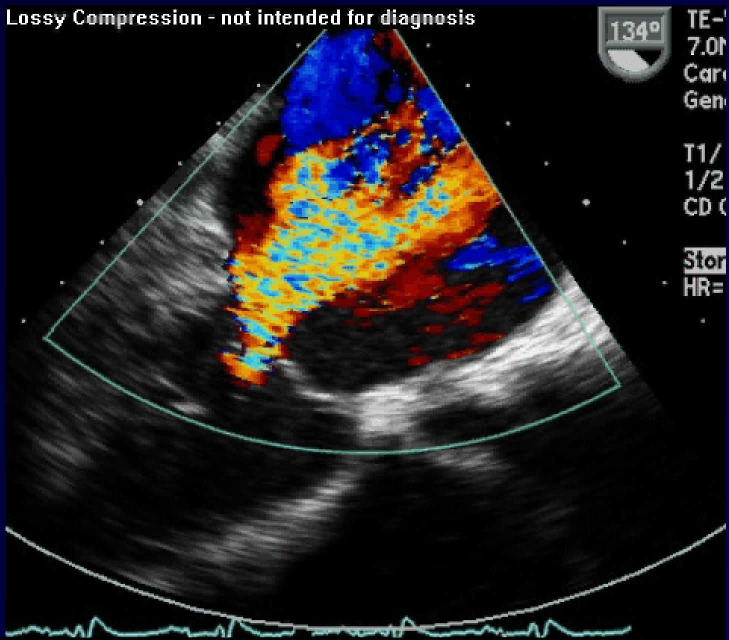
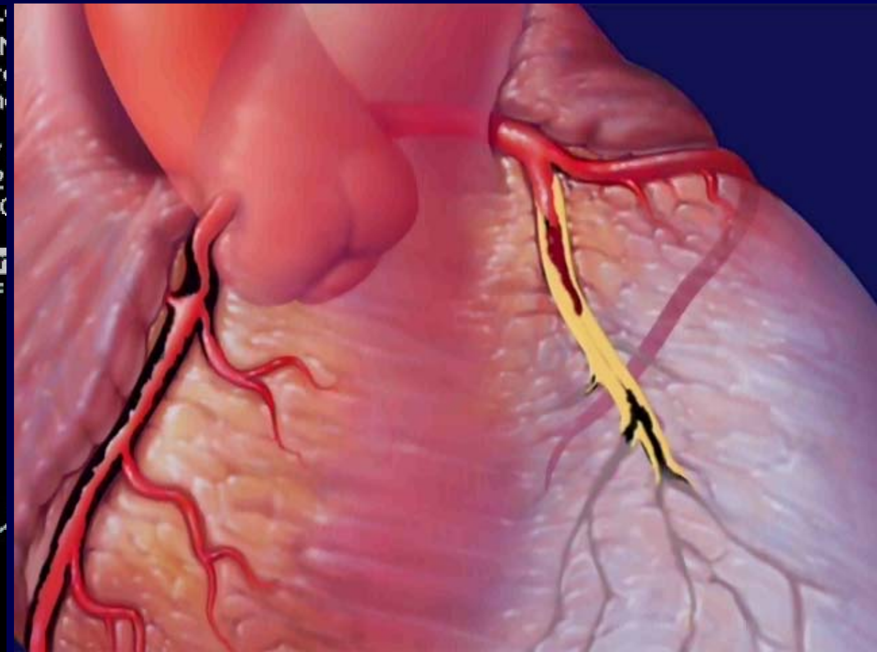
Imaging the Hemodynamics

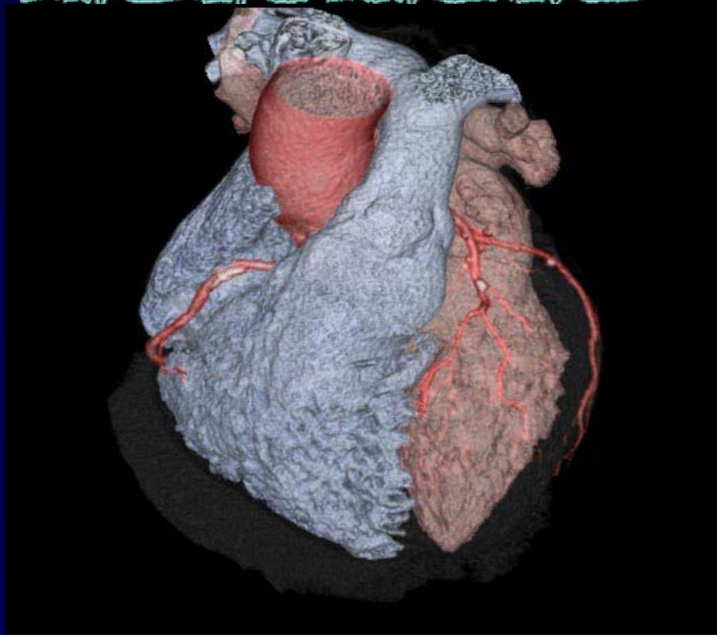
Hemodynamics by Echocardiography

홍 그 루
연세의대 심장내과

The Present: Image Guided Diagnosis and Intervention







Echocardiography

Anatomic Information

Functional Information

Echocardiography

Functional Information

- Systolic Function
- *Wall Motion Analysis*
- Diastolic Function
- Valvular Function
- Hemodynamic Function

- Christian Johann Doppler(1842) -

Christian Doppler was an Austrian mathematician who lived between 1803-1853. He is known for the principle he first proposed in ***Concerning the coloured light of double stars*** in 1842. He hypothesised that the pitch of a sound would change if the source of the sound was moving. He didn't test this hypothesis until 1845.

Doppler Echocardiography History

- ***1959 Satomura***
  detected arterial flow
- ***1961 Franklin***
  measurement of flow velocity
- ***1973 Johnson***
  located place of cardiac murmur
- ***1978 Hatle***
  measured PG between LA and LV
- ***1982 Namekawa***
  real time color Doppler using autocorrelator technique

Hemodynamic data that can be obtained with Doppler echocardiography

- ***Volumetric measurements***
  - Stroke volume and cardiac output
  - Regurgitant volume and fraction
  - Pulmonary-systemic flow ratio(Qp/Qs)
- ***Pressure gradients***
  - Maximal instantaneous gradient
  - Mean gradient
- ***Valve area***
  - Stenotic valve area
  - Regurgitant orifice area
- ***Intracardiac pressure***
  - Pulmonary artery pressure, LA pressure, LVEDP

Stroke Volume, Cardiac Output, Cardiac Index

- SV(cc) = TVI(cm) x CSA(cm^2)
- CO(liters/min) = SV(cc) x HR(beats/min)
- CI(liters/min/m^2) = CO(liters/min) x BSA(m^2)

Pressure gradient from Doppler measurements

- ***Pressure gradient*** →

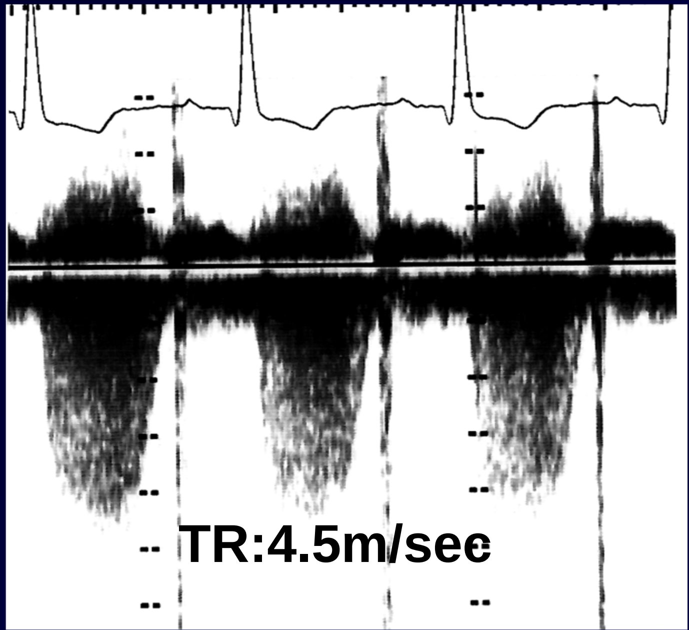
- *Modified Bernoulli Eq.*

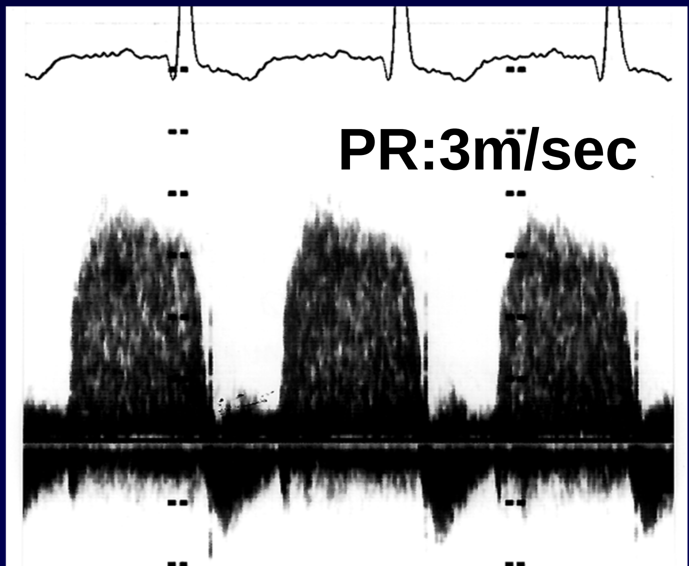
$$\Delta P = 4 V^2$$

Limitation of Doppler velocity

(and pressure gradient derived thereof)

→ ***Volume and Rate-dependent***





Estimation of Pulmonary Arterial Pressure

Assume RAP 10mmHg

PASP $= TR^2 \times 4 + RAP$

$= 4.5^2 \times 4 + 10$

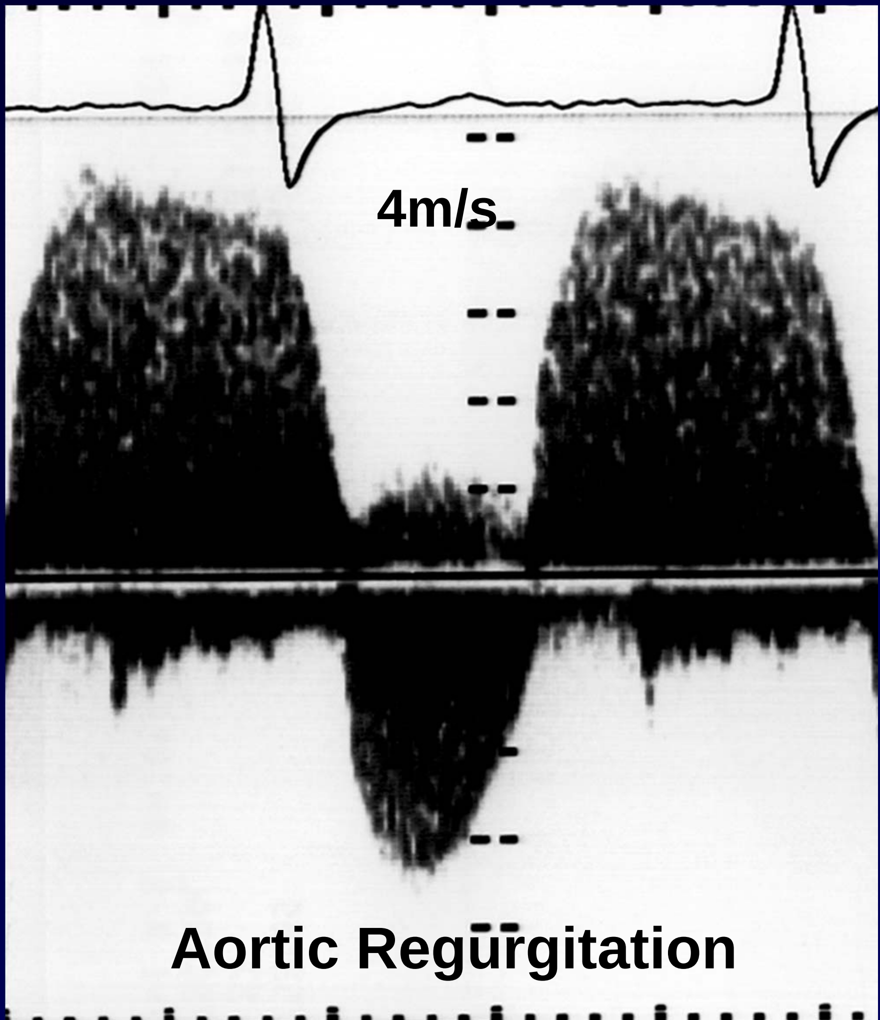
$= 81 + 10 = 91$ mmHg

PADP $= PR^2 \times 4 + RAP$

$= 3^2 \times 4 + 10$

$= 36 + 10 = 46$ mmHg

Estimation of Left Ventricular Enddiastolic Pressure



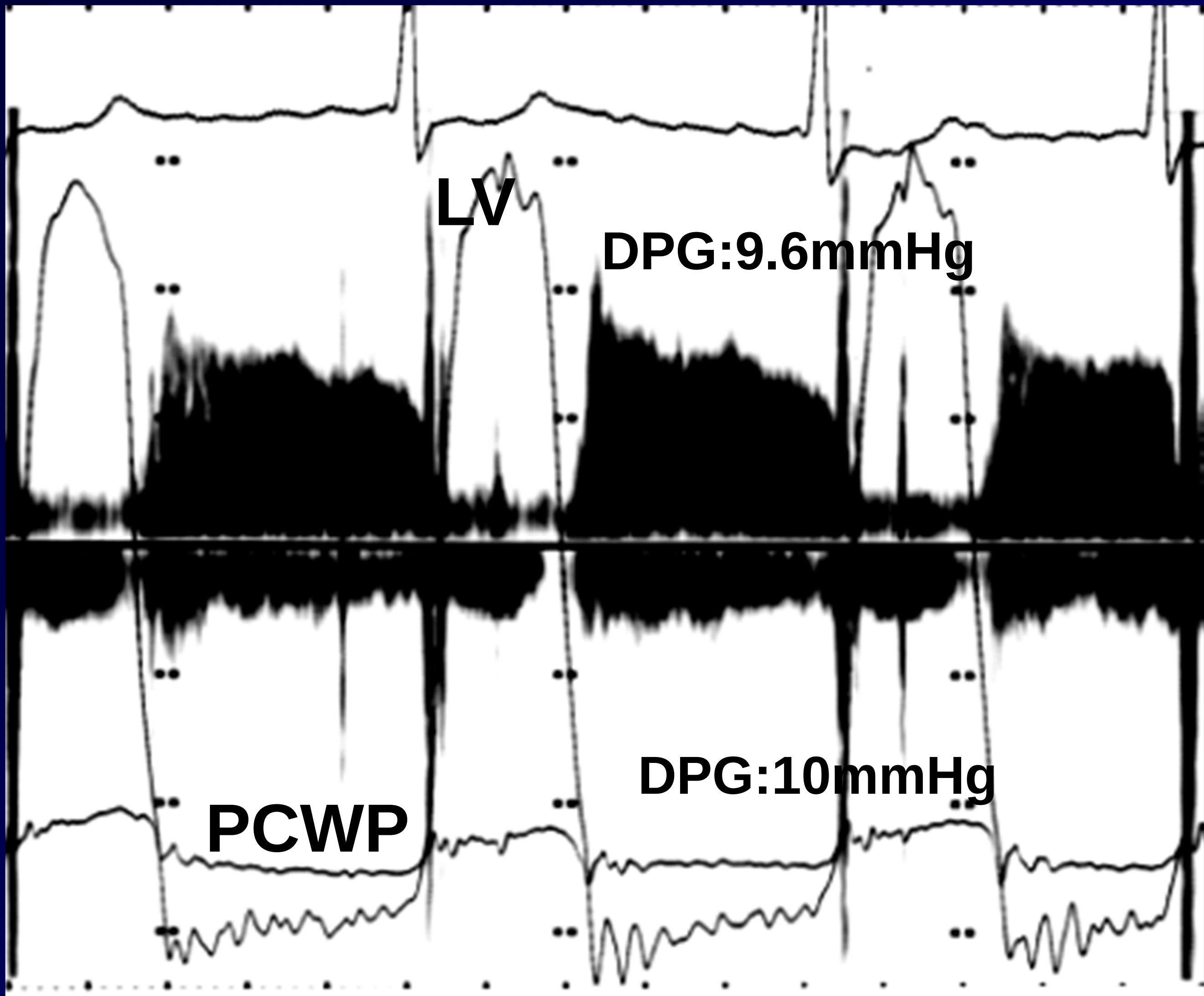
Systemic BP : 160/80mmHg

Diastolic BP=LVEDP+(AR enddiastolic velocity)^2 x 4

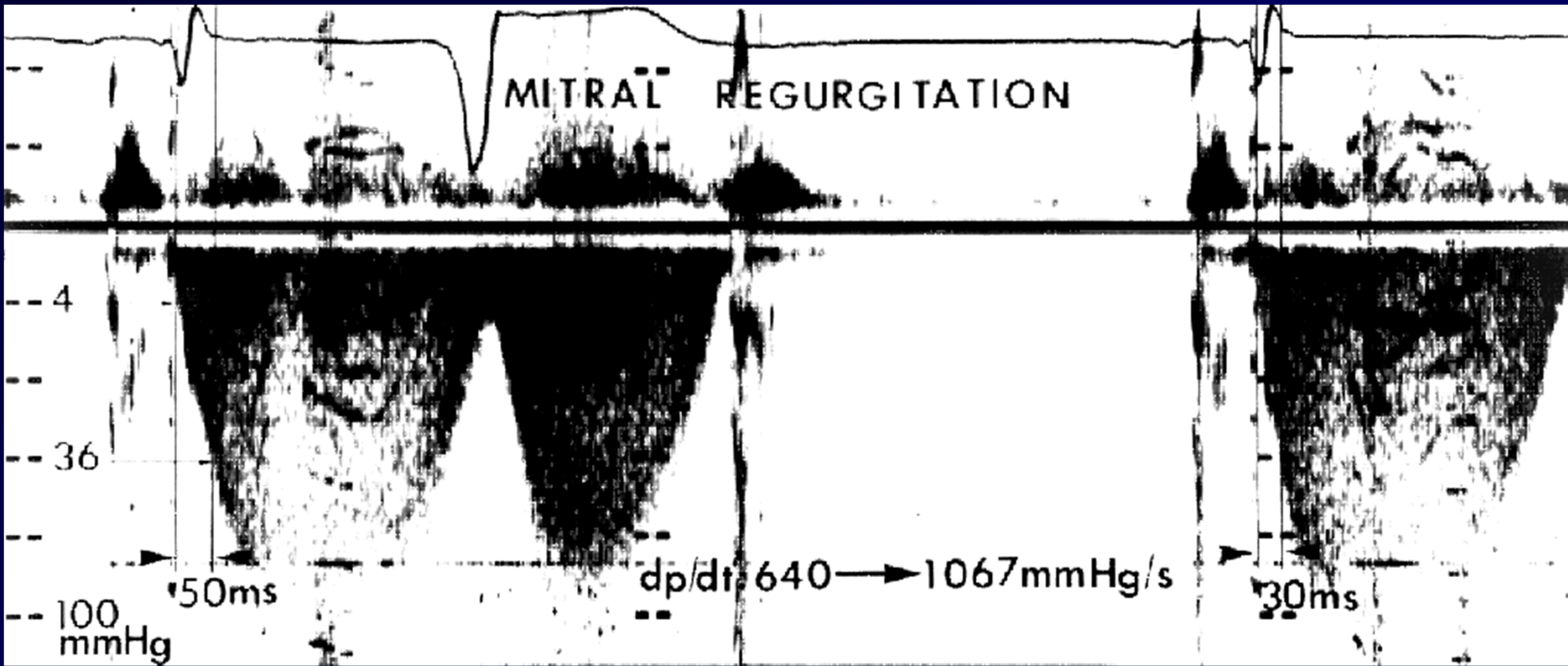
80 mmHg= LVEDP + 4^2 x 4

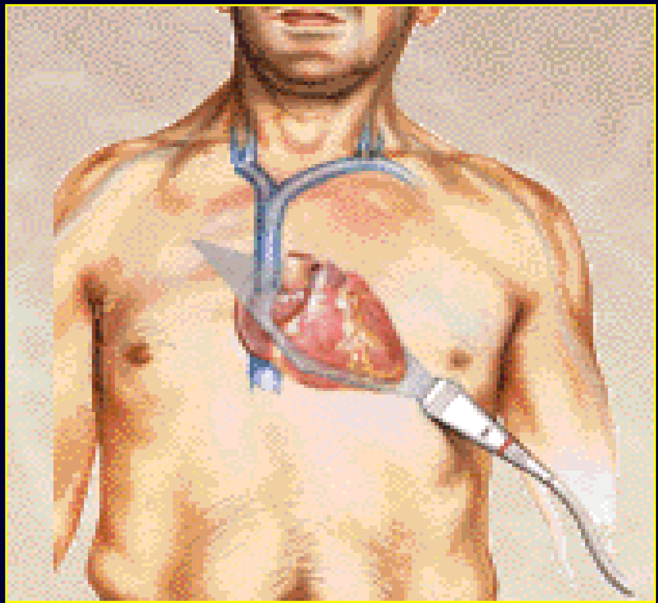
LVEDP= 80-64=16mmHg

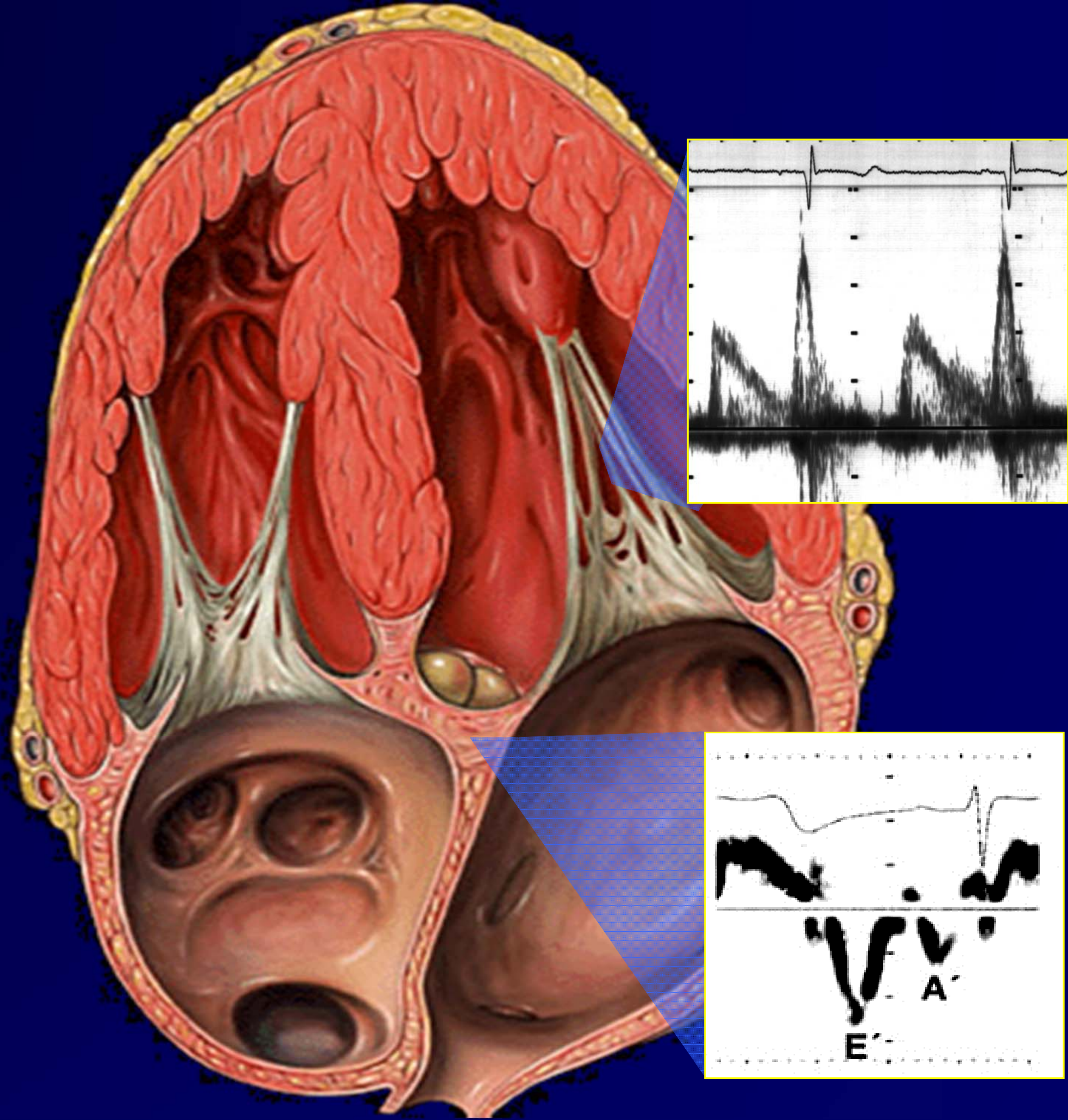
Simultaneous Measurement of Doppler and Catheter Derived Pressures

