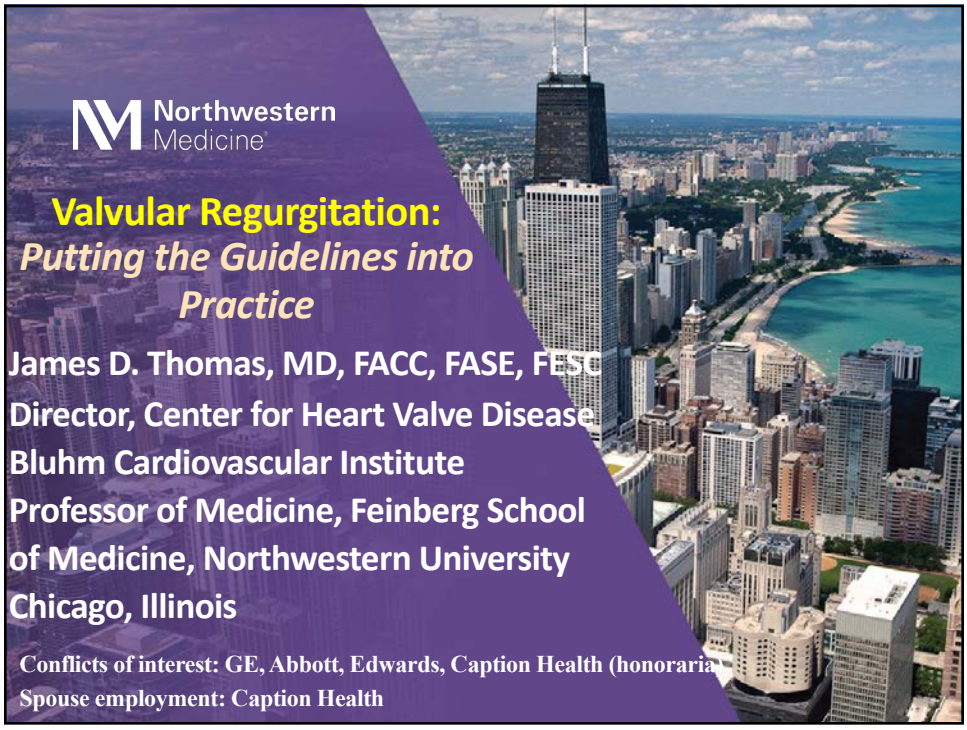
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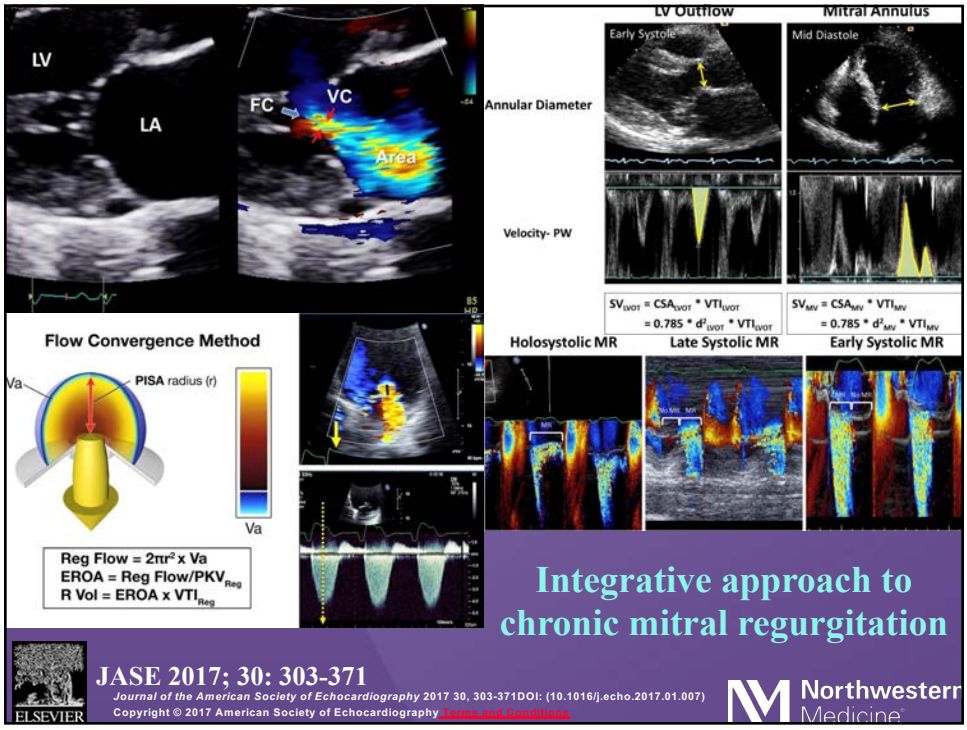
Valvular Regurgitation:
Putting the Guidelines into Practice
James D. Thomas, MD, FACC, FASE, FESC
Director, Center for Heart Valve Disease
Bluhm Cardiovascular Institute
Professor of Medicine, Feinberg School of Medicine, Northwestern University
Chicago, Illinois
Conflicts of interest: GE, Abbott, Edwards, Caption Health (honoraria)
Spouse employment: Caption Health

1


Happy to be back at Echo Hawaii!

2

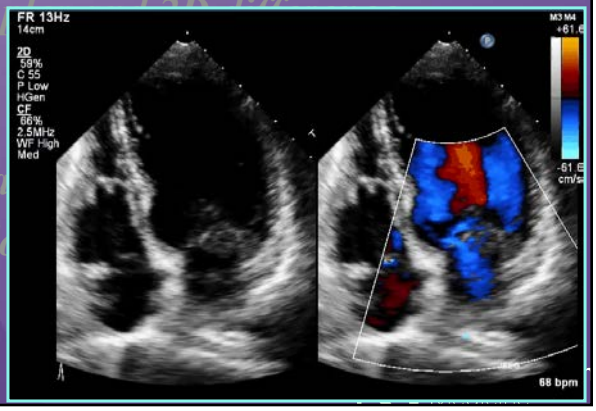


9

Quantifying Mitral Regurgitation

What are the Alternatives?

- ***Color jet area***
  - **Pro: Easy, fast, helps assess mechanism**
  - **Con: Impacted by BP, jet eccentricity, instrumentation factors, only 3 or 4 grades**
- ***Pulsed Dop… methods***
- ***Pulmonary***
- ***Vena contra***
- ***Proximal fl…***



10

Factors Effecting Color Doppler Jet Size

- *Jet momentum*
  - Flow rate x velocity
  - Record BP during examination
- *Chamber constraint*
  - Eccentric jets only 40% the size of free jets
- *Instrumentation*
  - Jet size directly related to gain, transmit power, ensemble length
  - Inversely related to pulse repetition frequency and wall filter
  - Transducer frequency has variable effect

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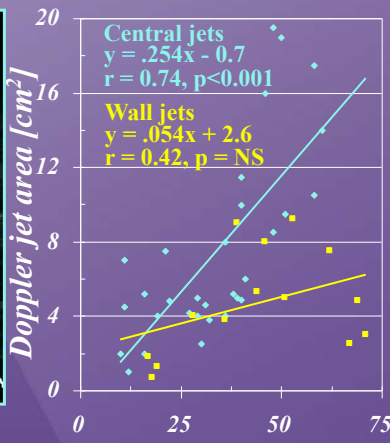
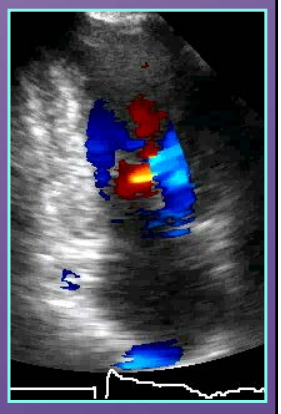
Determinants of Jet Size

Wall jets are 58% smaller than equivalent central jets





Central jet (Cardiomyopathy)

Wall jet (AML override)

Chen, et al., Circulation 1991; 84; 712-720

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Color Doppler Instrumentation
Changes that Increase Jet Size

- ⇑ Gain and power
- ⇓ Pulse repetition frequency
- ⇑ Transducer frequency
  - *Frequency effect*
- ⇓ Transducer frequency
  - *Attenuation effect*
- ⇓ Wall filter
- ⇑ Ensemble length

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Impact of Color Gain

CD Gain = 25 *CD Gain = 56*

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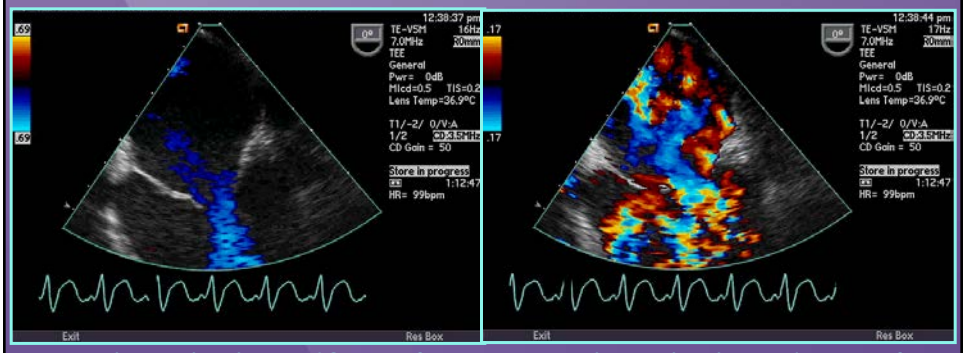
Impact of Velocity Scale



Nyquist Limit = 69 cm/sec
$V_{min} \approx 4$ cm/sec

Nyquist Limit = 17 cm/sec
$V_{min} \approx 1$ cm/sec

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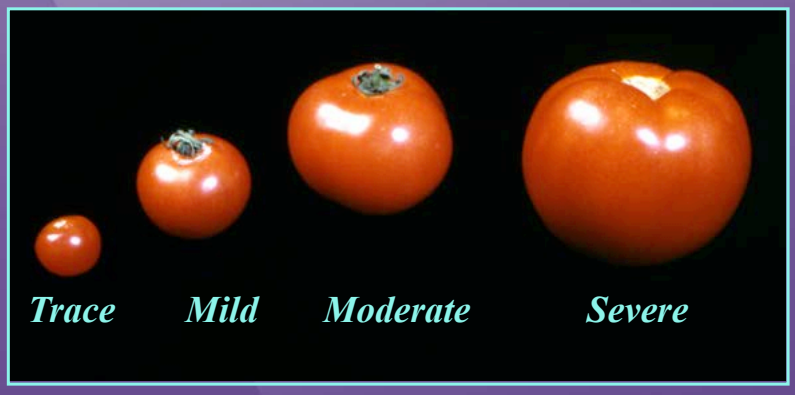
How We Usually Grade Regurgitation



Can't we do better????

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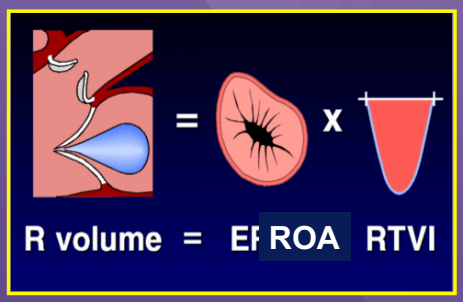
How Leaky IS That Valve?
Key Quantitative Concept

- ***Regurgitant orifice area (ROA)***
  - Actual size of the regurgitant lesion
  - Fundamental parameter of valve integrity



Mild: 0 - 20 mm^2
Moderate: 20 - 40 mm^2
Severe: > 40 mm^2

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PISA??
What are the Alternatives?

