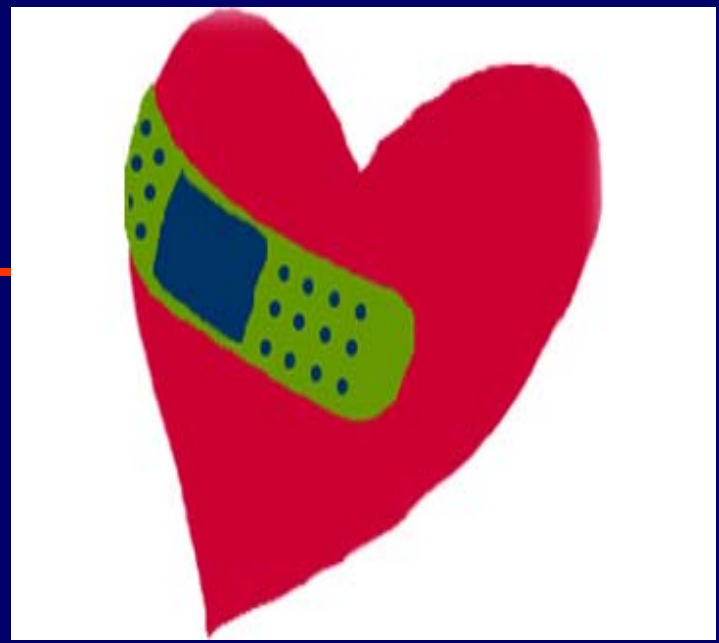
Tissue Doppler Imaging in Congenital Heart Disease



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"The potential advantage of ultrasound cardiography is to permit the study of the soft tissues without catheterization and the introduction of contrast media.
With regard to cardiovascular diagnosis the method is still in the stage of research."

from 1/2 page on ultrasonic cardiography in chapter-
"Phonocardiography and other graphic methods"

Friedberg, Diseases of the Heart, 1966

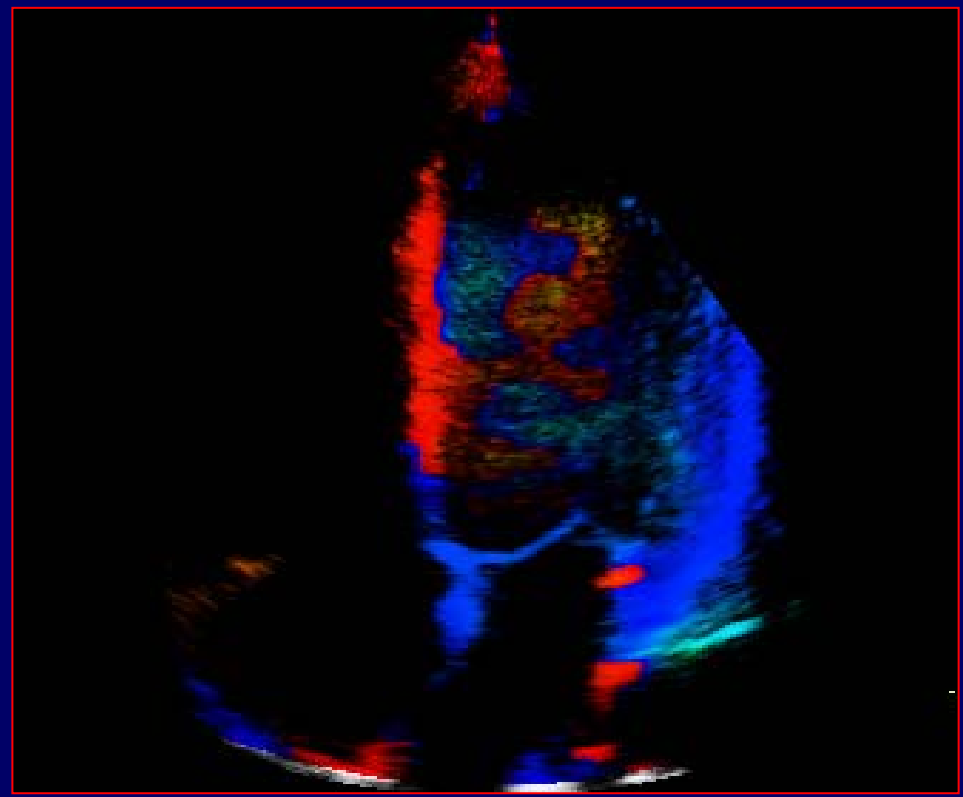
What is TDI?