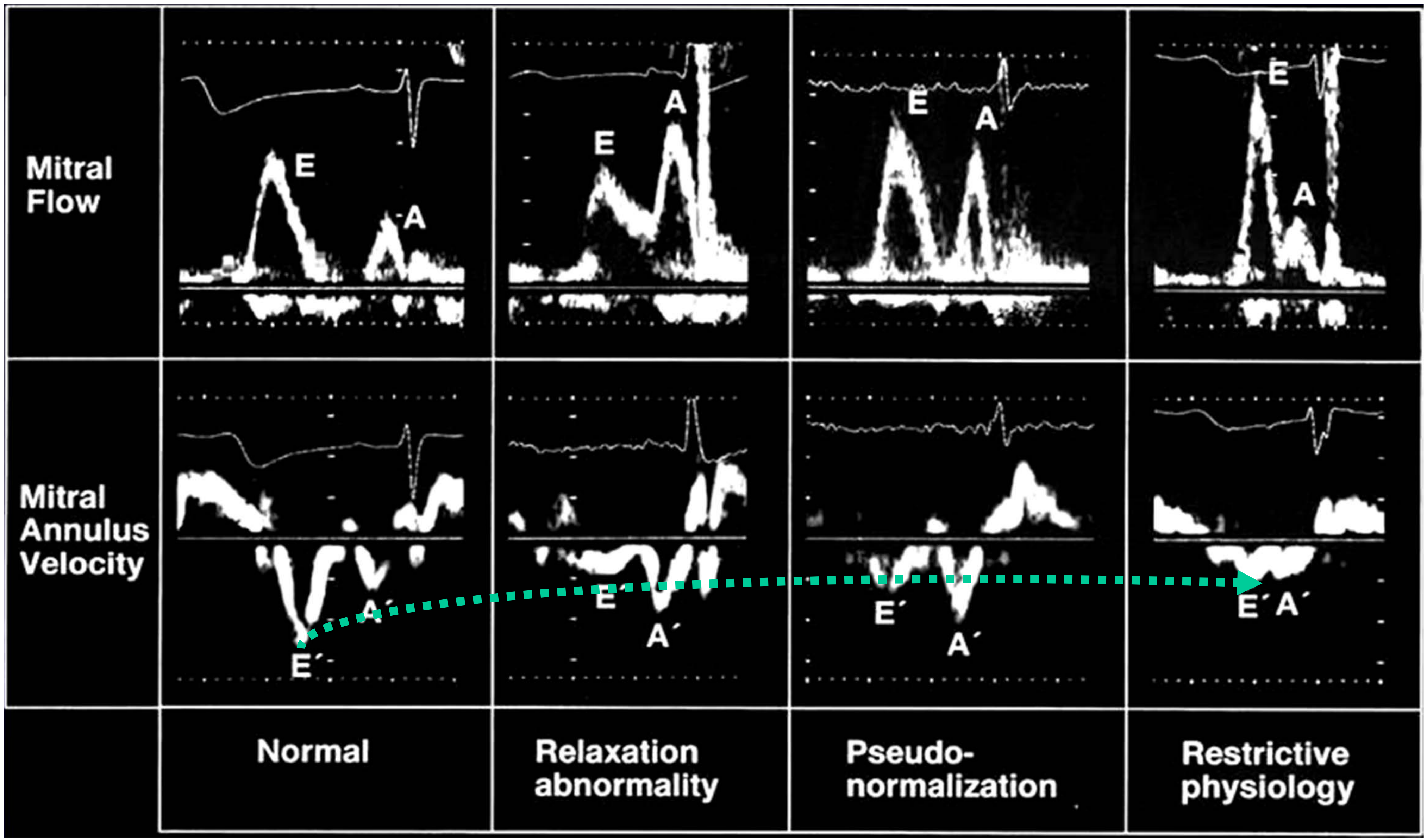


Meaurement of dp/dt





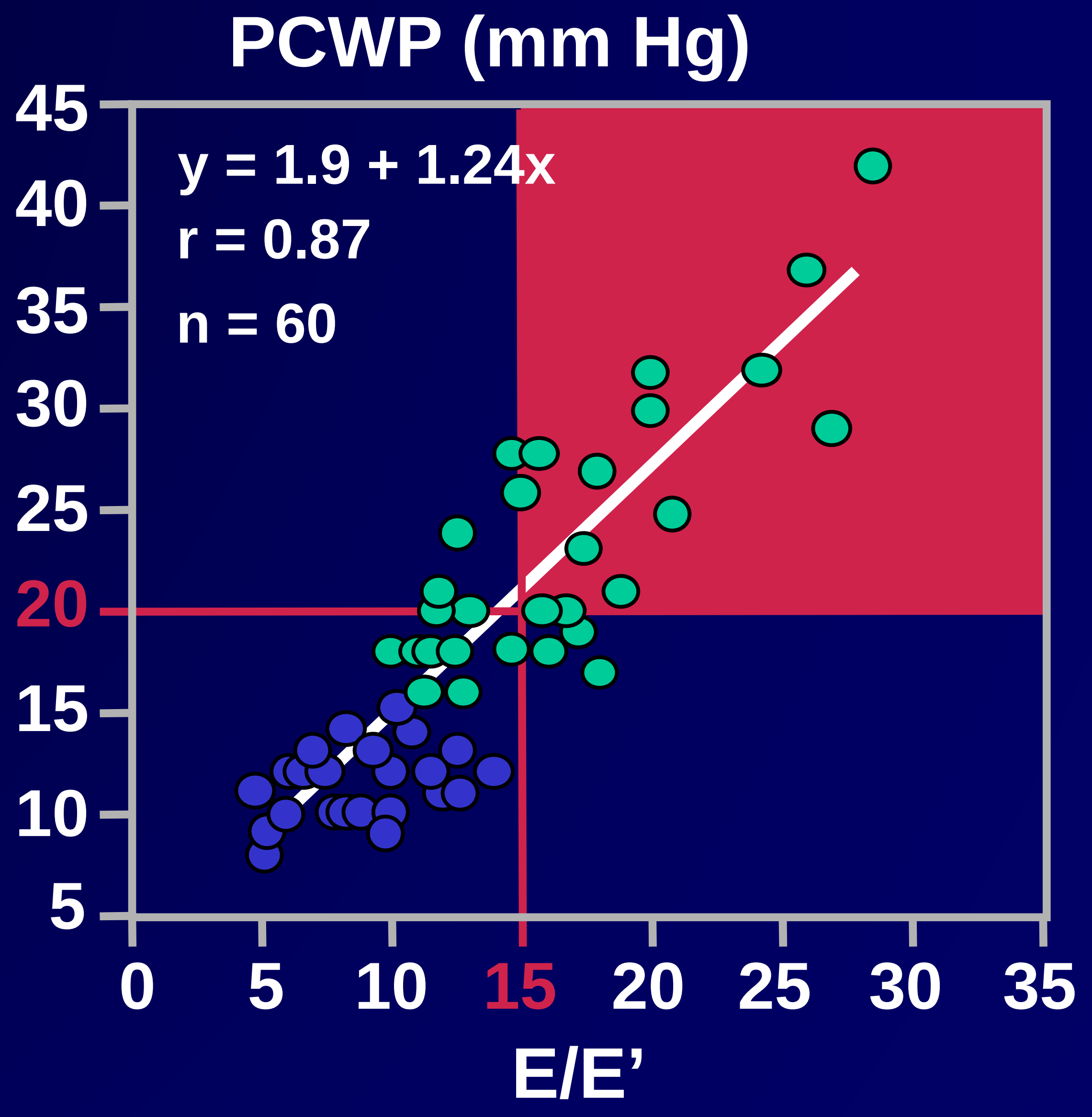

A´
E´



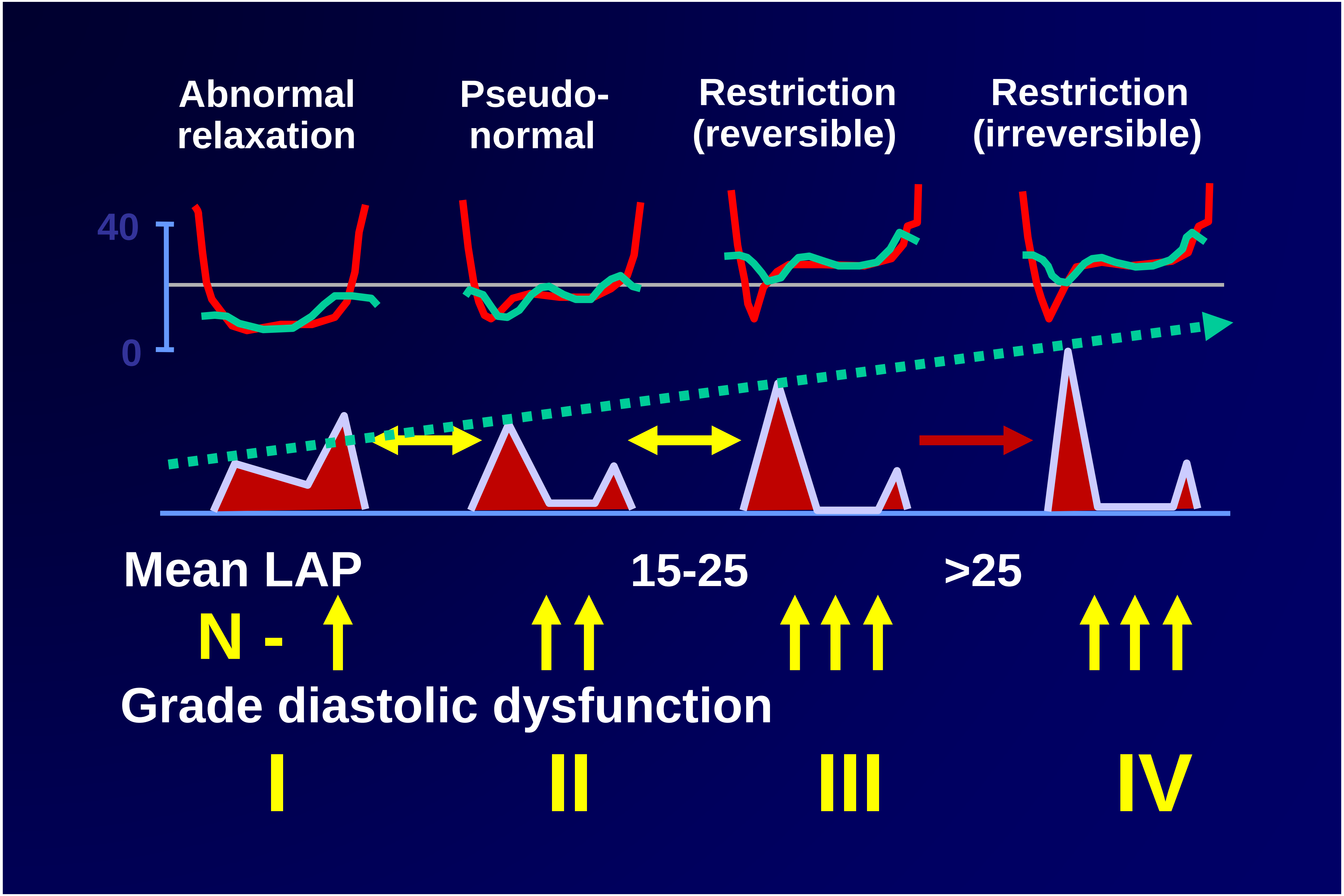
Sohn DW et al. JACC

As LV filling pressure ↑

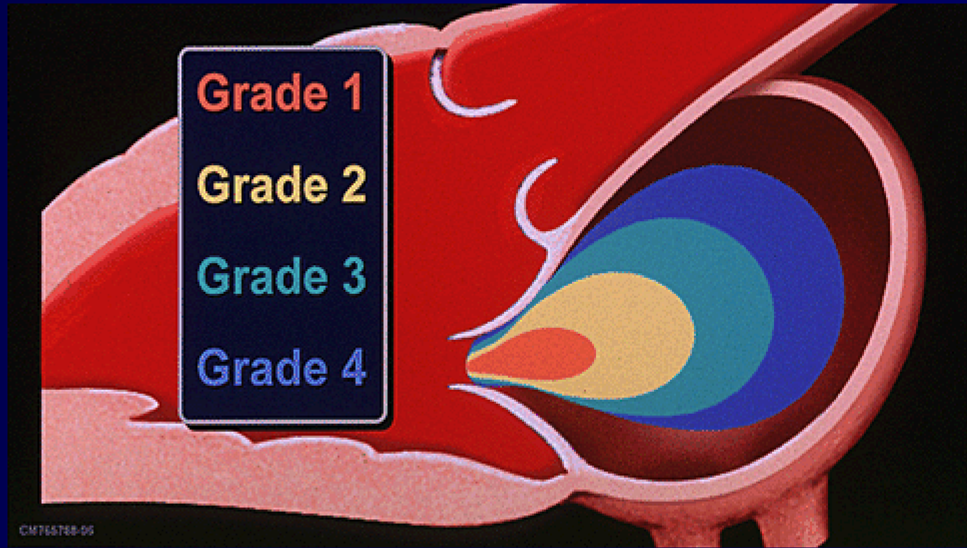
Mitral E	↑
Annulus E’	↓
E/E’	↑

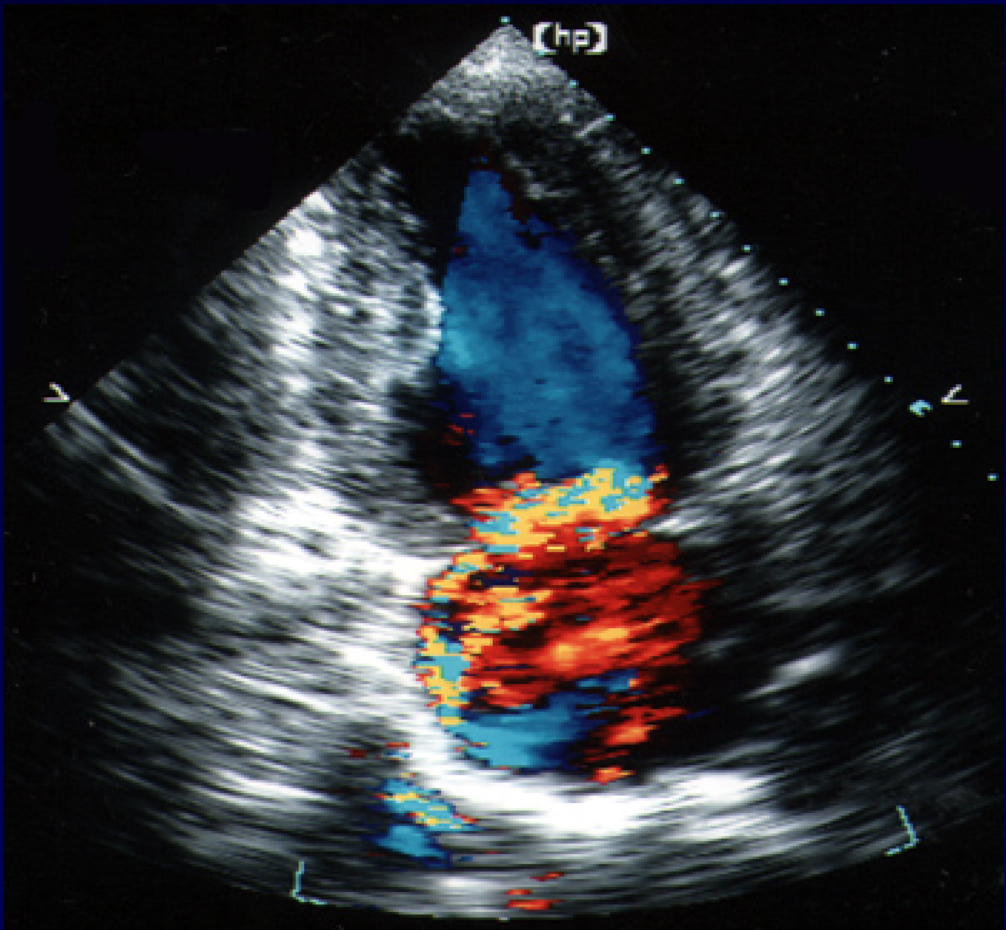


Nagueh et al: JACC, 1997
Ommen et al: Circ, 2000


Abnormal relaxation
Pseudo-normal
Restriction (reversible)
Restriction (irreversible)
40
0
Mean LAP
15-25
>25
N -
Grade diastolic dysfunction
I
II
III
IV

Measurement of jet area



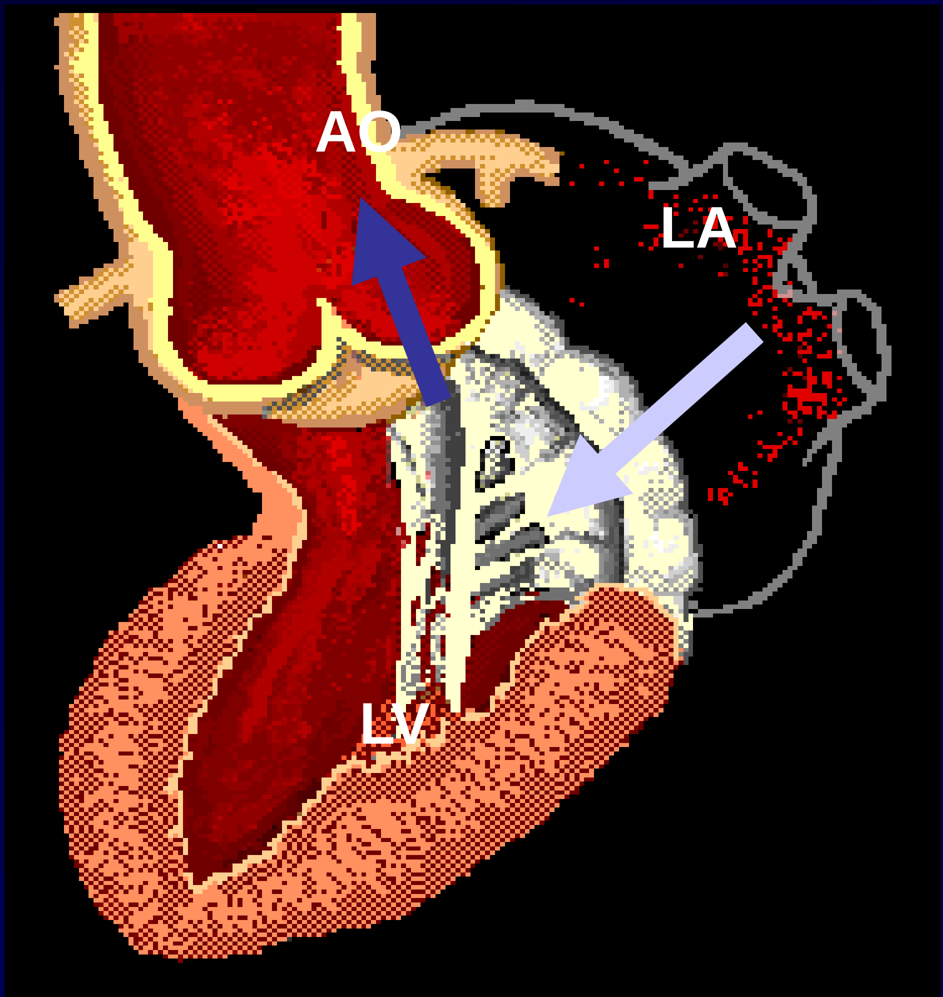


Jet area(cm^2)

Grade 1 : 4 - 8
Grade 2 : 8 - 12
Grade 3 : 12 - 16
Grade 4 : > 16

Quantification of MR

- Volumetric method -



MV Reg V = MV flow – LVOT flow

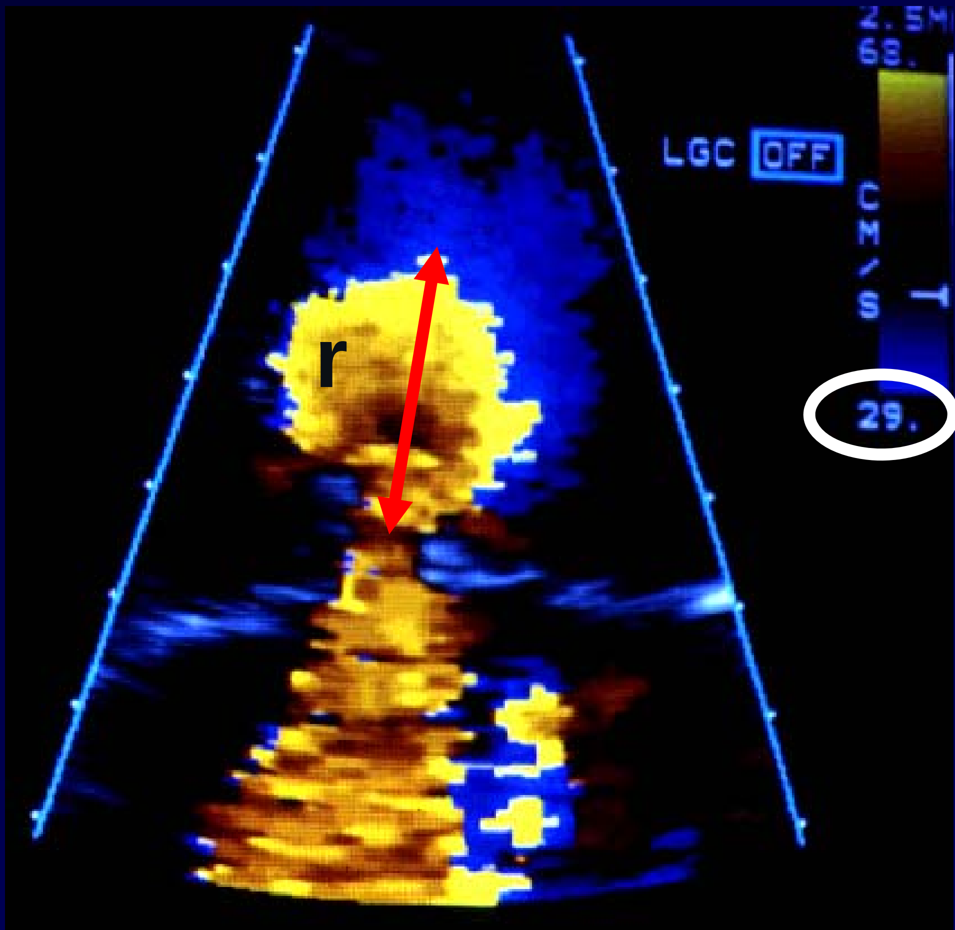
MV RF = MV Reg V/MV flow x 100

MV Reg V : mitral valve regurgitant volume

MV RF : mitral valve regurgitant fraction(%)

Quantification of MR

- PISA method -



r = 1.1 cm

Alias Velocity = 29 cm/sec

MR Velocity = 4.3 m/sec

$$ERO = \frac{6.28 \times (1.1)^2 \times 29}{430}$$

RV = ERO × MR TVI

= 0.51 × 114 = 58 ml

Advantage of Echo

- **Inexpensive**
- **Safe**
- **Portable**
- **Repeat**
- **Hemodynamic information**
  - Do not require offline analysis

Pitfalls of Echocardiography

- **Image quality**
  - Good vs poor
- **Operator dependent**
  - Expert vs beginner
- **Subjective**
- **Machine factor**

Echocardiography

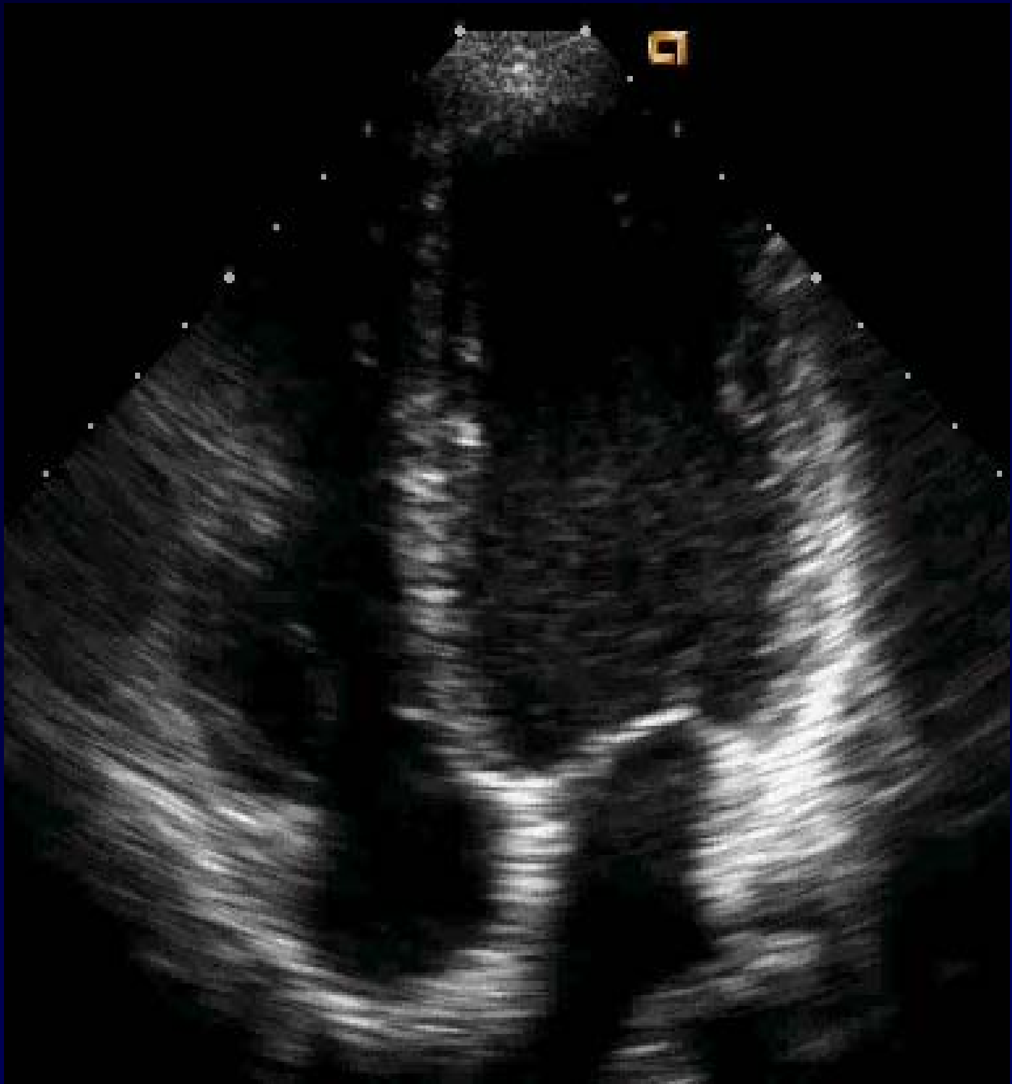
Sometimes there are some discrepancies with patient's clinical status……….

New Advanced Technology in Echo

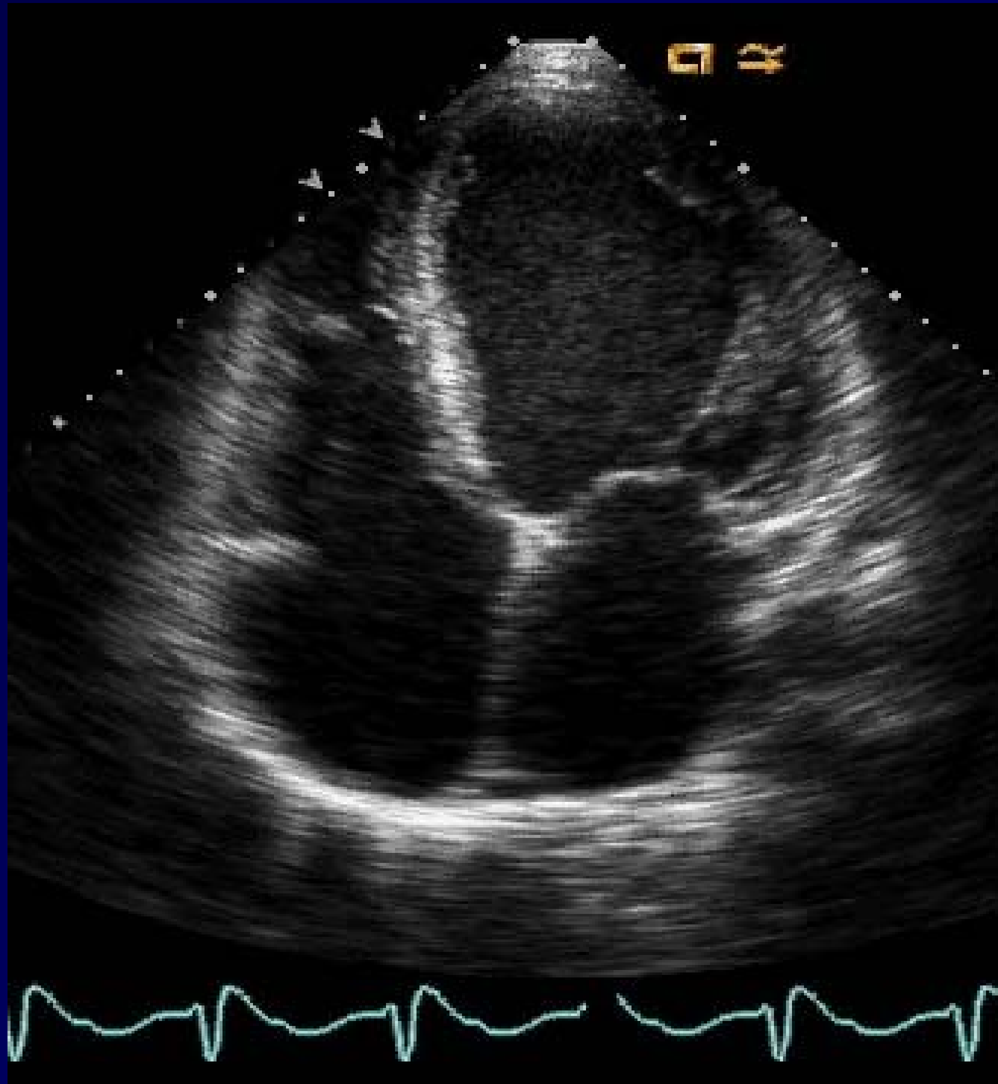
- Evaluation of LV Mechanics
  - 2D Strain and Strain rate
  - Twist and torsion
- Real time 3D Echo
  - Single beat 3D Echo
- LV vortex flow analysis with contrast Echocardiography