- *Color jet area*
- ***Pulsed Doppler and 2D difference methods***
  - Pro: Well validated, quantitative
  - Con: Complex, multiple windows and measurements, propagation of errors compounded by subtraction
- *Pulmonary veins*
- *Vena contracta*
- *Proximal flow convergence (PISA)*

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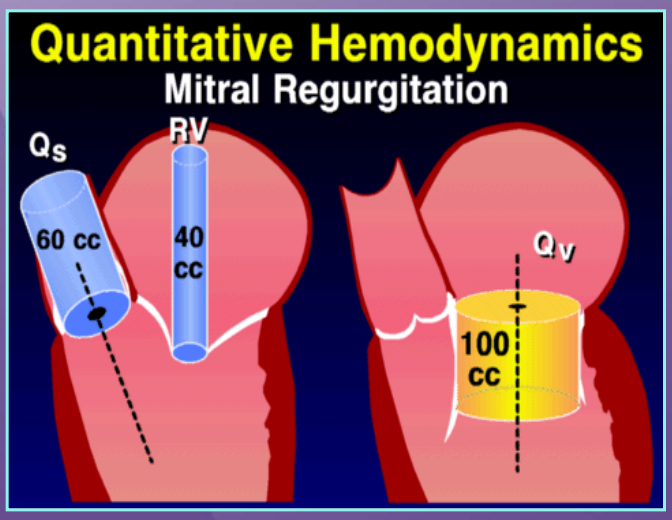

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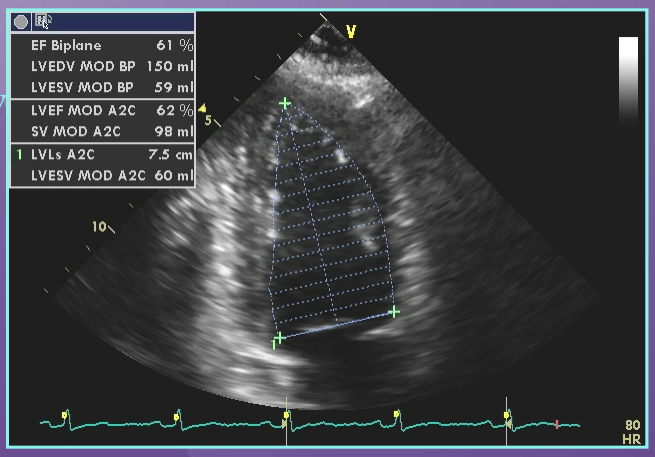
Quantification of Stroke Volume

2D or 3D Volumetric Assessment

LVEDV
150 ml



LVESV
59 ml

Stroke volume = 91 ml; ejection fraction = 61%

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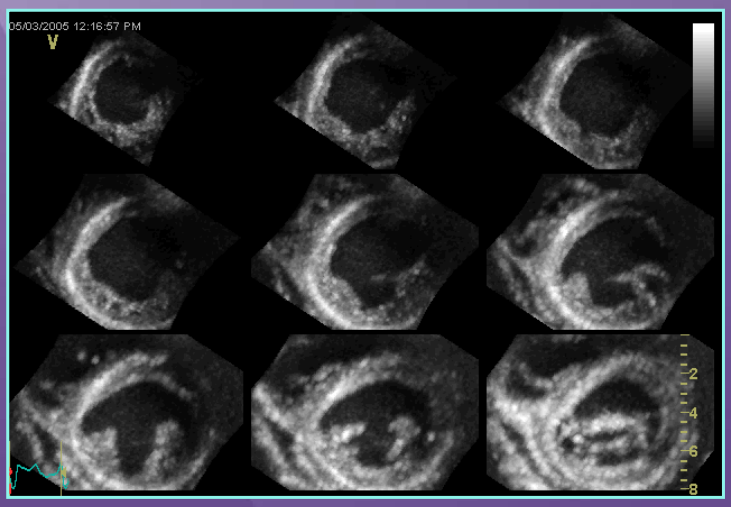
Quantification of Stroke Volume

2D or 3D Volumetric Assessment



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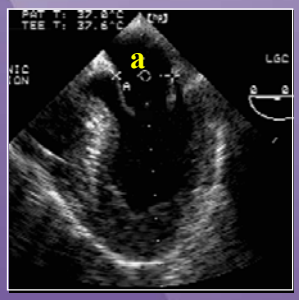
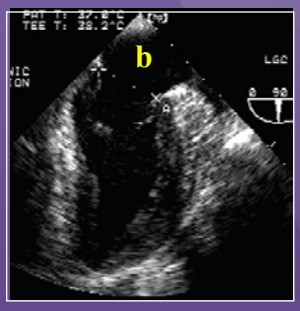
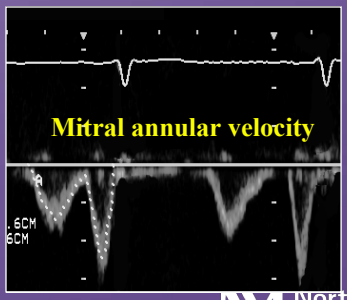




Calculation of Mitral Inflow By Biplane Transesophageal Echocardiography

Annular area = $\pi ab/4$

Stroke volume = $TVI_{MA} \times A_{MA}$



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Why Aren't Volumetric Methods Always Used?

Propagation of Errors

Subtracting two large numbers with an error that is magnified as the root sum square of the individual errors

$SV_{LV} = 100 \pm 10$ mL

$SV_{LVOT} = 60 \pm 10$ mL

$RV_{MV} = 40 \pm 14$ mL

95% CI for $RV_{MV} = (10, 70)$ mL

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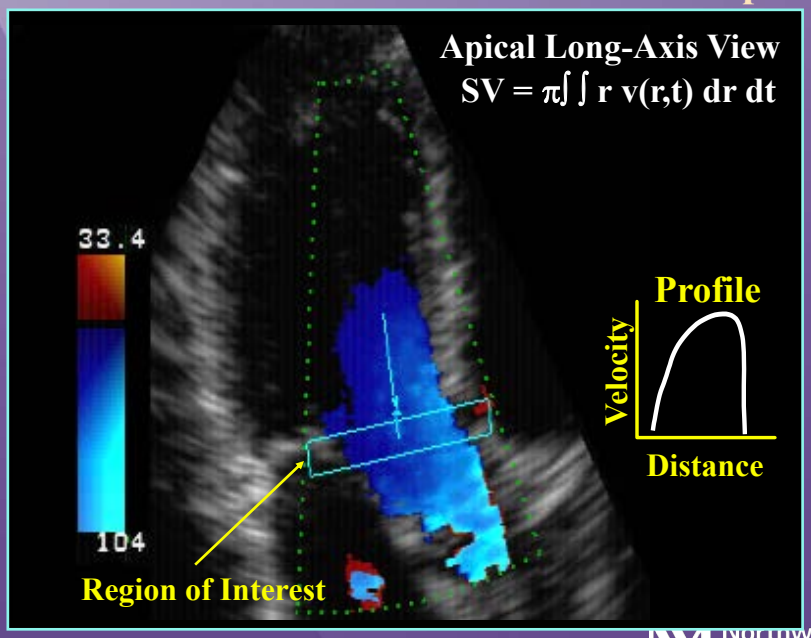
Automated Calculation of Cardiac Output



Sun et al, *Circulation* 1997; 95: 932-939

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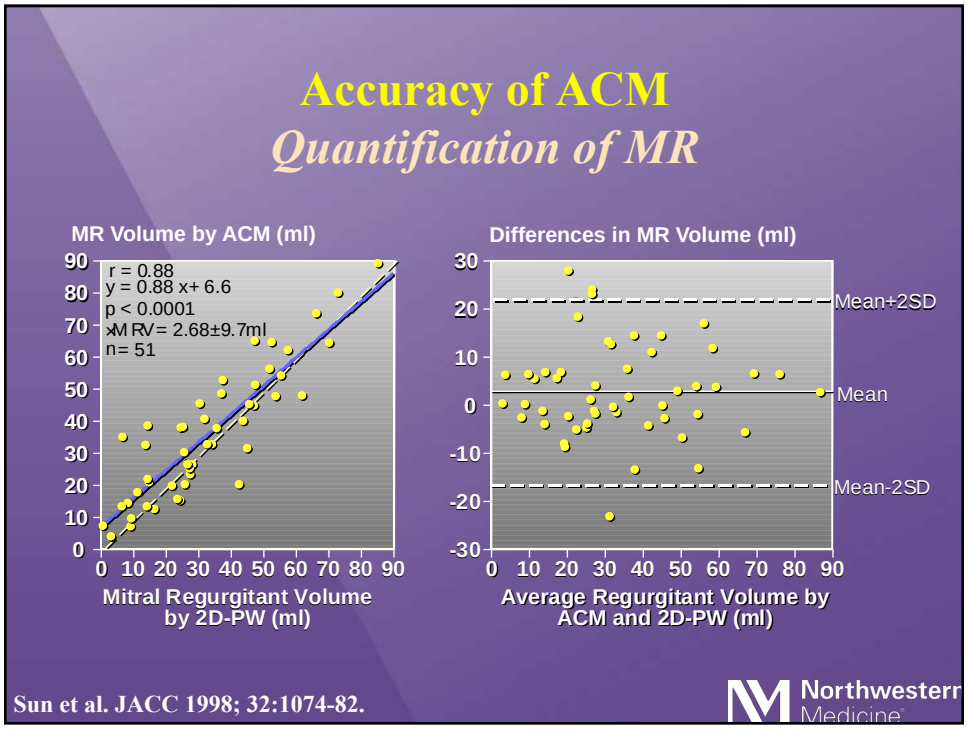
Accuracy of ACM
Quantification of MR
MR Volume by ACM (ml)
r = 0.88
y = 0.88 x+ 6.6
p < 0.0001
MRV= 2.68±9.7ml
n= 51
Mitral Regurgitant Volume by 2D-PW (ml)
Differences in MR Volume (ml)
Mean+2SD
Mean
Mean-2SD
Average Regurgitant Volume by ACM and 2D-PW (ml)
Sun et al. JACC 1998; 32:1074-82.
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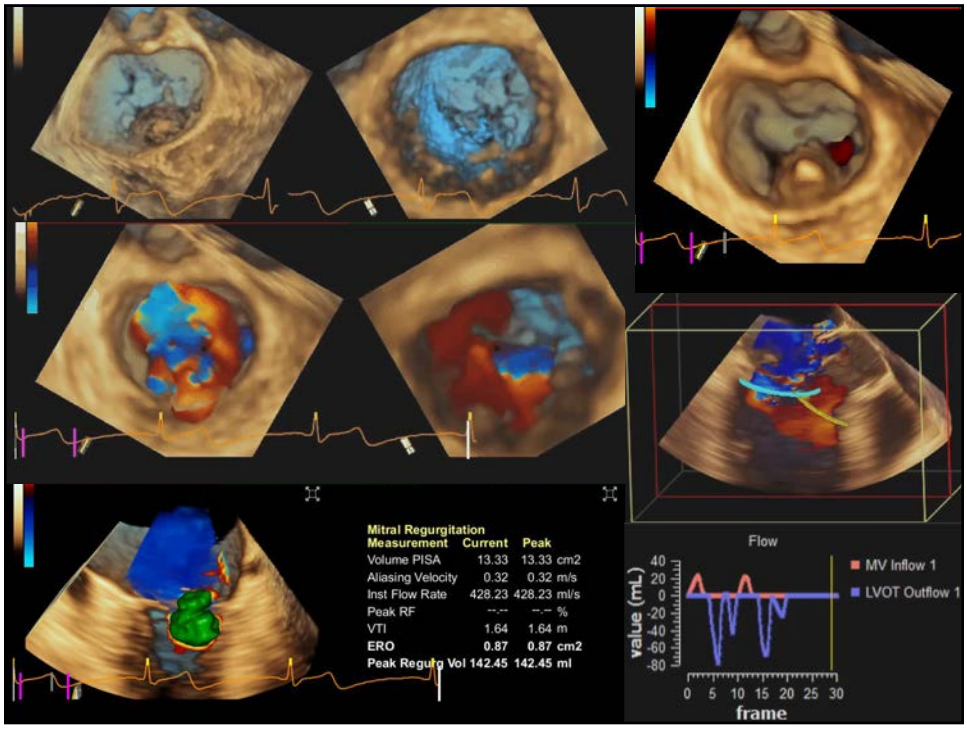
Mitral Regurgitation
Measurement Current Peak
Volume PISA 13.33 13.33 cm2
Aliasing Velocity 0.32 0.32 m/s
Inst Flow Rate 428.23 428.23 ml/s
Peak RF --.-- --.-- %
VTI 1.64 1.64 m
ERO 0.87 0.87 cm2
Peak Regurg Vol 142.45 142.45 ml
Flow
MV Inflow 1
LVOT Outflow 1
value (mL)
frame