Quantitative

Tissue

Doppler

Imaging



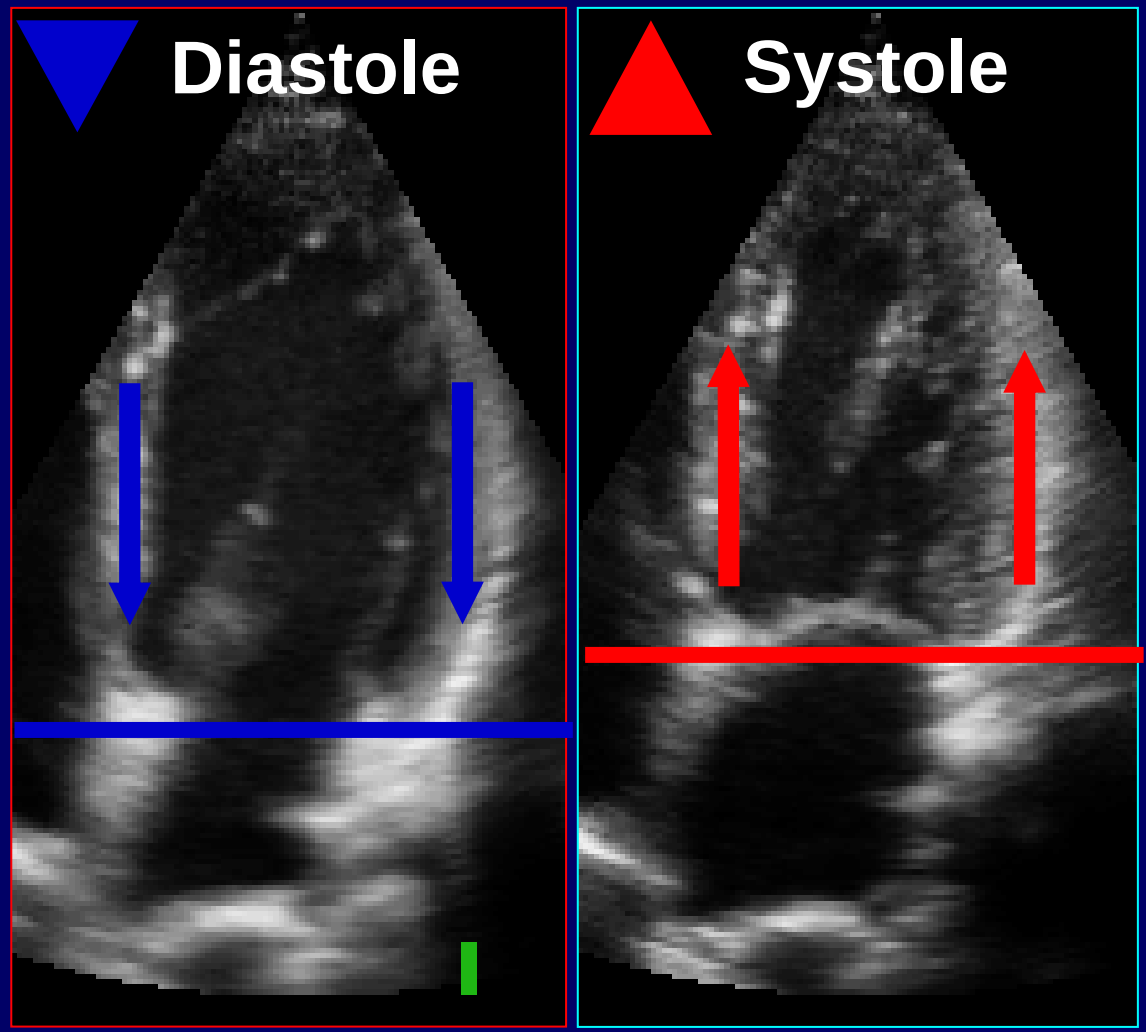
What is the Principle of TDI?