Evaluation of LV systolic function

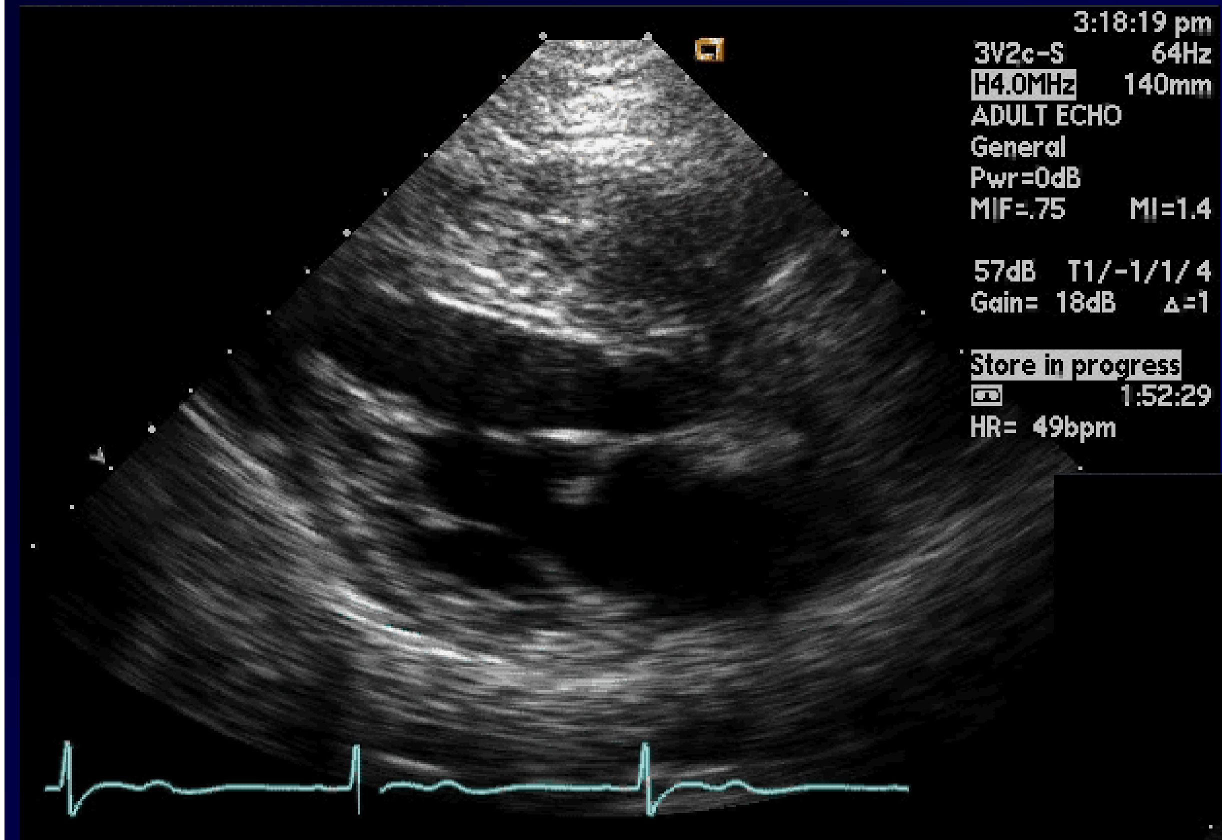
- Normal

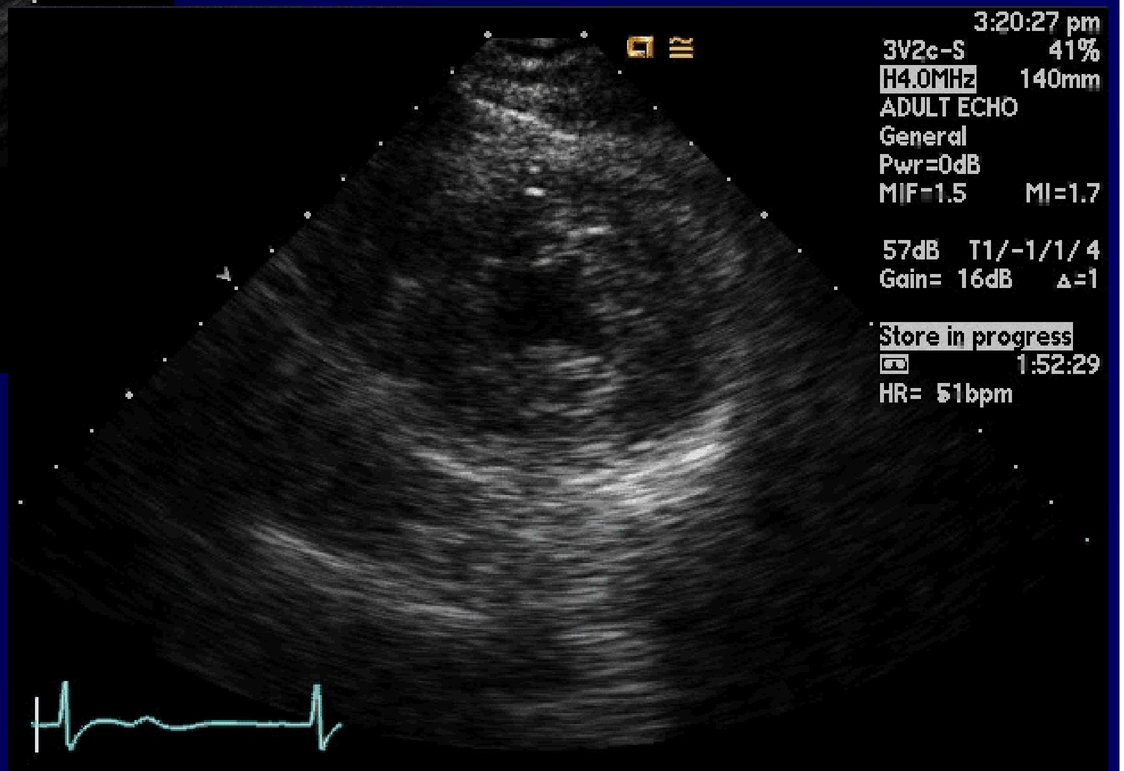


- CHF



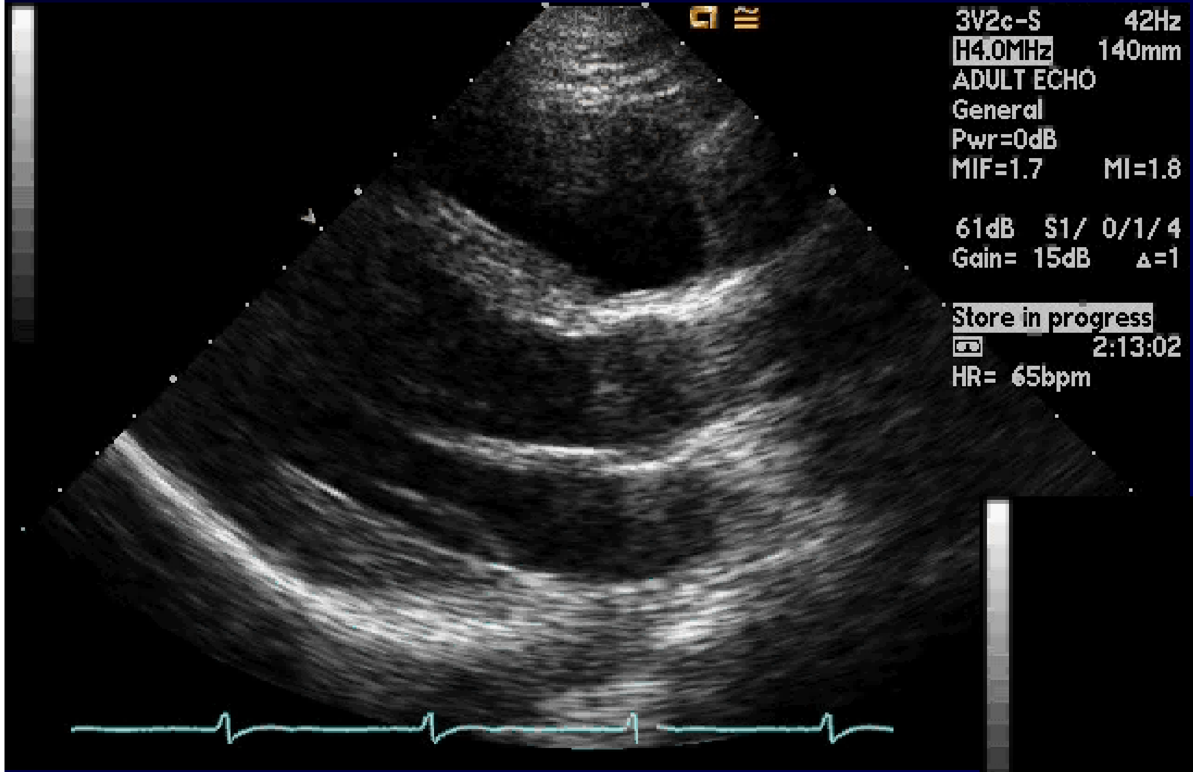
73 year old man with DOE

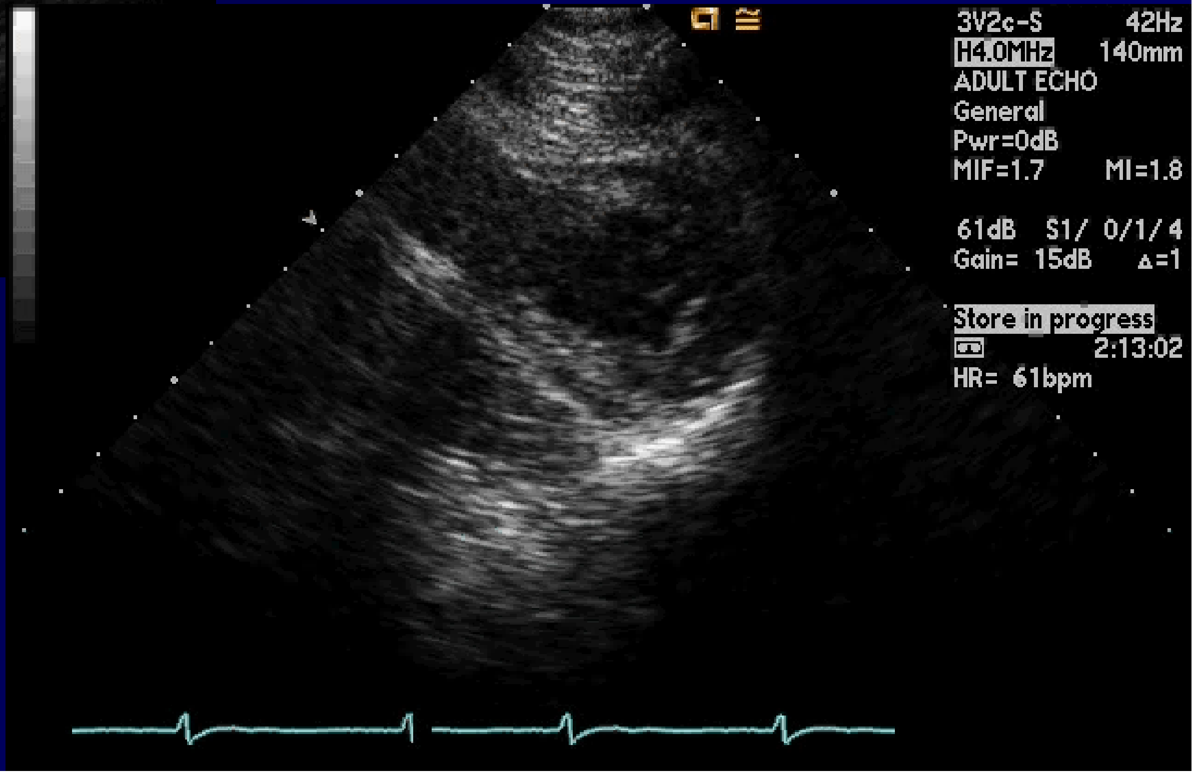


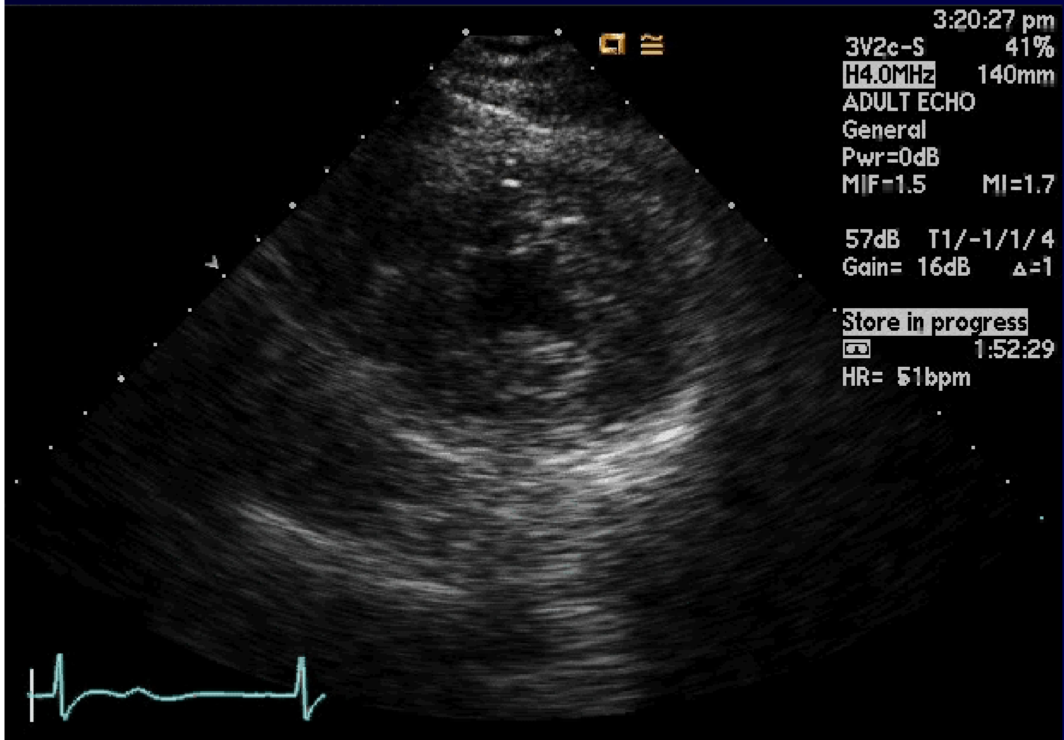


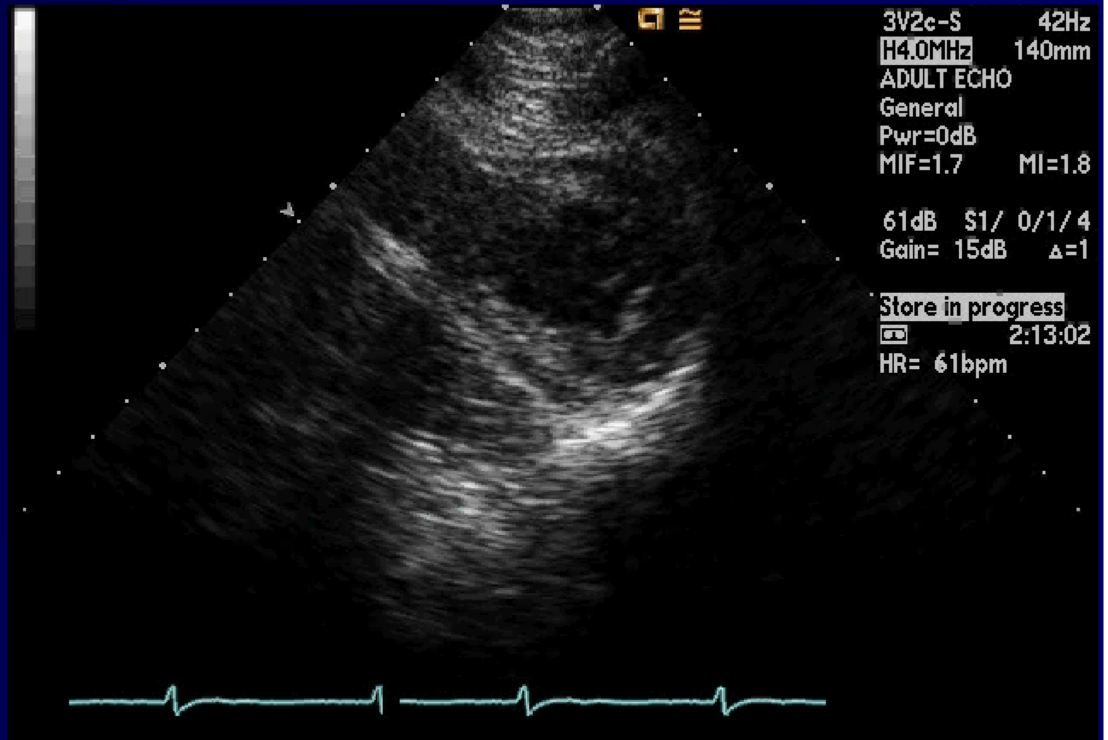
HTN, DM for 10 yrs

20 year old man with ECG abnormality

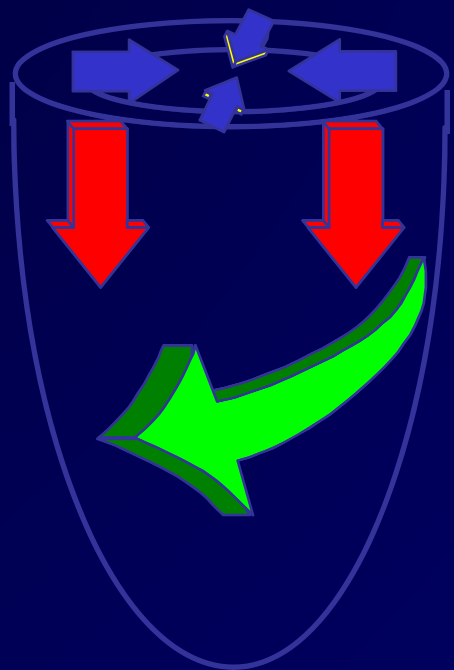


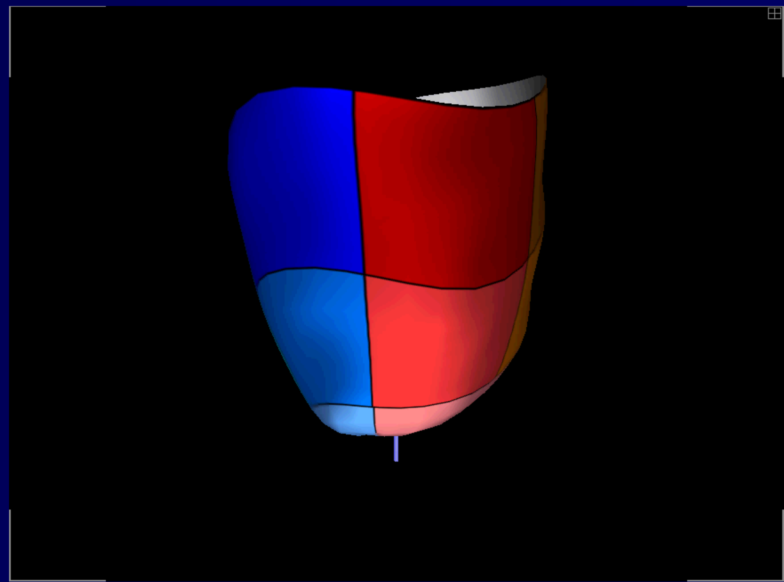



3:20:27 pm
3V2c-S 41%
H4.0MHz 140mm
ADULT ECHO
General
Pwr=0dB
MIF=1.5 MI=1.7
57dB T1/-1/1/4
Gain= 16dB ∆=1
Store in progress
1:52:29
HR= 51bpm


3V2c-S 42Hz
H4.0MHz 140mm
ADULT ECHO
General
Pwr=0dB
MIF=1.7 MI=1.8
61dB S1/ 0/1/4
Gain= 15dB ∆=1
Store in progress
2:13:02
HR= 61bpm

Myocardial motion, strain

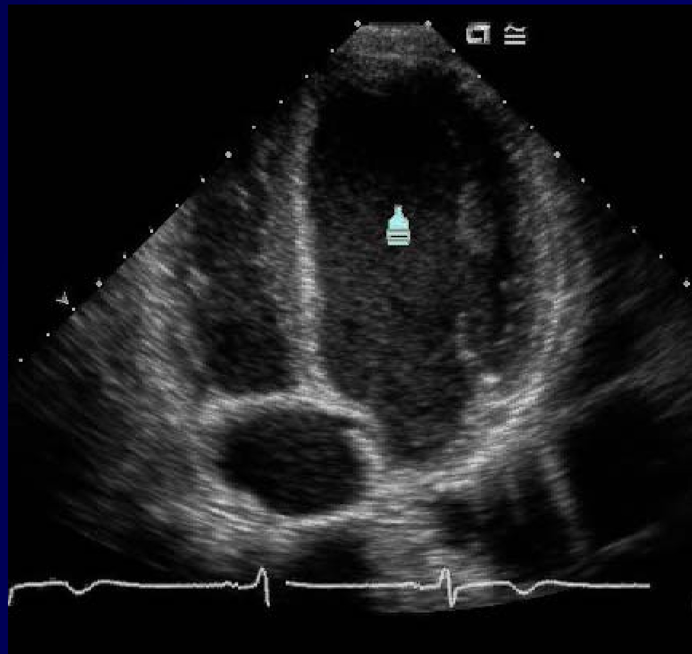




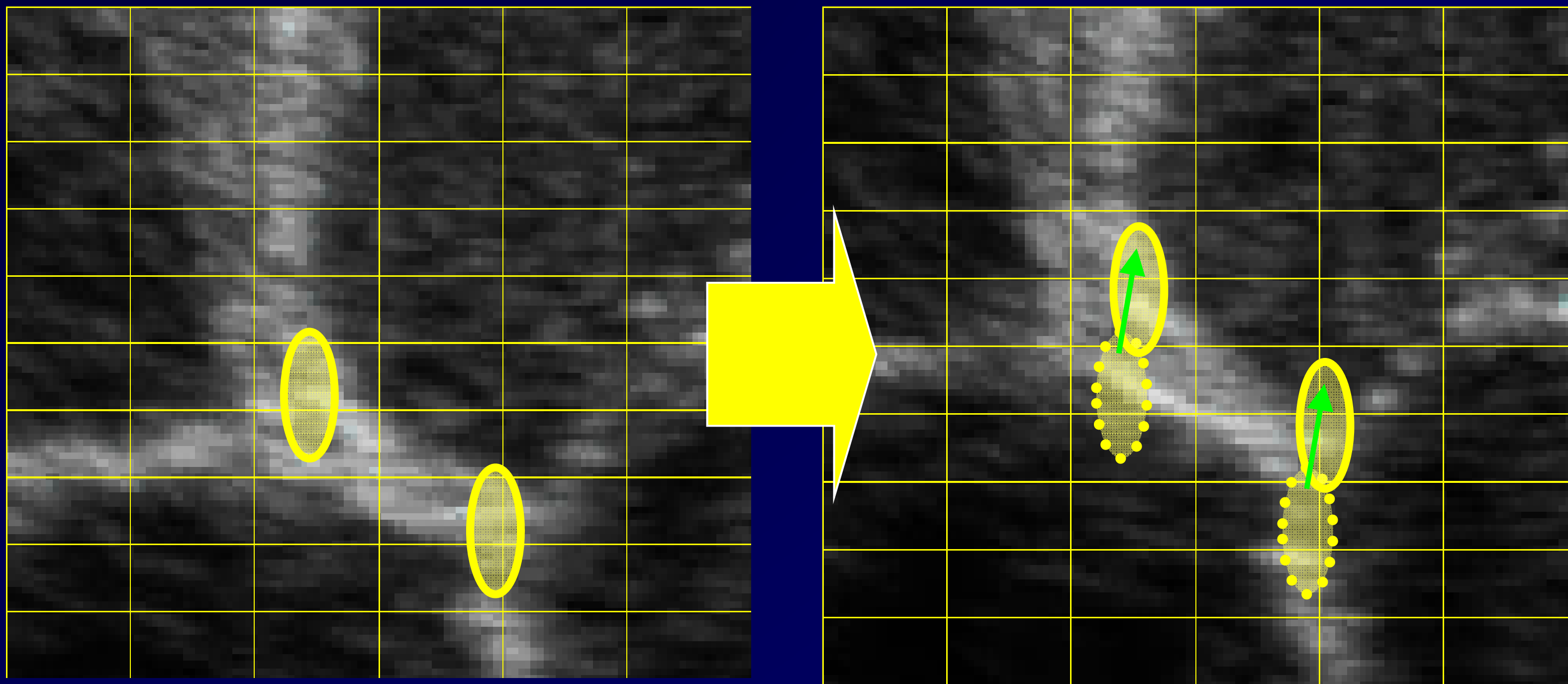
Tissue “*Speckle or Feature*” tracking

The basic concept

gray tissue is displaced
from one frame to another

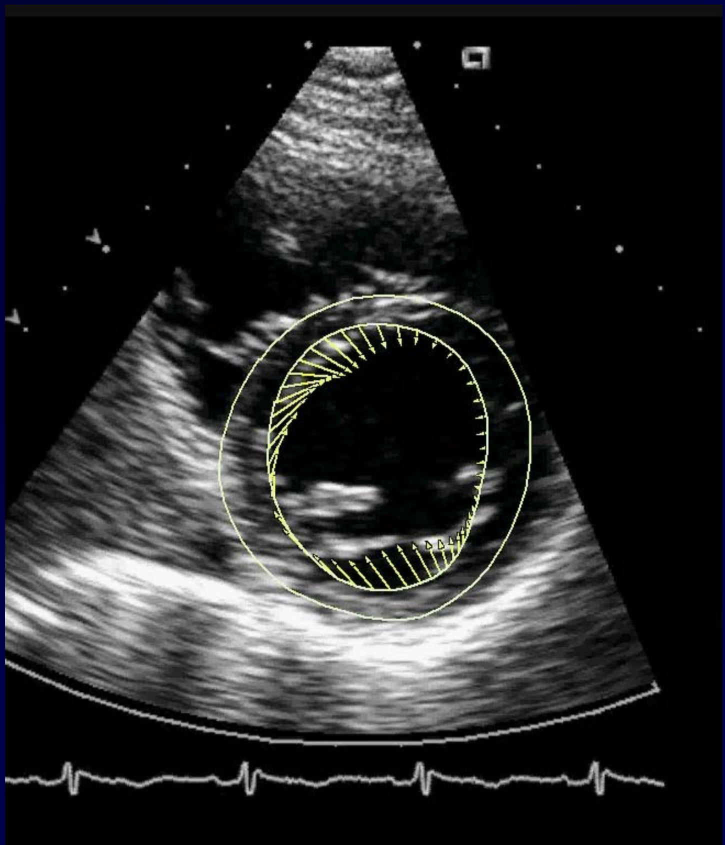


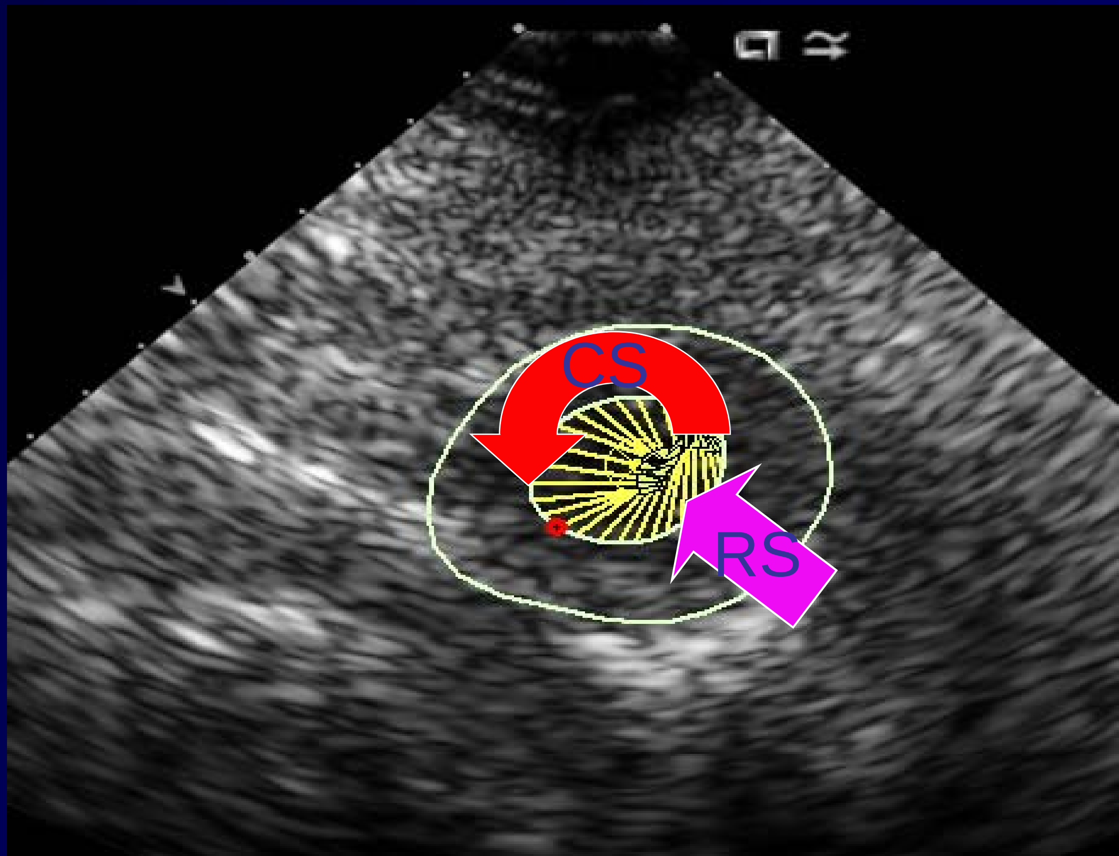
evaluate such a displacement
at every point

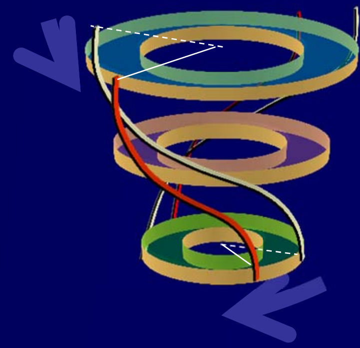


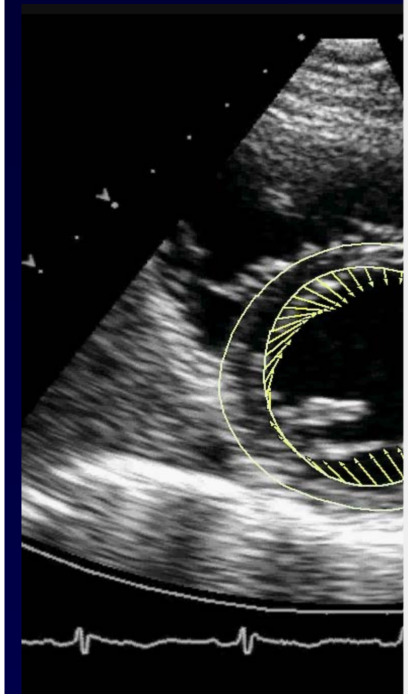
Apical Rotational Mechanics

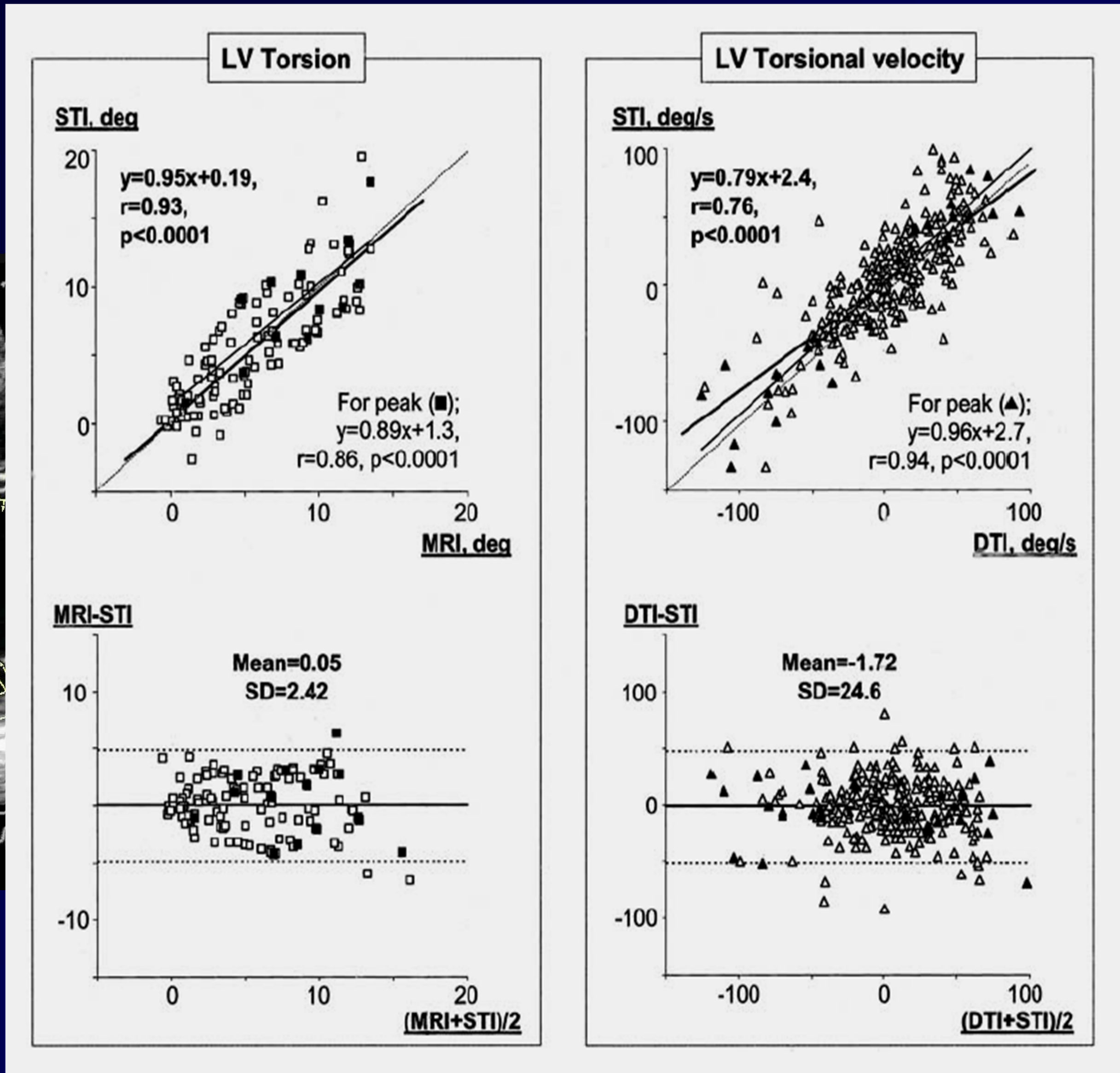
What to Measure ?

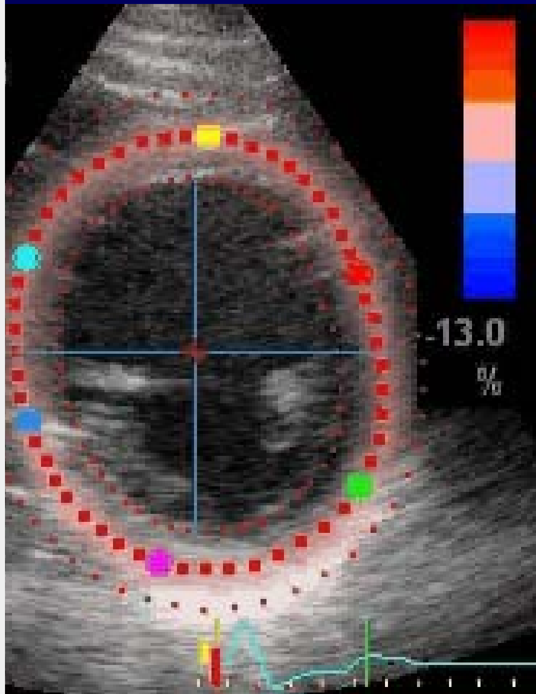




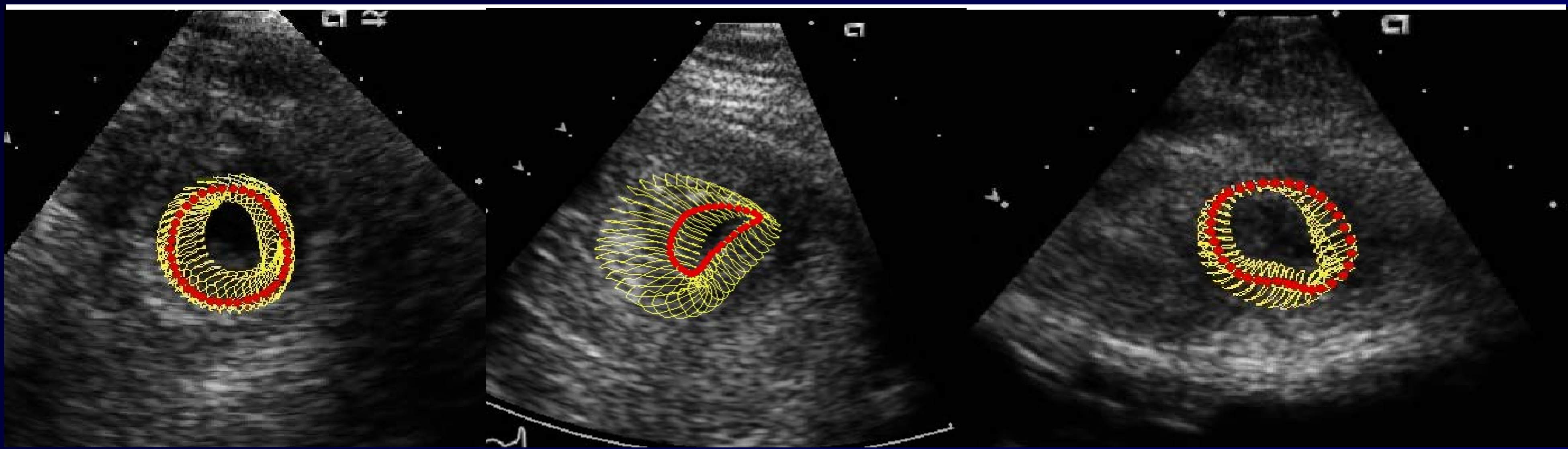








Nozomi Y, et al. J Am Coll Cardiol 2005;45:2034



LVEF 75%
E/A = 0.76
E/E'= 5.4
LAV 20 ml/m^2
Rotation 19.8 deg
R Rate 109.5 deg/s
Rev Rot rate 113.5 deg/s

Normal

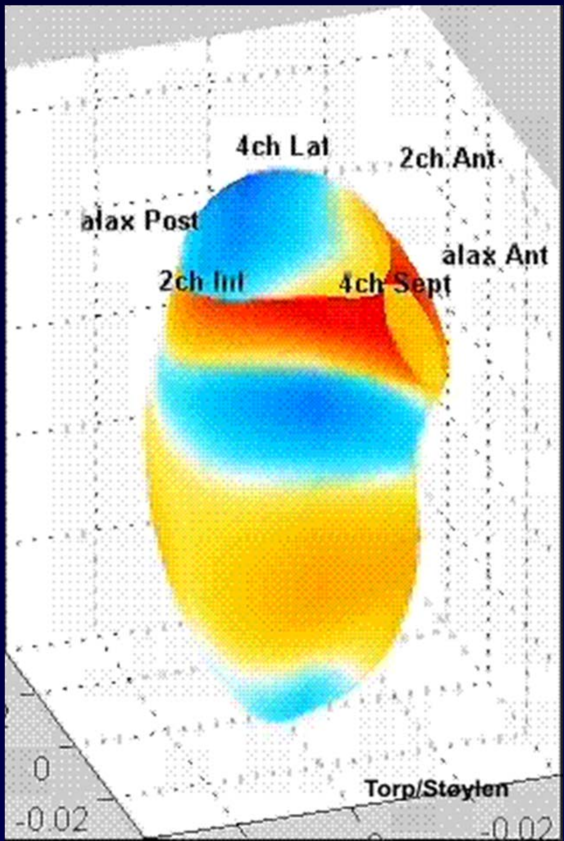
LVEF 62%
E/A = 0.79
E/E'= 8.6
LAV 36 ml/m2
Rotation 18.5 deg
R Rate 109.1 deg/s
Rev Rot Rate 100.5 deg/s

