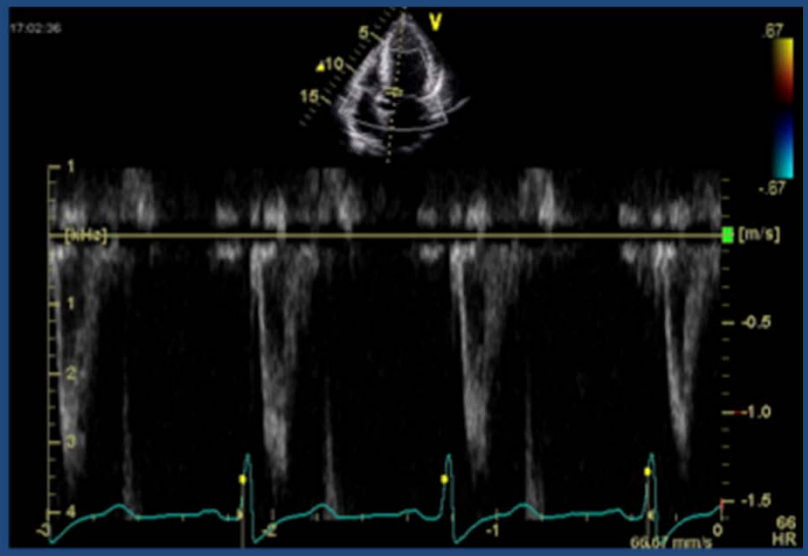
Doppler Volumetric Method

- **In MR**

–Systemic SV

–= LVOT X LVOT TVI





Doppler Volumetric Method

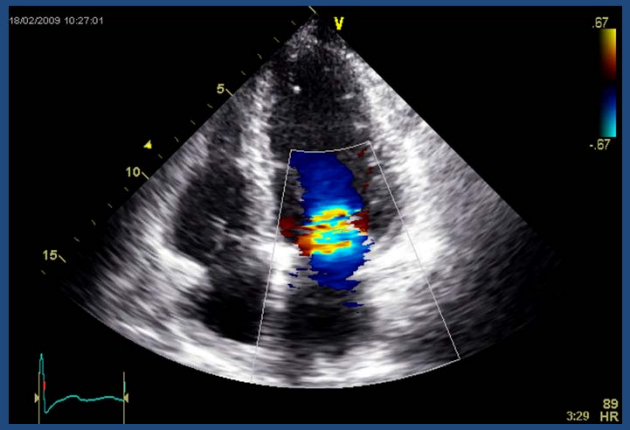
- **In MR**
  - Systemic SV in the presence of significant AR
    - Systemic flow could be calculated at the pulmonary annulus, although this site is often less accurate

Doppler Volumetric Method

- In AR
  - Regurgitant volume
    - Difference between LVOT SV (total) and the mitral inflow volume (competent)

Doppler Volumetric Method

- EROA
- = Regurgitant volume/ TVI of the regurgitant jet velocity recorded by CW Doppler



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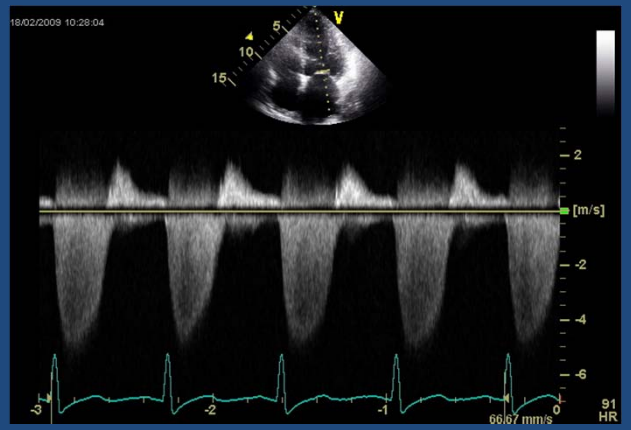