- ♥ TDI is based on the difference between signals returned from blood and tissue.
- ♥ ***It filters out the high velocity, low amplitude signals,*** *leaving the tissue motion information visible.* *(low velocity, high amplitude)*

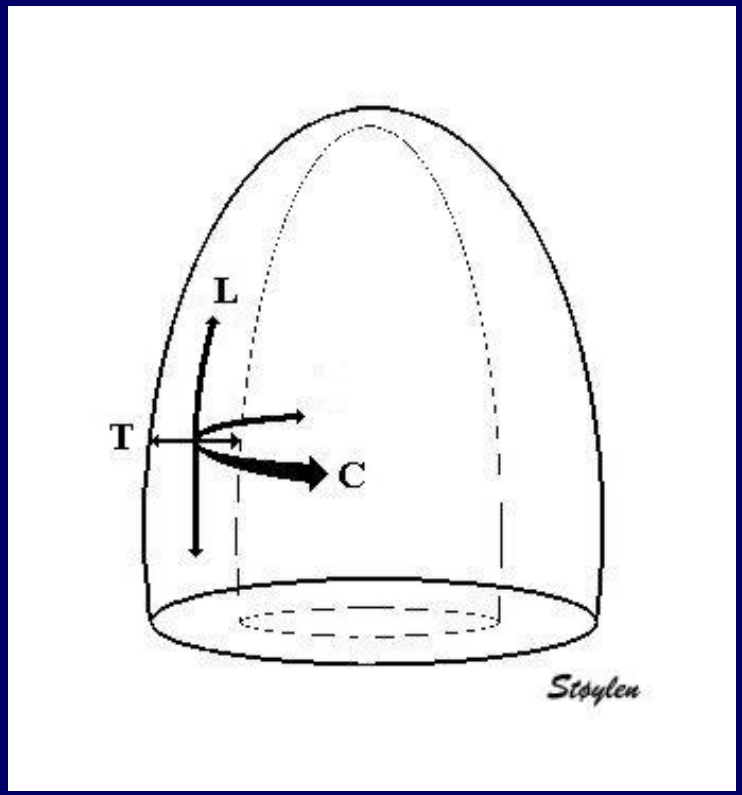
- The familiar color coding of color Doppler signals
  - red-to-yellow scale : tissue movement towards the transducer
  - blue-to-green scale : movement away
  - red and blue --- low velocities
  - yellow and green--- high velocities