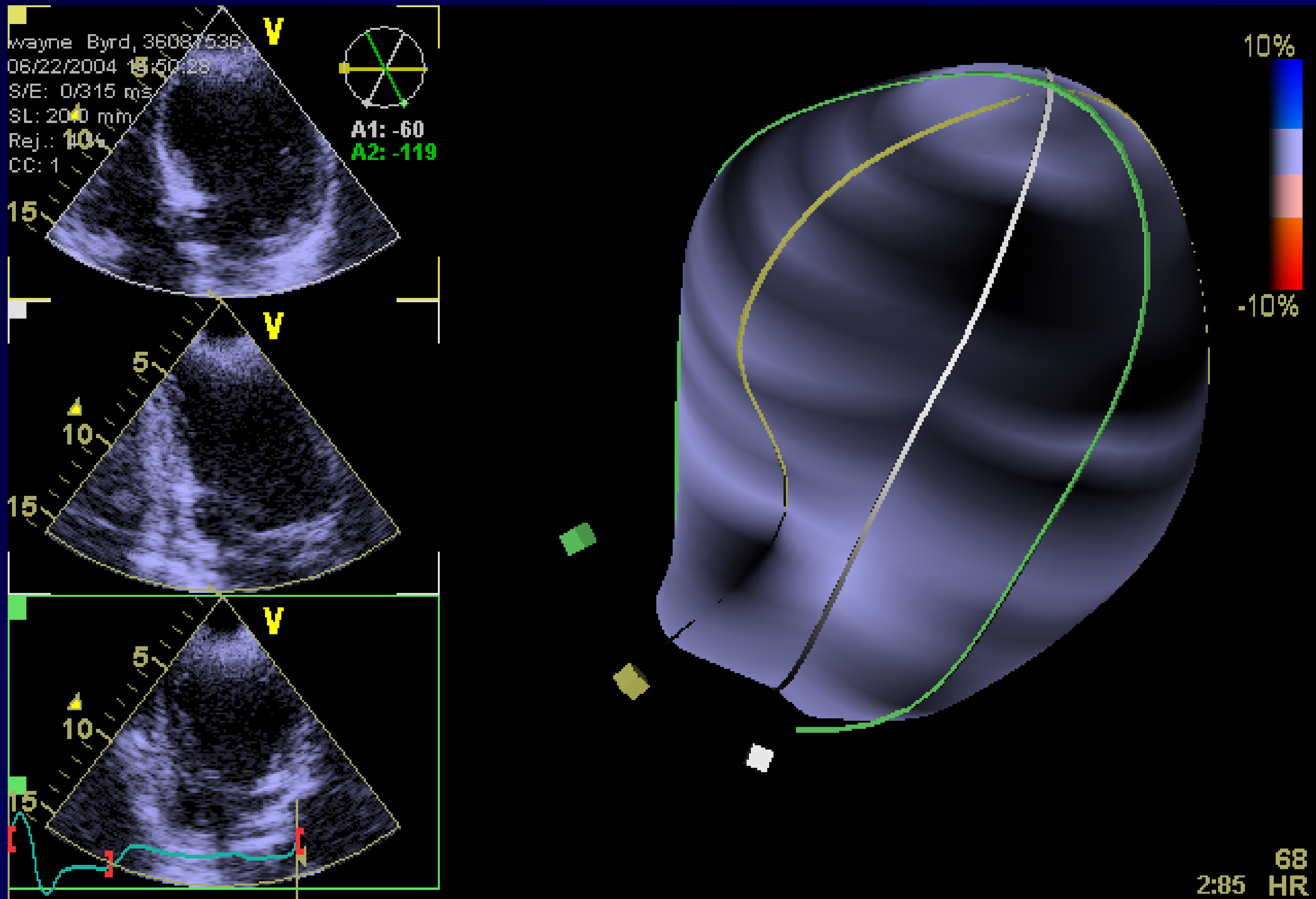
DD ± DHF

LVEF 40%
E/A = 2.34
E/E' = 10.8
LAV 42 ml/m2
Rotation 6.8 deg
R Rate 45.6 deg/s
Rev Rot Rate 20.5 deg/s

SHF + DHF

3D Strain


4ch Lat
2ch Ant
alax Post
alax Ant
2ch Inf
4ch Sept
0
-0.02
Torp/Støylen
0.02


V
A1: -60
A2: -119
S/E: 0/315 ms
CC: 1
5
10
15
10%
-10%
68
2:85 HR

3-D Echocardiography

ASE Position Paper

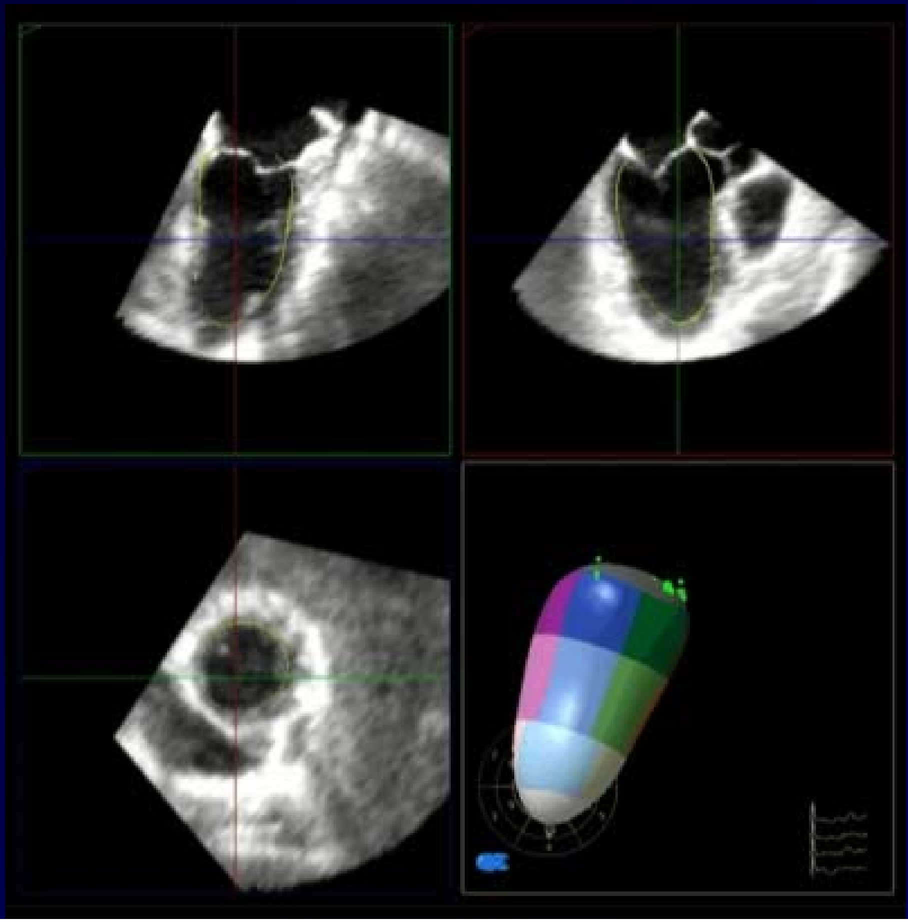
"*3D echocardiography* …..

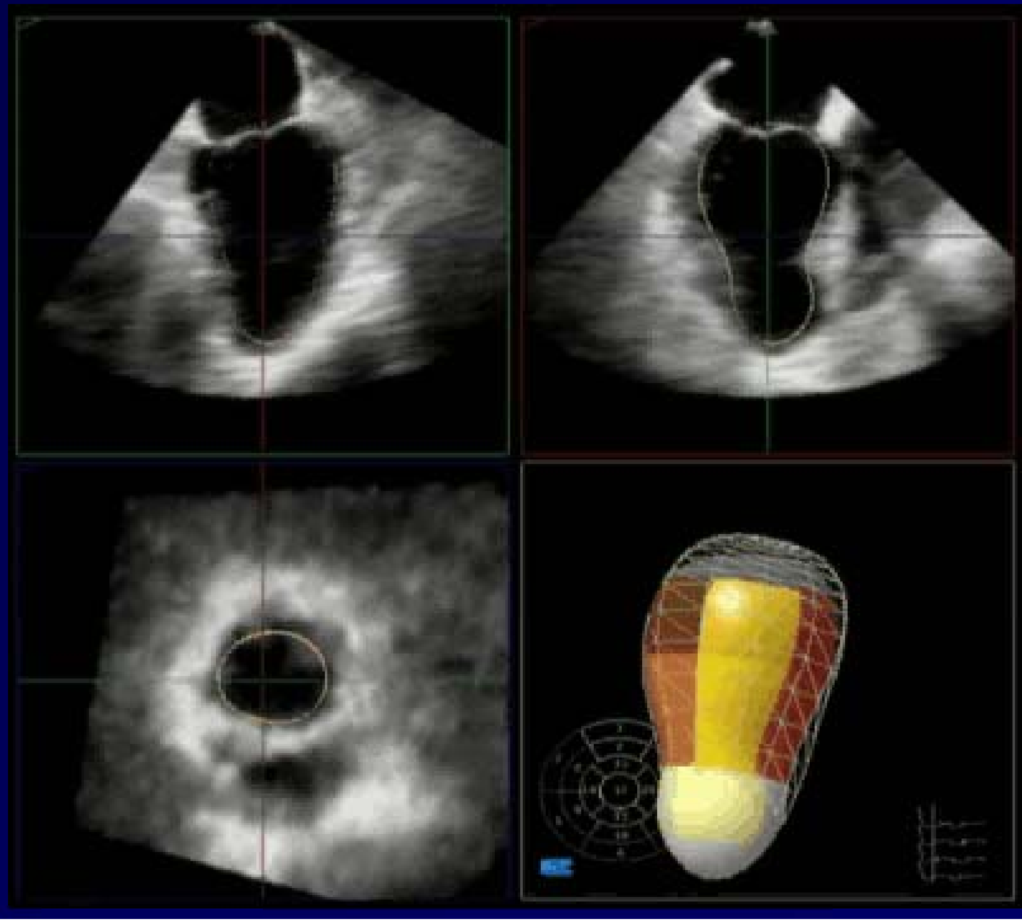
At present, available evidence suggests that provides improved accuracy and reproducibility over 2D methods for *LV volume and function calculation and the derivation of mitral valve area* in patients with …..

J Am Soc Echogr 2007; 20: 213-239

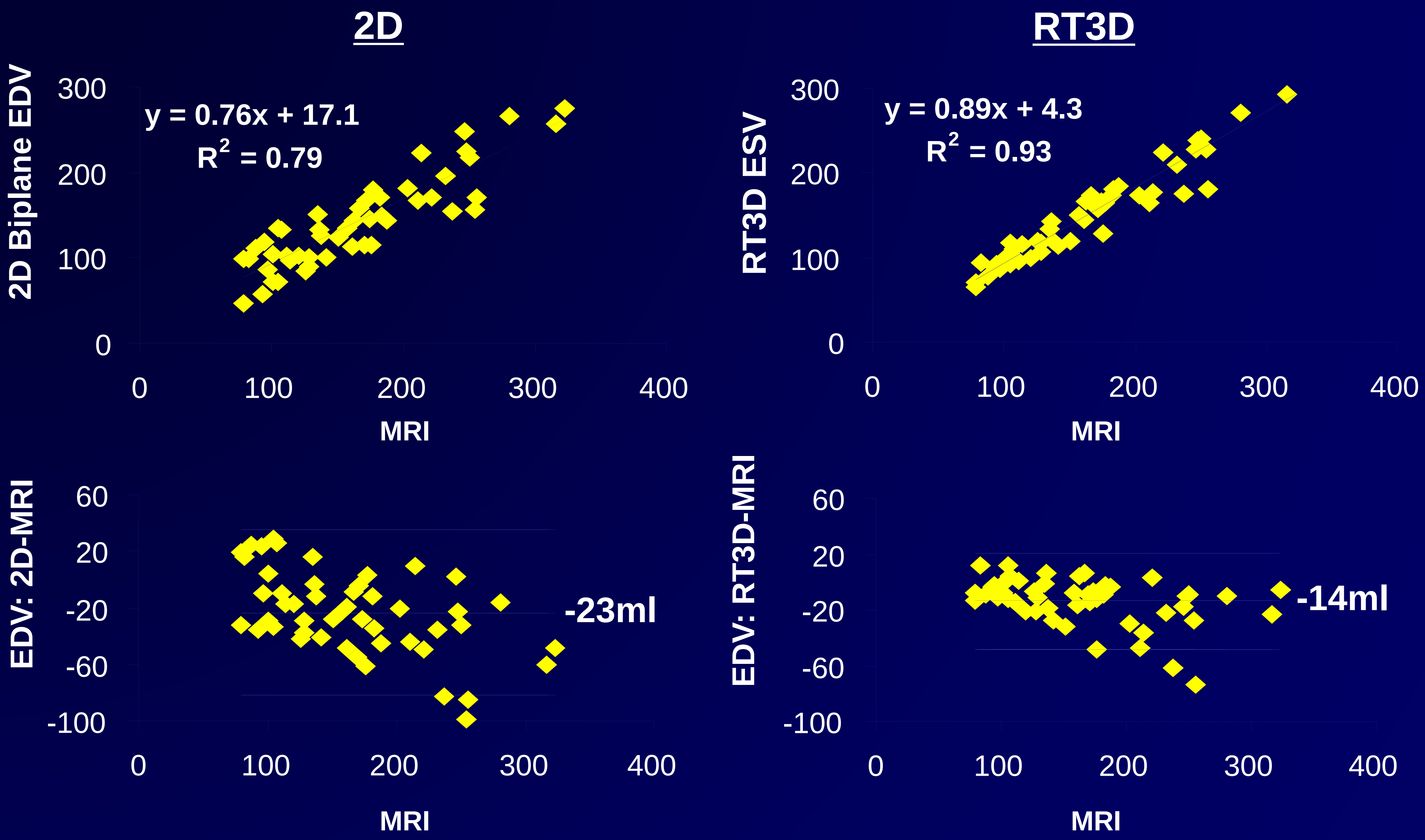
3D Echocardiography

Real time 3-Dimensional Echocardiographic Volume Measurements



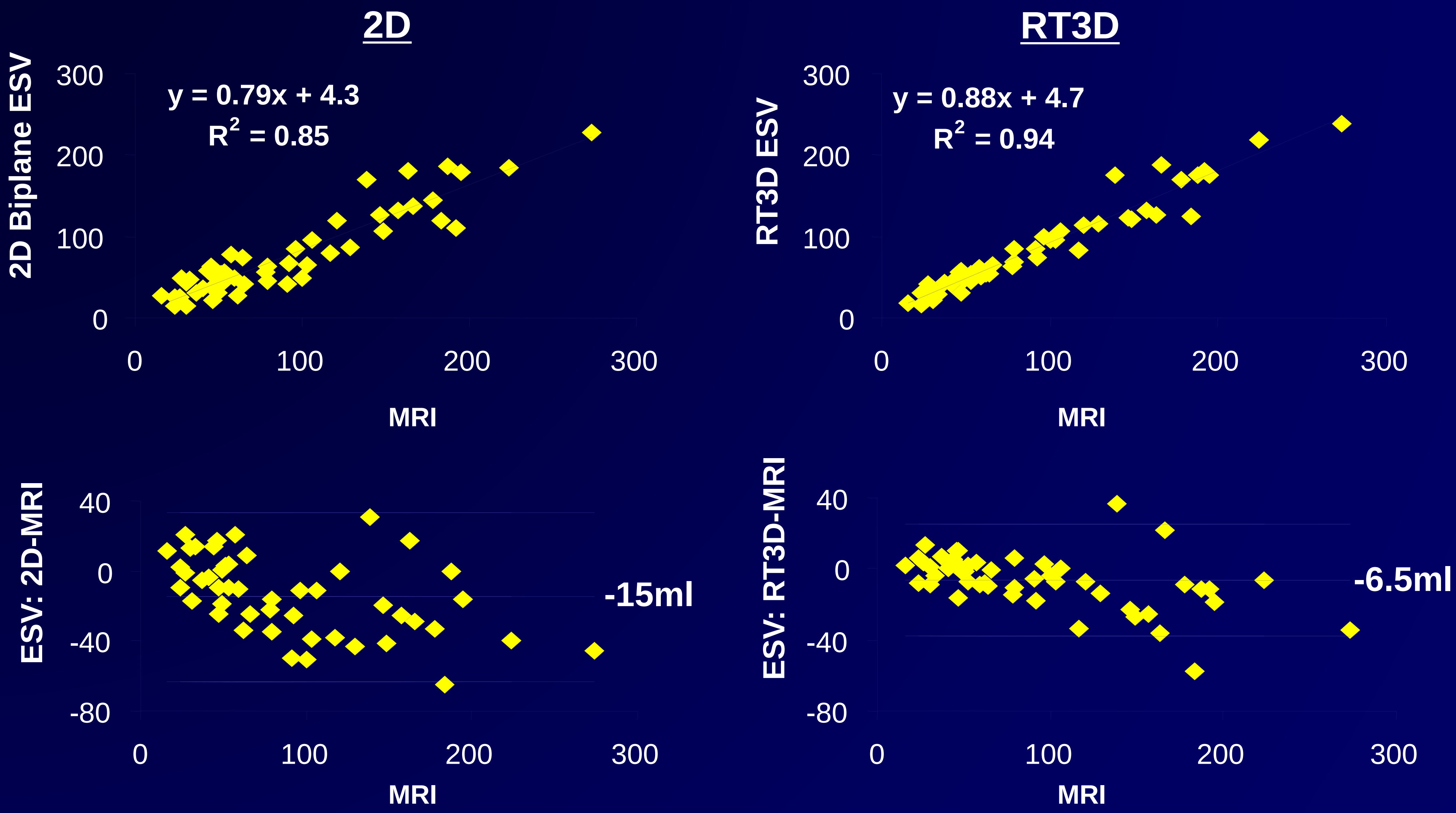


End Diastolic Volume



Jacobs L et al.,European Heart Journal 27: 460-468, 2006

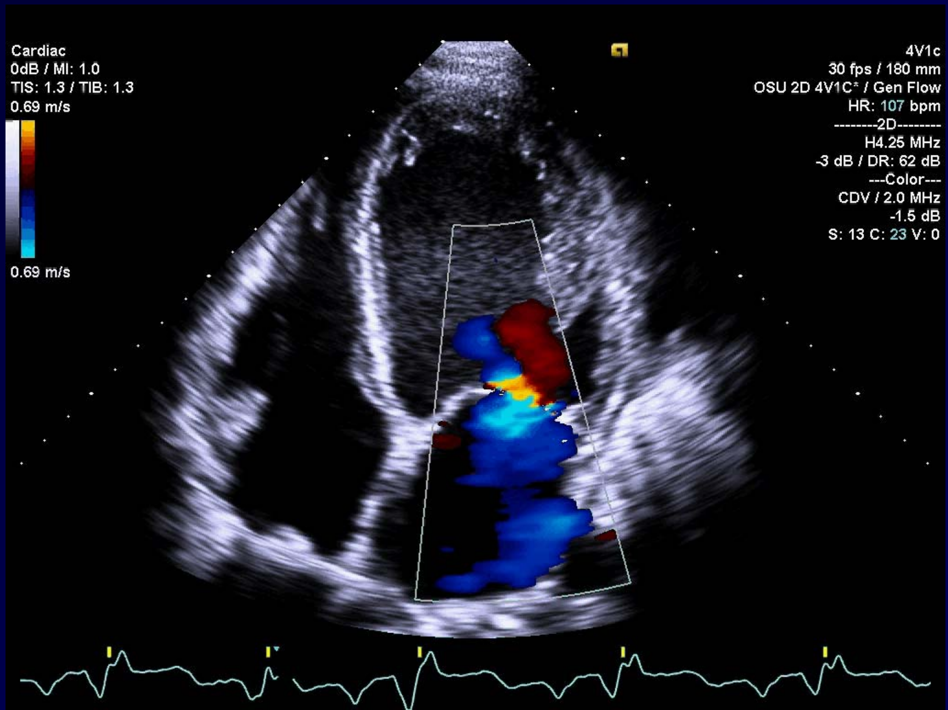
End Systolic Volume

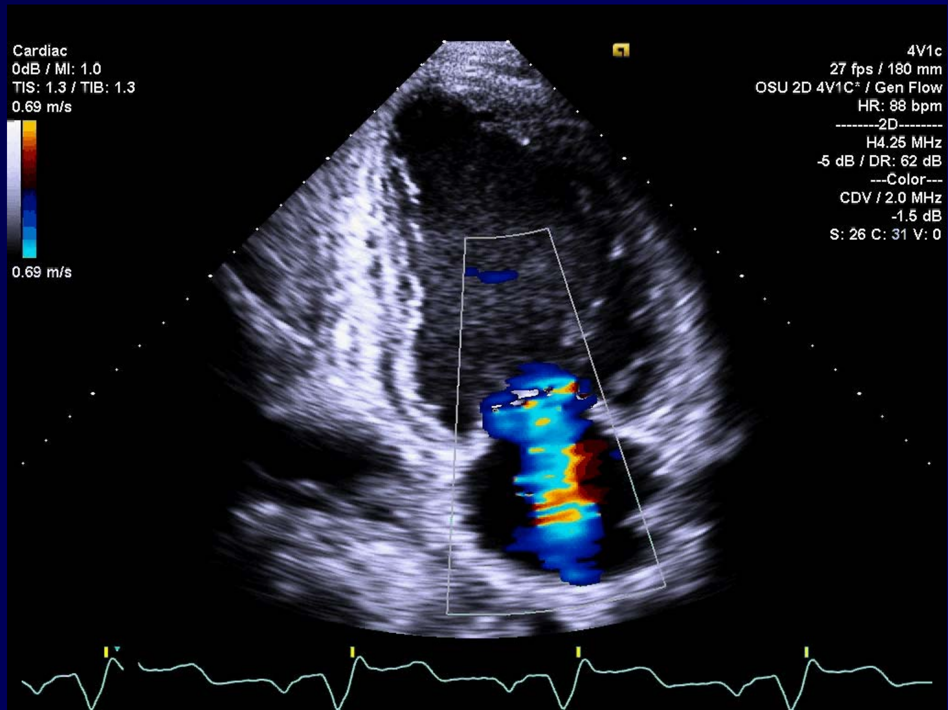


Jacobs L et al.,European Heart Journal 27: 460-468, 2006

2-D Echocardiography

Mitral Regurgitation

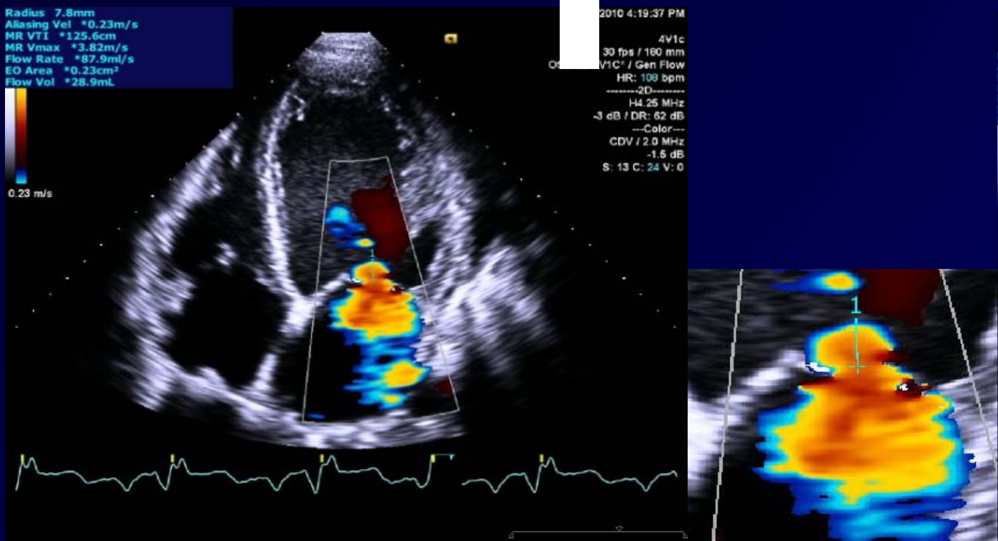




2-D Quantification of MR

Flow EROA by PISA

A4C

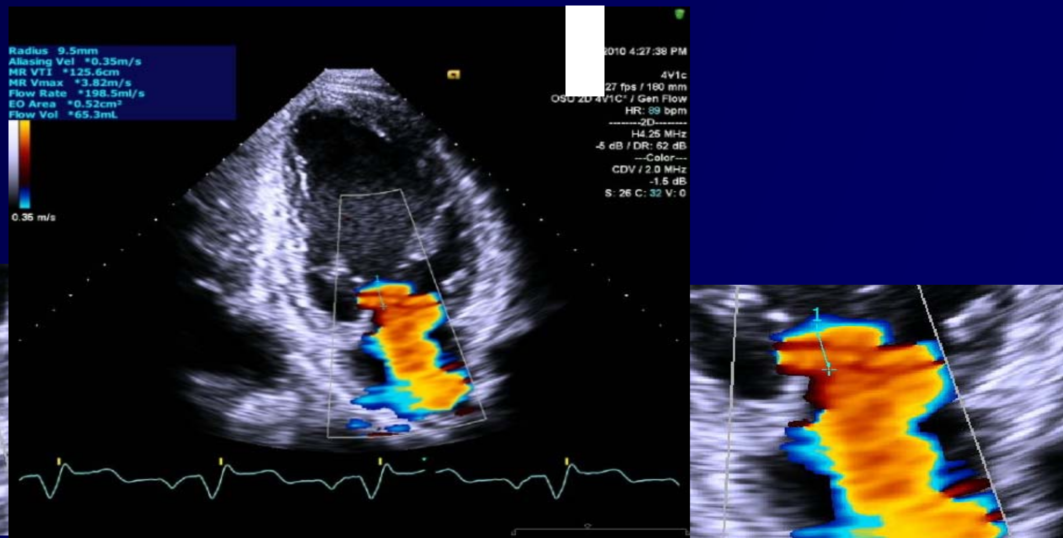


Radius 7.8 mm

$V_{aliasing}$ 23 cm/s

EROA: 0.23 cm^2

A2C



Radius 9.5 mm

$V_{aliasing}$ 35 cm/s

EROA: 0.52 cm^2

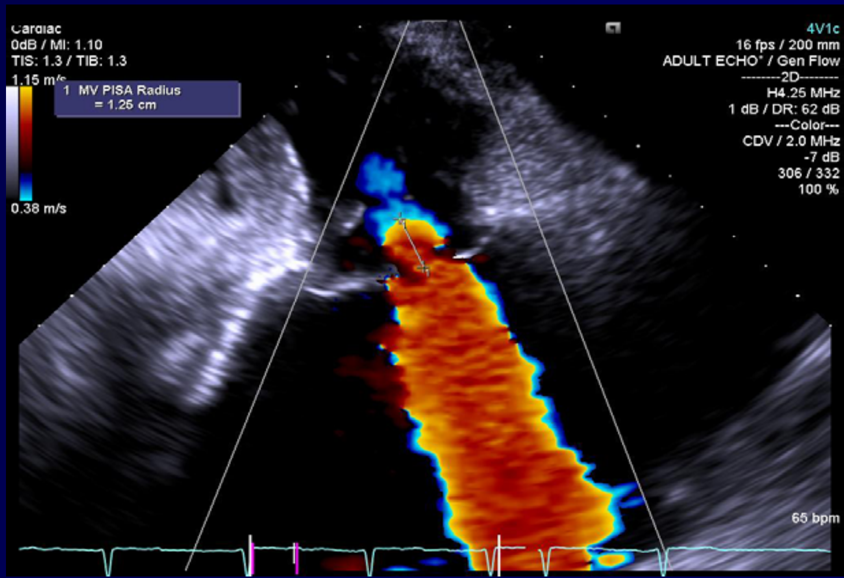
Limitations of 2D PISA

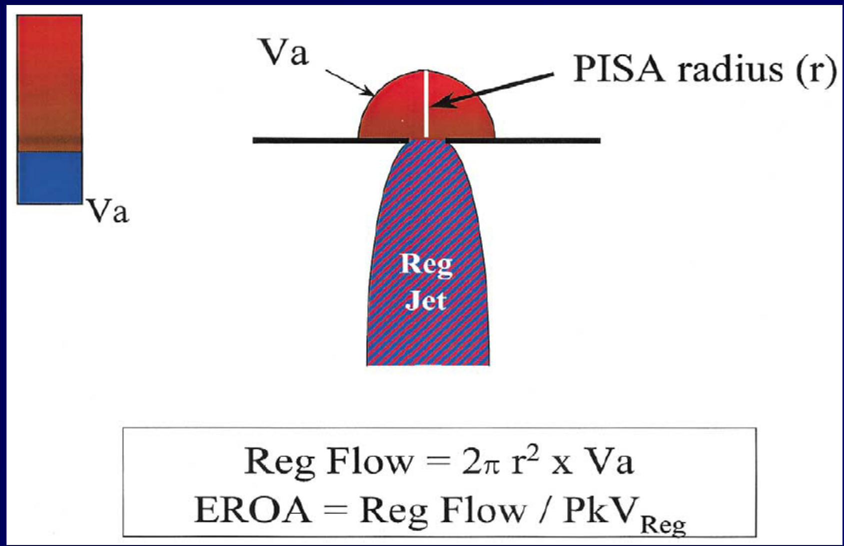
Today's Assumptions

– Centralized regurgitant jets
– Orifices are circular
– PISA shape is hemispheric

Today's Results

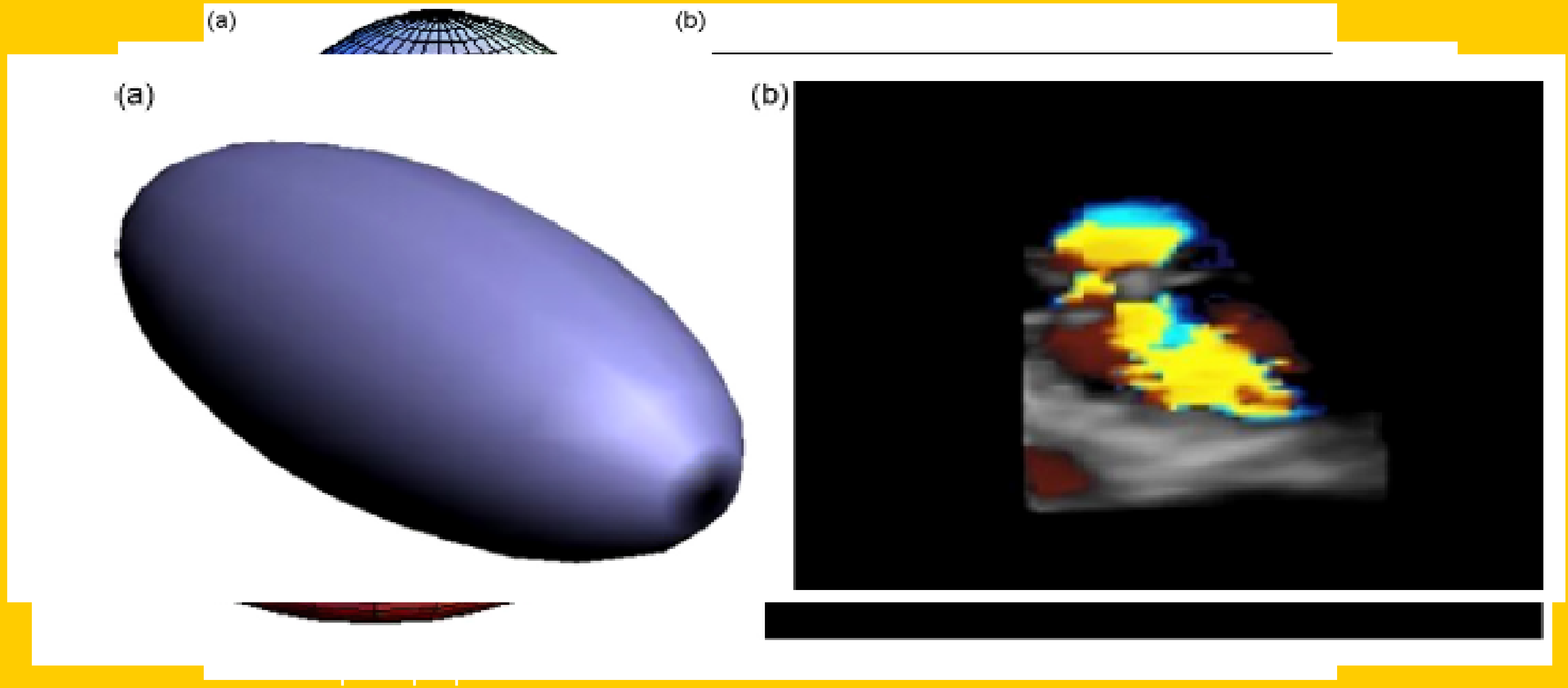
– Manual multi-step process
– User dependency
– Excludes patients with eccentric jets





Assessment of PISA:

Pediatric Population



Arch Cardiovasc Dis (2009), doi:10.1016/j.acvd.2008.12.008

Real time volume color Doppler

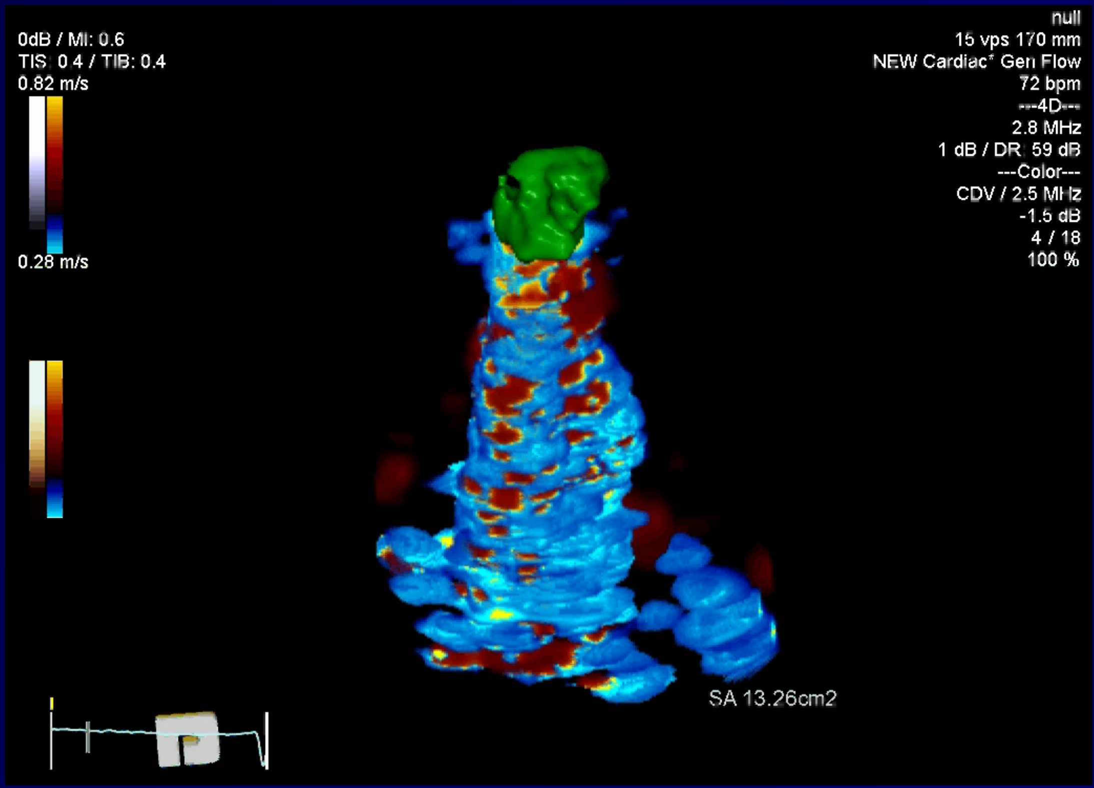
Real time volume Doppler - Volume PISA

Quantification of regurgitation based on 3D volume color Doppler

Accurate measurement free of geometric assumptions

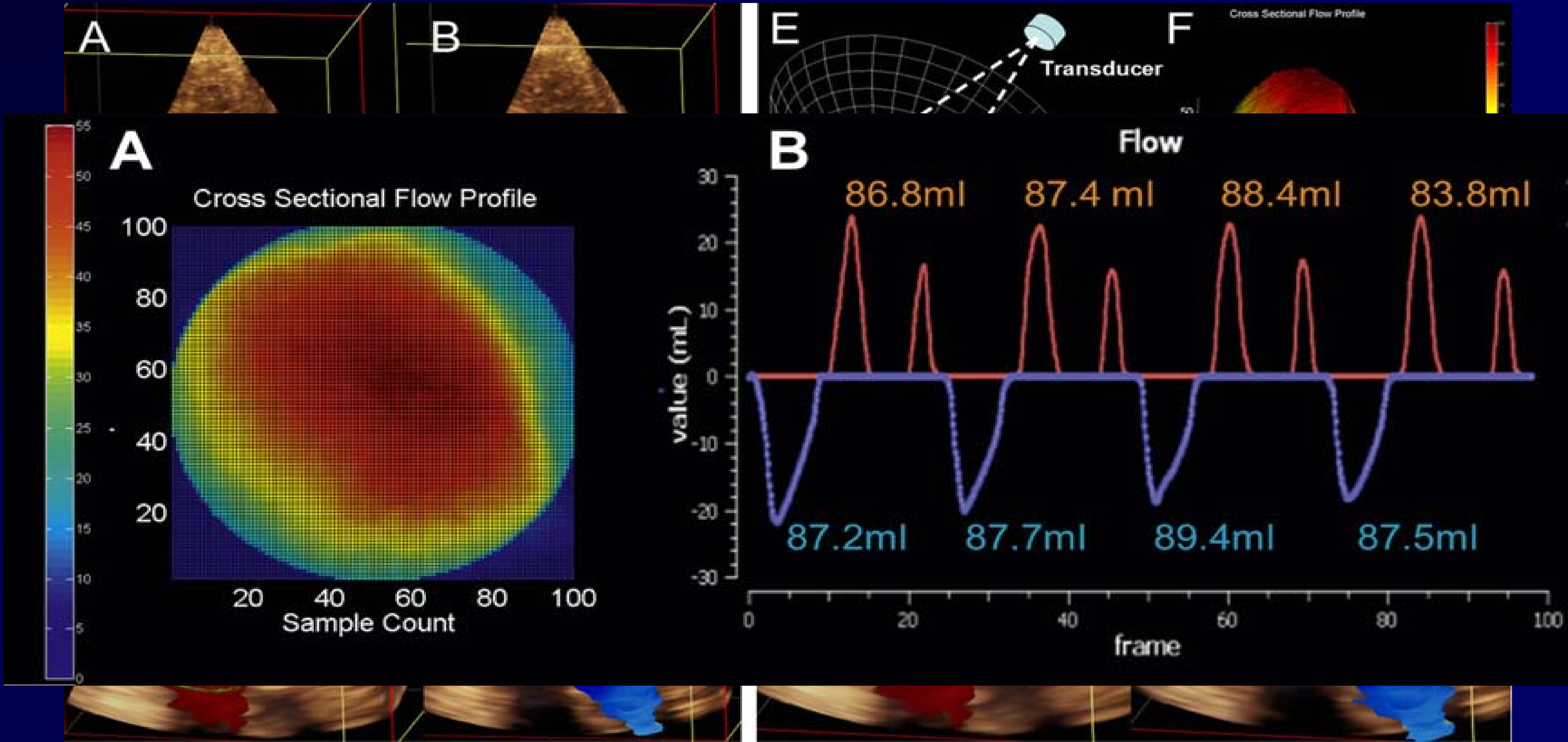
Accurate measurement of derived clinical parameters
(e.g. EROA, RV and RF)

Easy workflow



Quantification of Flow

RT-VCFD flow quantification



Automated quantification of mitral regurgitation

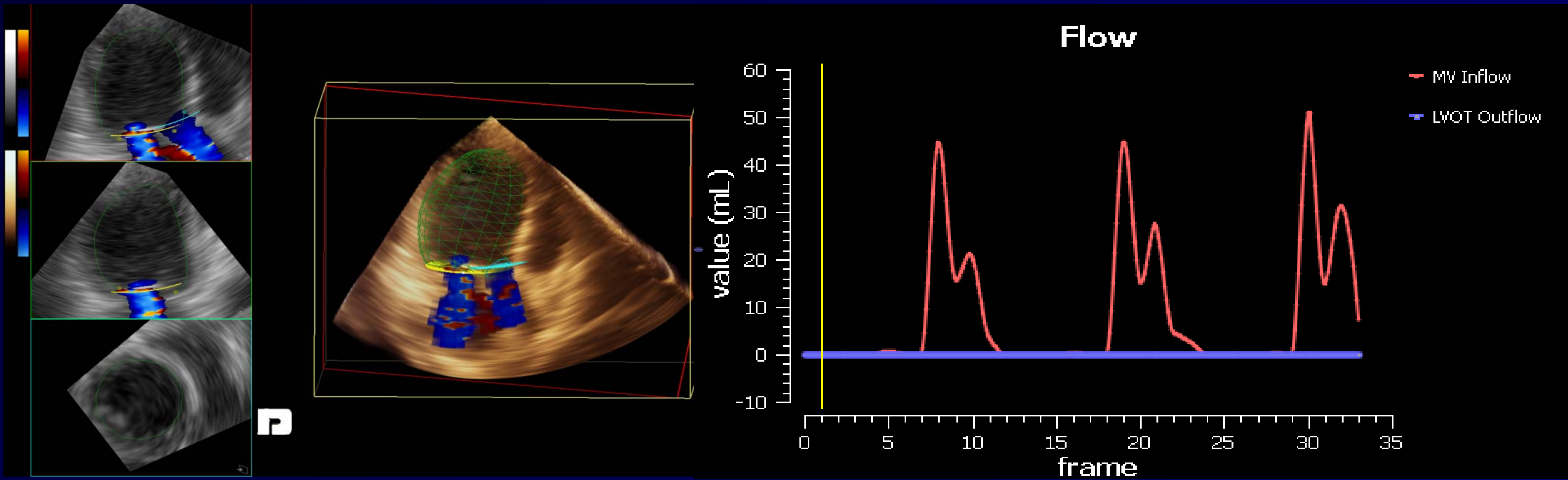
By 3D Real-Time Volume Color Doppler

- Regurgitant Volume

  - *Mitral Inflow and LVOT Flow*

Quantification of Flow

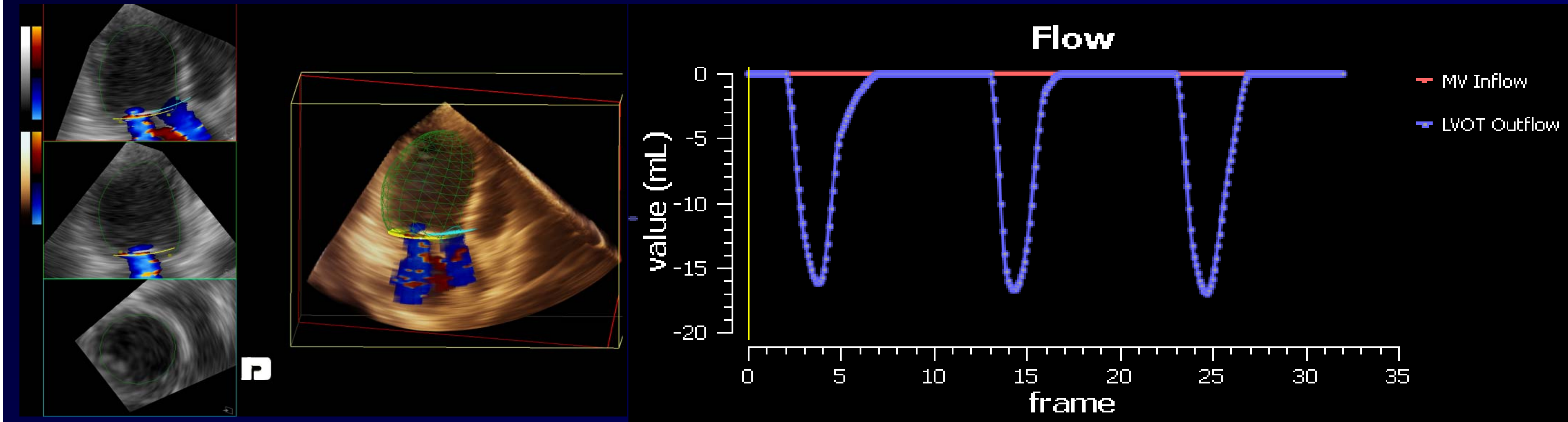
Automated Regurgitant Volume



81.7ml 95.5 ml 107.9ml

Quantification of Flow

Automated Regurgitant Volume

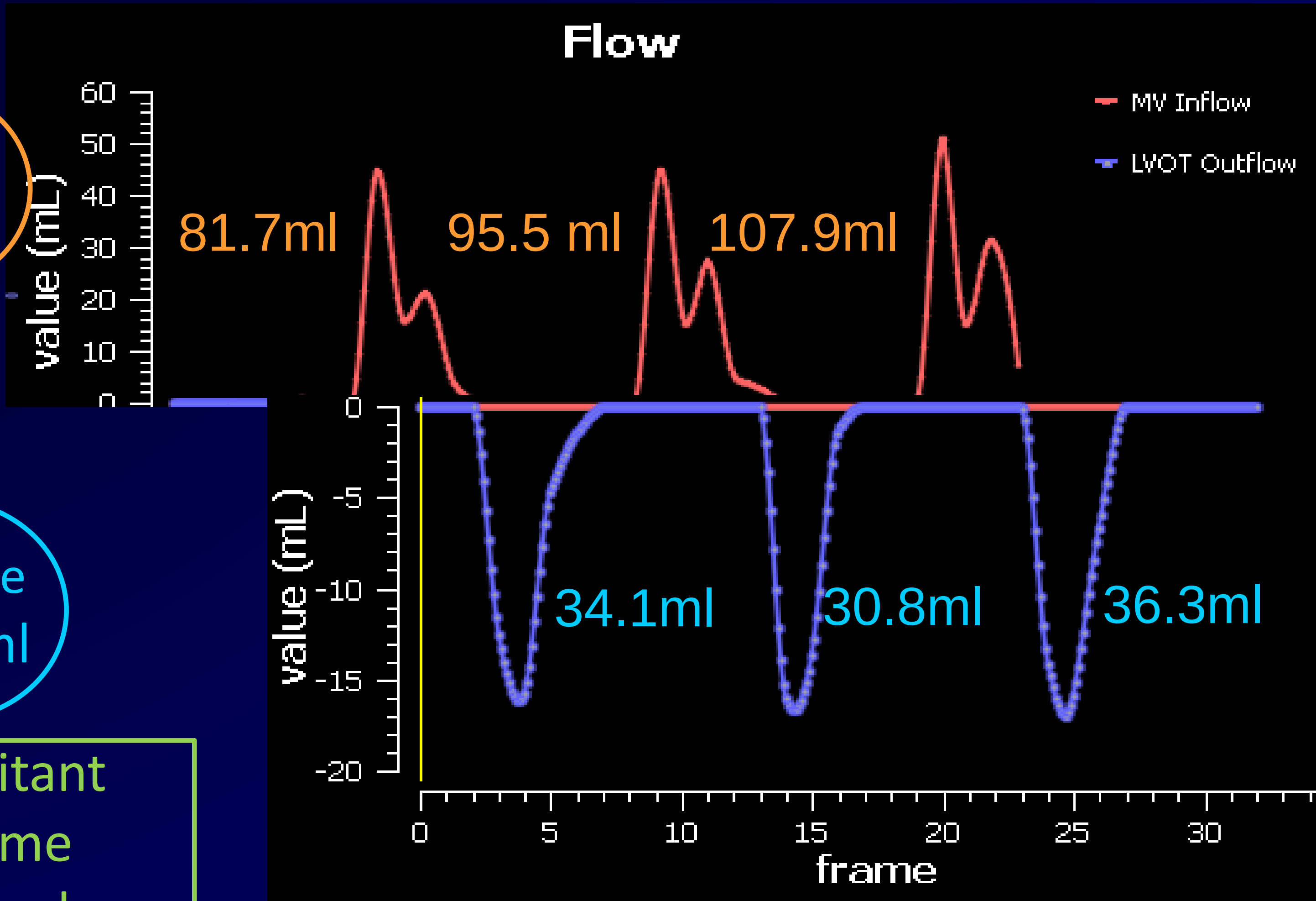


34.1ml 30.8ml 36.3ml

Quantification of Flow

Automated Regurgitant Volume

Average
95 ml



Average
33.7 ml

Regurgitant
Volume
61.3 ml

Methods

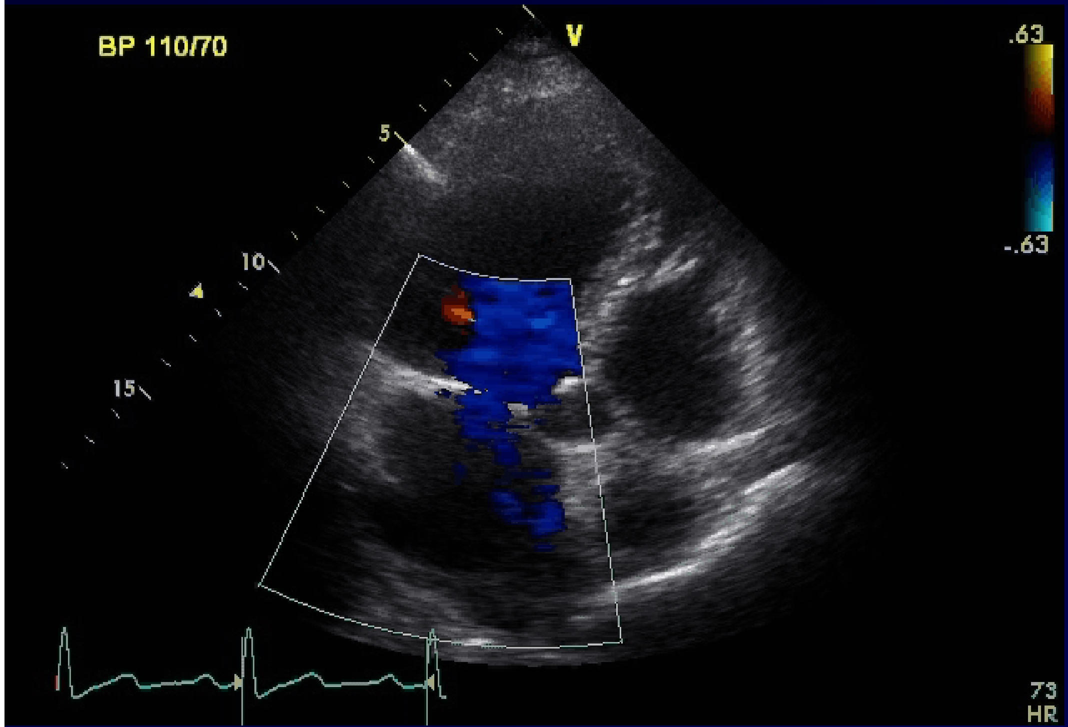
- *Study population*
  - Consecutively enrolled 9 patients with
  - More than moderate degree of MR on 2D transthorac ic echocardiography (TTE)
  - Undergoing CMR

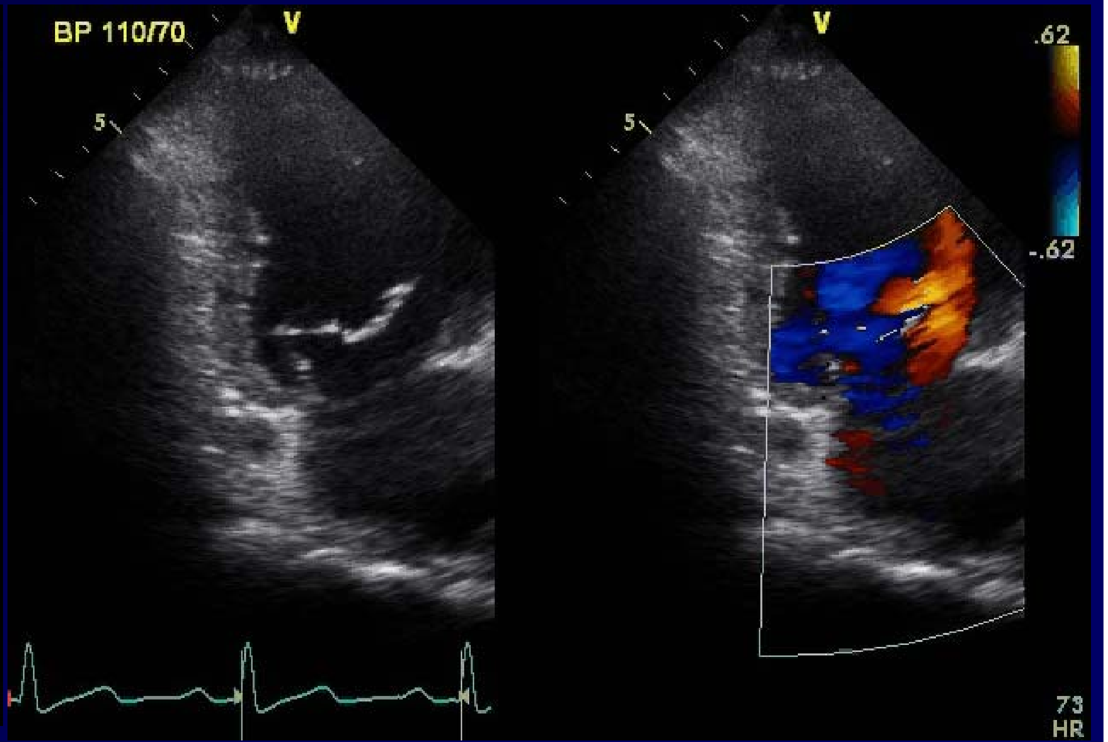
- *2D TTE*
  - MR volume quantificatinon by using
    - Proximal isovelocity surface area (PISA) method
    - Continuity equation (CE).

Methods

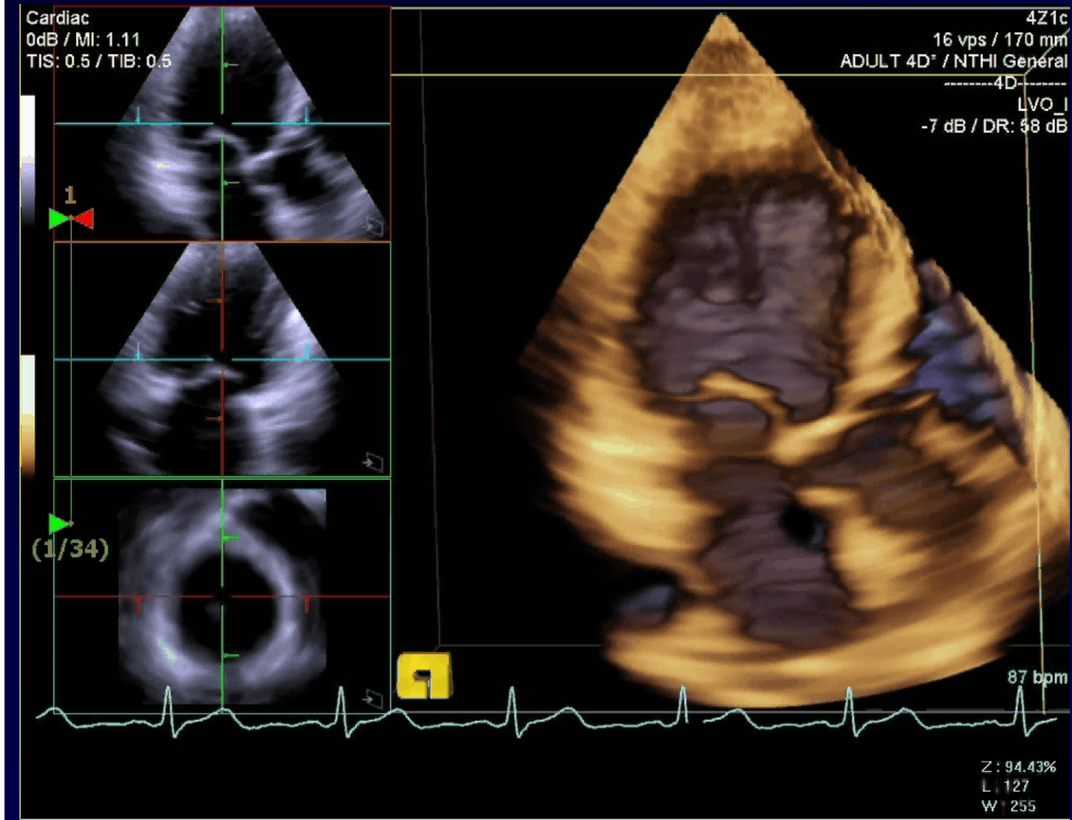
- ***RT-VCFD***
  - Siemens Acuson SC2000, 4Z1c real-time volume imaging transducer (2.8 MHz).
  - Offline analysis using prototype software (Siemens Medical Solutions USA Inc.)
- ***Cardiac MRI***
  - Phase contrast (PC)-CMR
  - Volumetric Stroke volume
  - Aortic VE Flow