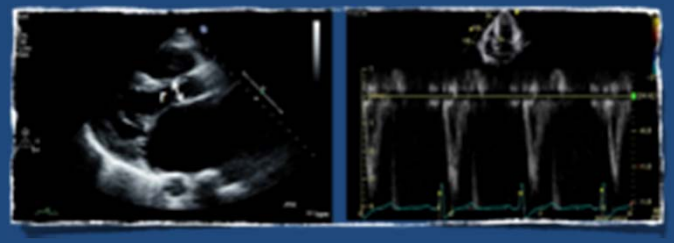
Doppler Volumetric Method

- Regurgitant fraction
- = Regurgitant Flow/ Total flow

Doppler Volumetric Method

Technically demanding

Multiple Measurement



Source of many errors

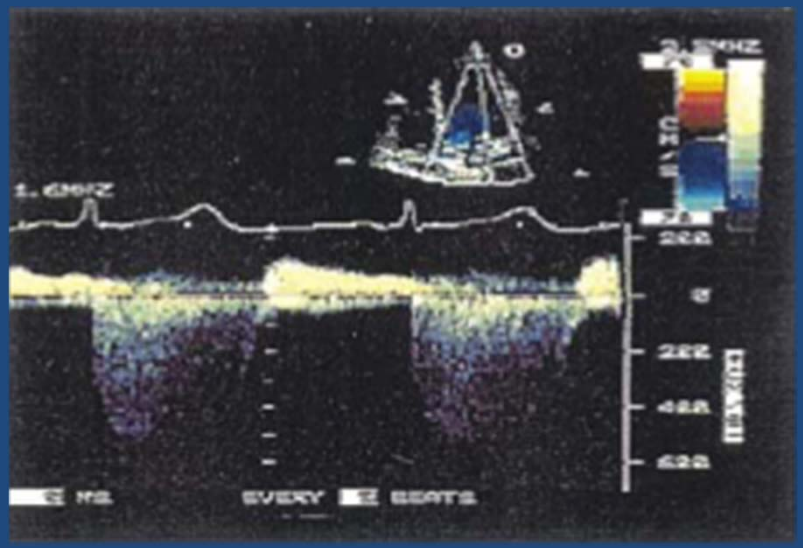
Multistage Calculations

Doppler Volumetric Method

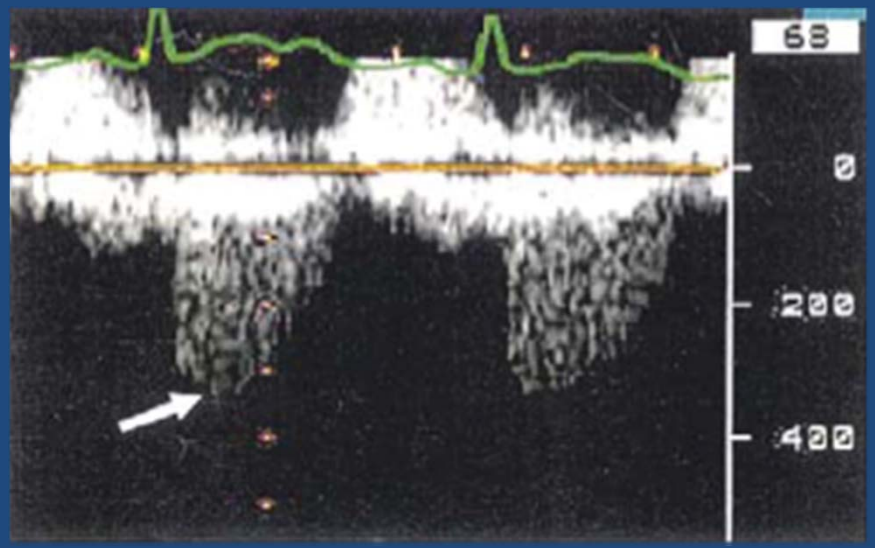
- Optional or reserved to experienced laboratories

Other Doppler Approaches

- Signal intensity of the CW



Mild MR



Severe MR

Doppler Evaluation of AR

- Color flow Doppler

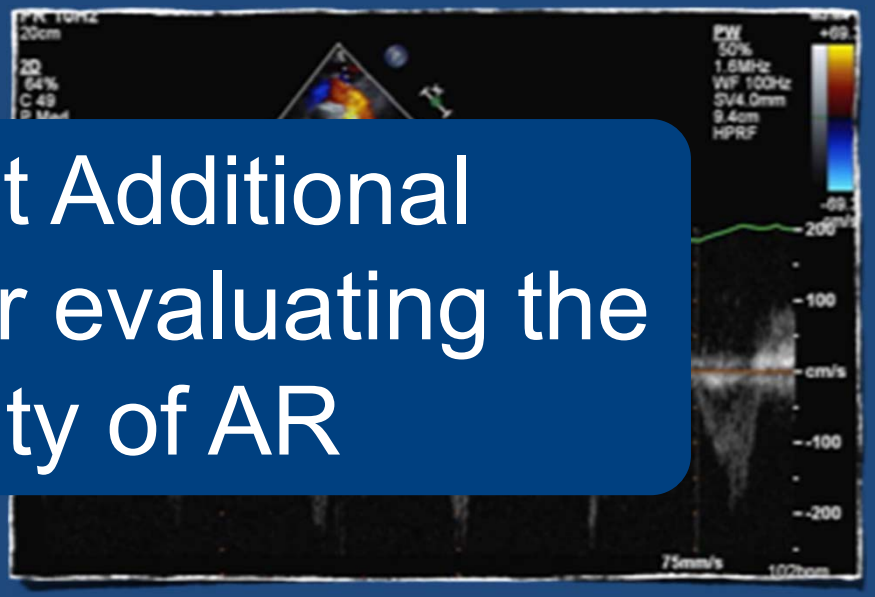
Color flow imaging
Vena contracta width
Flow convergence method