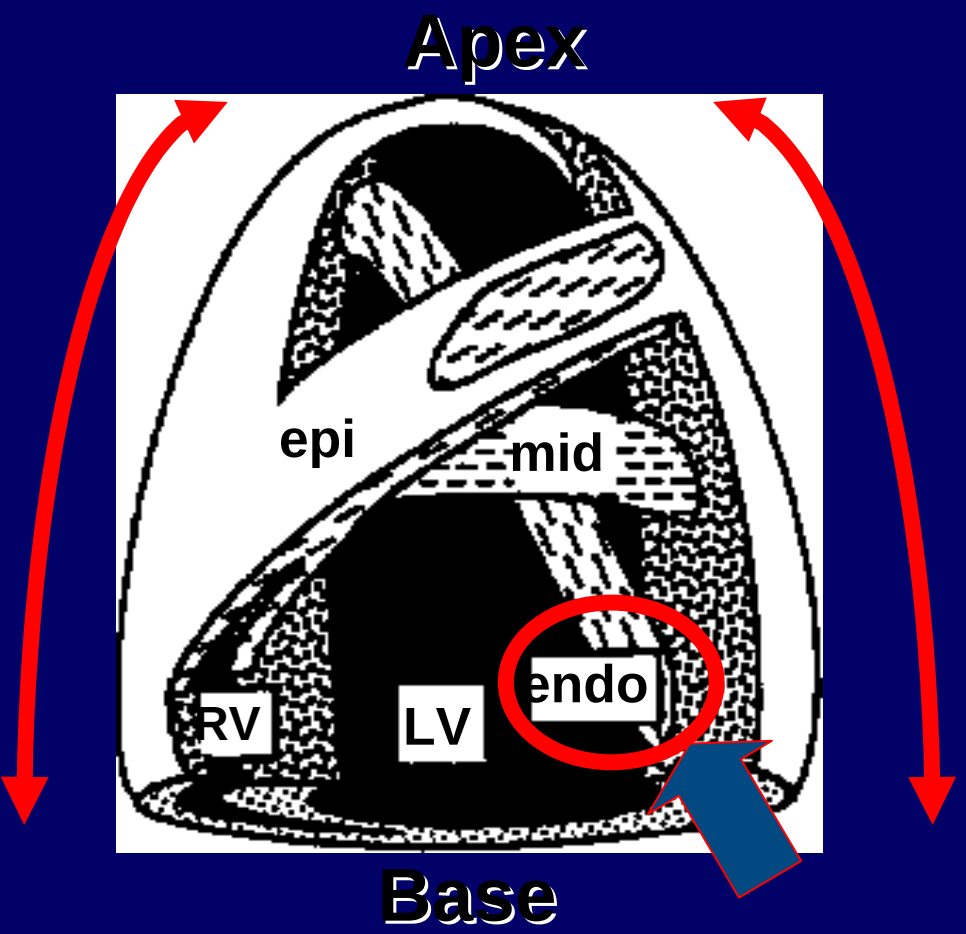
LV Longitudinal Shortening

2D



Why do TDI exam in Apical View?





70% of fibers are longitudinal!

Tissue Doppler Echocardiography

- Simple, non-invasive and reproducible method for assessing cardiac physiology.
- Provide a velocity value for every point in the myocardial wall.
- Assessing wall motion not only regionally, but also quantitatively.
- This may afford the opportunity to study regional systolic and diastolic function.

Where can TDI be used ?

- Quantify myocardial velocities in multiple segments of the myocardium from different echocardiographic windows
- Accurate estimate of LV relaxation
  - Insensitive to the effects of preload compensation
- Potential to assess regional systolic and diastolic function in both LV and RV
- Diastolic regional change is an early marker of ischemia

(regional isovolumic relaxation time obtained by DTI)
--- before the development of regional systolic dysfunction

How is Tissue Doppler displayed ?

Color B-scan : the best overall impression
provide good view of a heart chambers and walls
frame rate limitations :
maximum frame rate 30 –90 frames/s

M-mode : dramatically improves time resolution
sampling is only performed on a single line
such a line– positioned on a clinically significant position

PW analysis :
produces the maximum amount of information
highest temporal and velocity range resolution