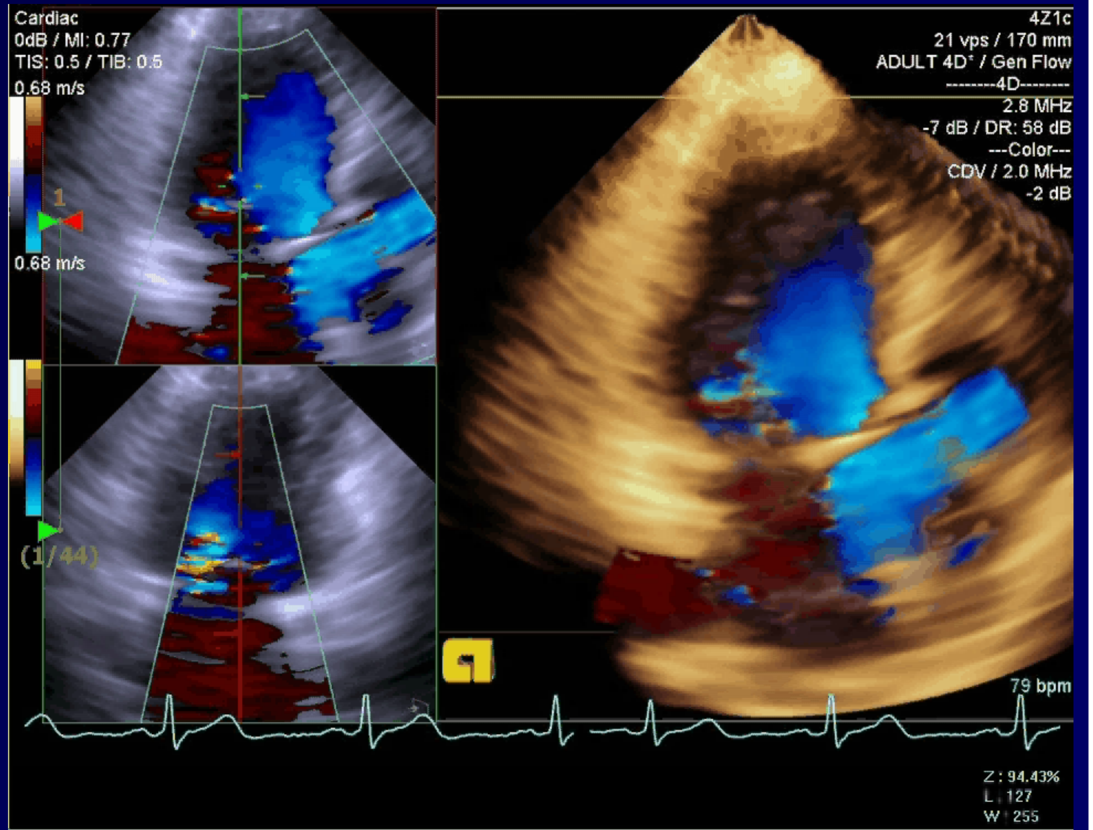
RT-VCFD Analysis



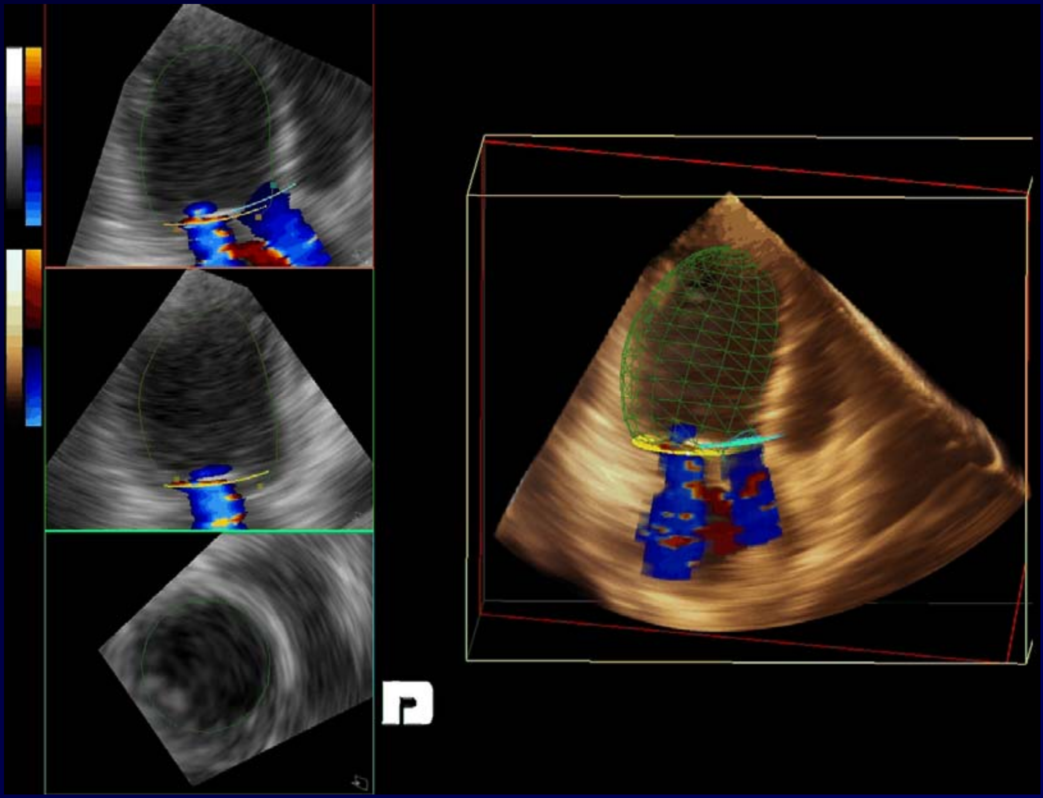


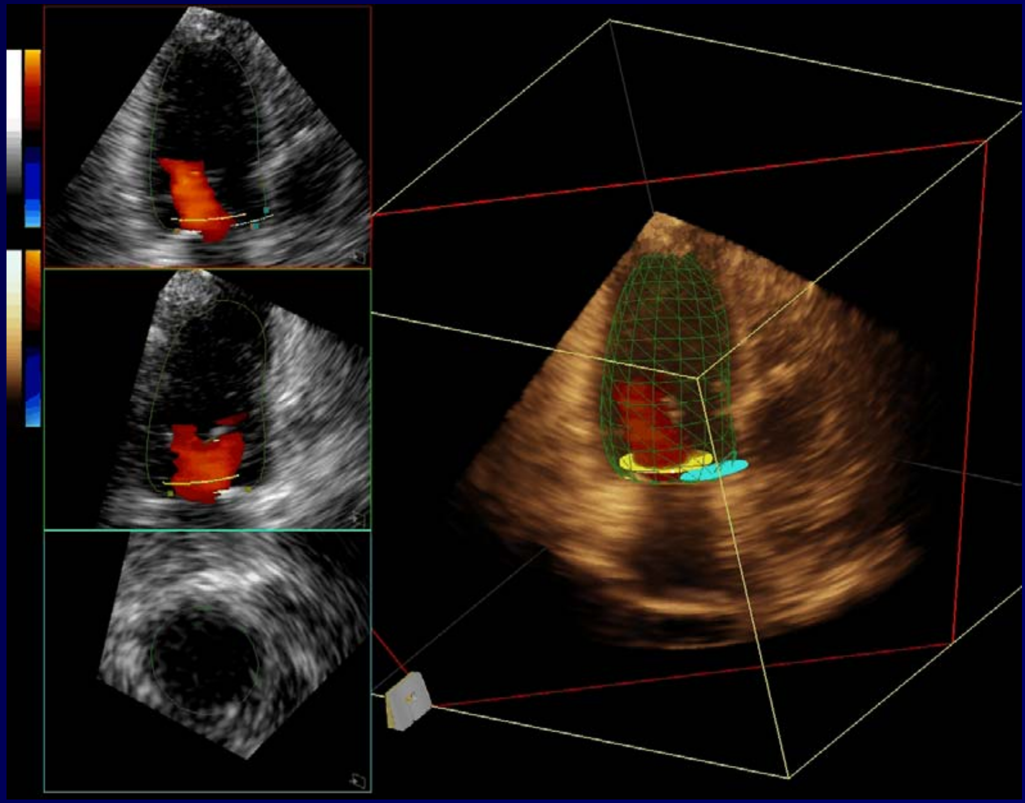
RT-VCFD Analysis



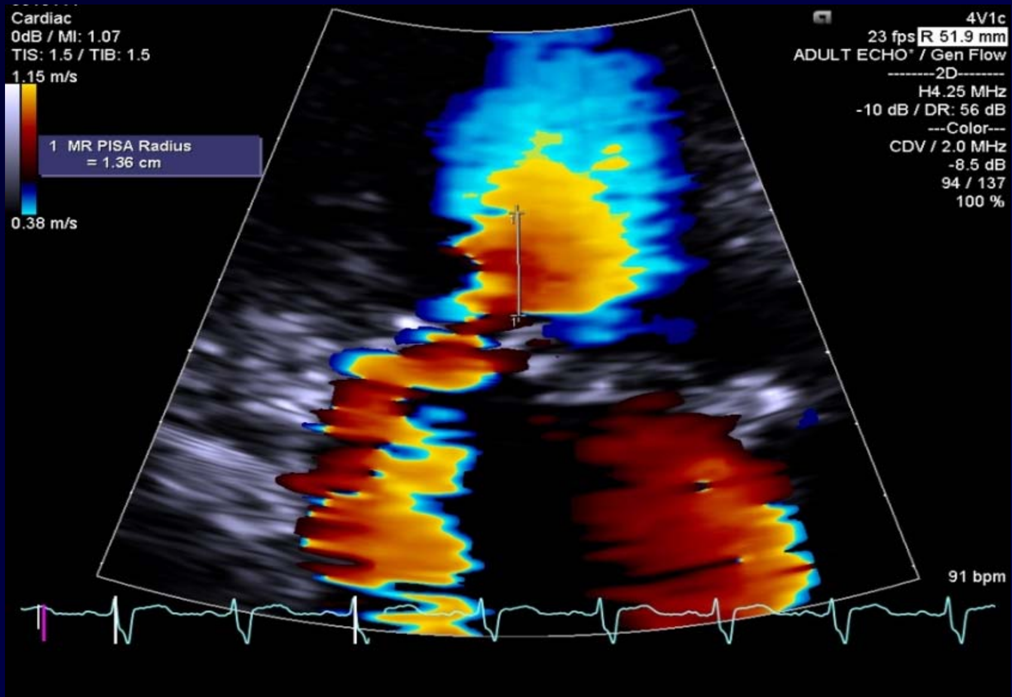


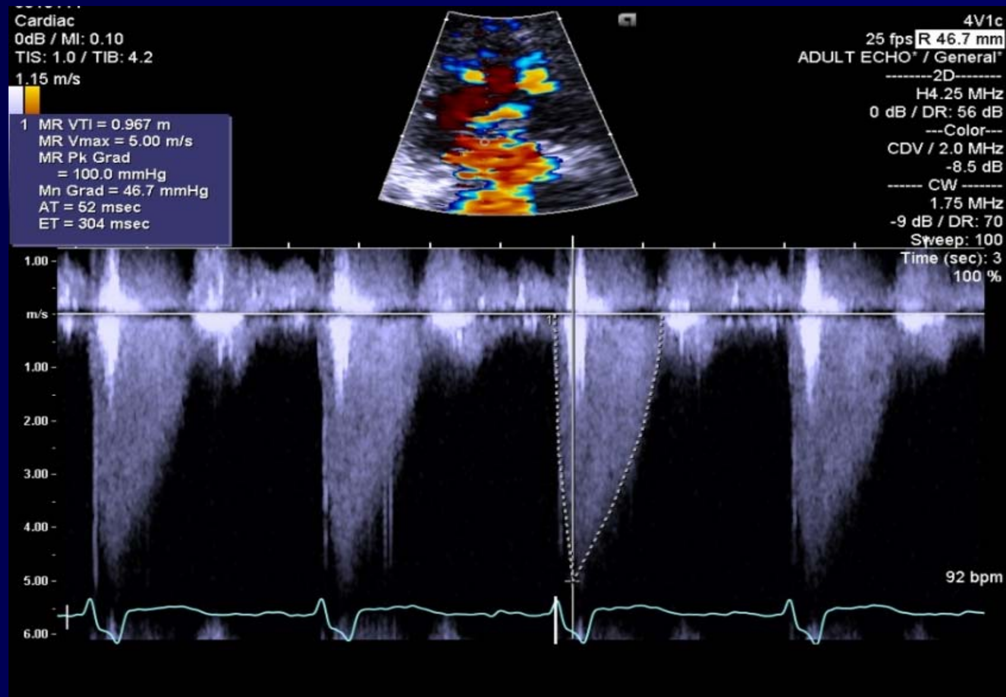
RT-VCFD Analysis





2D TTE: PISA

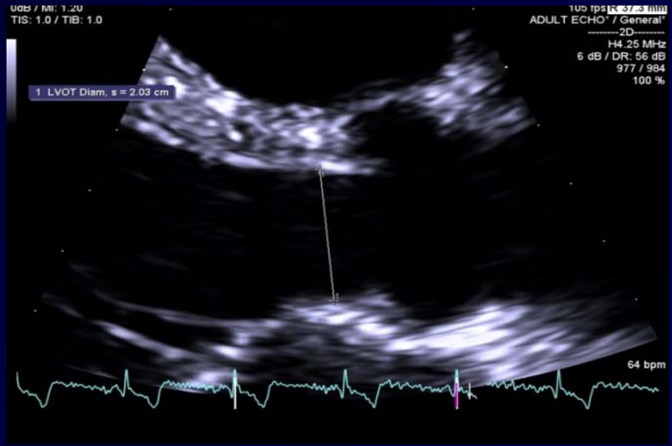


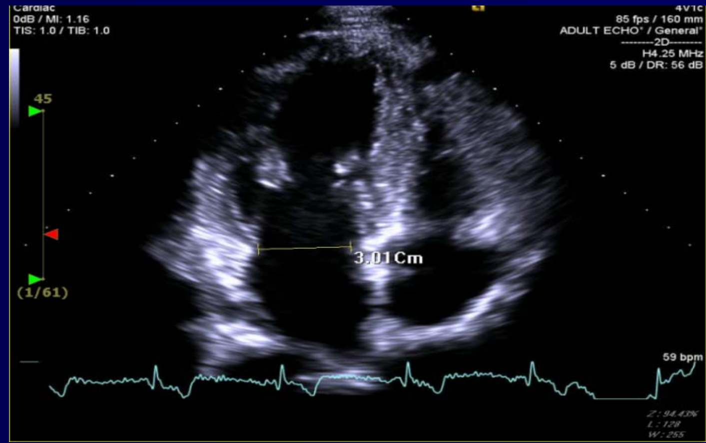


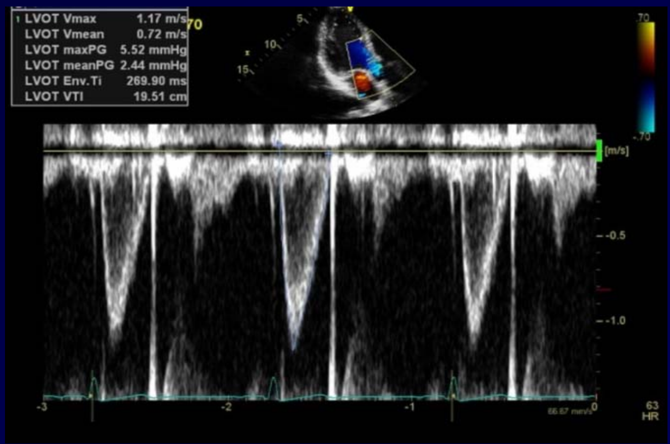
ERO = 1.9 cm^2

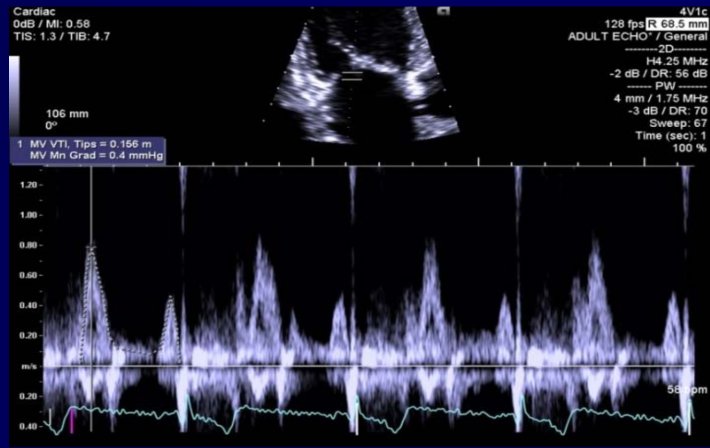
Regurgitant Volume = ERO X VTI = 1.9 X 96 = 182 ml

2D TTE: Continuity equation



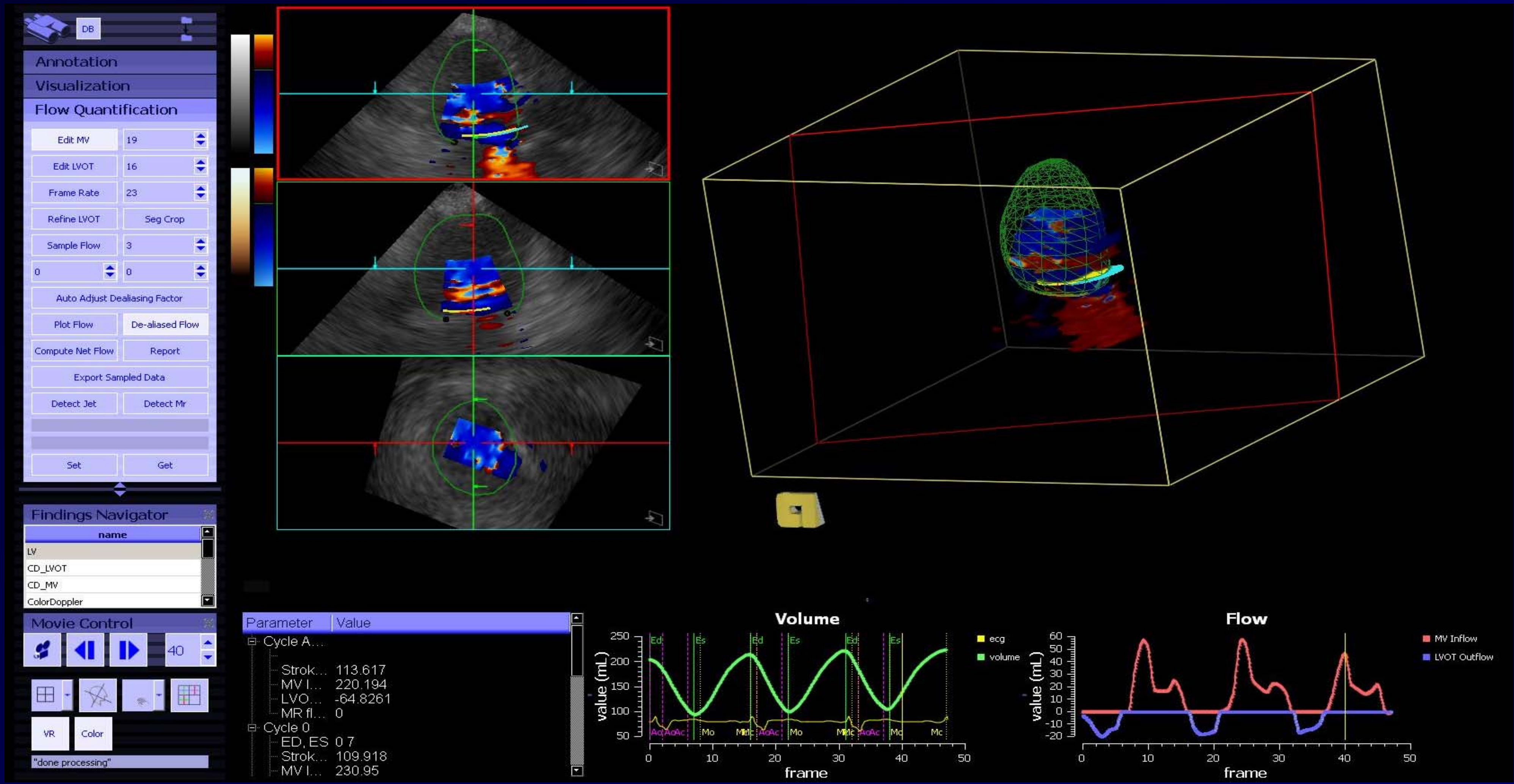






Mitral SV: 225cc - LVOT SV: 60cc = 165cc

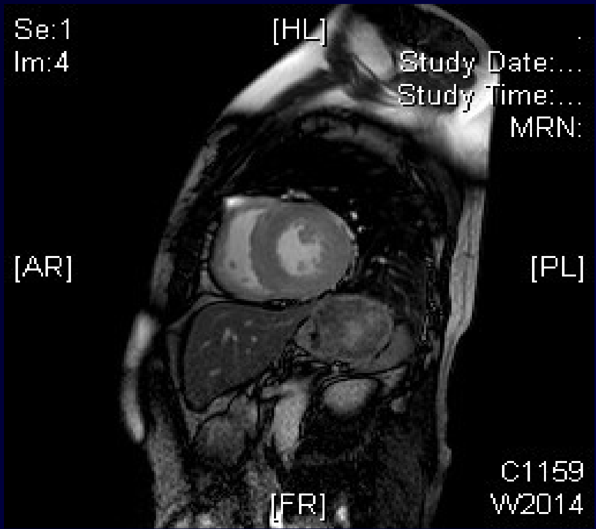
RT-VCFD Analysis



MVI = 220.2 cc   LVO = 64.8 cc

Regurgitant Volume = MVI - LVO = 220.2 – 64.8 = 155.4 cc

MRI



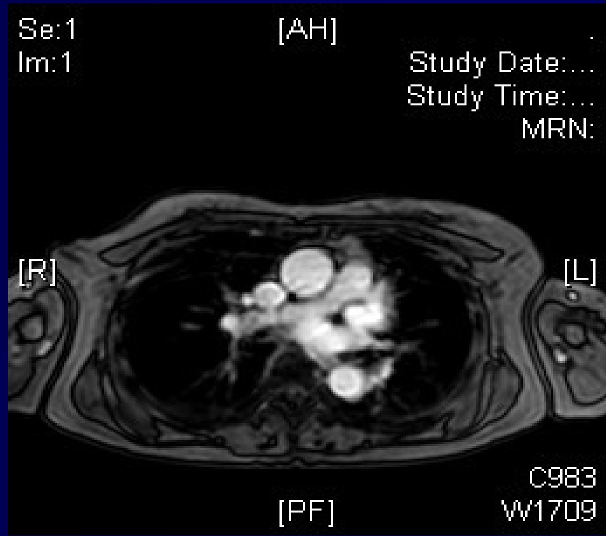

```
SESSION INFORMATION:

LV analysis: LV (validated).

RESULTS SUMMARY:

Ejection fraction  :  73.8 %
Stroke volume      : 169.7 ml
Cardiac output     :  14.9 l/min

ED phase                           :  618.0 ms  ( phase 24  )
ED volume                          :  230.0 ml
ES phase                           :  295.0 ms  ( phase 12  )
ES volume                          :   60.3 ml
ED wall mass                       :   64.6 g
ED wall + papillary mass           :    n/a
ED wall - correct. mass            :    n/a
ED wall + papillary - correct. mass :   n/a
Heart rate                         :   88.0 bpm
```




```
SESSION INFORMATION:

Q-Flow: AA (validated).

RESULTS SUMMARY:

Heart rate              :       86 bpm

RR-interval             :      698 ms        (from heart rate)

ANALYSIS RESULTS:

slice 1                   | Vessel
                          |      1
----------------------------------
Stroke volume (ml)        |   68.1
Forward flow vol. (ml)    |   69.6
Backward flow vol. (ml)   |    1.6
Regurgitant fract. (%)    |    2.2
Abs. stroke volume (ml)   |   71.2
Mean flux (ml/s)          |   97.6
Stroke distance (cm)      |    6.1
Mean velocity (cm/s)      |    8.7
```

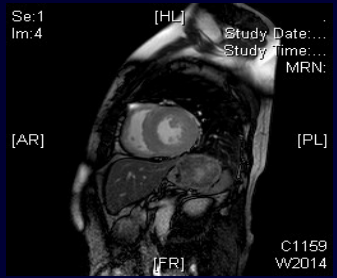
Stroke volume
= 191.6 ml

AA forward flow volume
= 36.9 ml

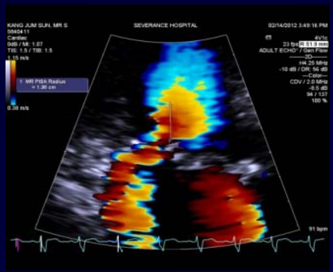
Regurgitant Volume = Stroke volume – AA forward flow volume

= 191.6 – 36.9 = 154.7 ml

Comparison

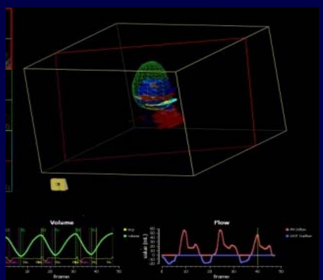


Regurgitant Volume = 154.7 ml



Regurgitant Volume = 182 ml

Regurgitant Volume = 165 ml



Regurgitant Volume = 155.4 ml

RESULTS

Quantification of Mitral regurgitant volume

MR volume (ml)	
2D PISA	47.5 ± 24.2
2D CE	73.7 ± 50.8
3D RT-VCFD	78.1 ± 47.4
MRI	73.6 ± 44.3

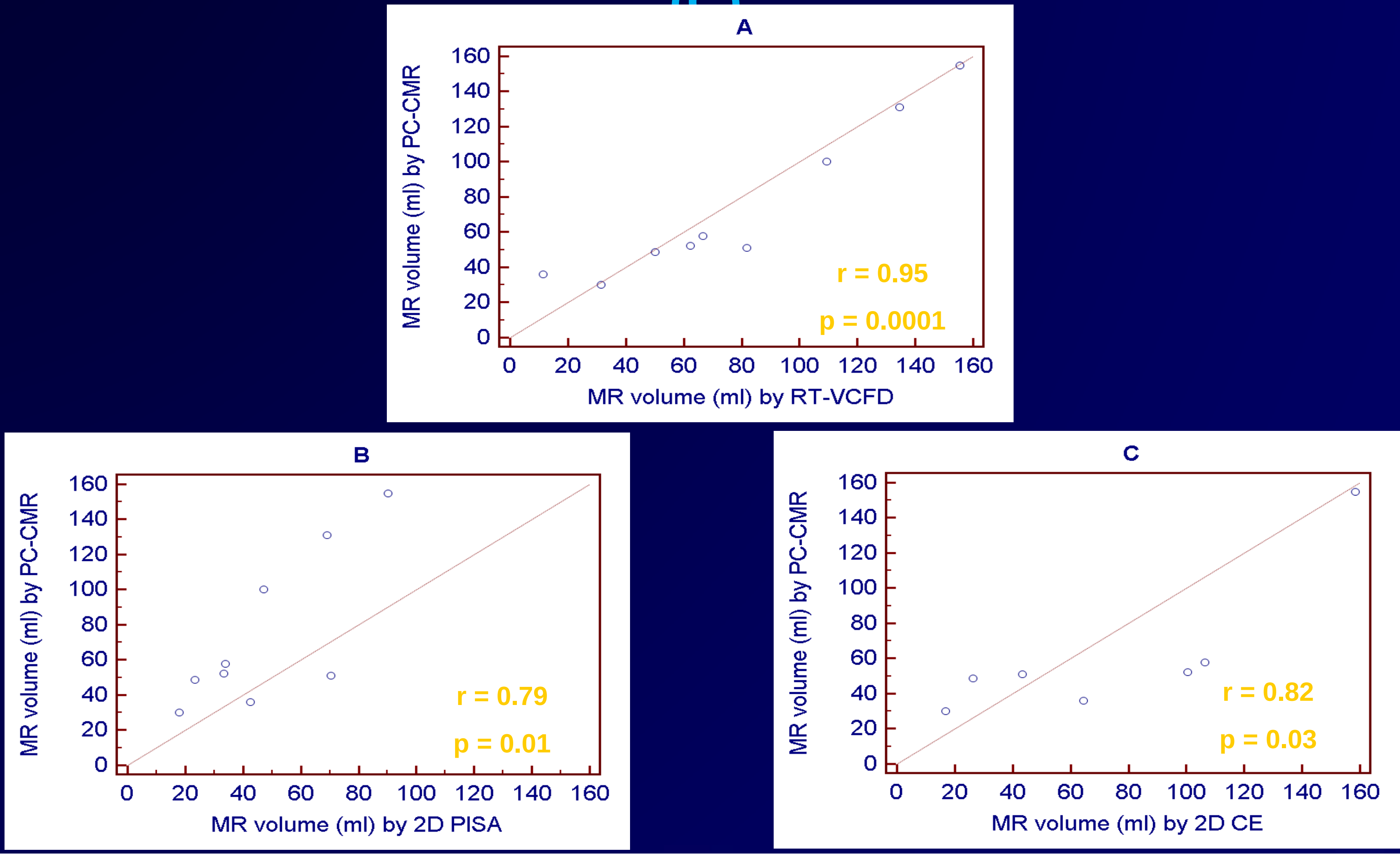
Differences in MR volume compared with PC-CMR

2D PISA (ml)	25.7 ± 26.4
2D CE (ml)	26.9 ± 16.5
3D RT-VCFD (ml)	9.9 ± 10.8

P = 0.016

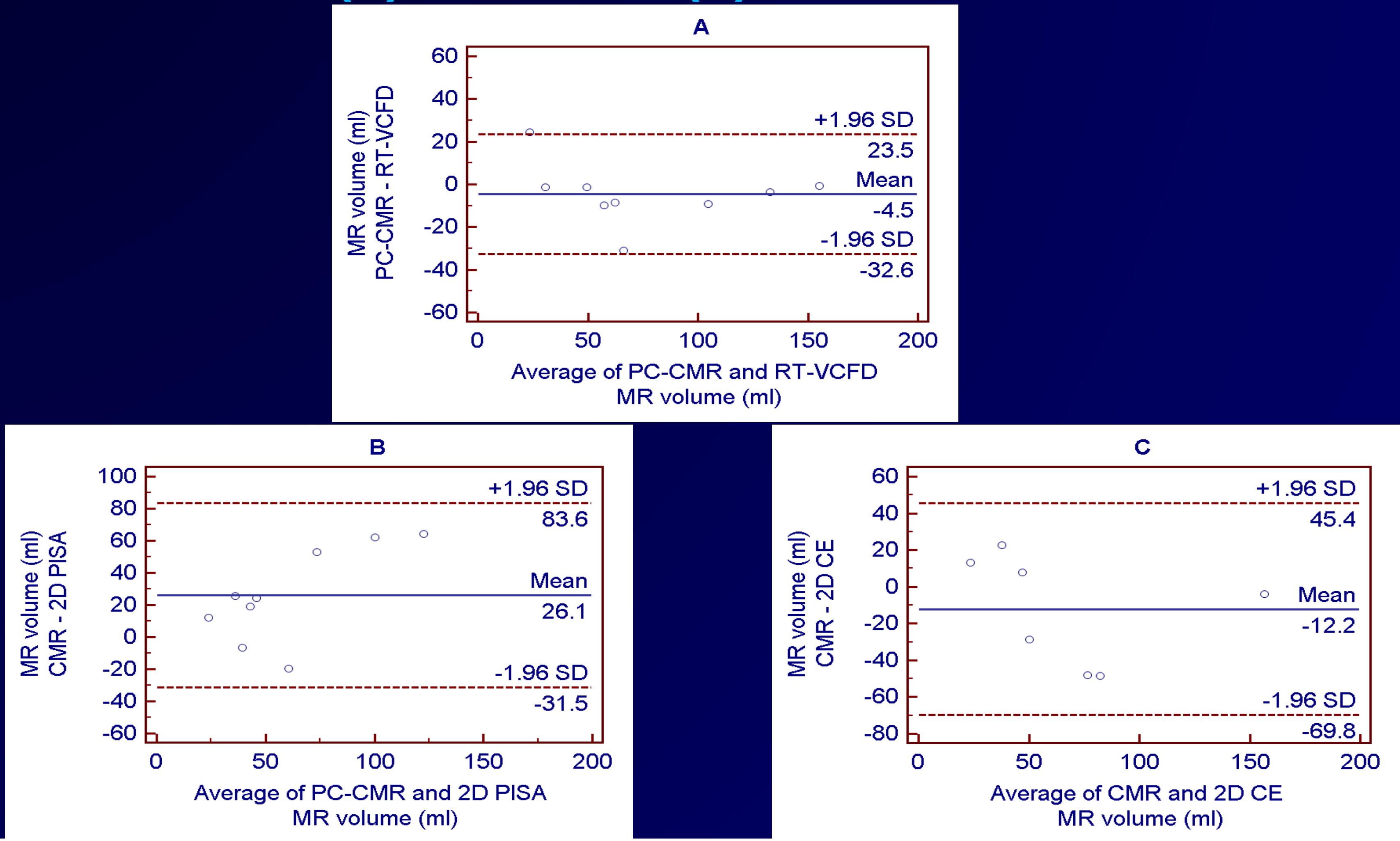
RESULTS

Correlation between PC-CMR and RT-VCFD (A), 2D PISA (B), 2D CE (C)

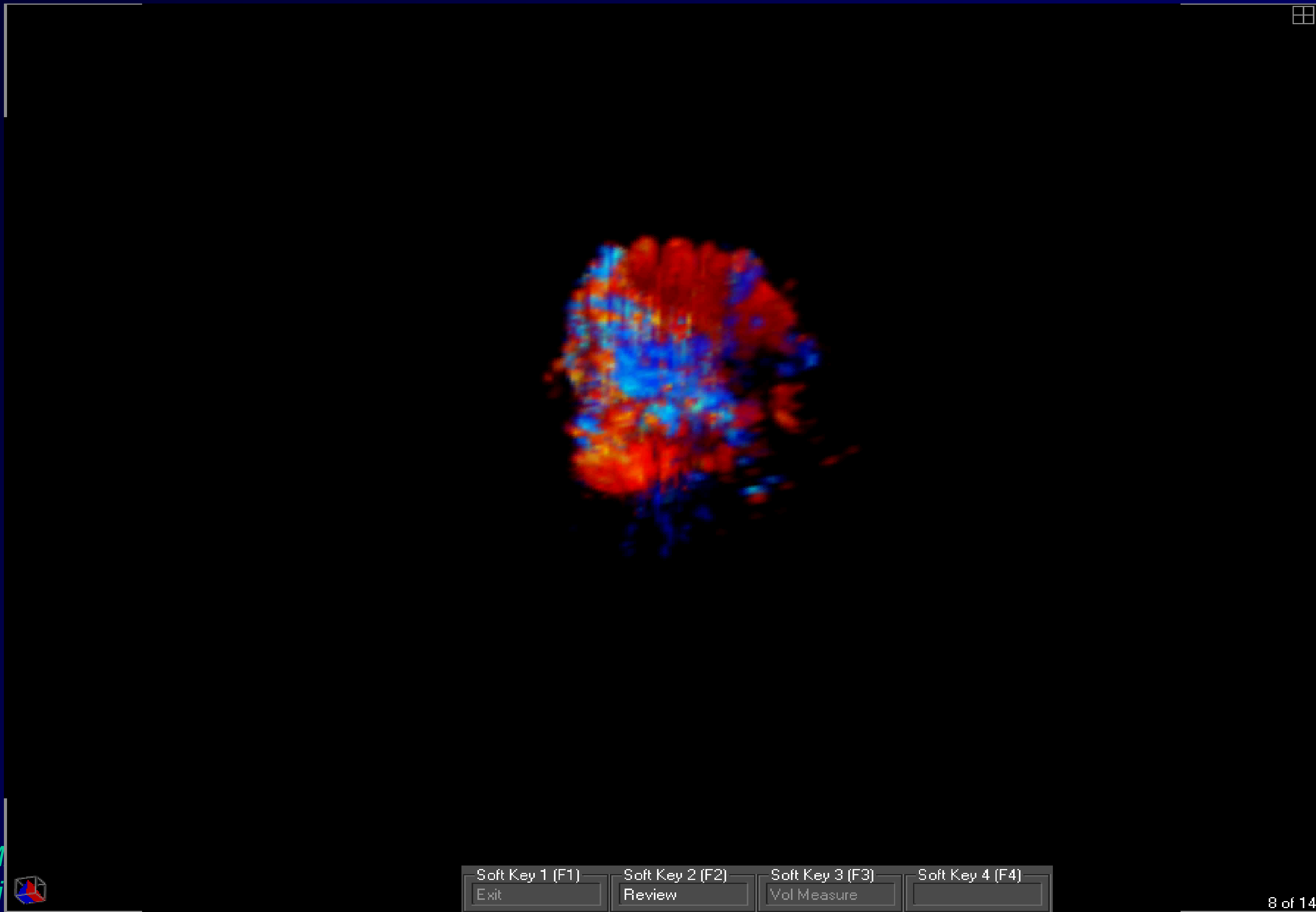


RESULTS

Bland-Altman analysis comparing MR volume by RF-VCFD (A), 2D PISA (B), and 2D CE (C) with PC-CMR

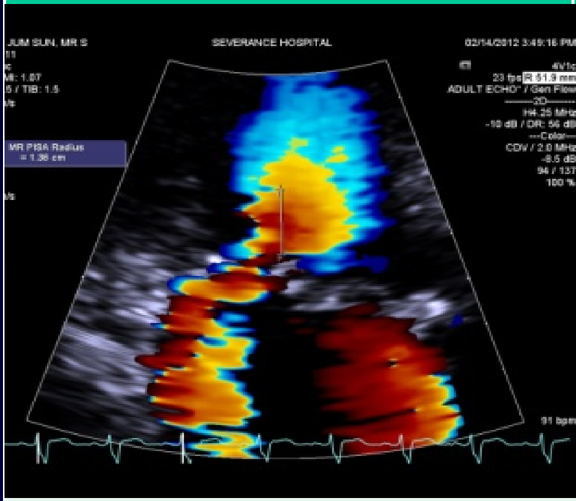
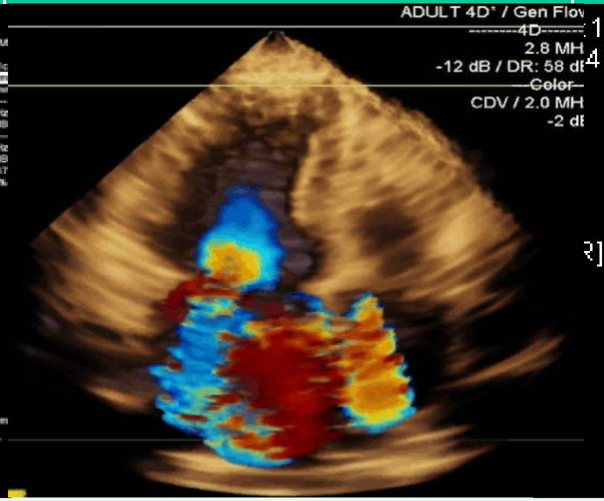
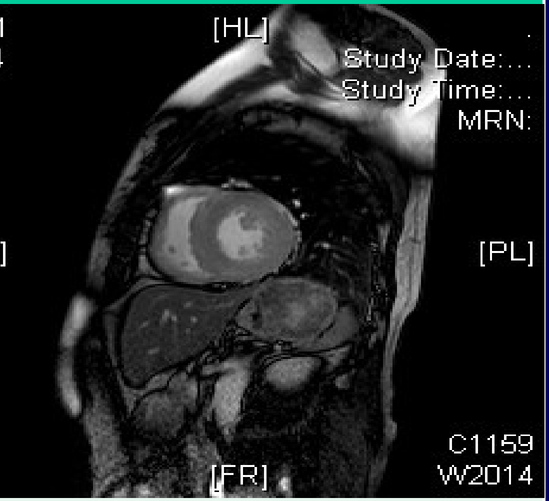