- Pulsed Doppler

Doppler volumetric method
Diastolic flow reversal

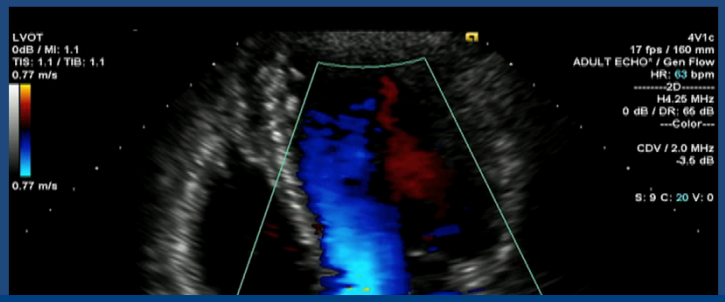
- Continuous wave Doppler of the AR jet

Diastolic Flow Reversal: AR

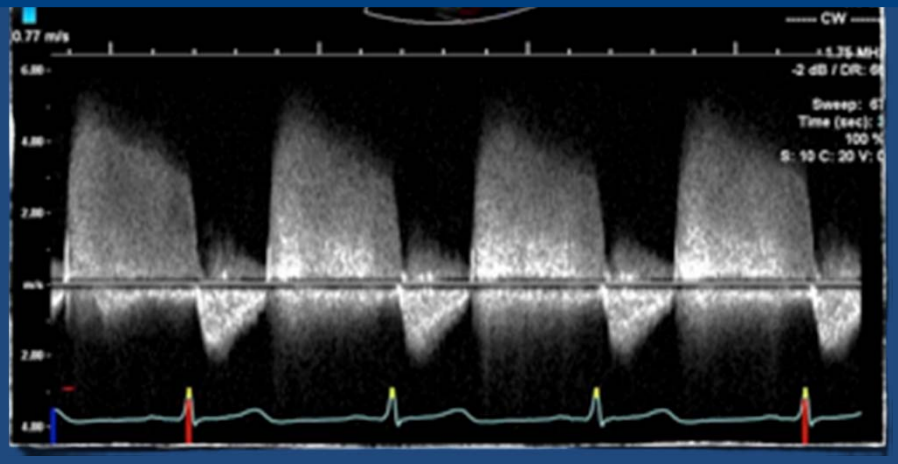


Strongest Additional Parameter for evaluating the severity of AR

CW Doppler of the AR Jet



Complimentary finding for the assessment of AR severity



Doppler Evaluation of PR

- Color flow Doppler
  - Color flow imaging
  - Vena contracta width
  - The flow convergence method
- Pulsed Doppler
- Continuous wave Doppler

Doppler Evaluation of MR

- Color flow Doppler

Color flow imaging
Vena contracta width
Flow convergence method

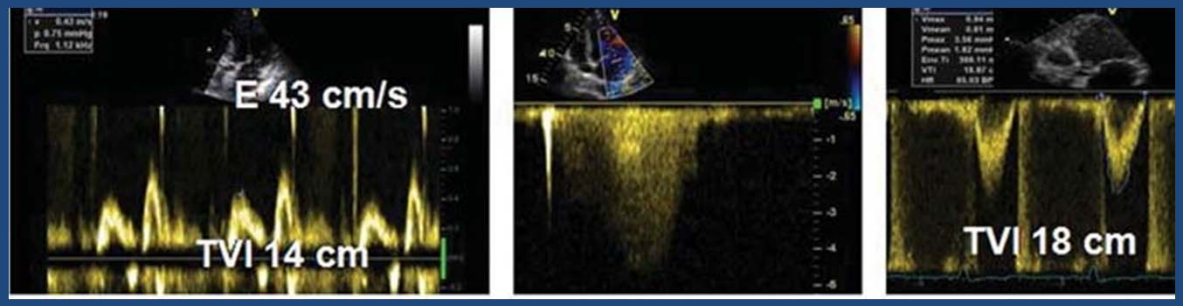
- Pulsed Doppler

Doppler volumetric method
Anterograde velocity of mitral inflow
: mitral to aortic time-velocity integral (TVI) ratio
Pulmonary venous flow