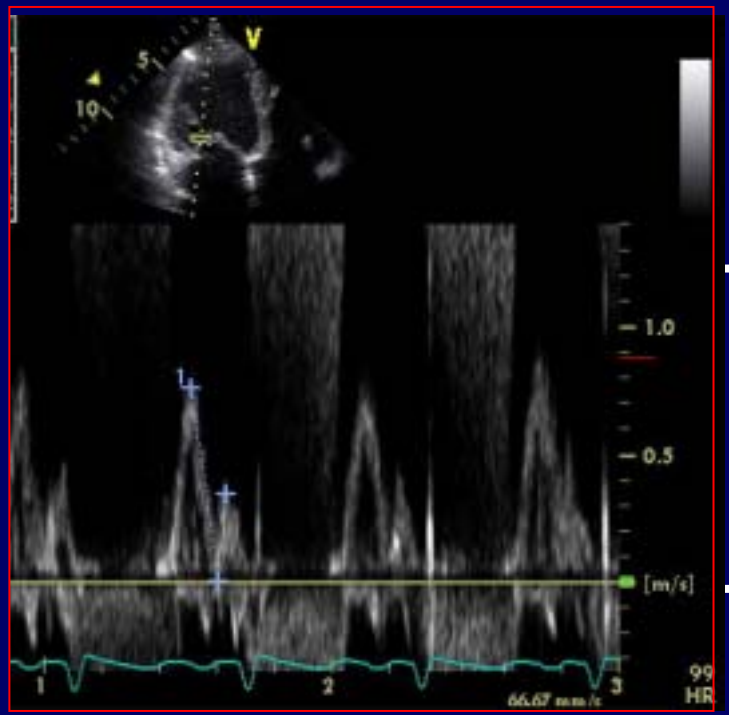
Conventional Doppler vs TDI

Conventional Doppler

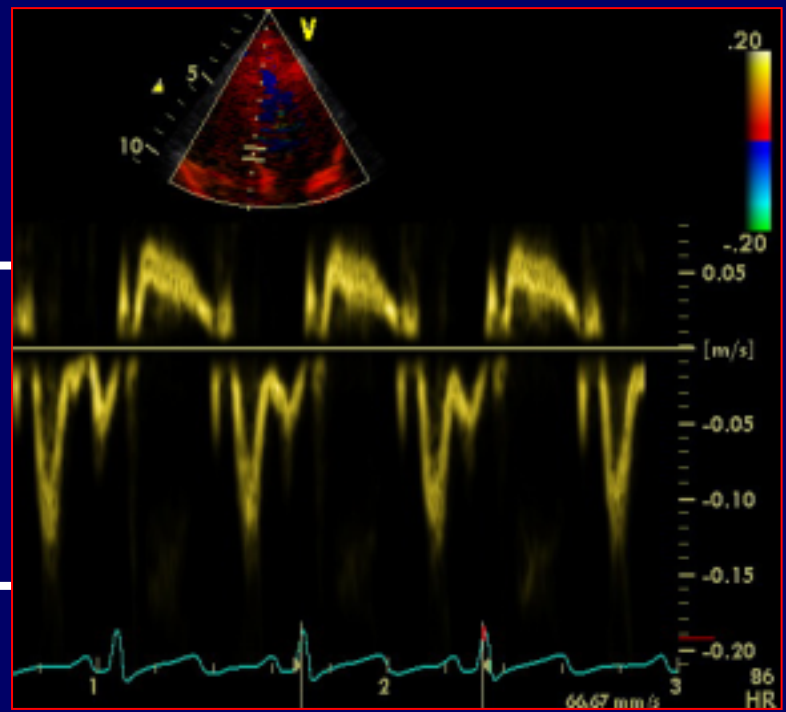
- velocity and direction of blood flow (RBC)