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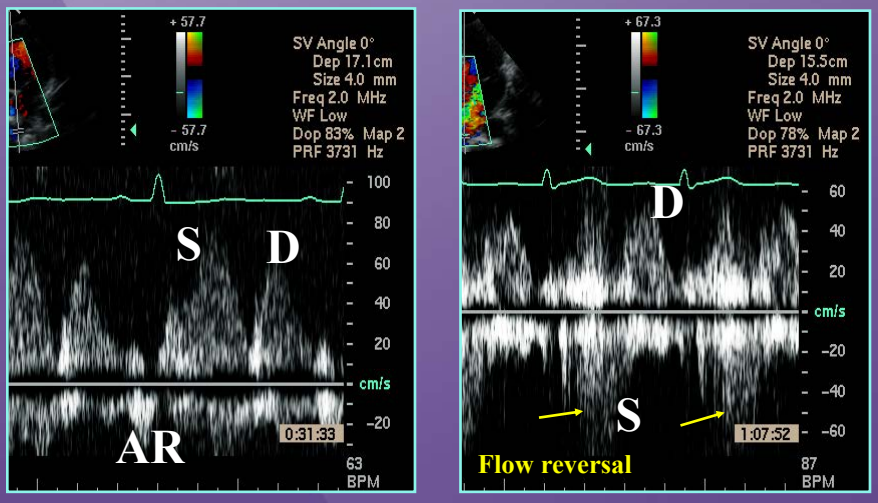
Assessment of Regurgitation
Pulmonary Venous Flow



Mild MR

Severe MR

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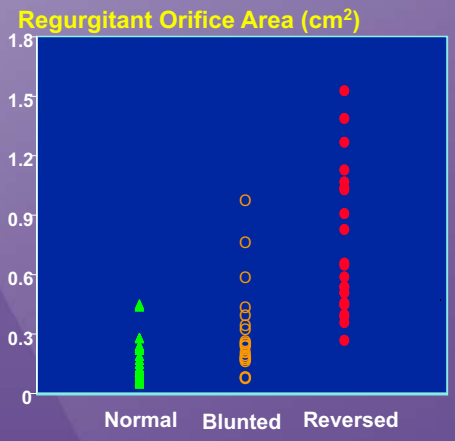
Quantification of MR
Limitations of Pulmonary Vein Patterns



Normal = mild; reversed = severe; blunted = anything

Pu et al. JASE 1999; 12: 736-743

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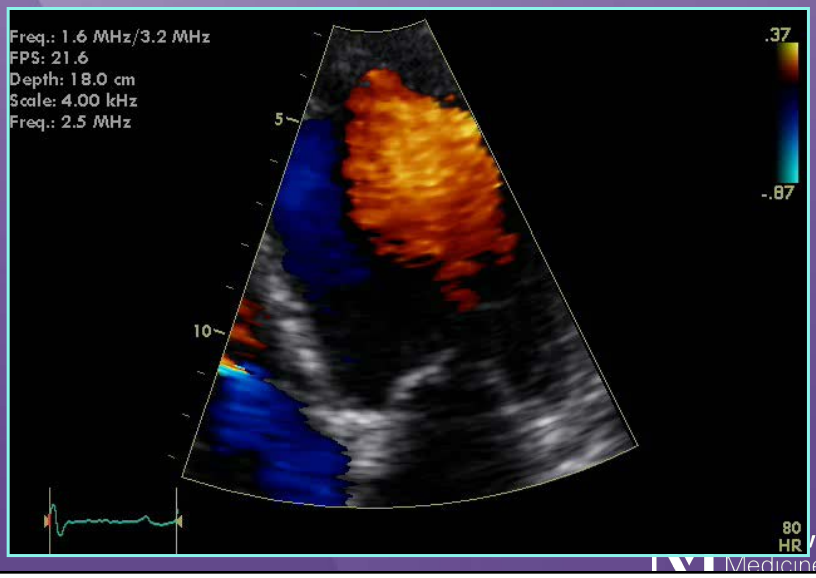
Quantification of MR
Vena Contracta Diameter



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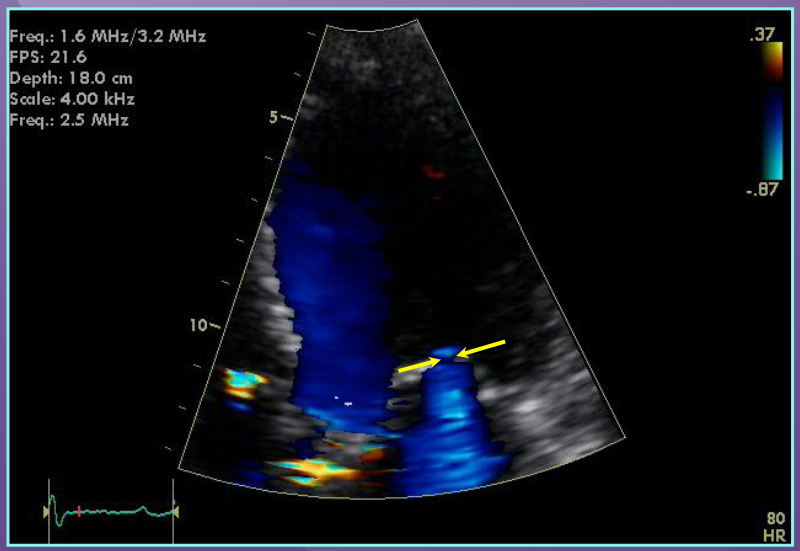
Quantification of MR
Vena Contracta Diameter



Limited by lateral resolution of echo

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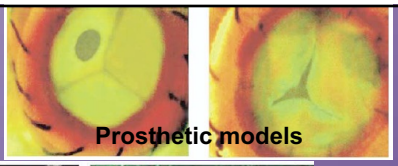
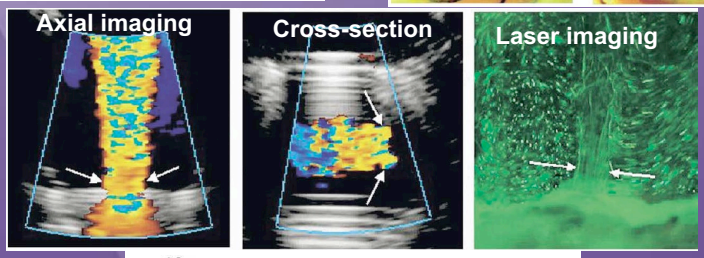
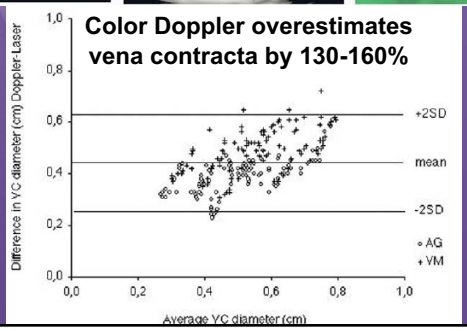
Doppler Echocardiographic Assessment of Valvular Regurgitation Severity by Measurement of the Vena Contracta: An In Vitro Validation Study

Julia Mascherbauer, MD, Raphael Rosenhek, MD, Barbara Bittner, PhD, Josefa Binder, MD, Paul Simon, MD, Gerald Maurer, MD, Heinrich Schima, PhD, and Helmut Baumgartner, MD, *Vienna, Austria*







JASE 2005; 18: 999

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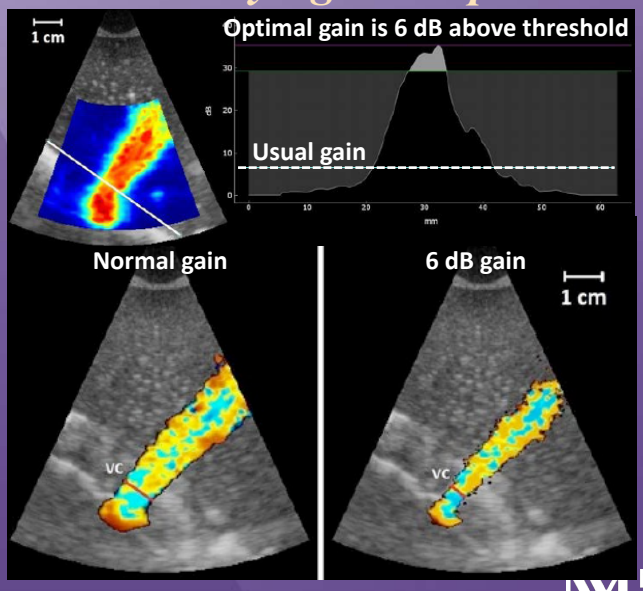
Adaptive Gain to Improve Vena Contracta

Underlying Principle



Kozlowski et al. Ultrasound in Med & Biol 2018; 44: 1770-7

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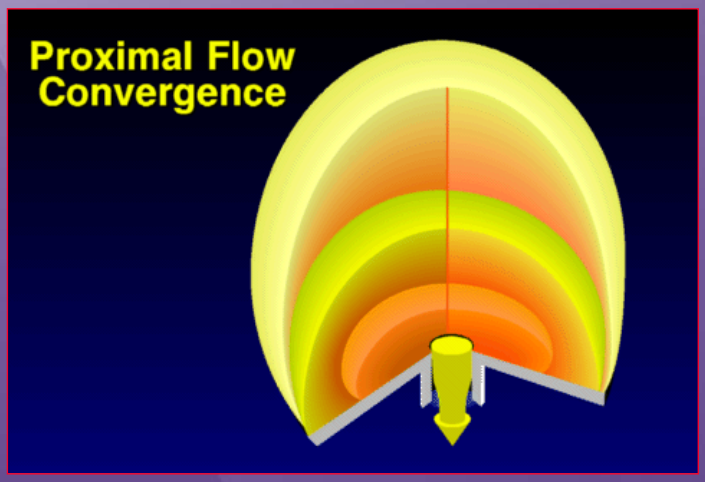
Proximal Convergence Method
Underlying Principle



Flow thru any isovelocity shell is equal to instantaneous orifice flow

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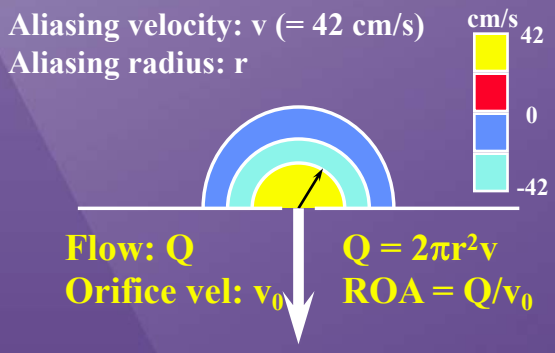
Quantification of Regurgitation

Proximal Convergence Method
Practical Implementation



Comprehensive, but there's an easier way.

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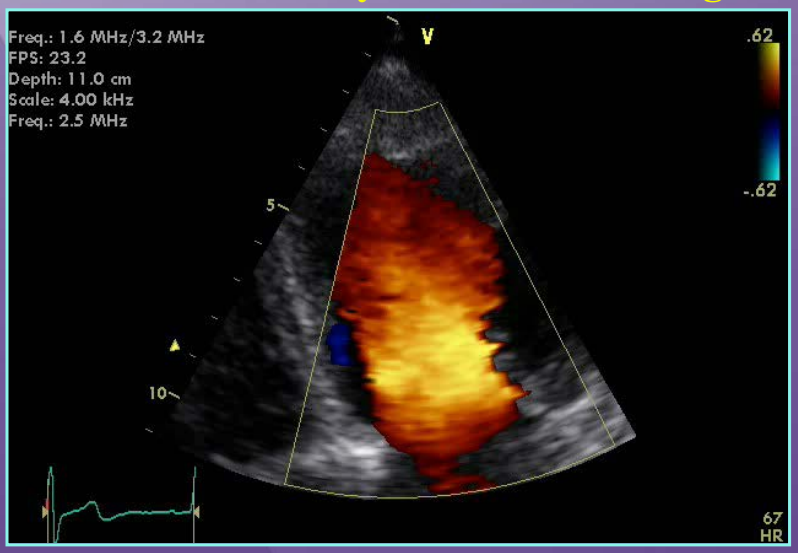
Assessment of MR by Proximal Convergence



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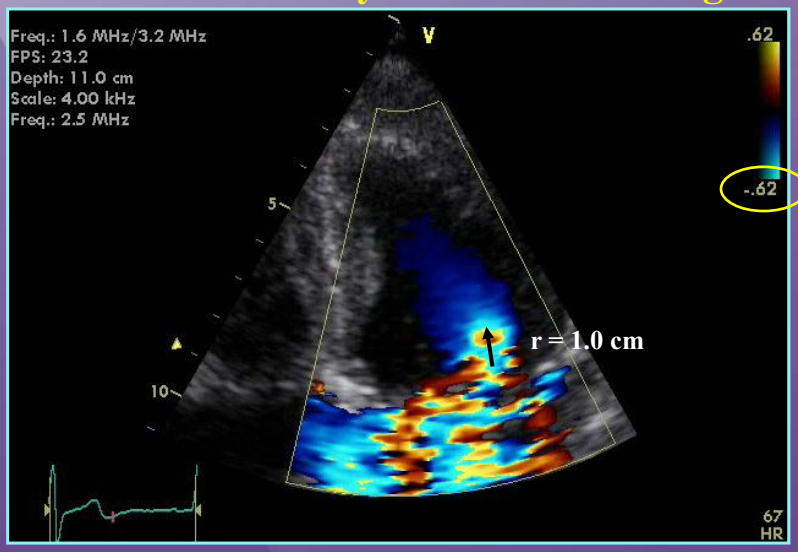
Assessment of MR by Proximal Convergence