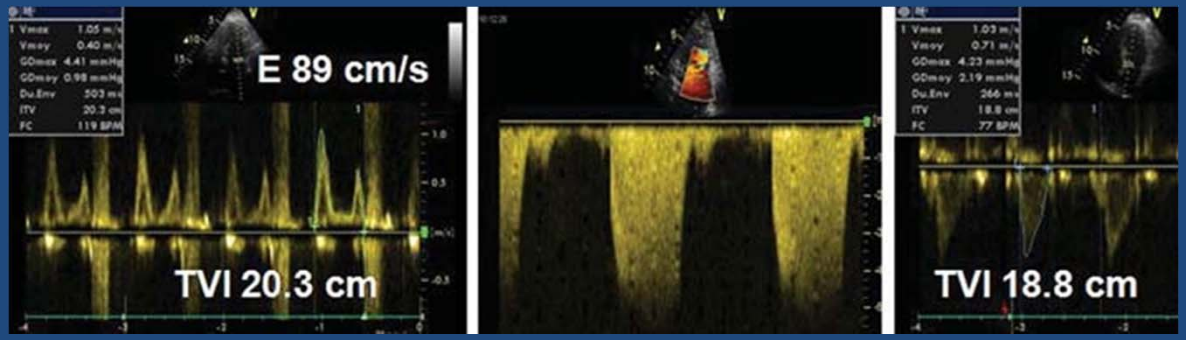
- Continuous wave Doppler of the MR jet

Mitral to Aortic TVI Ratio

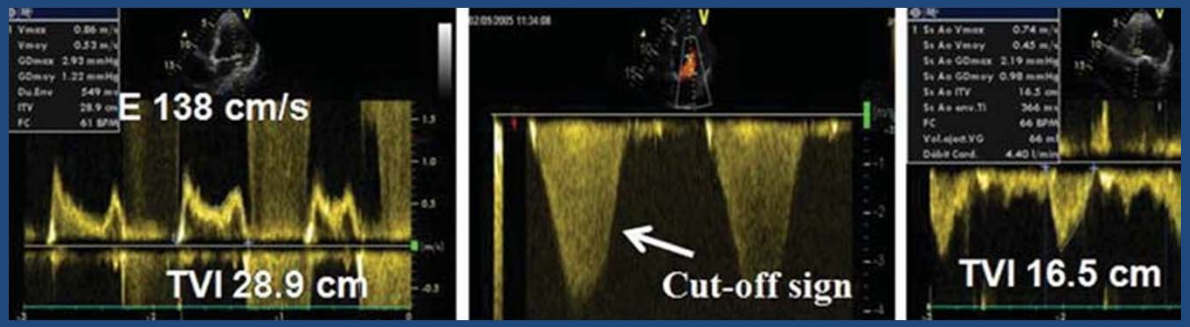
Mild



Moderate



Severe



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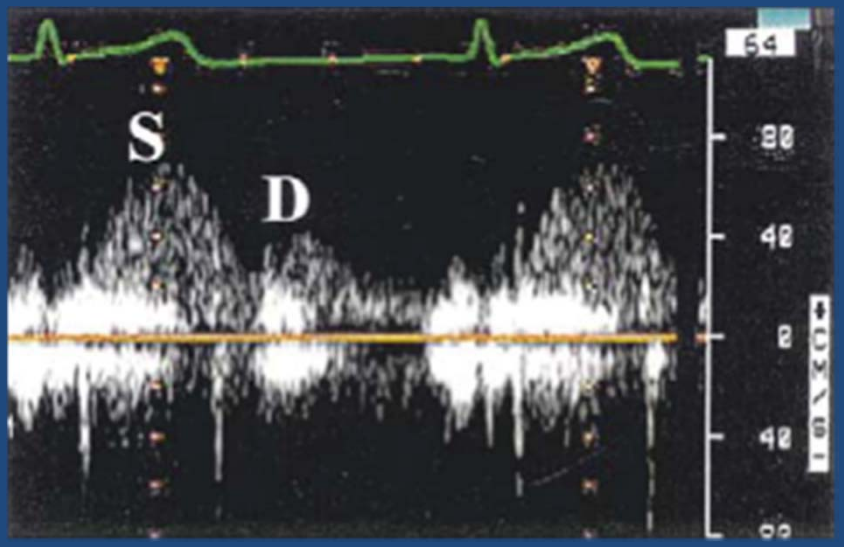
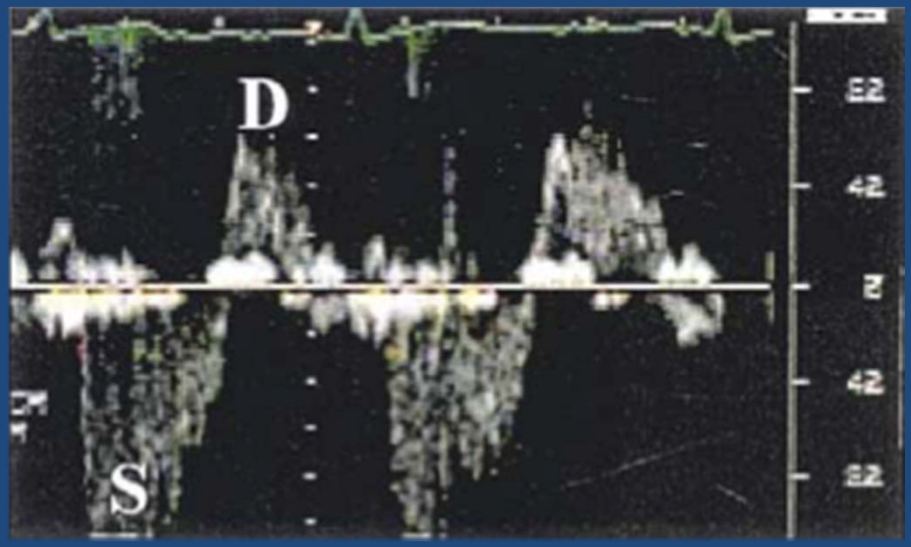
Pulmonary Venous Flow