3-D Echocardiography



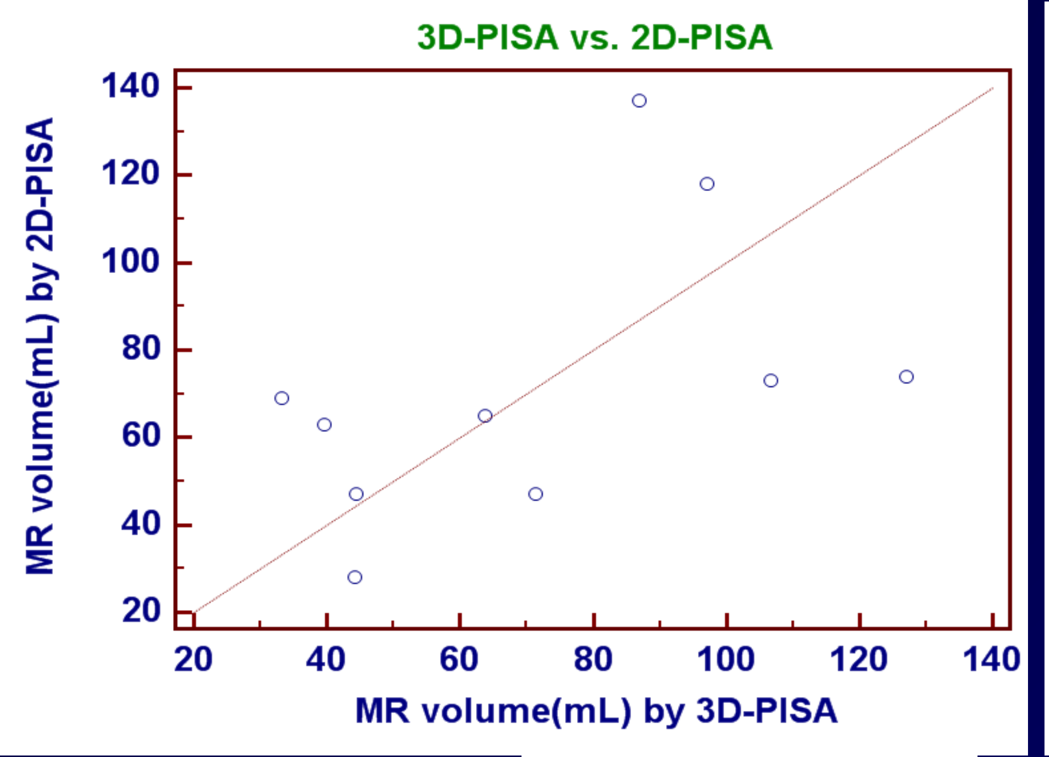
Vannan M
Echocardi

CASE

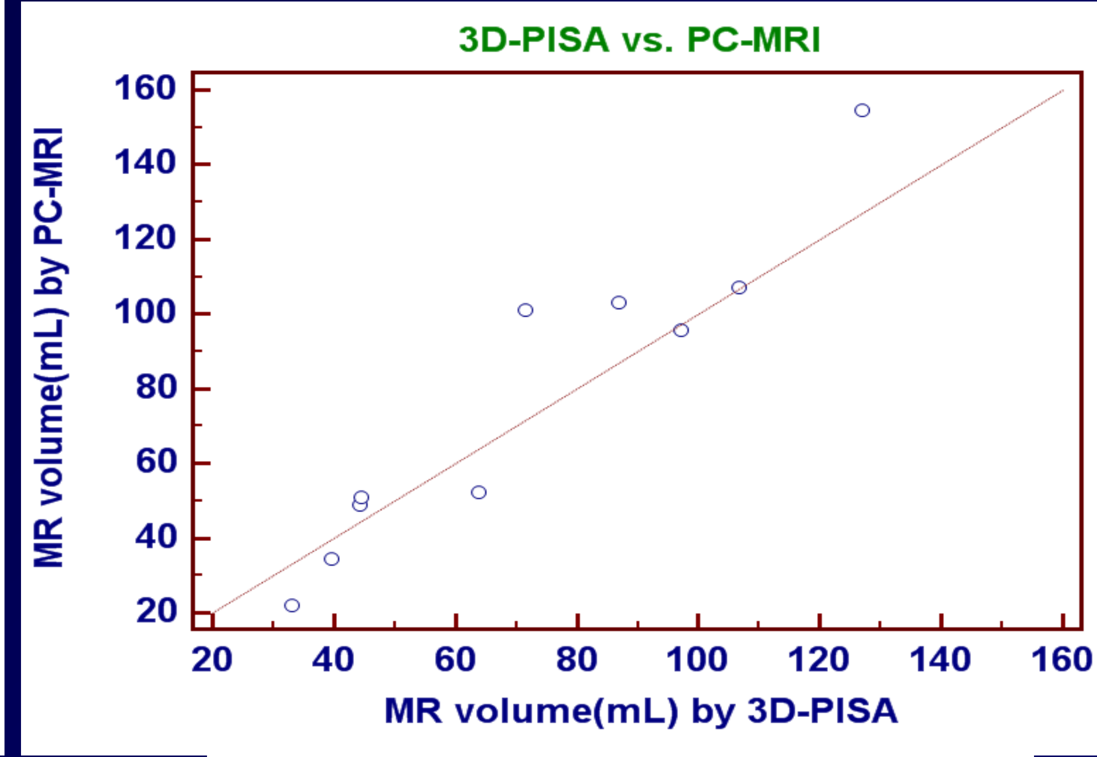
2D PISA	3D PISA	MRI
		
MR Regurgitant volume		
73.0 mL	**106.0 mL**	**107.2 mL**

RESULT

Correlation between methods



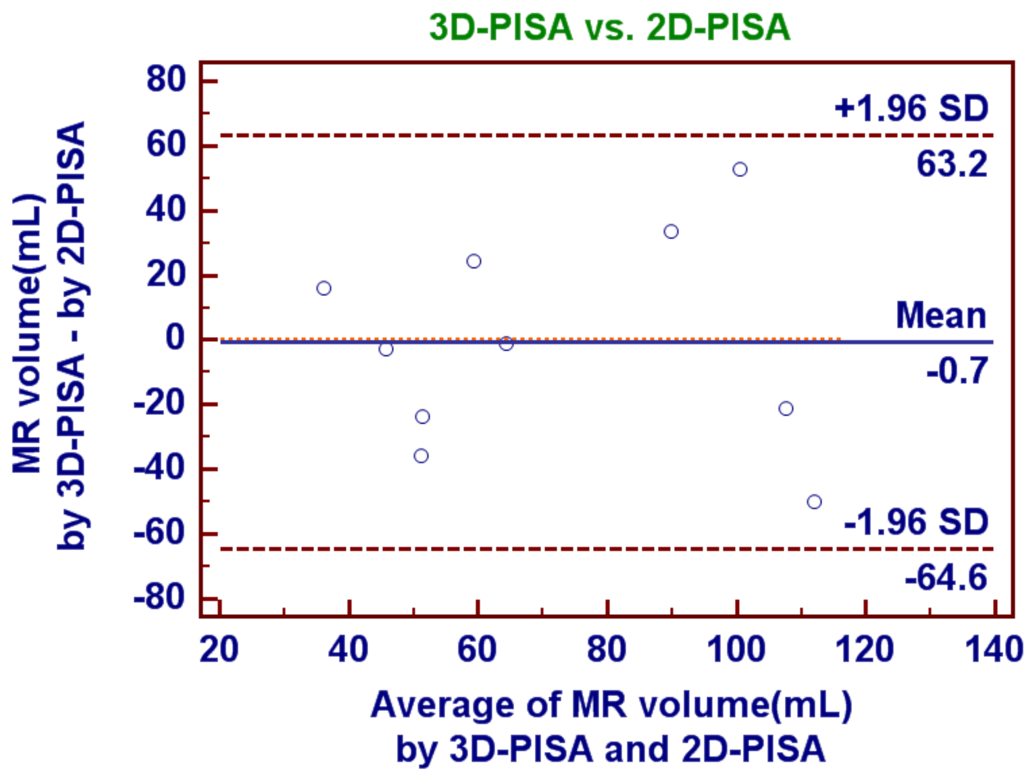
r=0.49, P=0.15

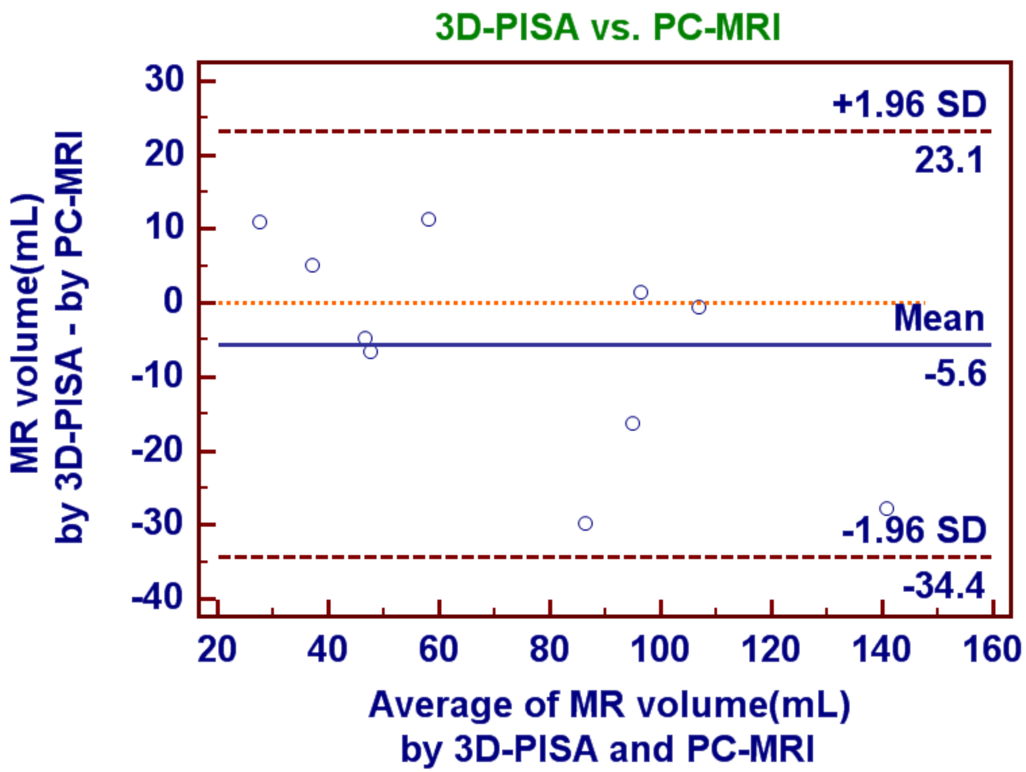


r=0.95, P<0.01

RESULT

Agreement between methods





Mean= -0.7

±1.96 SD = *-64.6 ~ 63.2*

Mean= -5.6

±1.96 SD = *-34.4 ~ 23.1*

SUMMURY

- **Automated quantification of MR with RT-V CFD**
  - **Feasible**
  - **Mitral regurgitation volume can be computed automatically from CFD data**
  - **More accurate than 2D TTE (PISA or continuity equation)**
  - **Improves quantification of regurgitation**

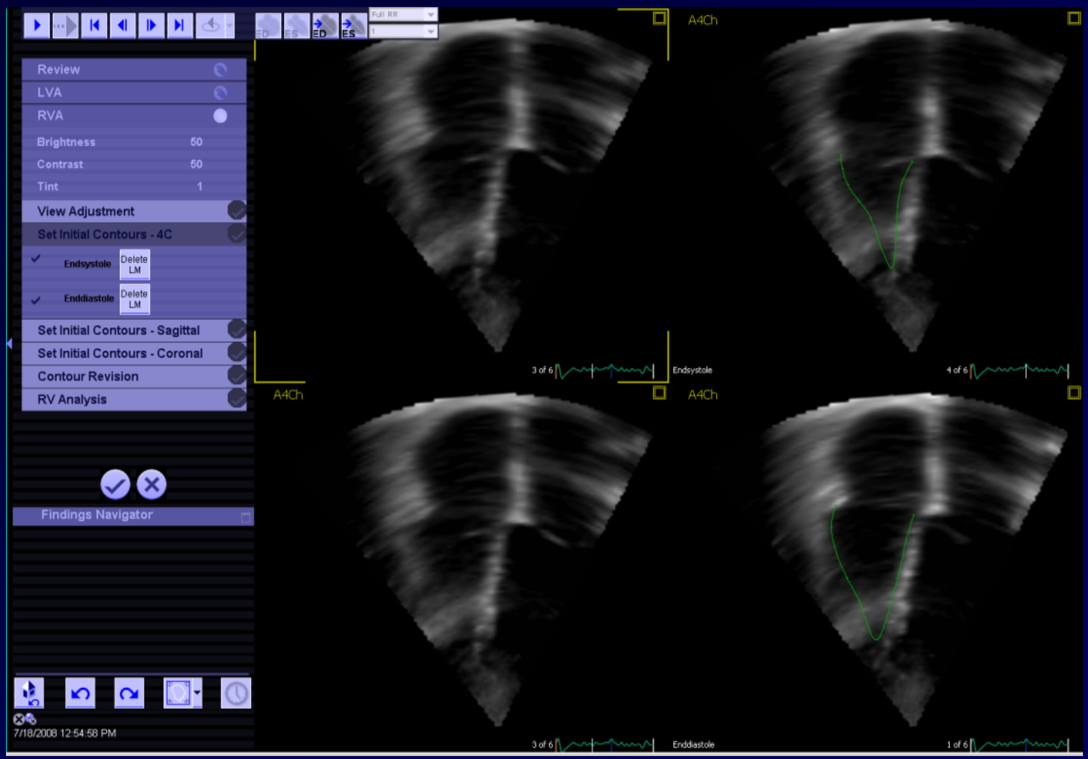
Conclusion

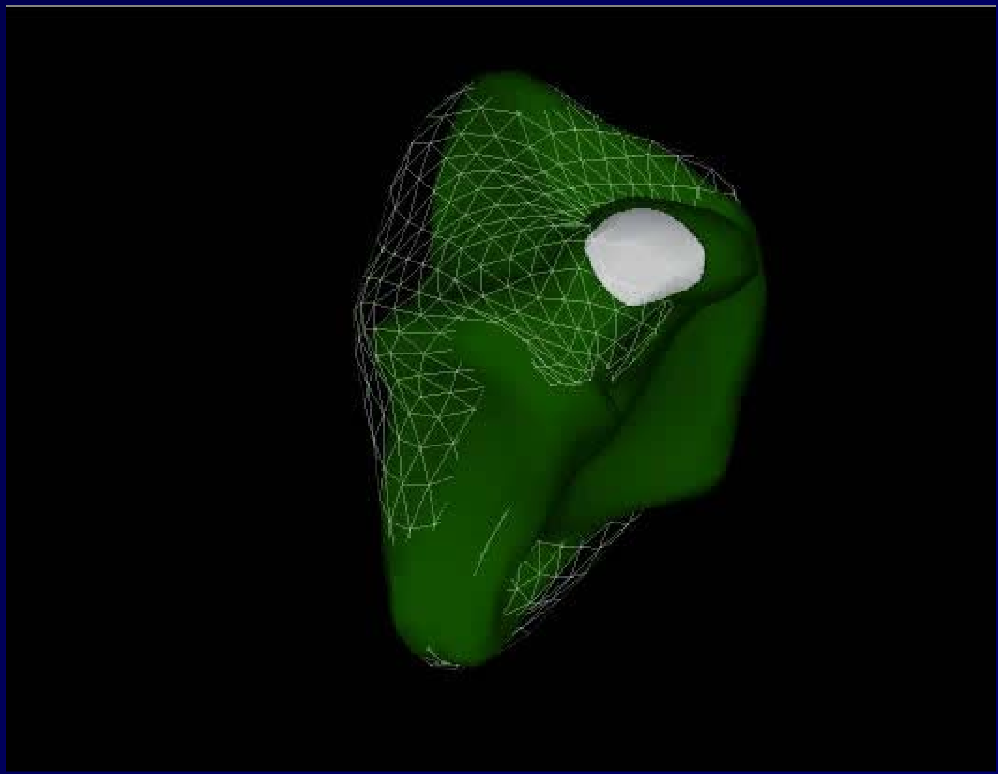
- **Using RT-VCFD**
  - Automated quantification of MR is feasible and accurate.
  - It should be a promising tool of real-time 3D echocardiography in the evaluation of patients with MR.

- **Can be applicated in**
  - Evaluating response to medical or device therapy
  - Quantification of AR
  - Rt side valvular regurgitation and pul HTN
  - Qp / Qs

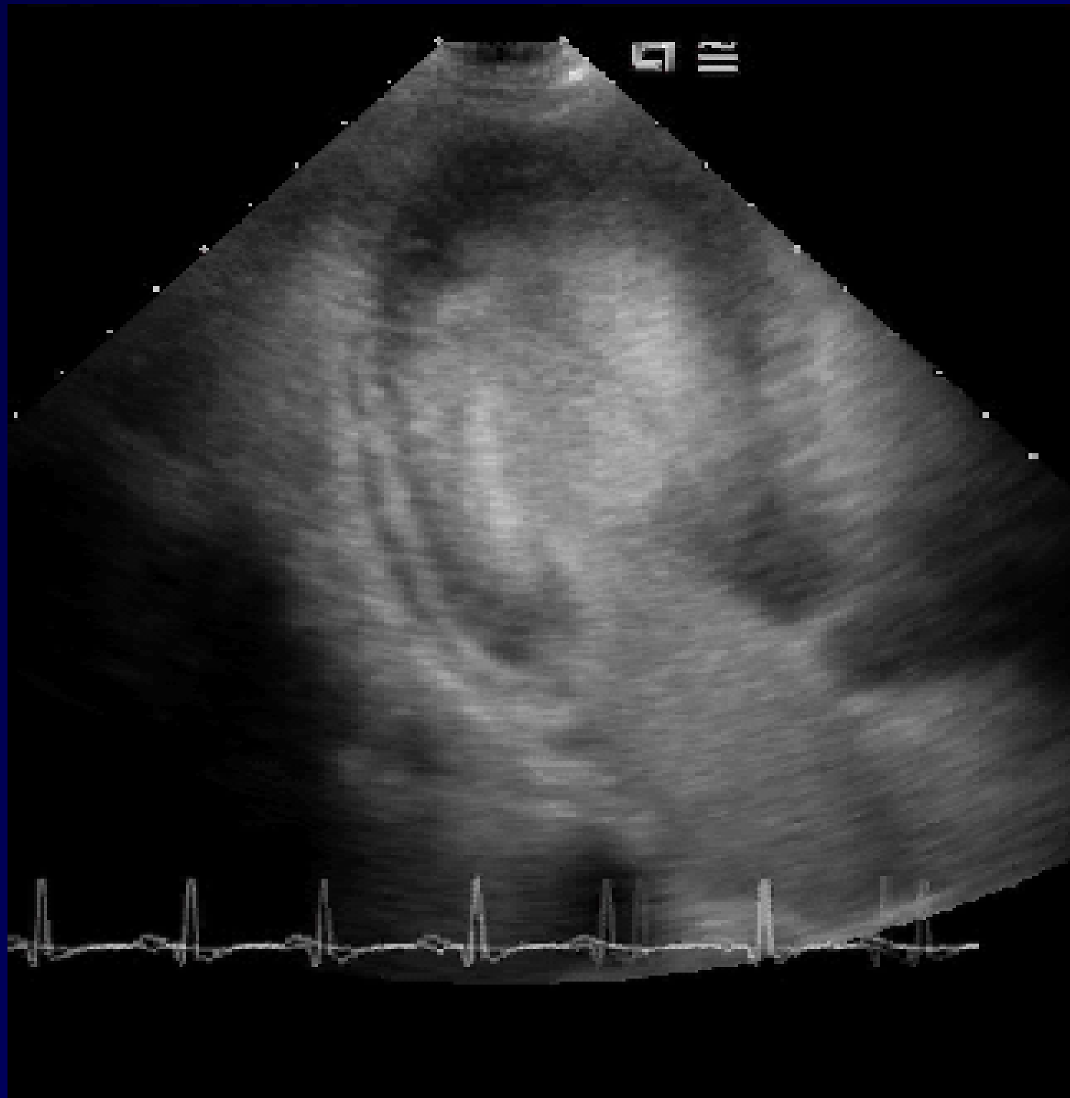
Echo in a Heart Beat

Automated RV Function Analysis

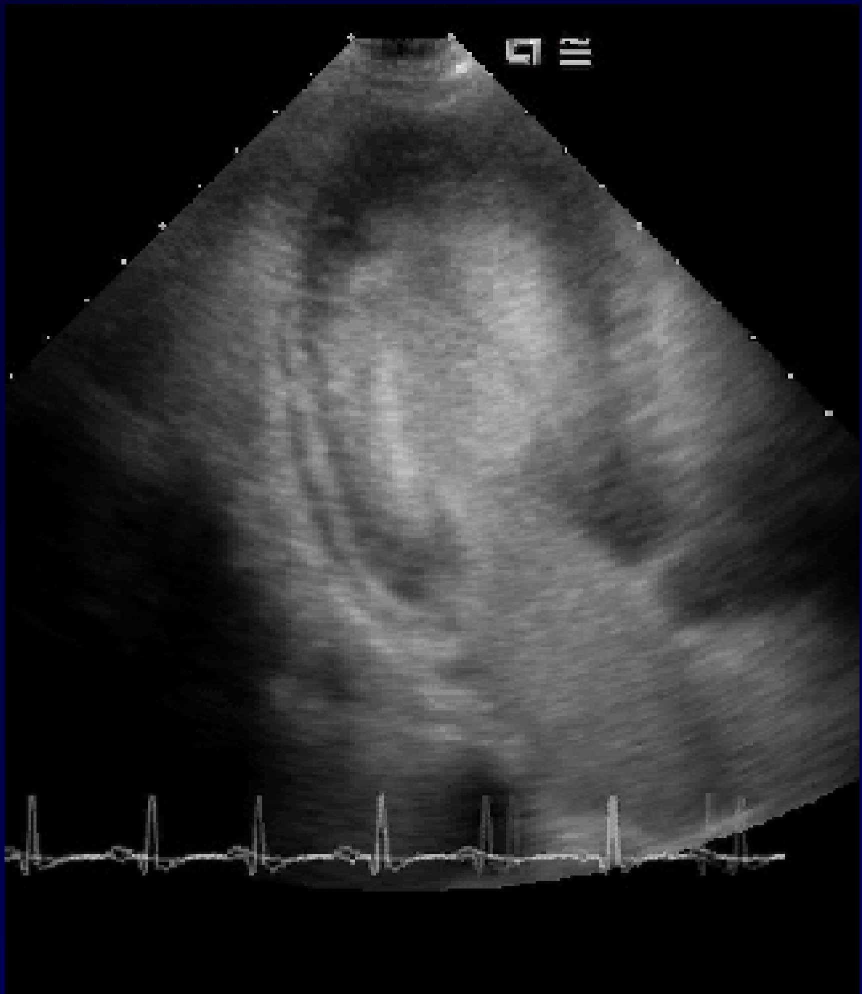


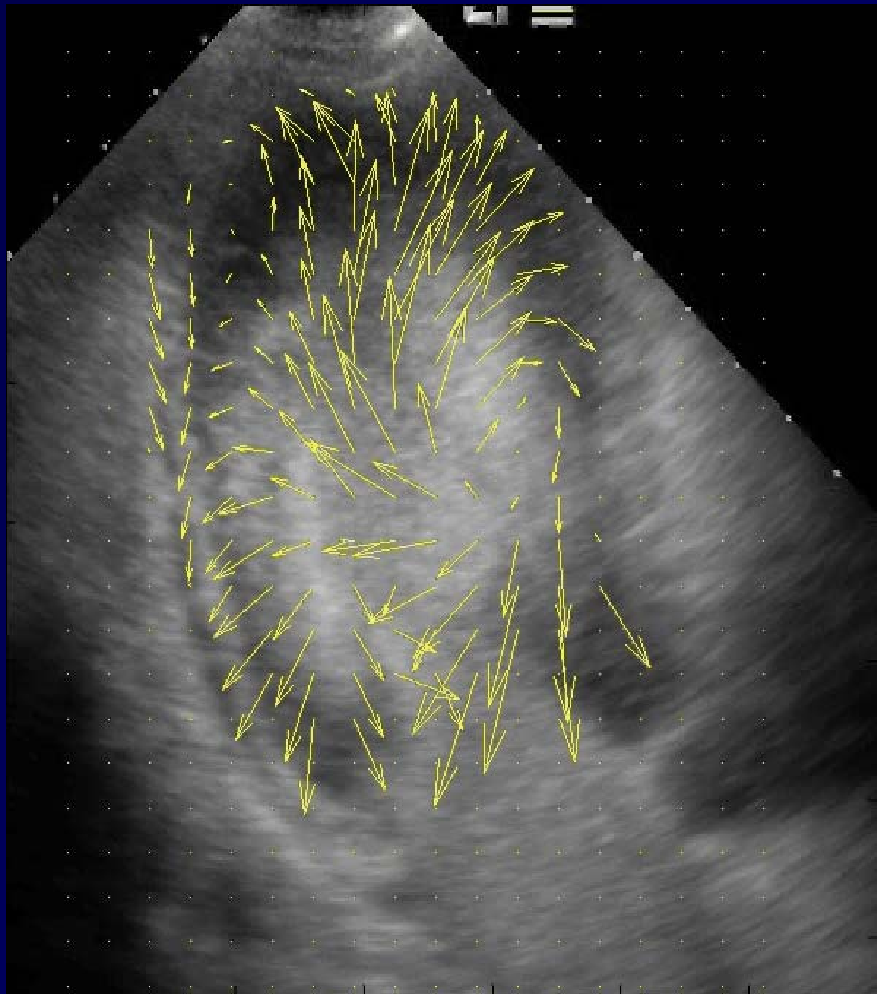


Vortex...



LV Vortex Flow Analysis by Contrast Echo

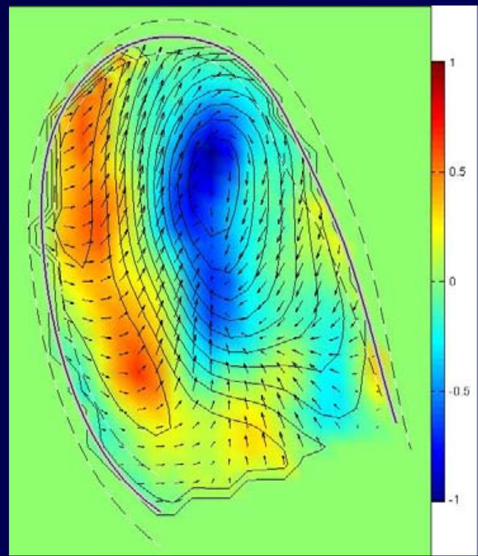




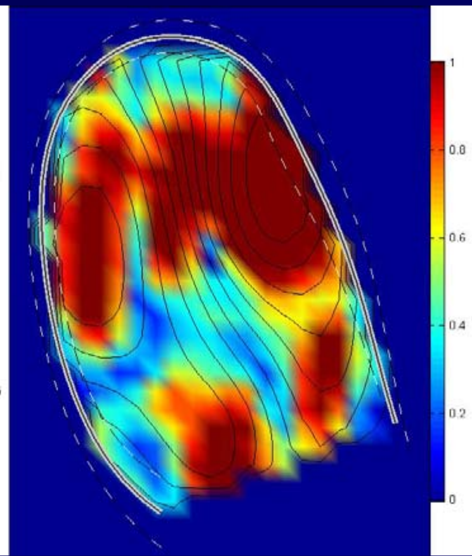
LV Vortex Flow Analysis

LV vortex flow in normal

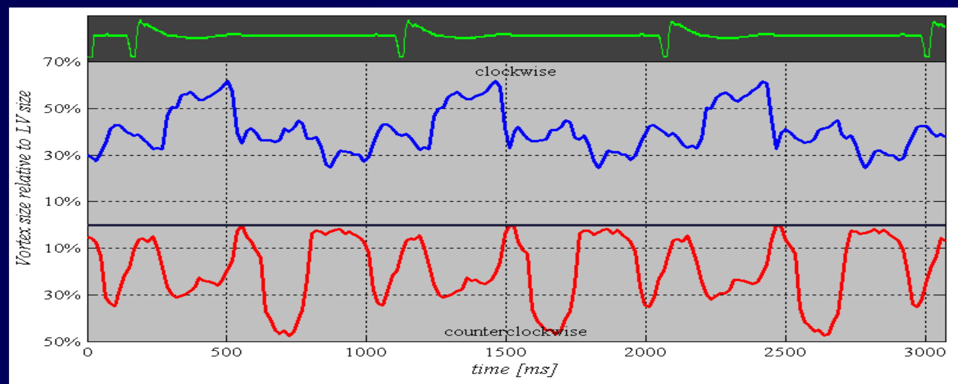
Hong et al. J Am Coll Cardiol Img.2008;1: 705-717



Steady streaming



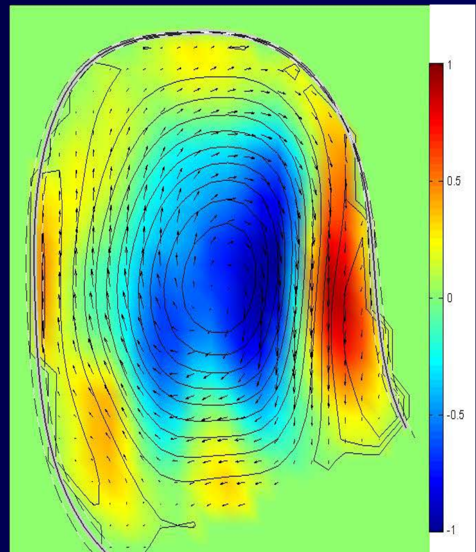
Pulsatility intensity



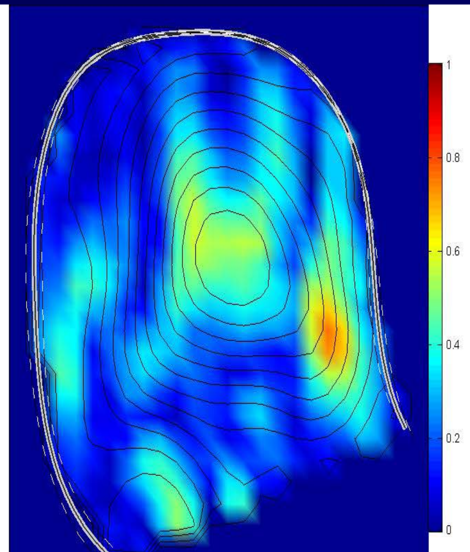
Change of vortex size during cardiac cycle