$Q = 2\pi r^2 v = 6.28\ (1.0)^2\ 62 = 389$ ml/sec

$ROA = Q/v_0 = 389/550 = 0.7\ cm^2$

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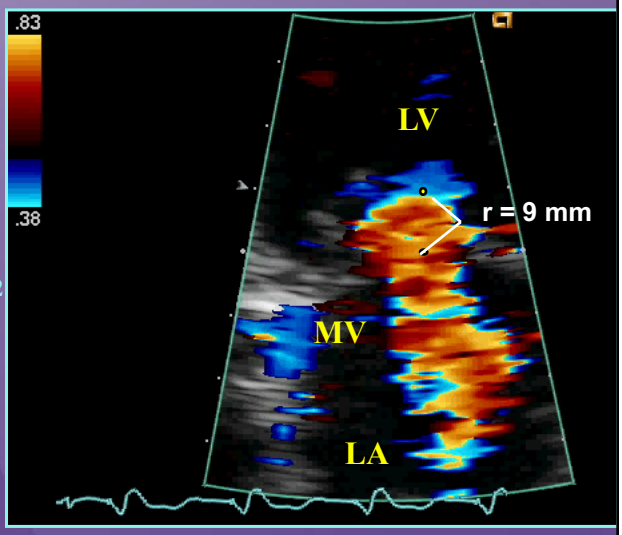
Measurement of Mitral ROA
Simplified PISA Formula

- *Assume LV-LA Δp is 100 mmHg*
- *Set aliasing velocity to (near) 40 cm/sec*
- *Then ROA = r²/2*

ROA = 9²/2 = 40 mm²



Pu et al., JASE 2001;14:180-5

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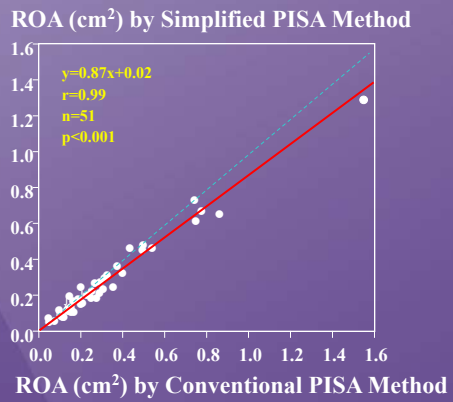
ROA by Simplified PISA Method: r²/2



Pu et al., JASE 2001;14:180-5

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PISA Adjustments
Pitfalls and Refinements to Keep in Mind

1. Nonholosystolic MR
2. Contour flattening near orifice
3. Proximal constraint distorting hemisphere
4. Noncircular orifice

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PISA Adjustments
Pitfalls and Refinements to Keep in Mind

1. Nonholosystolic MR
2. Contour flattening near orifice
3. Proximal constraint distorting hemisphere
4. Noncircular orifice

Dynamics of Mitral Regurgitant Flow and Orifice Area

Physiologic Application of the Proximal Flow Convergence Method: Clinical Data and Experimental Testing

Circulation 1994; 90: 307-322

Ehud Schwammenthal, MD; Chunguang Chen, MD; Frank Benning, BS; Michael Block, MD; Günter Breithardt, MD, FESC, FACC; Robert A. Levine, MD, FACC

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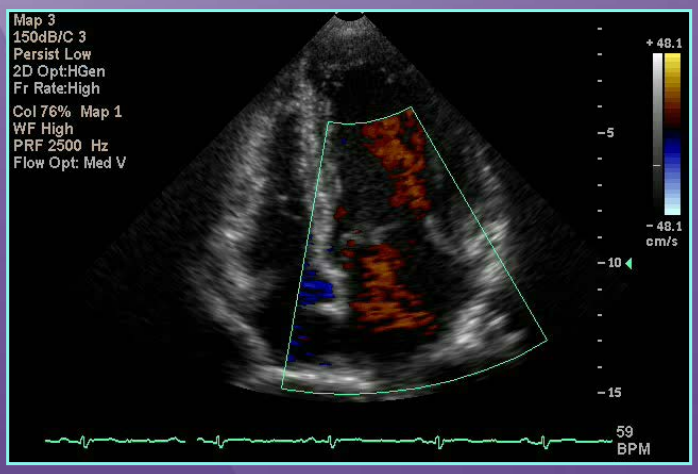
How Bad is this Regurgitation??

46 Year Old Woman Referred for Surgery



Large jet, large proximal convergence zone

ROA ~ 0.6 cm²

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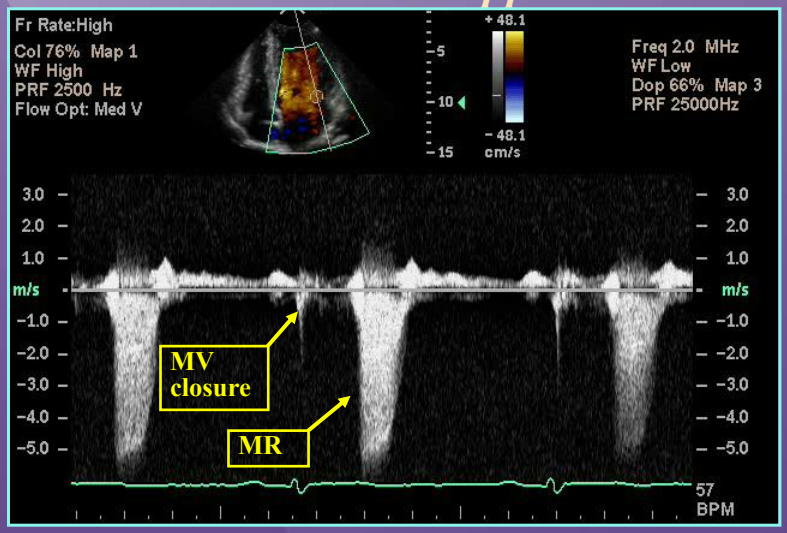
But Only Briefly!

Mitral CW Doppler



Significant MR only in latter half of systole

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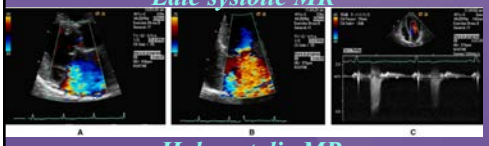
Impact of Duration of Mitral Regurgitation on Outcomes in Asymptomatic Patients With Myxomatous Mitral Valve Undergoing Exercise Stress Echocardiography

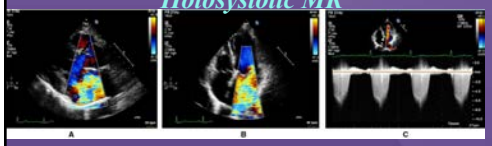
Peyman Naji, MD; Fadi Asfahan, MD; Tyler Barr; L. Leonardo Rodriguez, MD; Richard A. Grimm, MD; Shikhar Agarwal, MD, MPH; James D. Thomas, MD; A. Marc Gillinov, MD; Tomislav Mihaljevic, MD; Brian P. Griffin, MD; Milind Y. Desai, MD

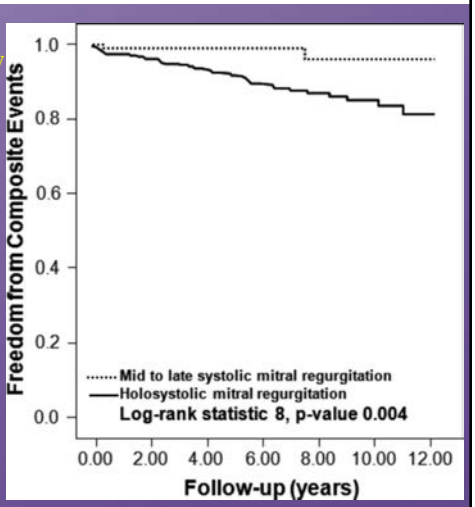
- 609 pts w/ ≥ 3+ MR (122 late systolic)
- All underwent stress echocardiography
- Late MR pts were younger and more likely female
- Endpoints: death and CHF
- HS vs LS: 4.99x more likely endpoints

Late systolic MR



Holosystolic MR





Naji et al., JAHA 2015; 4: e001348

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What's New in MR Quantification?

3D PISA Analysis!

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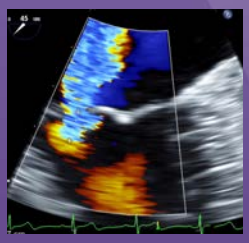
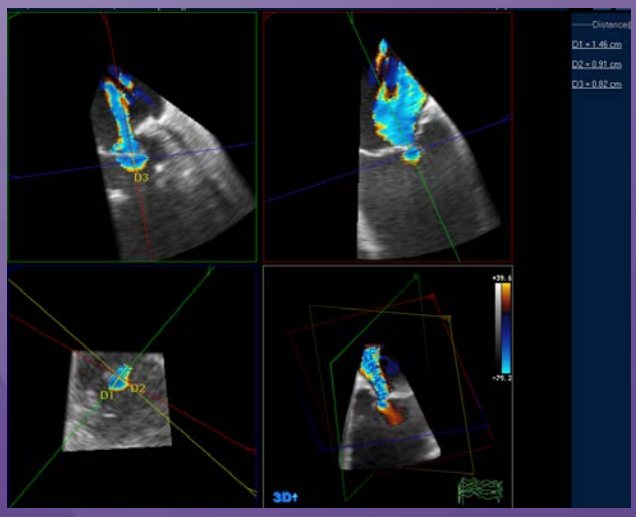
Proximal Isovelocity Surface Area





Thavendiranathan et al, JACC Cardiovascular Imaging, 2012, 5(11):1161-75.
Thavendiranathan et al, JACC 2012, 60(16): 1470-83

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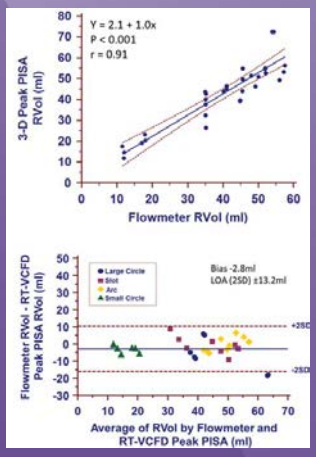
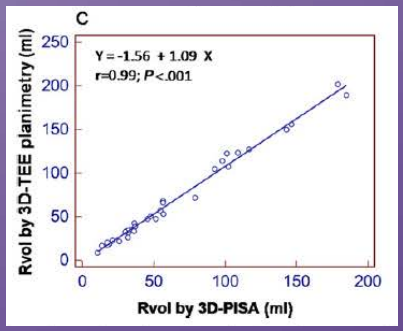
Proximal Isovelocity Surface Area



Thavendiranathan et al. Circulation cardiovascular imaging 2013, 6(1): 125-33



De Augustin JA et al, J Am Soc Echocardiogr. 2012 Aug;25(8):815-23

Biblical degree of accuracy?