Mild MR



Severe MR

Doppler Evaluation of TR

- Color flow Doppler

Color flow imaging

Vena contracta width

Flow convergence method

- Pulsed Doppler

Doppler volumetric method

Anterograde velocity of tricuspid inflow

Hepatic vein flow

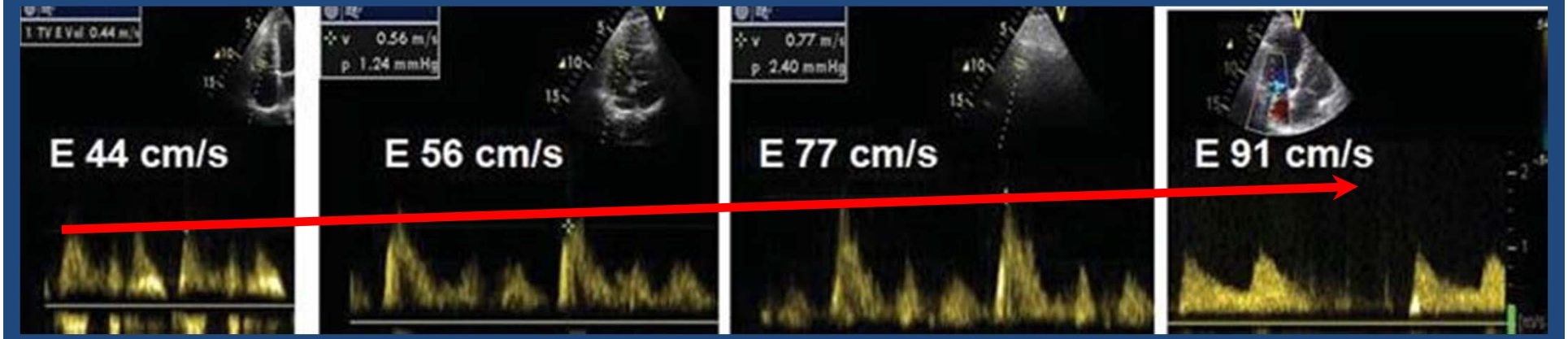
- Continuous wave Doppler of the MR jet

Signal intensity and shape

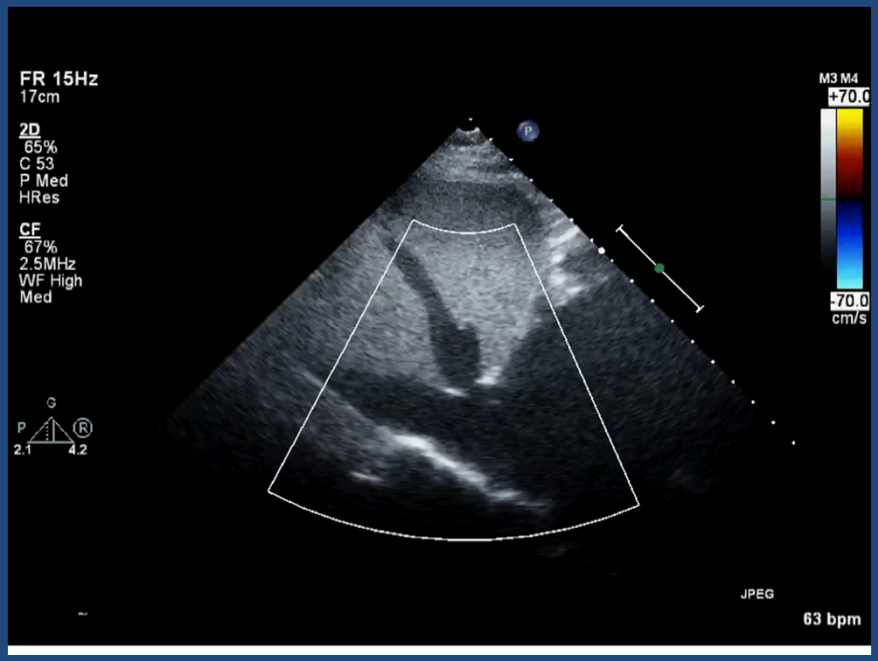
Pulmonary artery pressure

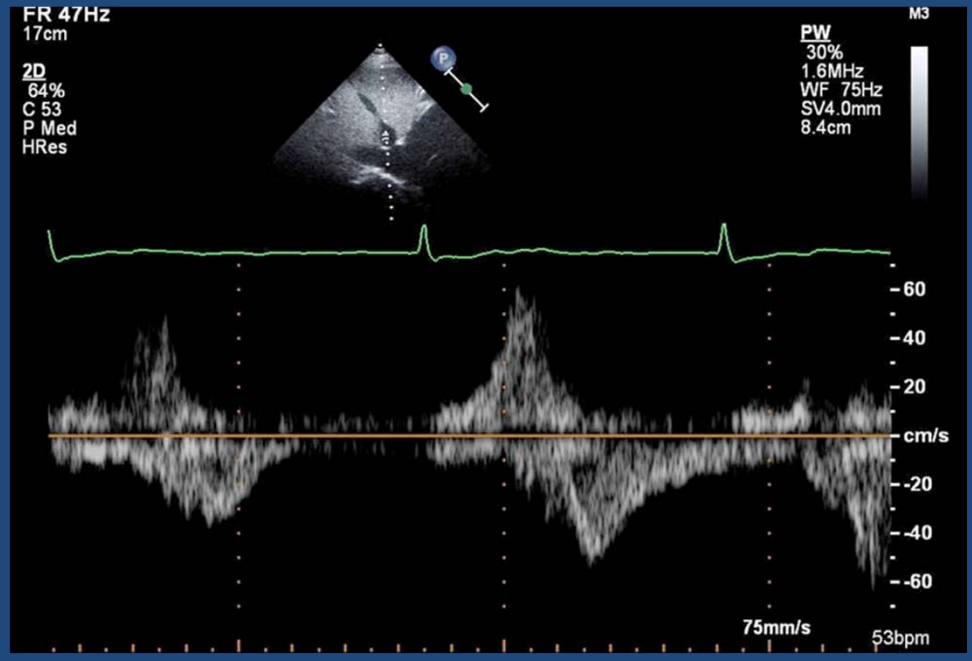
Anterograde velocity of Tricuspid inflow