Tissue Doppler

- velocity and direction of myocardial tissue

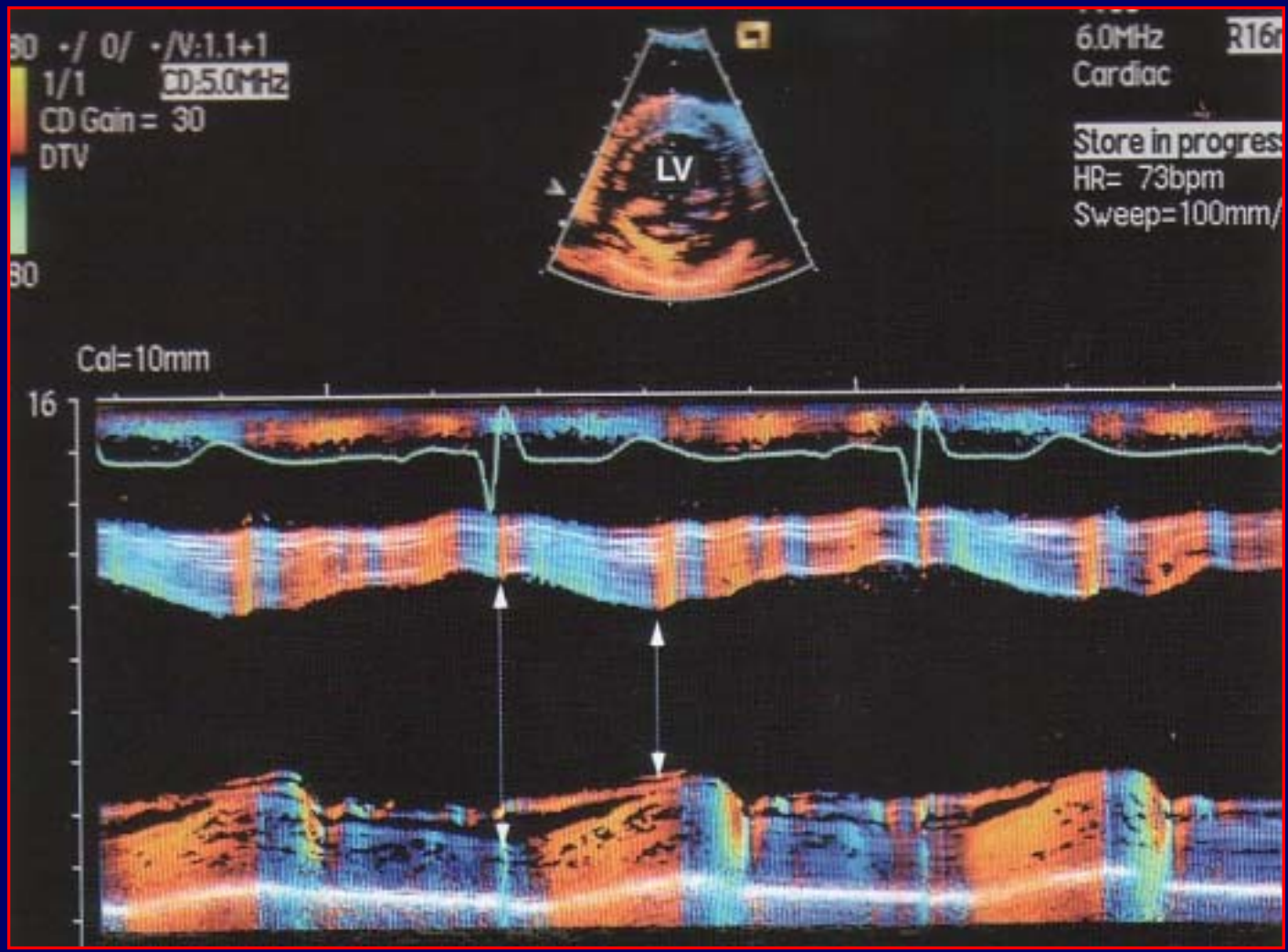


Blood: Mitral Flow



Tissue: MV Ring Motion

Tissue Doppler in M-mode



Advantages of Color M-mode

- better temporal resolution of systolic diastolic velocity
  high frame rate obtained with M-mode

- represent in the same image
  both systolic diastolic velocities

- accurate quantitative information about myocardial motion
  during the cardiac cycle
- accurately assess in one scan plane the different phases
  of the cardiac cycle

What is the Limitation of TDI ?

- The Angle dependency
- The agreement between pulsed and color Doppler derived velocities has not been systematically studied.
----- pulsed Doppler derived velocities are higher.
- Sometimes difficult to distinguish whether the lack of color due to akinesia or to uncontrolled technical factors
- The Tethering effect

The assessment of ventricular function

TDE has the potential to assess
- segmental systolic and diastolic function in both LV and RV

- transmural velocity gradient
- asynchronous ventricular contraction and relaxation visualized online
- global and regional systolic and diastolic time interval

The amount of color in an image can be increased by
-increasing the Doppler tissue imaging or color Doppler gain
-Modifying the depth gain to take away some of the underlying gray scale image
-increasing the gate size
-using lower filter settings
-decreasing the scale
-adjusting the ROI size
-changing the transducer position or orientation

* Gain settings must be carefully adjusted to obtain the most homogeneous non-saturated color filling.