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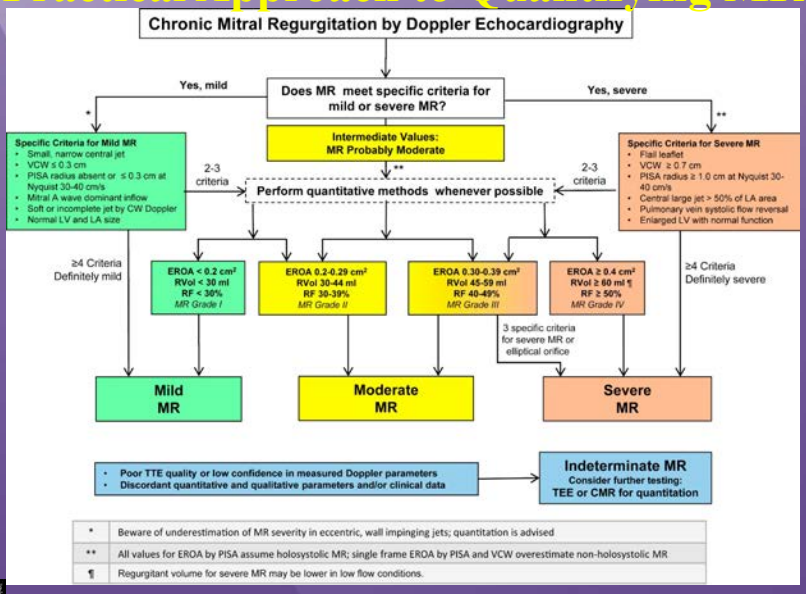
Practical Approach to Quantifying MR



JASE 2017; 30: 303-371
Journal of the American Society of Echocardiography 2017 30, 303-371DOI: (10.1016/j.echo.2017.01.007)

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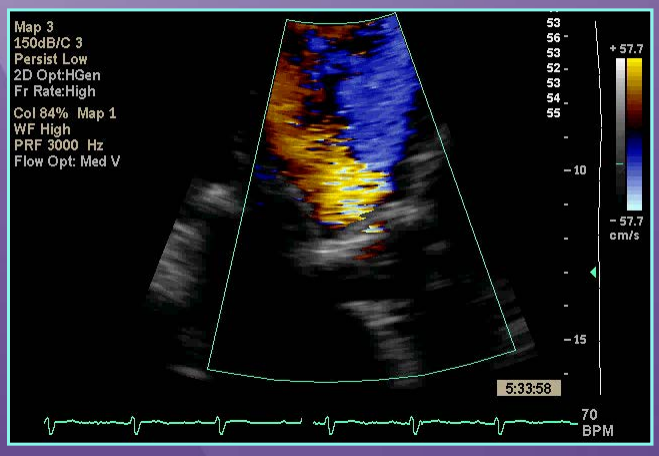
What About AR???



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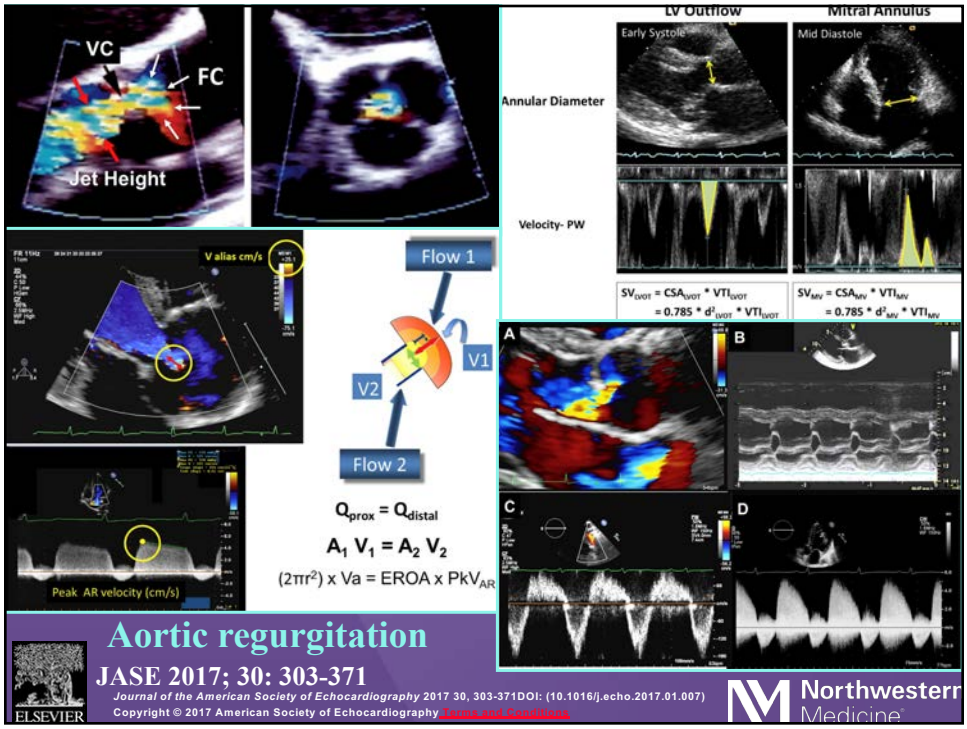

55

Quantification of AR
What are the Alternatives?

- *Color jet area*
- *Vena contracta*
- *AR pressure half-time*
- *Aortic flow reversal*
- *Pulsed Doppler and 2D difference methods*
- *ACOM methods*
- *Proximal convergence method*

Many parameters similar to MR

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Quantification of AR
What are the Alternatives?

- *Color jet area*
- *Vena contracta*
- ***AR pressure half-time***
- *Aortic flow reversal*
- *Pulsed Doppler and 2D difference methods*
- *ACOM methods*
- *Proximal convergence method*

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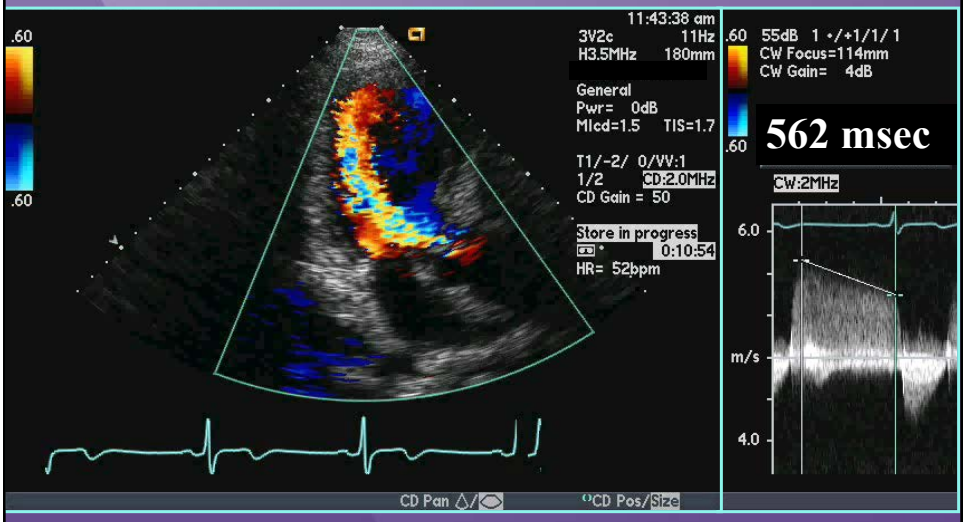
AR Pressure Half-Time



Chronic Moderate AR

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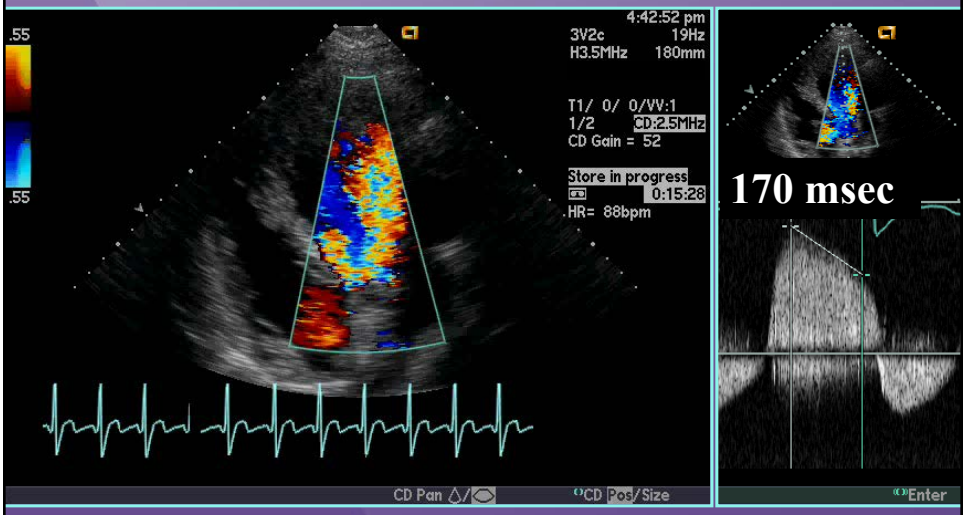
AR Pressure Half-Time



Acute Severe AR (endocarditis)

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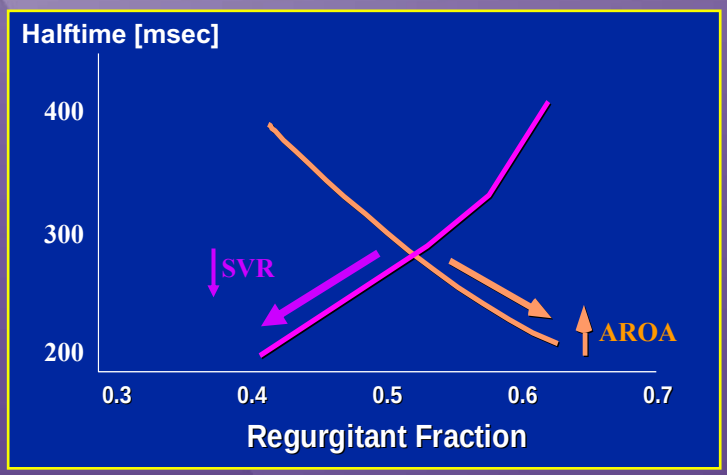
AR Halftime vs RF
Contrasting Effect of ROA and SVR



Griffin et al *Am Heart J* 1991;122:1049-1056, *Eur Heart J* 199[illegible] 681-685.

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Quantification of AR
What are the Alternatives?

- *Color jet area*
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- ***Aortic flow reversal***
- *Pulsed Doppler and 2D difference methods*
- *ACOM methods*
- *Proximal convergence method*

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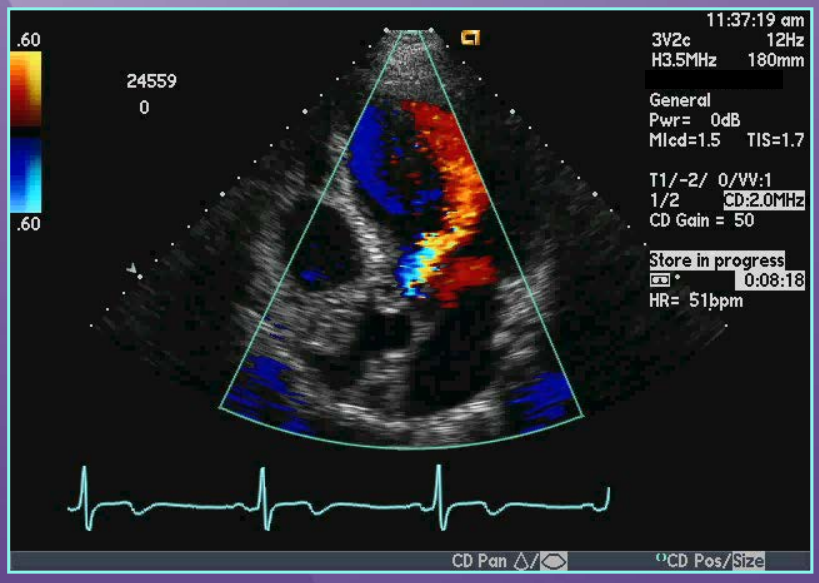
Apical Five-Chamber View



AR of Unclear Severity

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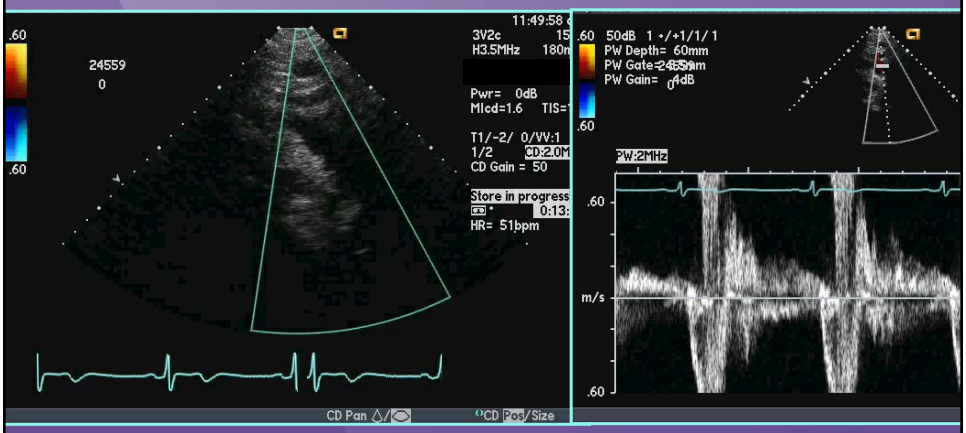
Aortic Arch Doppler