Mild Moderate Severe Massive



Hepatic Vein Flow





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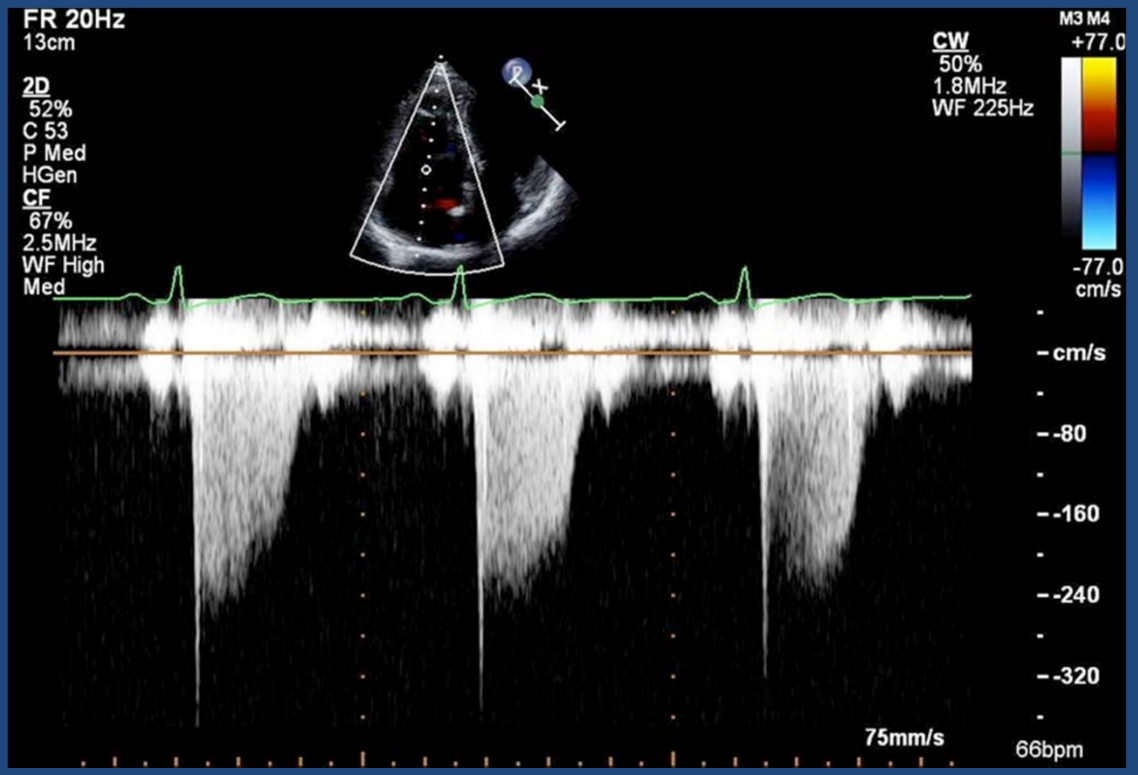
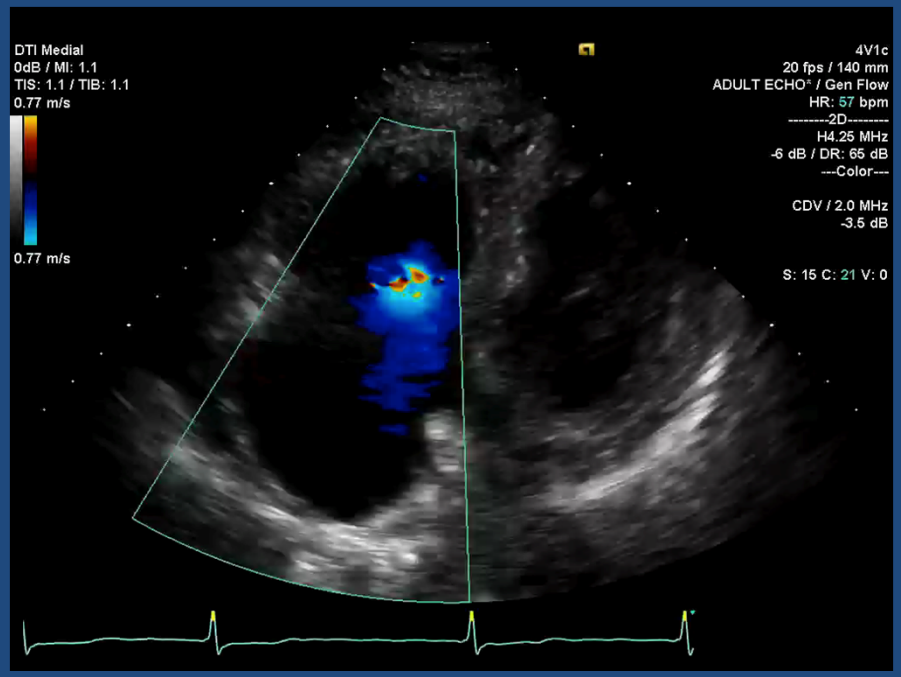
Pulmonary Artery Pressure



- Modified Bernoulli equation

Pulmonary Artery Pressure



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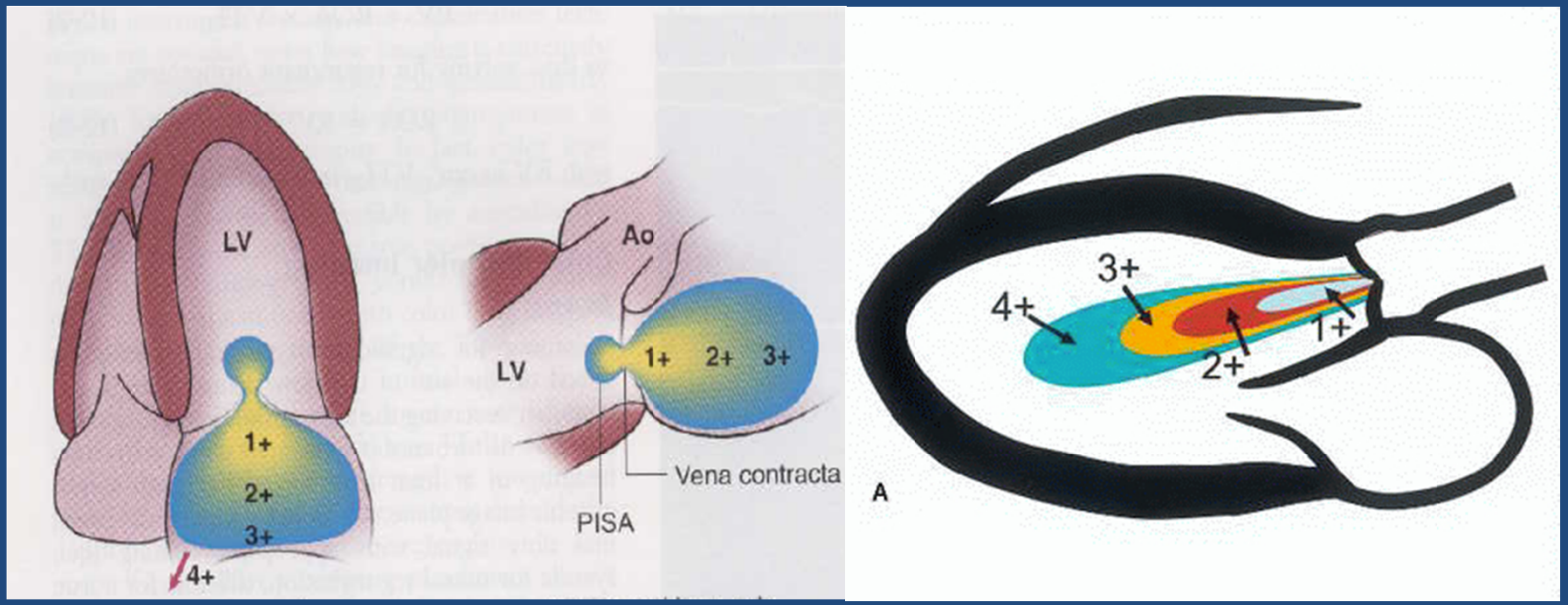
Estimation of Valvular Regurgitation : Recommendations by EAE