LV Vortex Flow Analysis

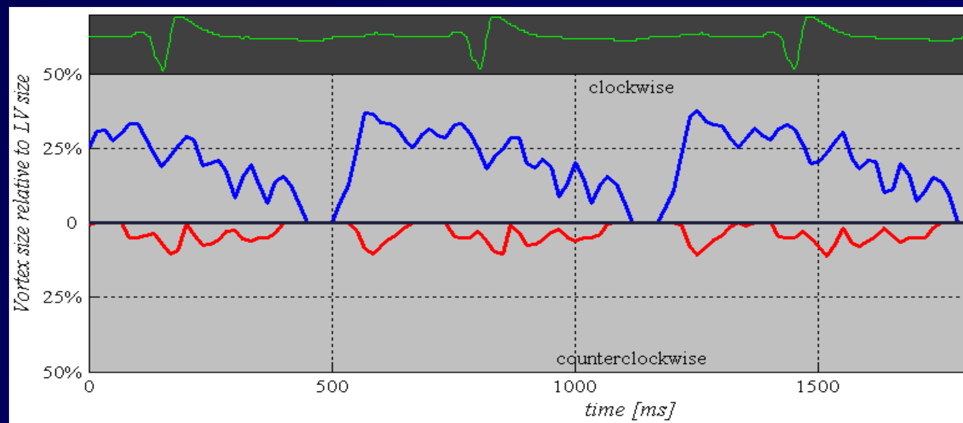
LV vortex flow in heart failure



Steady streaming



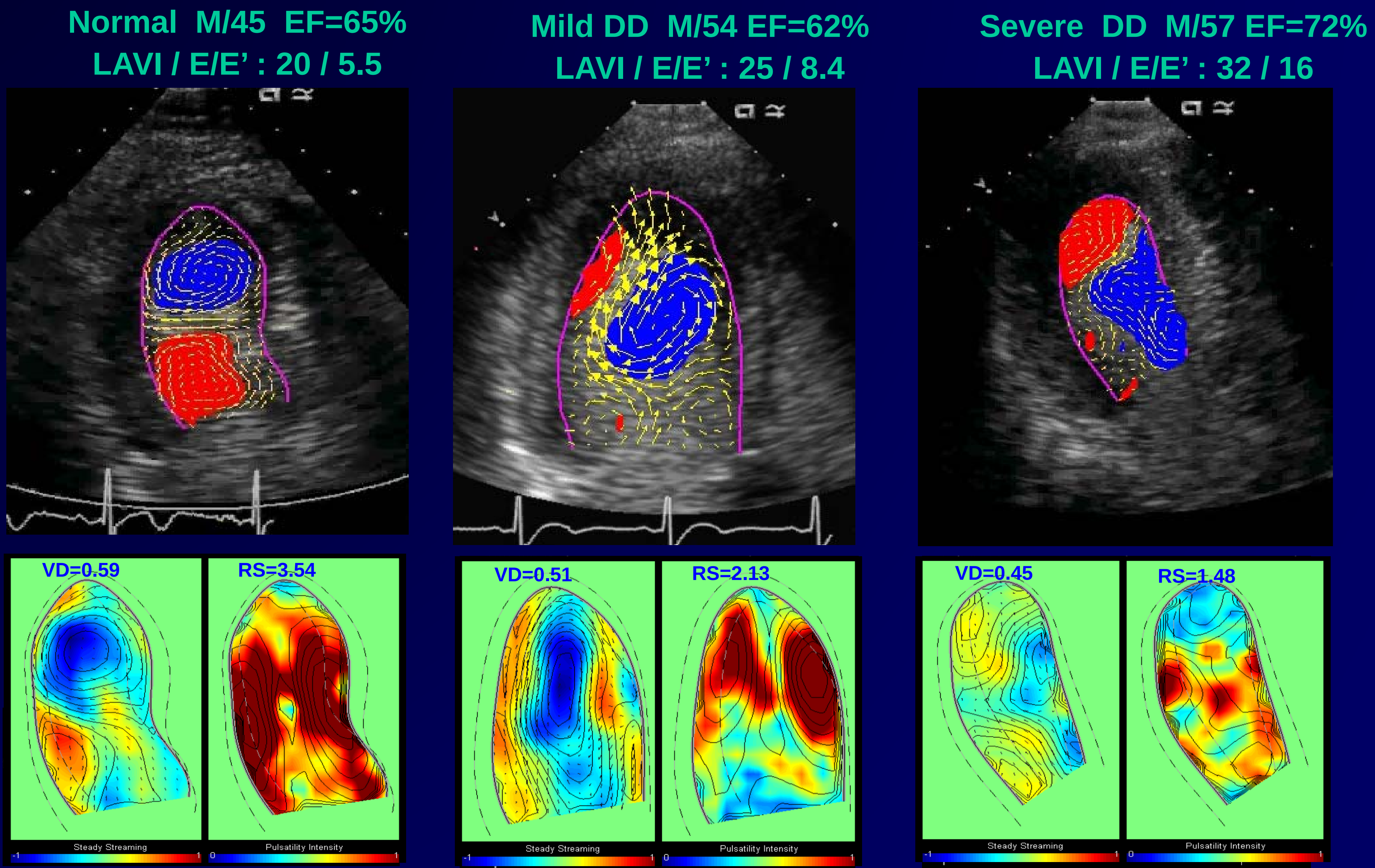
Pulsatility intensity



Change of vortex size during cardiac cycle

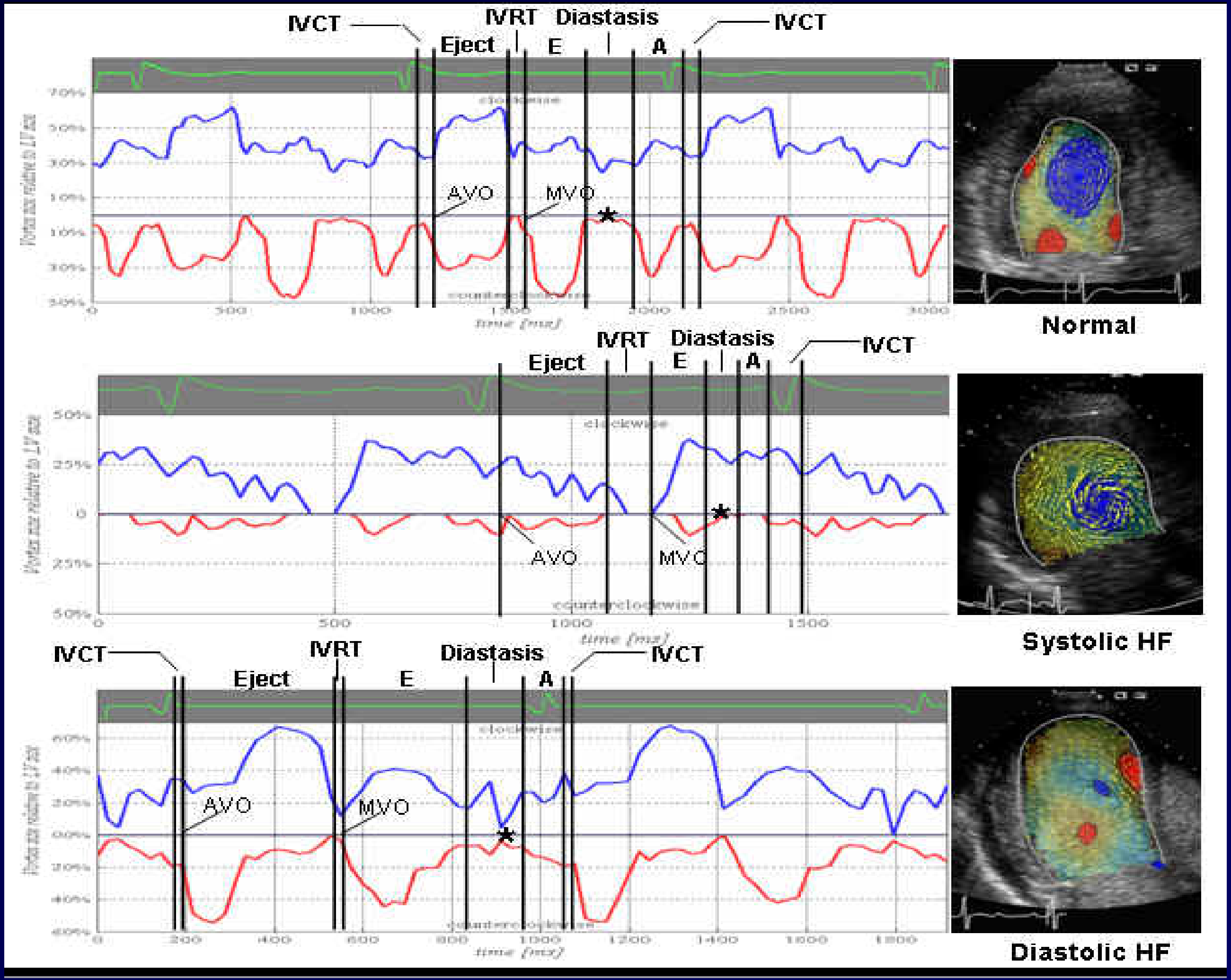
Hong et al. J Am Coll Cardiol Img.2008;1: 705-717

LV vortex flow in LV diastolic function



Hong et al. ACC 2008 (abstract)

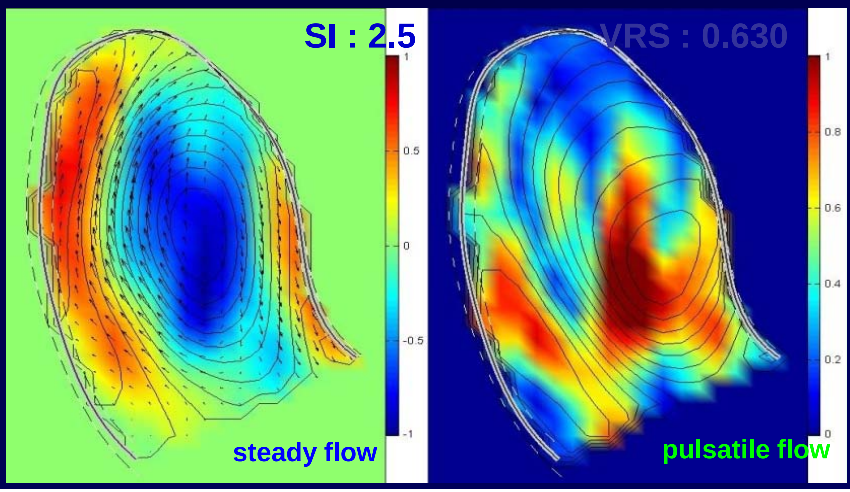
Vorticity Imaging
Phasic Changes- Normal vs SHF vs DHF



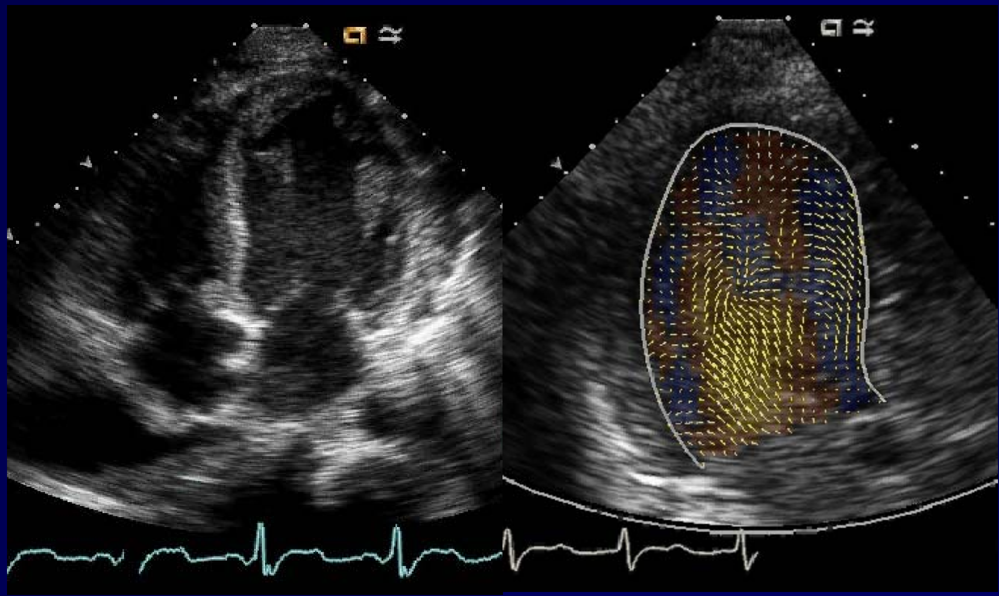
LV Vortex Flow Analysis in HF

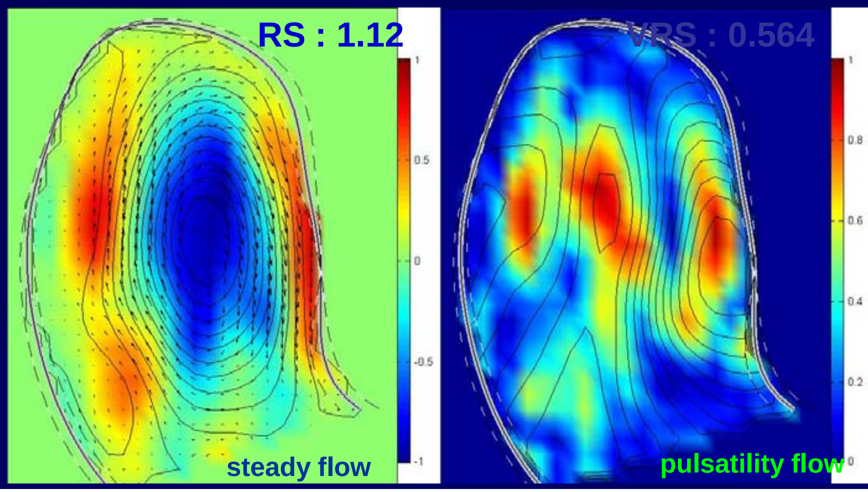
Correlation to symptomatic status in NYHA I-II compensated HF

M/53, DOE (-), EF=29%, E/E'=11, LAVI=28



M/32 DOE (+), EF=27%, E/E'=13, LAVI=30





LV Vortex Flow Analysis in HF

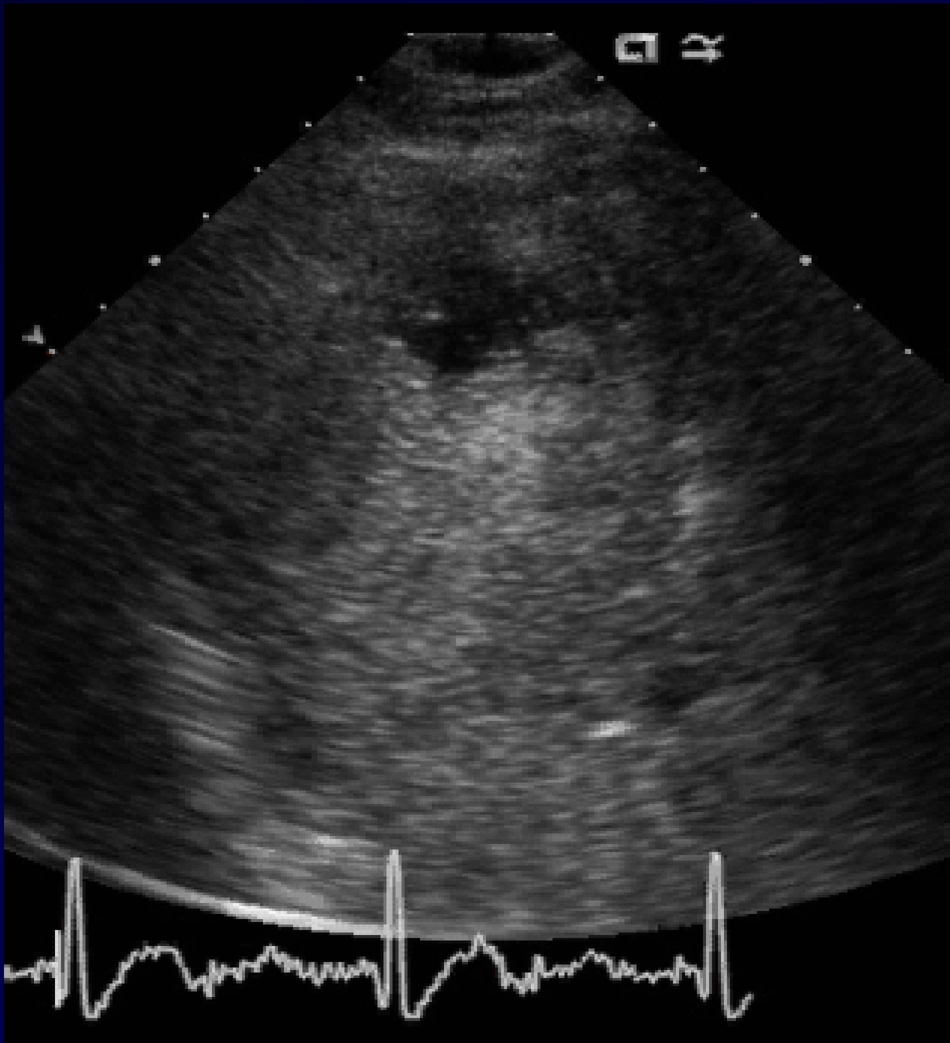
Comparison of conventional and vorticity parameters to symptomatic status in NYHA I-II compensated HF

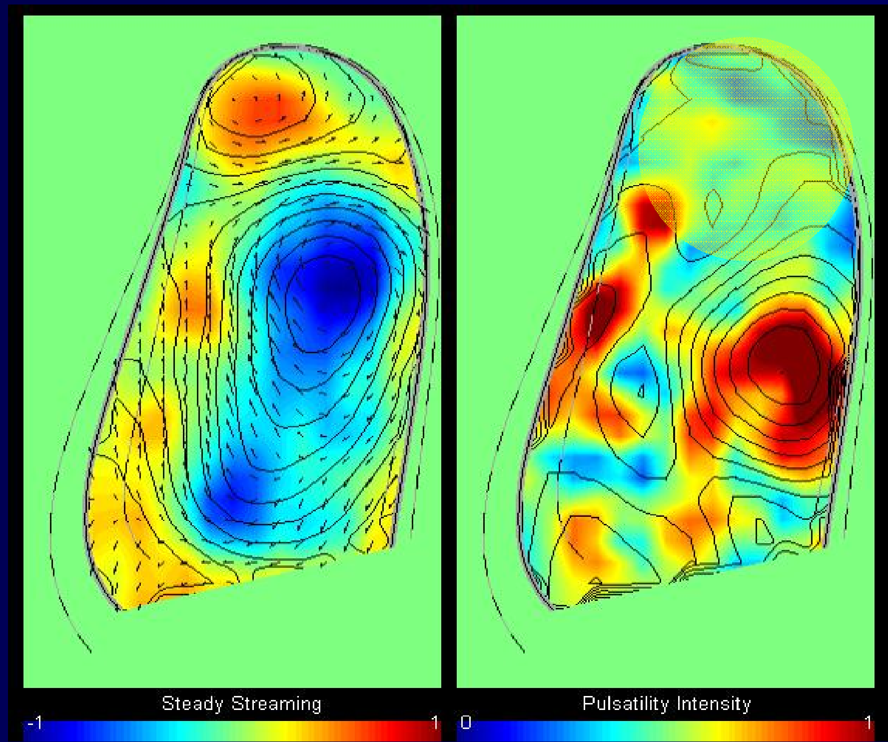
	DOE (-) (n=7)	DOE (+) (n=6)	p value
EF (%)	35.8 ± 5.7	32.5 ± 6.4	NS
LAVI (ml/m²)	28.4 ± 4.7	30.5 ± 5.7	NS
E/E’	10.8 ± 3.7	12.3 ± 4.5	NS
LVEDP	10.5 ± 3.2	13.8 ± 5.2	0.07
CI (l/min/m2)	2.9 ± 0.8	1.9 ± 0.7	0.02
RS	1.65 ± 0.3	1.18 ± 0.2	0.01
VRS	0.81 ± 0.2	0.59 ± 0.2	0.01
VPC	0.84 ± 0.2	0.67 ± 0.1	0.01

Hong et al. 2007 AHA (abstract) & In Submission

LV Vortex Flow Analysis

LV vortex flow in ischemic cardiomyopathy





Steady streaming   Pulsatility intensity

Clinical Usefulness of LV Vortex Flow Analysis for Predicting Apical Thrombus Formation in Patients with LV Dysfunction

Jang-Won Son, Geu-Ru Hong, Sang-Hee Lee, Jong-Seon Park, Dong-Gu Shin, Young-Jo Kim, Bong-Sup Shim

Division of Cardiology, Yeungnam University, Daegu, Korea

Presented at 2011 AHA, and In Revision

Apical thrombus with LV dysfunction

Thrombus (+)

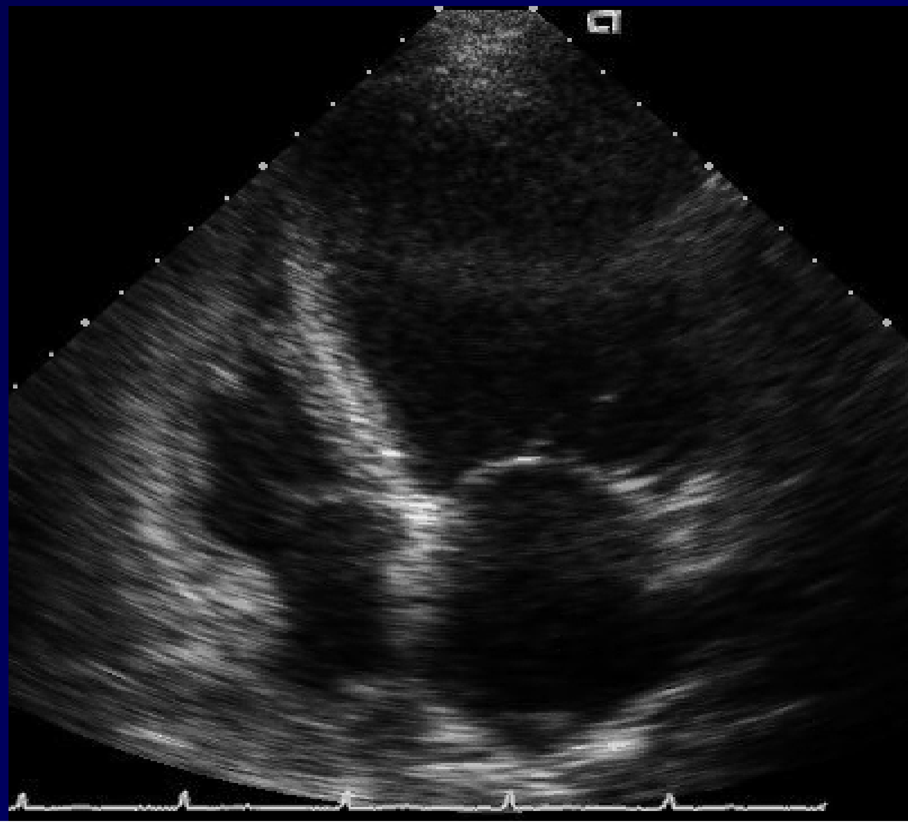
M/73, LVEF 27%

LVEDD 67mm, LVMI 162g/m^2

Thrombus (-)

F/70, LVEF 20%

LVEDD 63mm, LVMI 160g/m^2



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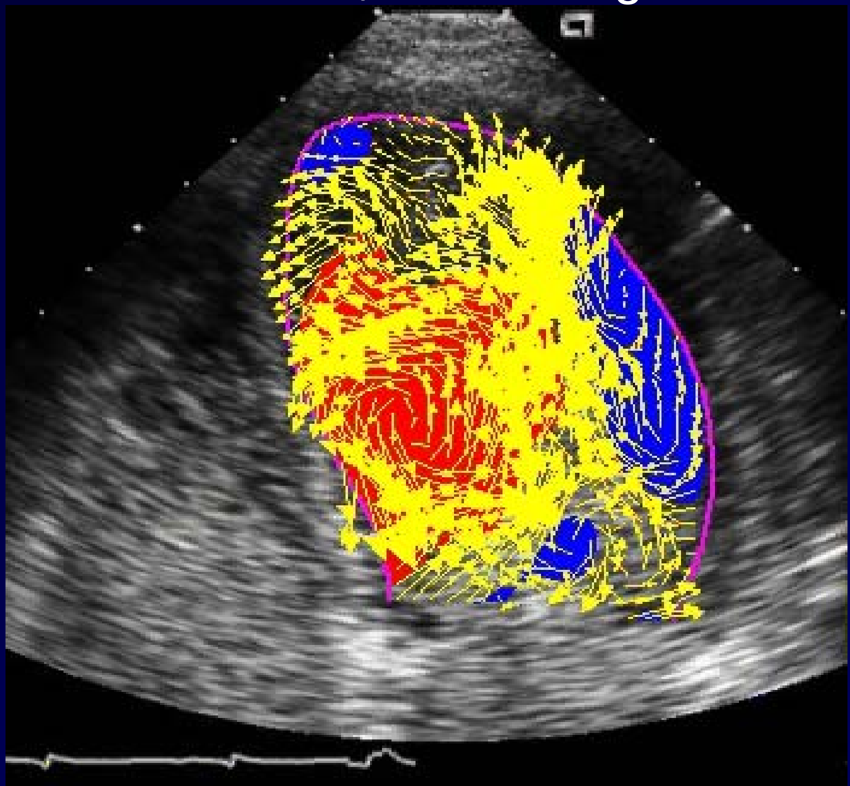
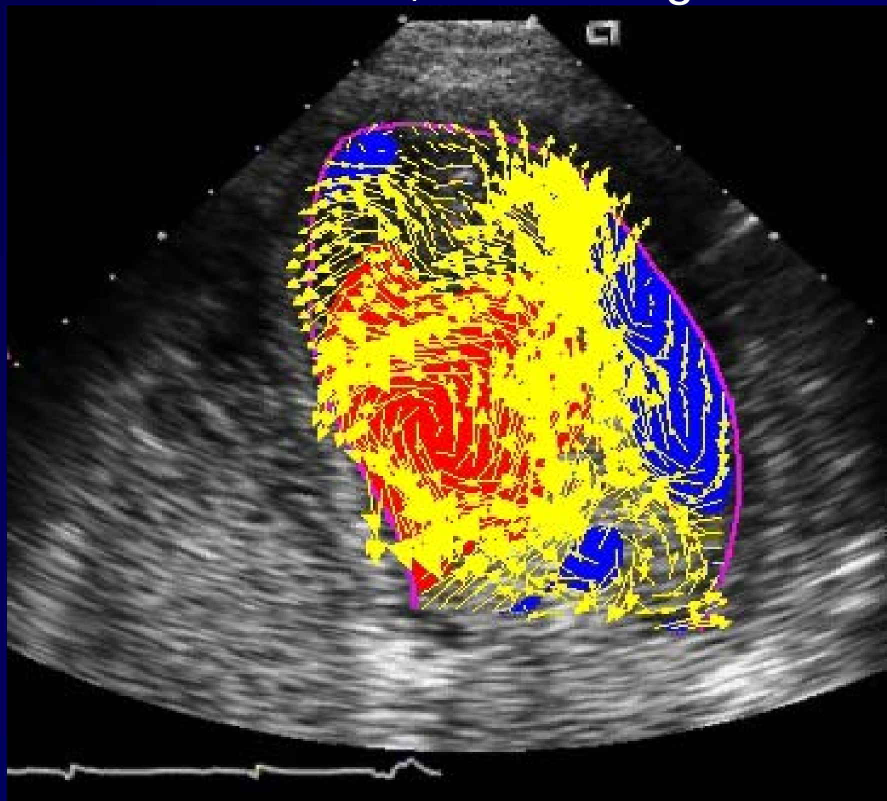


Thrombus (-)

F/70, LVEF 20%

LVEDD 63mm, LVMI 160g/m^2



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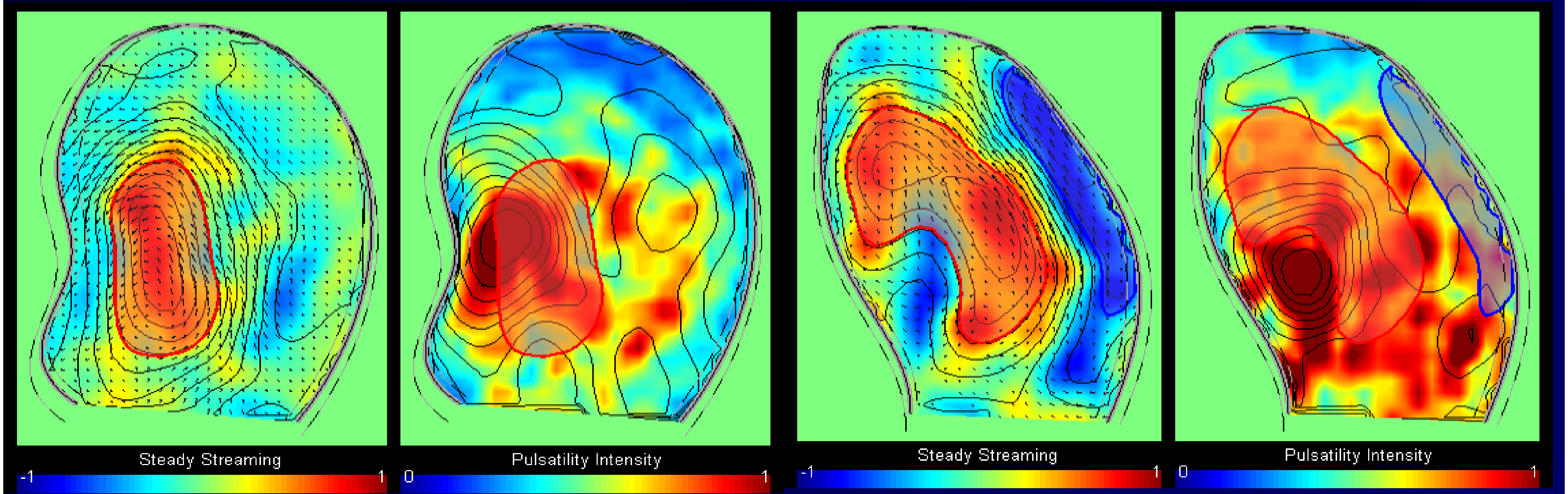
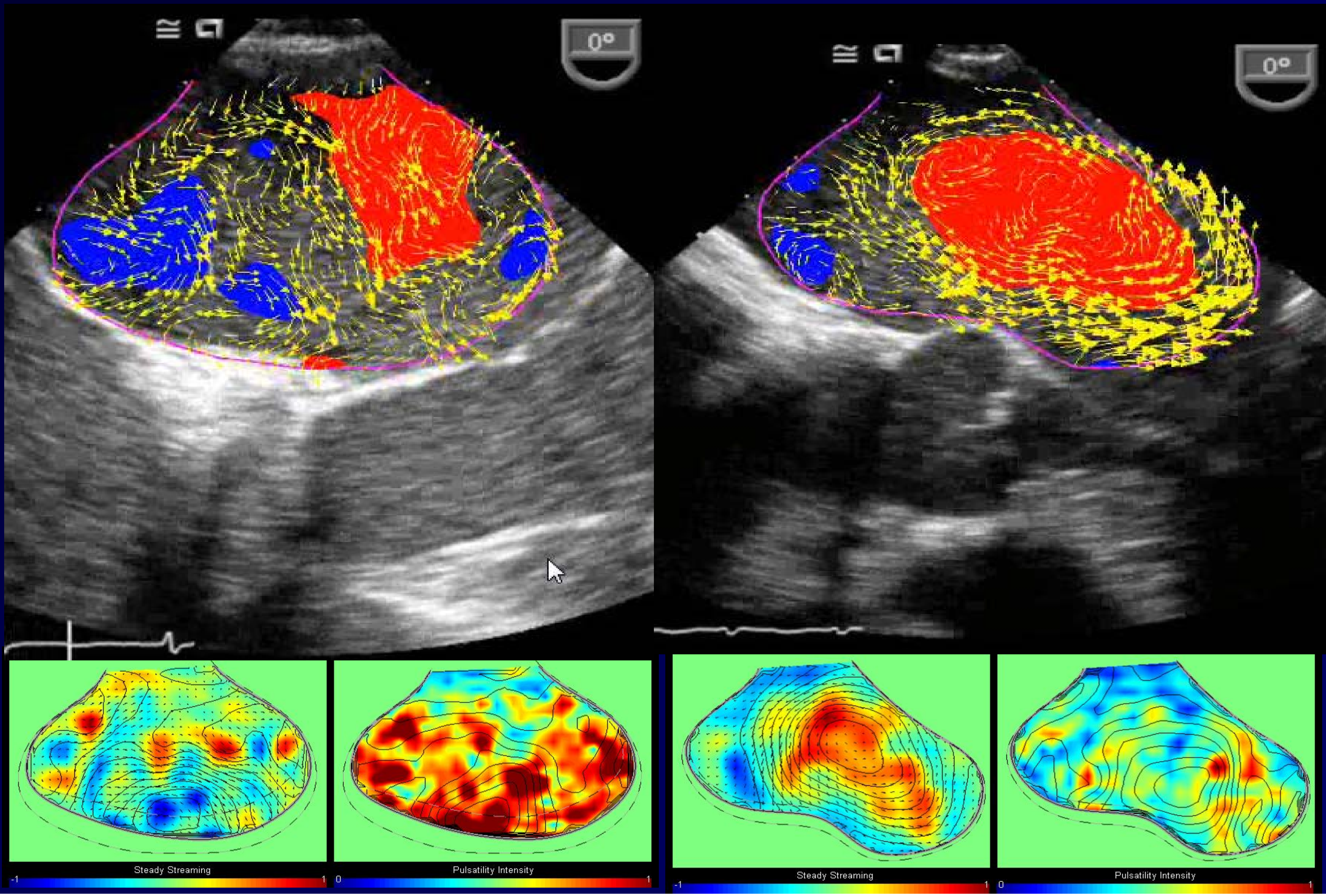


VD=0.42 RS=1.10 VD=0.51 RS=2.15

Hong et al. In Revision

LA Vortex Flow Analysis

Normal　　　　　　　　　　Af



New Environment: Equipment

Editorial

Echocardiography as a Noninvasive Swan-Ganz Catheter

Jae K. Oh, MD

Diwan and co-investigators report in this issue of *Circulation* that the interval between onset of mitral E and annular early diastolic velocity (Ea) by tissue Doppler, T_{E-Ea}, can be used to estimate left ventricular (LV) filling pressure in patients with mitral valve disease.[1] Garcia and colleagues were the first to report that the onset of Ea occurred 7.5±3.5 ms after peak mitral inflow velocity in 7 patients with restrictive cardiomyopathy, whereas Ea started 22±19 ms earlier than did E in the normal group.[2] Subsequently, T_{E-Ea} has been shown to correlate with the time constant of LV relaxation (τ) demonstrated by Hasegawa and associates in their elegant animal experiment.[3] With worsening of heart failure by rapid pacing, Ea progressively decreased in velocity and delayed in onset. Mitral E occurred confirmed that both the ratio of IVRT to T_{E-Ea} and to τ correlate well with PCWP in patients with mitral valve disease or atrial fibrillation. These authors proposed different IVRT/T_{E-Ea} ratio cutoff values for different patient populations to predict PCWP >15 mm Hg: <3 for patients with mitral regurgitation, <4.16 for patients with mitral stenosis, and <5.59 for patients with mitral regurgitation who were evaluated prospectively or with atrial fibrillation. On repeat studies after the mitral valve procedure, an increase in the ratio by ≥1.5 identified most patients who had a decrease in mean PCWP ≥5 mm Hg.

Tajik and I wrote an editorial[5] for the article by Rivas-Gotz and associates,[4] in which history and clinical applications of various cardiac time intervals were reviewed, and our views

Take Home Messages

- Echocardiography provides important data for therapeutic decision making in cardiology field
- New techniques for the ventricular mechanics, vortex flow analysis and 3D echocardiography hold great promise for improving the quality of care to the patients

경청해 주셔서
감사합니다.

Echo remains the best imaging tool