Moderately severe AR

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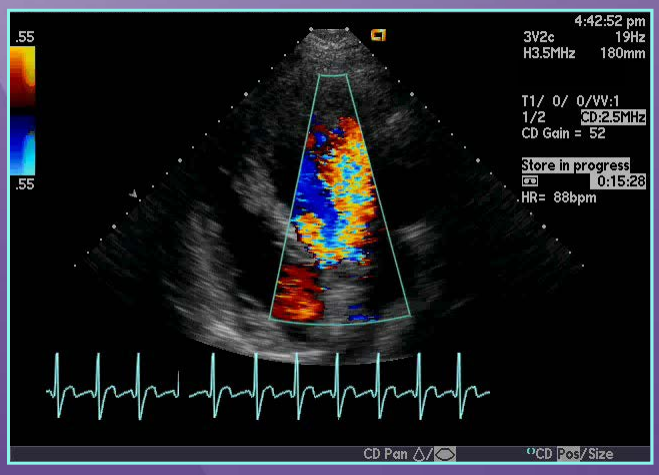
Apical Five-Chamber View



AR of Unclear Severity

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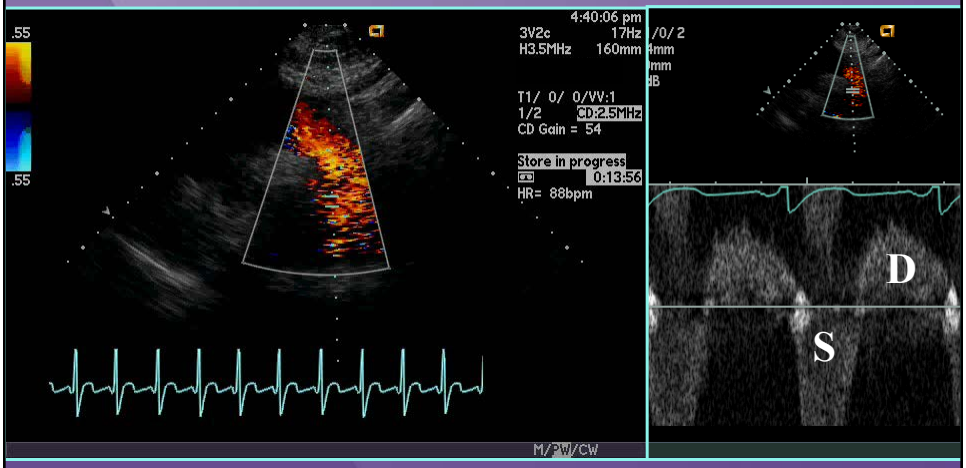
Aortic Arch Doppler



Severe AR

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If I could have only one piece of data regarding AR severity……

…….it would be an aortic arch pulsed Doppler recording.

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Quantification of AR
What are the Alternatives?

- *Color jet area*
- *Vena contracta*
- *AR pressure half-time*
- *Aortic flow reversal*
- *Pulsed Doppler and 2D difference methods*
- *ACOM methods*
- ***Proximal convergence method***

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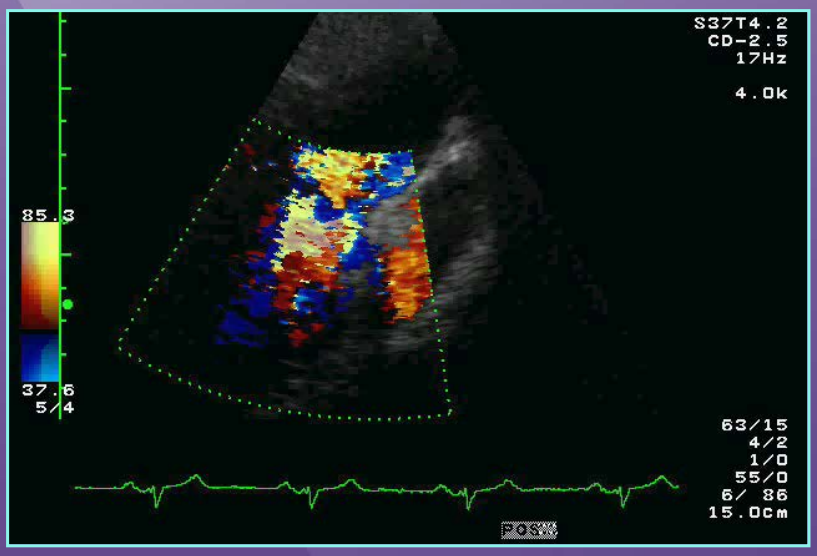
Right Parasternal View



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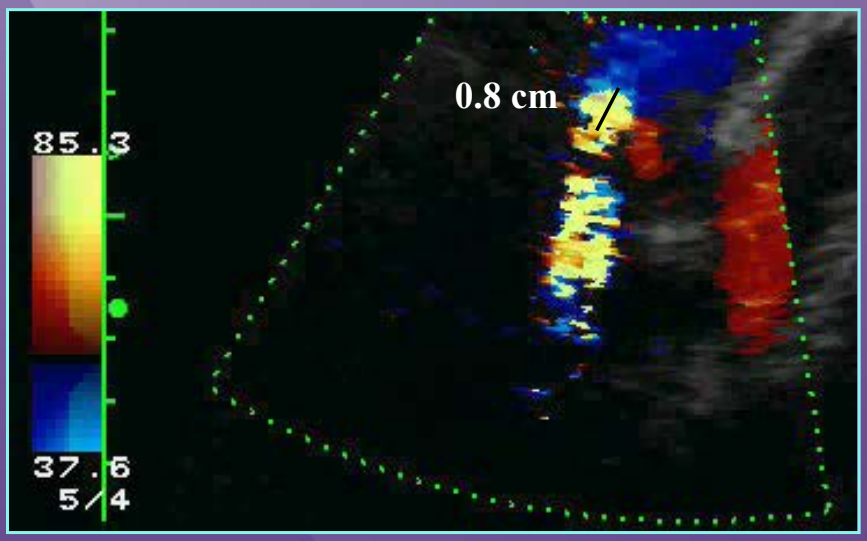
PISA in AR



$Q = 2\pi r^2 v = 6.28\ (0.8)^2\ 38 = 150$ ml/sec

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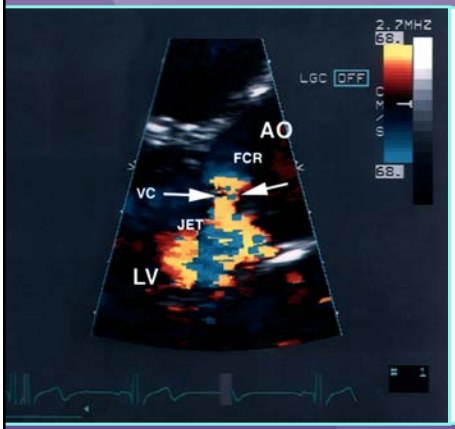
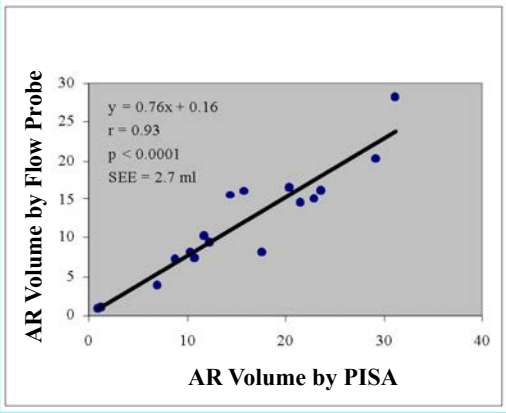
Validation of AR PISA





Shiota et al Am J Cardiol 1999; 83:1064-1068.

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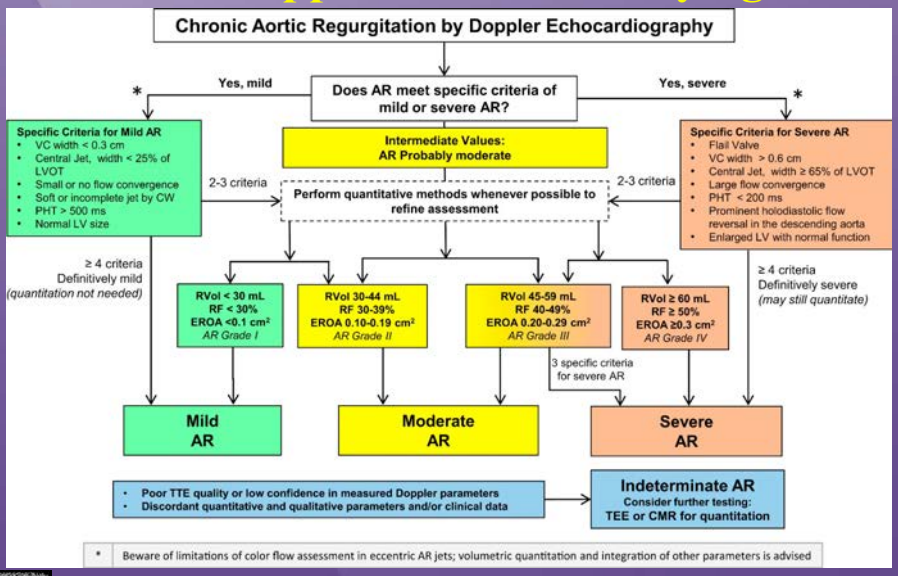
Practical Approach to Quantifying AR



JASE 2017; 30: 303-371
Journal of the American Society of Echocardiography 2017 30, 303-371DOI: (10.1016/j.echo.2017.01.007)

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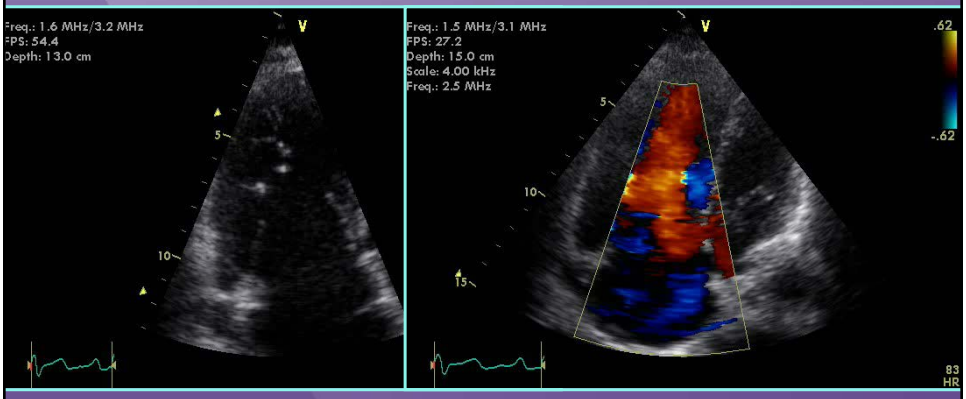
How About TR?