Estimation of Valvular Regurgitation : Recommendations by EAE

Estimation of Valvular Regurgitation : Recommendations by EAE

Grading the Severity of AR

Parameters	Mild	Moderate	Severe
Qualitative			
Color flow AR jet width	small in central jets	Intermediate	Large in central jet. variable in eccentric jet
CW signal of AR jet	Incomplete/faint	Dense	Dense
Diastolic flow reversal in descending aorta	Brief, protodiastolic flow reversal	Intermediate	Holodiastolic flow reversal (end-diastolic velocity > 20cm/s)
Semi-quantitative			
VC width (mm)	< 3	Intermediate	> 6
PHT (ms)	> 500	Intermediate	< 200
Quantitative			
EROA (mm^2)	< 10	10-19;20-29	≥ 30
R vol (mL)	< 30	30-44;45-59	≥ 60

Recommendations by EAE 2010

Doppler for the evaluation of AR: Advantages and Limitations

	Advantages	Limitations
Color flow AR jet width and area	•Ease of use •Evaluates the spatial orientation of AR jet •Quick screening for AR	•Influenced by technical and hemodynamic factors •Inaccurate for AR jet •Expands unpredictably below the orifice
VC width	•Relatively quick and easy •Relatively independent of hemodynamic and instrumentation factors •Not affected by other valve leak •Good for extremes AR: mild vs. severe •Can be used in eccentric jet	•Not valid for multiple jets •Small values: small measurement errors leads to large % error •Intermediate values need confirmation •Affected by systolic changes in regurgitant flow

Recommendations by EAE 2010

Doppler for the evaluation of AR: Advantages and Limitations

	Advantages	Limitations
PISA method	•Can be used in eccentric jet •Quantitative: estimate lesion severity (EROA) and volume overload (R vol)	•PISA shape affected -by the aliasing velocity -in case of non-circular orifice -by systolic changes in regurgitant flow -by adjacent structures (flow constrainment) •PISA is more a hemi-ellipse •Error in PISA radius measurement are squared •Inter-observer variability •Not valid for multiple jets •Feasibility limited by aortic valve calcifications

Recommendations by EAE 2010

Doppler for the evaluation of AR: Advantages and Limitations

	Advantages	Limitations
Doppler volumetric method	•Quantitative: estimate lesion severity (ERO) and volume overload •Valid in multiple jets	•Time consuming •Requires multiple measurements: source of errors •Not applicable in case of significant MR (use the pulmonic site)
CW AR jet profile	Simple, easily available	•Qualitative, complementary finding •Complete signal difficult to obtain in eccentric jet
Pressure half-time	Simple	Affected by LV compliance, blood pressure, acuity of AR
Diastolic flow reversal in descending aorta	Simple	•Affected by sample volume location and acuity of AR •Affected by aortic compliance •Brief velocity reversal is normal •Cut-of validated for distal aortic arch

Recommendations by EAE 2010

Grading the Severity of PR

	Mild	Moderate	Severe
Qualitative			
Color flow PR jet width	Small, usually < 10 mm in length with a narrow origin	Intermediate	Large, with a wide origin; maybe brief in duration
CW signal of PR jet	Faint/slow deceleration	Dense/variable	Dense/steep deceleration, early termination of diastolic flow
Pulmonic vs Aortic flow by PW	Normal or slightly increased	Intermediate	Greatly increased
Semi-quantitative			
VC width (mm)	Not defined	Not defined	Not defined
Quantitative			
EROA (mm^2)	Not defined	Not defined	Not defined
R vol (mL)	Not defined	Not defined	Not defined

Recommendations by EAE 2010

Doppler for the evaluation of PR: Advantages and Limitations

	Advantages	Limitations
Color flow PR jet	•Ease of use •Evaluates the spatial orientation of PR jet •Quick screening for mild vs. severe PR	Influenced by technical and hemodynamic factors
VC width	•Possible if the pulmonic valve is well visualized •Relatively independent of hemodynamic and instrumentation factors •Not affected by other valve leak •Normally good as for the other valves	•Difficult to perform in the majority of patients •Lacks published data
PISA method	•Quantitative •Normally good as for the other valves	•Difficult to perform in the majority of patients •Lacks published data
CW PR jet profile	Simple, easily available	Qualitative, complementary finding

Recommendations by EAE 2010

Grading the Severity of MR

	Mild	Moderate	Severe
Qualitative			
Color flow MR jet	Small, central	Intermediate	Very large central jet adhering. swirling and reaching the posterior wall of the LA
Flow convergence zone	No or small	Intermediate	Large
CW signal of MR jet	Faint/Parabolic	Dense/Parabolic	Dense/Triangular
Semi-quantitative			
VC width (mm)	< 3	Intermediate	≥ 7 (> 8 for biplane)
Pulmonary vein flow	Systolic dominance	Systolic blunting	Systolic flow reversal
Mitral inflow	A wave dominant	Variable	E wave dominant (> 1.5 cm/s)
TVI mit/TVI Ao	< 1	Intermediate	> 1.4
Quantitative			
EROA (mm^2)	< 20	20-29; 30-39	≥ 40
R vol (mL)	<30	30-44; 45-59	≥ 60

Recommendations by EAE 2010

Doppler for the evaluation of MR: Advantages and Limitations

	Advantages	Limitations
Color flow MR jet	•Ease of use •Evaluates the spatial orientation of MR jet •Good screening test for mild vs. severe MR	•Can be inaccurate for estimation of MR severity •Influenced by technical and hemodynamic factors •Underestimates eccentric jet adhering the LA wall (Coanda effect)
VC width	•Relatively quick and easy •Relatively independent of hemodynamic and instrumentation factors •Not affected by other valve leak •Good for extremes MR: mild vs. severe •Can be used in eccentric jet	•Not valid for multiple jets •Small values: small measurement errors leads to large % error •Intermediate values need confirmation •Affected by systolic changes in regurgitant flow

Recommendations by EAE 2010

Doppler for the evaluation of MR: Advantages and Limitations

	Advantages	Limitations
PISA method	•Can be used in eccentric jet •Not affected by the etiology of MR or other valve leak •Quantitative: estimate lesion severity (EROA) and volume overload (R vol) •Flow convergence at 50 cm/s alerts to significant MR	•PISA shape affected -by the aliasing velocity -in case of non-circular orifice -by systolic changes in regurgitant flow -by adjacent structures (flow constrainment) •PISA is more a hemi-ellipse •Error in PISA radius measurement are squared •Inter-observer variability •Not valid for multiple jets
Doppler volumetric method	•Quantitative: estimate lesion severity (ERO) and volume overload •Valid in multiple jets	•Time consuming •Requires multiple measurements: source of errors •Not applicable in case of significant AR (use the pulmonic site) •Difficulties in assessing mitral annulus diameter and mitral inflow in case of calcific mitral valve/annulus •Affected by sample volume location (mitral flow)

Recommendations by EAE 2010

Doppler for the evaluation of MR: Advantages and Limitations

	Advantages	Limitations
CW MR jet profile	Simple, easy available	•Qualitative, Complementary finding •Complete signal difficult to obtain in eccentric jet
Pulmonary vein flow	•Simple •Systolic flow reversal is specific for severe MR	•Affected by LA pressure, atrial fibrillation •Not accurate if MR jet directed into sampled vein
Peak E velocity	•Simple, easy available •Dominant A-wave almost excludes severe MR	•Affected by LA pressure, atrial fibrillation, LV relaxation •Complementary finding

Recommendations by EAE 2010

Grading the Severity of TR

	Mild	Moderate	Severe
Qualitative			
Color flow of TR jet	Small, central	Intermediate	Very large central or eccentric impinging jet
CW signal of TR jet	Faint/Parabolic	Dense/Parabolic	Dense/Triangular with early peaking (peak < 2 m/s in massive TR)
Semi-quantitative			
VC width (mm)	Not defined	< 7	≥ 7
PISA radius	≤ 5	6-9	> 9
Hepatic vein flow	Systolic dominance	Systolic blunting	Systolic flow reversal
Tricuspid inflow	Normal	Normal	E wave dominant (≥ 1 cm/s)
Quantitative			
EROA (mm^2)	Not defined	Not defined	≥ 40
R Vol (mL)	Not defined	Normal	≥ 45

Recommendations by EAE 2010

Doppler for the evaluation of TR: Advantages and Limitations

	Advantages	Limitations
Color flow TR jet	•Ease of use •Evaluates the spatial orientation of TR jet •Good screening for mild vs. severe TR	•Can be inaccurate for estimation of TR severity •Influenced by technical and hemodynamic factors •Underestimates eccentric jet adhering to the RA wall (Coanda effect)
VC width	•Relatively quick and easy •Relatively independent of hemodynamic and instrumentation factors •Not affected by other valve leak •Good for extremes TR: mild vs. severe •Can be used in eccentric jet	•Not valid for multiple jets •Small values: small measurement errors leads to large % error •Intermediate values need confirmation •Affected by systolic changes in regurgitant flow

Recommendations by EAE 2010

Doppler for the evaluation of TR: Advantages and Limitations

	Advantages	Limitations
PISA method	•Can be used in eccentric jet •Not affected by the etiology of TR or other valve leak •Quantitative: estimate lesion severity (EROA) and volume overload (R vol) •Large flow convergence at 28 cm/s alerts to significant TR	•PISA shape affected -by the aliasing velocity -in case of non-circular orifice -by systolic changes in regurgitant flow -by adjacent structures (flow constrainment) •Error in PISA radius measurement are squared •Inter-observer variability •Validated in only few studies
CW TR jet profile	Simple, easily available	•Qualitative, Complementary finding •Complete signal difficult to obtain in eccentric jet
Hepatic vein flow	•Simple •Systolic flow reversal is specific for severe TR	Affected by RA pressure, atrial fibrillation
Peak E velocity	•Simple, easily available •Usually increased in severe TR	•Affected by RA pressure, atrial fibrillation, RV relaxation •Complementary finding

Recommendations by EAE 2010

Doppler Evaluation of the Valvular Regurgitation