Incomplete TV closure with severe functional TR

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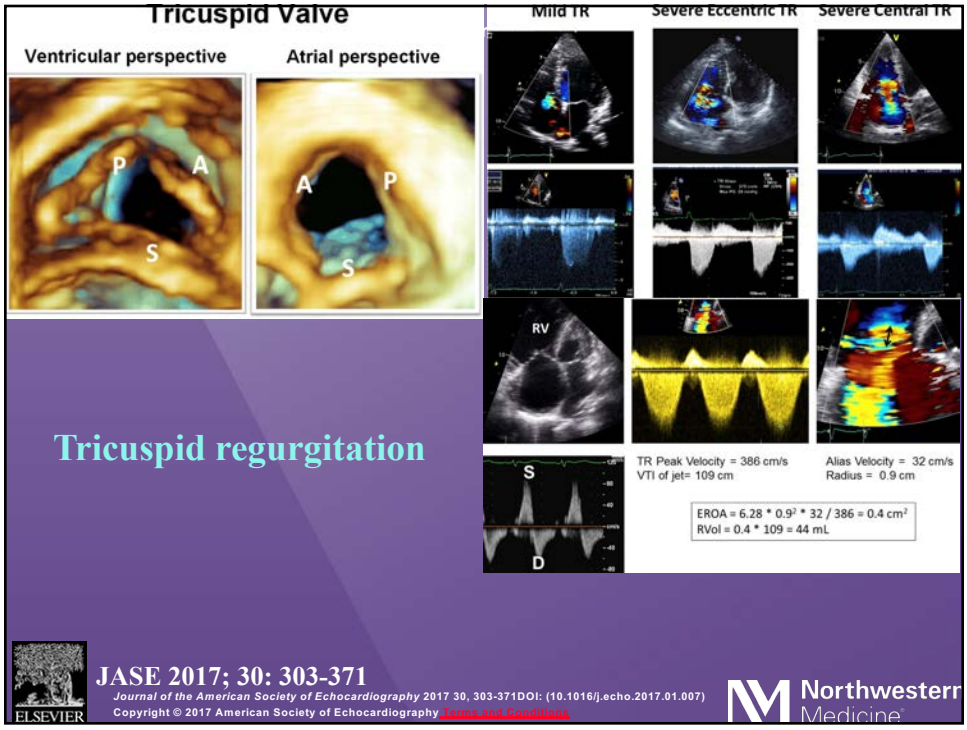
Tricuspid Valve
Ventricular perspective
Atrial perspective
P
A
S
A
P
S
Mild TR
Severe Eccentric TR
Severe Central TR
RV
S
D
TR Peak Velocity = 386 cm/s
VTI of jet= 109 cm
Alias Velocity = 32 cm/s
Radius = 0.9 cm
EROA = 6.28 * 0.9² * 32 / 386 = 0.4 cm²
RVol = 0.4 * 109 = 44 mL
Tricuspid regurgitation
JASE 2017; 30: 303-371
Journal of the American Society of Echocardiography 2017 30, 303-371DOI: (10.1016/j.echo.2017.01.007)
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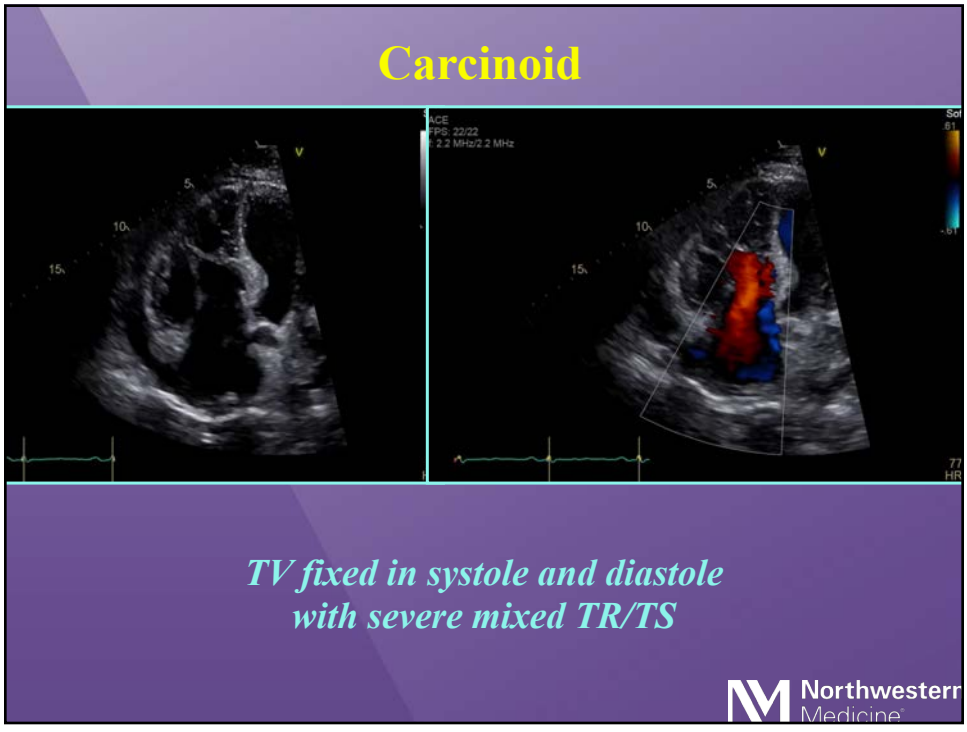
Carcinoid
TV fixed in systole and diastole
with severe mixed TR/TS
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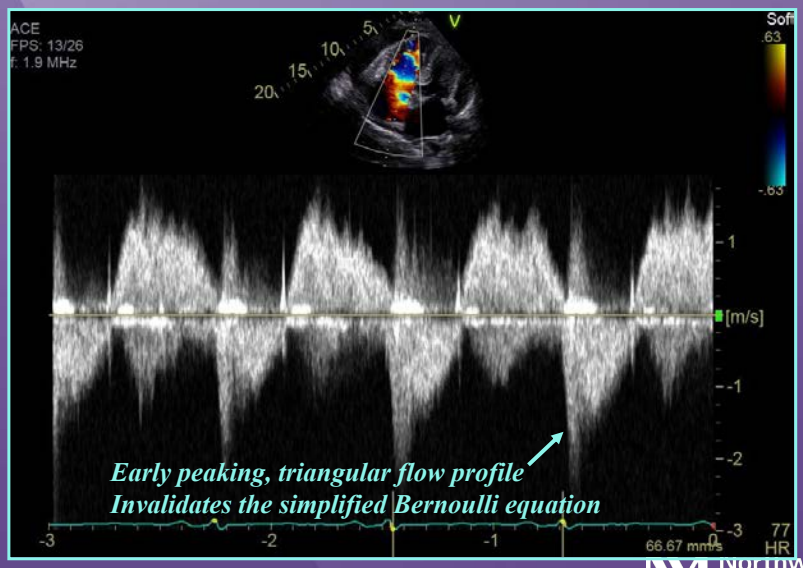
Tricuspid Valve CW
Severe TR



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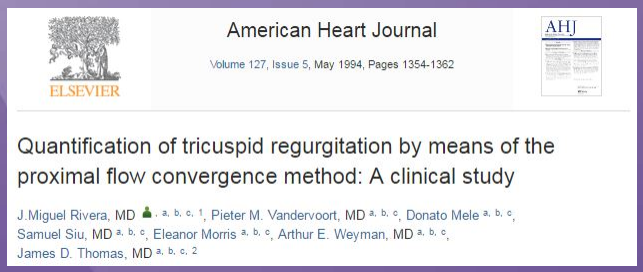
Can PISA be used in TR???
Yes, but…


American Heart Journal

Volume 127, Issue 5, May 1994, Pages 1354-1362

ELSEVIER

Quantification of tricuspid regurgitation by means of the proximal flow convergence method: A clinical study

J.Miguel Rivera, MD [a, b, c, 1], Pieter M. Vandervoort, MD [a, b, c], Donato Mele [a, b, c], Samuel Siu, MD [a, b, c], Eleanor Morris [a, b, c], Arthur E. Weyman, MD [a, b, c], James D. Thomas, MD [a, b, c, 2]

- **Limited validation and experience**
- **Contour flattening a bigger issue**
- **Orifices can be bizarrely shaped**

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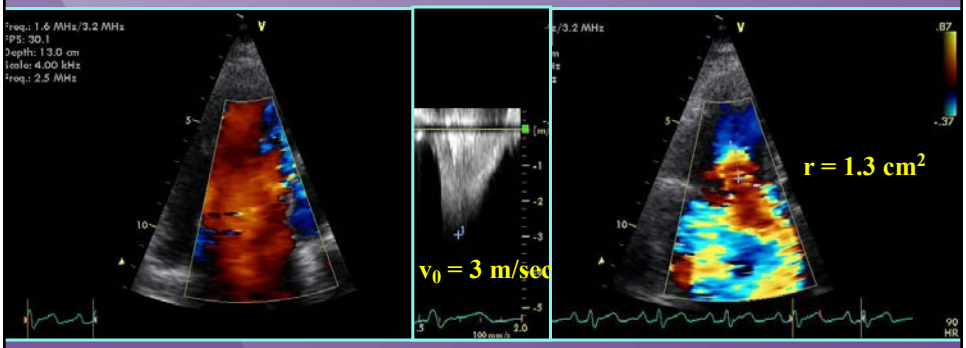
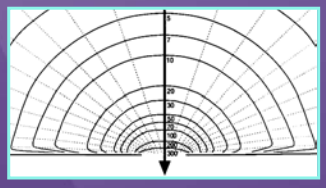
PISA in TR



$Q = 2\pi r^2 v = 6.28\ (1.3)^2\ 37 = 393$ ml/sec

$ROA = Q/v_0 = 393/300 = 1.3$ cm^2



But 37/300 is 0.12, so we're underestimating by 12%

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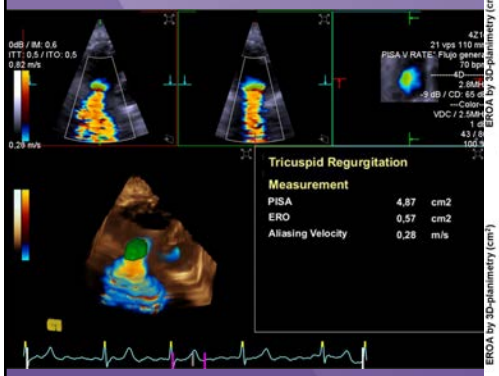
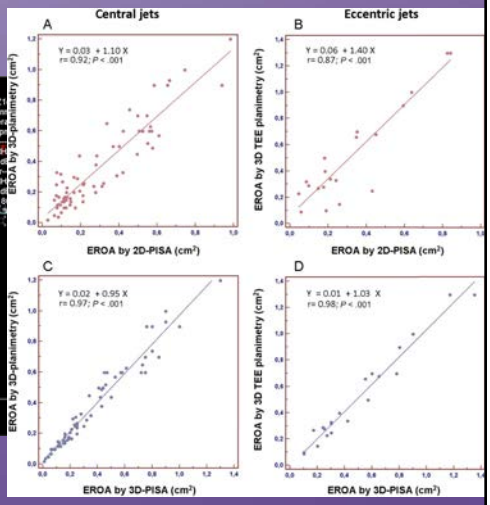
3D PISA in TR?





Again, biblical degree of accuracy?

De Augustin et al. JASE 2013: 28: 1063-72

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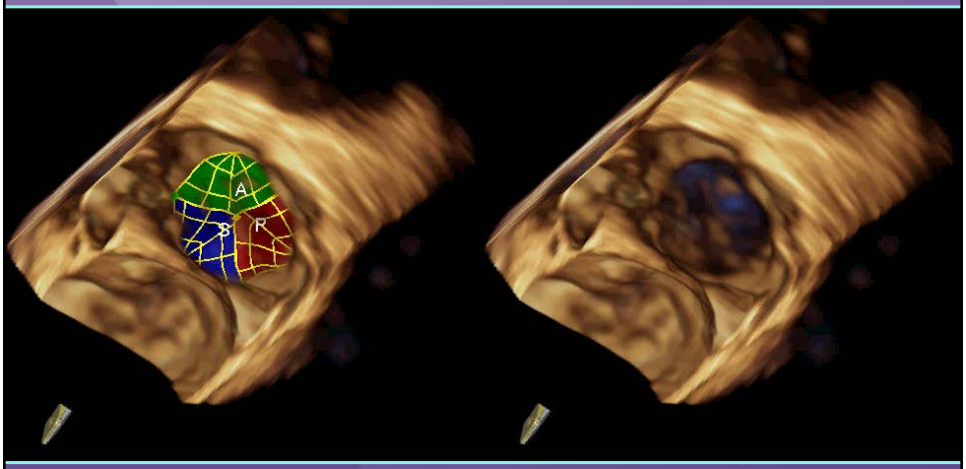
3D Tools are Progressing Rapidly



Clip courtesy of Helene Houle, Siemens

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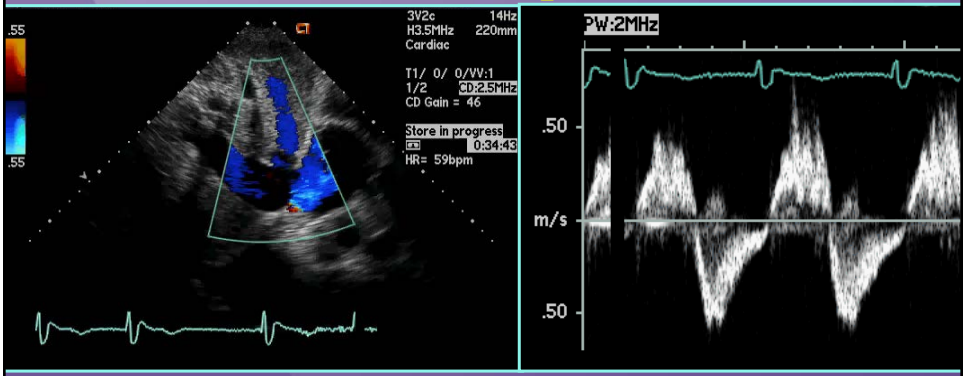
What about systolic flow reversal in the hepatic veins?



"Usually" a pretty specific sign of severe TR

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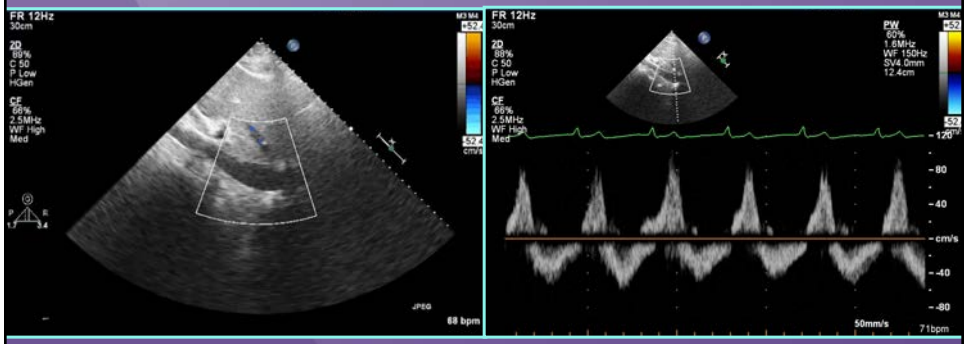
So how bad's the TR here?



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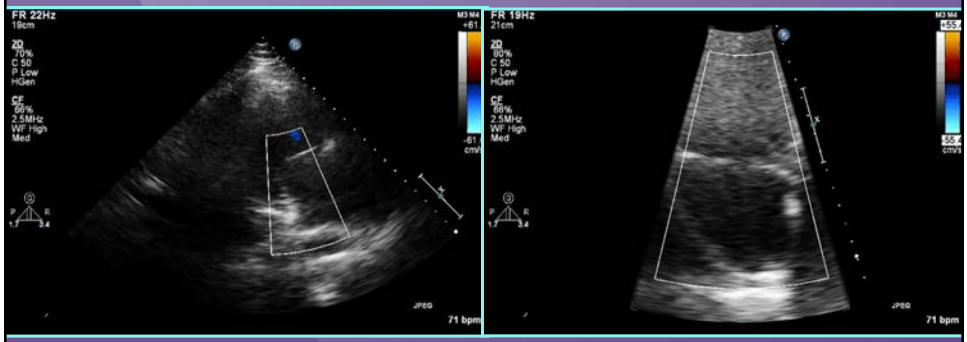
Not so bad



How come?

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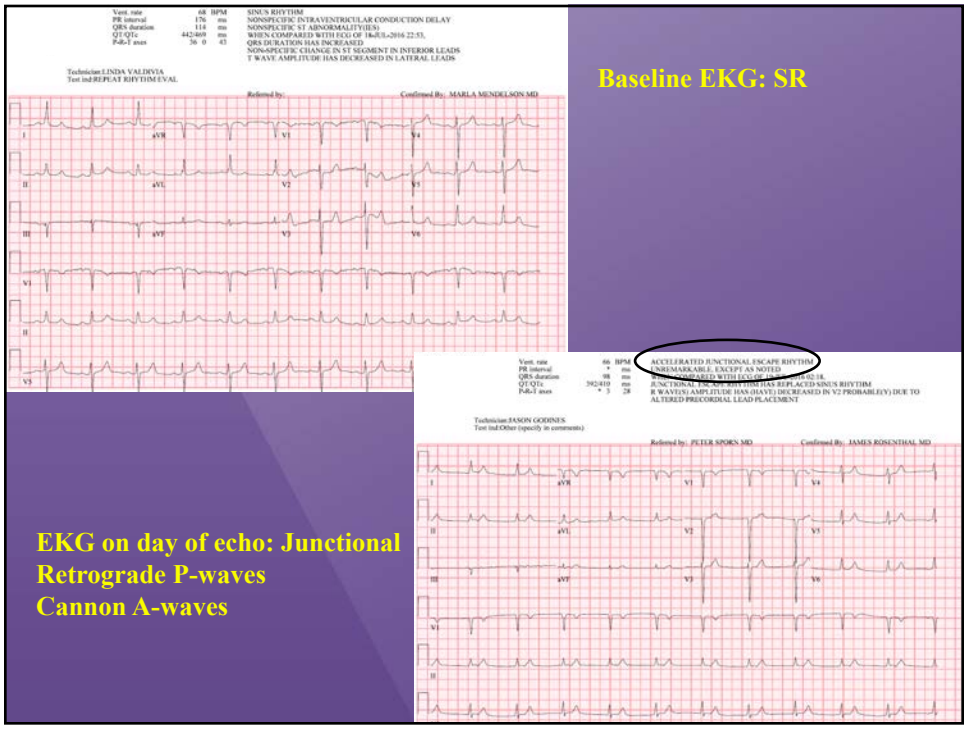
Baseline EKG: SR
EKG on day of echo: Junctional
Retrograde P-waves
Cannon A-waves

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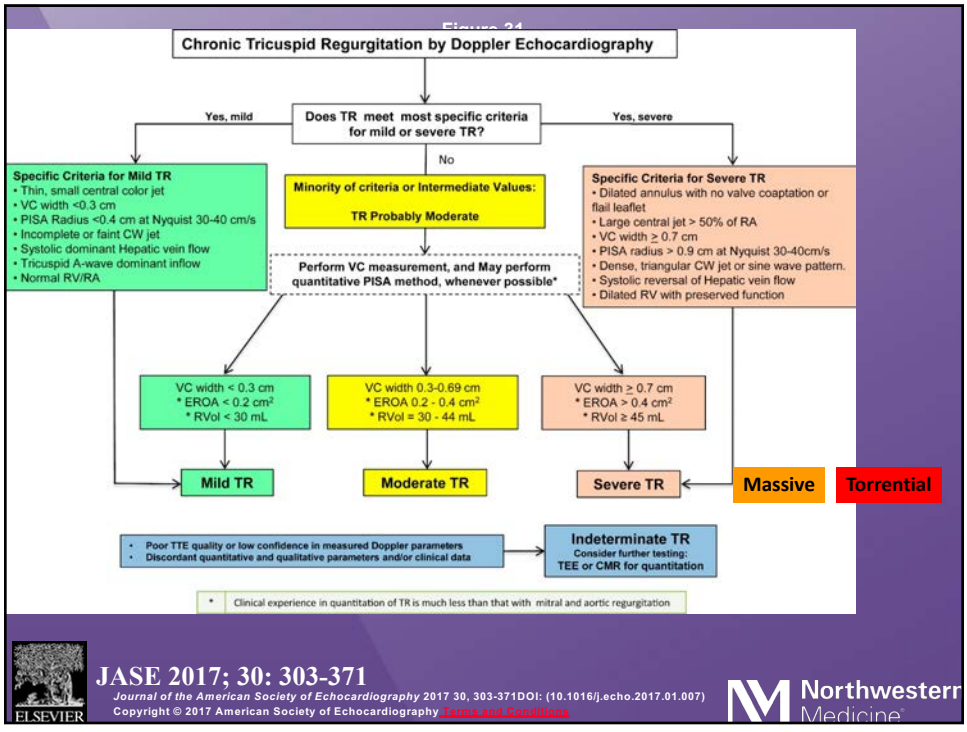
Chronic Tricuspid Regurgitation by Doppler Echocardiography
Does TR meet most specific criteria for mild or severe TR?
Yes, mild
Yes, severe
No
Specific Criteria for Mild TR
• Thin, small central color jet
• VC width <0.3 cm
• PISA Radius <0.4 cm at Nyquist 30-40 cm/s
• Incomplete or faint CW jet
• Systolic dominant Hepatic vein flow
• Tricuspid A-wave dominant inflow
• Normal RV/RA
Minority of criteria or Intermediate Values:
TR Probably Moderate
Specific Criteria for Severe TR
• Dilated annulus with no valve coaptation or flail leaflet
• Large central jet > 50% of RA
• VC width ≥ 0.7 cm
• PISA radius > 0.9 cm at Nyquist 30-40cm/s
• Dense, triangular CW jet or sine wave pattern.
• Systolic reversal of Hepatic vein flow
• Dilated RV with preserved function
Perform VC measurement, and May perform quantitative PISA method, whenever possible*
VC width < 0.3 cm
* EROA < 0.2 cm²
* RVol < 30 mL
VC width 0.3-0.69 cm
* EROA 0.2 - 0.4 cm²
* RVol = 30 - 44 mL
VC width ≥ 0.7 cm
* EROA > 0.4 cm²
* RVol ≥ 45 mL
Mild TR
Moderate TR
Severe TR
Massive
Torrential
Poor TTE quality or low confidence in measured Doppler parameters
Discordant quantitative and qualitative parameters and/or clinical data
Indeterminate TR
Consider further testing:
TEE or CMR for quantitation
Clinical experience in quantitation of TR is much less than that with mitral and aortic regurgitation
JASE 2017; 30: 303-371
Journal of the American Society of Echocardiography 2017 30, 303-371DOI: (10.1016/j.echo.2017.01.007)
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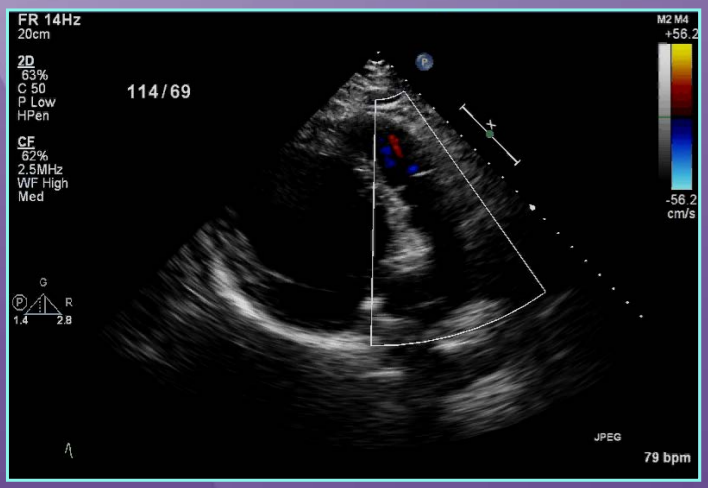
And What of PR?



Actually, no one cares about PR

With ONE exception

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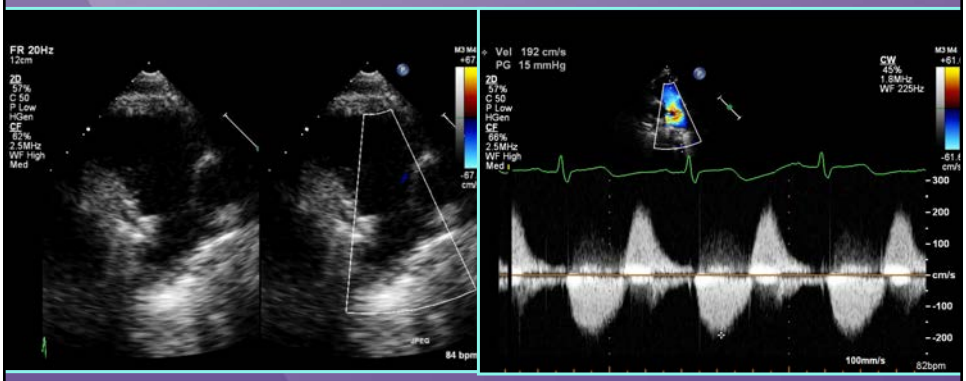
Severe PR s/p ToF Repair



The most severe PR is virtually inapparent by color Doppler. Look at the CW Doppler

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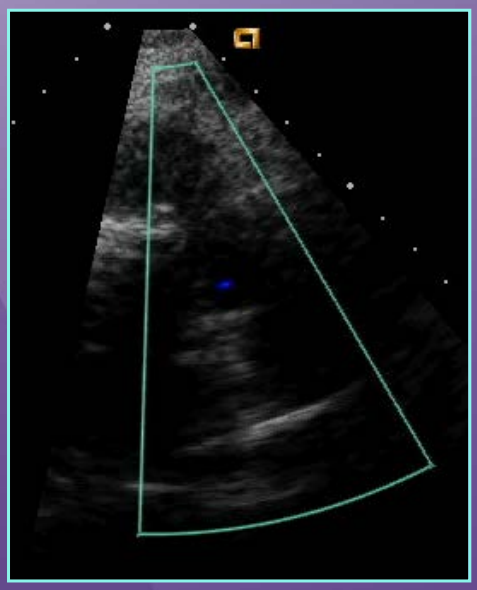
PR So Severe You Can't See It!!



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PISA

Is It the Best Way to Quantify Regurgitation??

Of Course!!

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