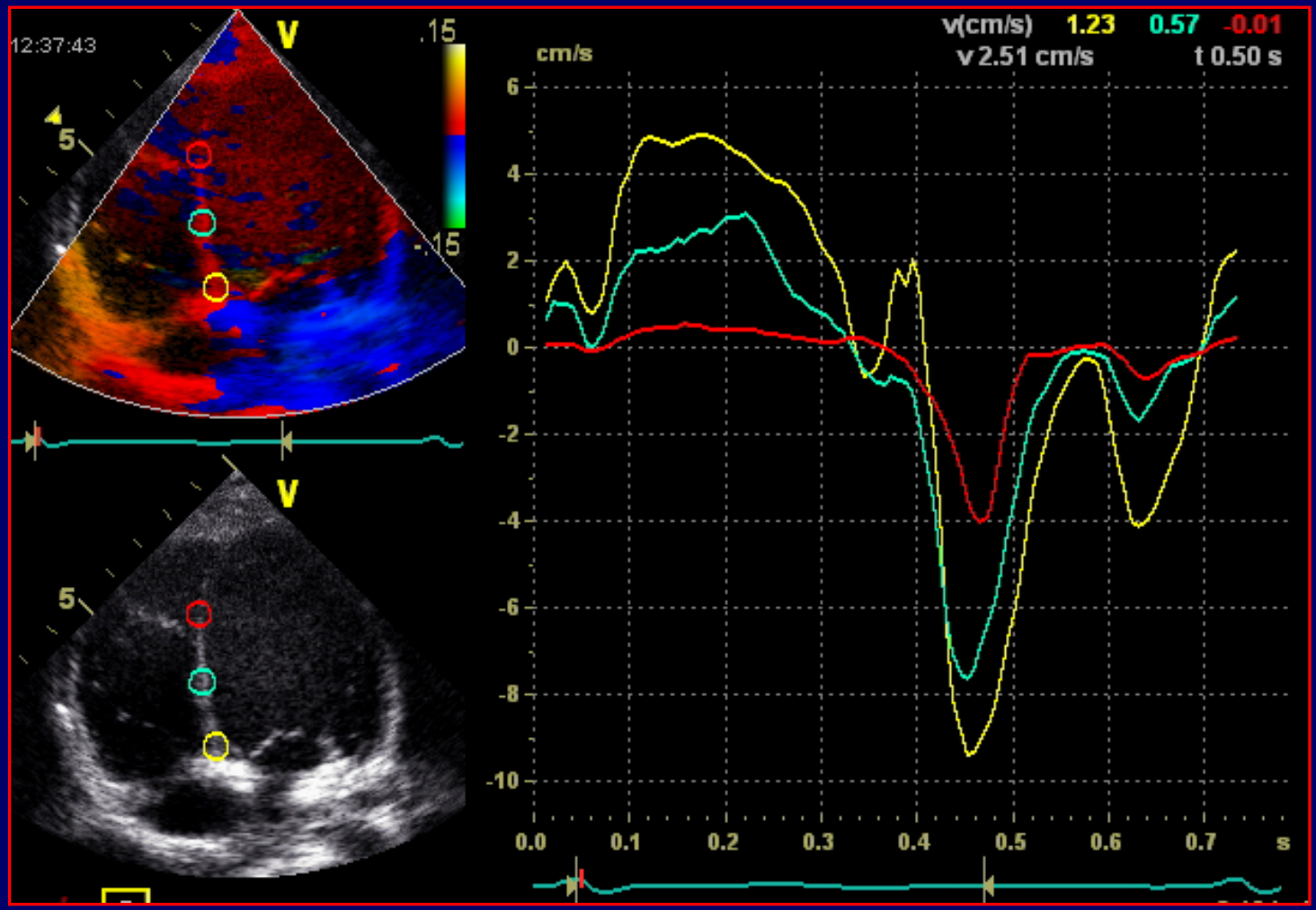
Myocardial Tissue Velocity

Normal heart : endocardium moves faster than epicardium
during myocardial contraction
because of the change of wall thickness
myocardial velocities are highest in the base of the heart
and decrease toward the apex, with reversal in apical area

The velocity gradient between the endo and epicardium
is an indicator of the regional myocardial contraction.
--- decrease in the velocity gradient should be expected in
infarcted myocardium when compared to a normal one

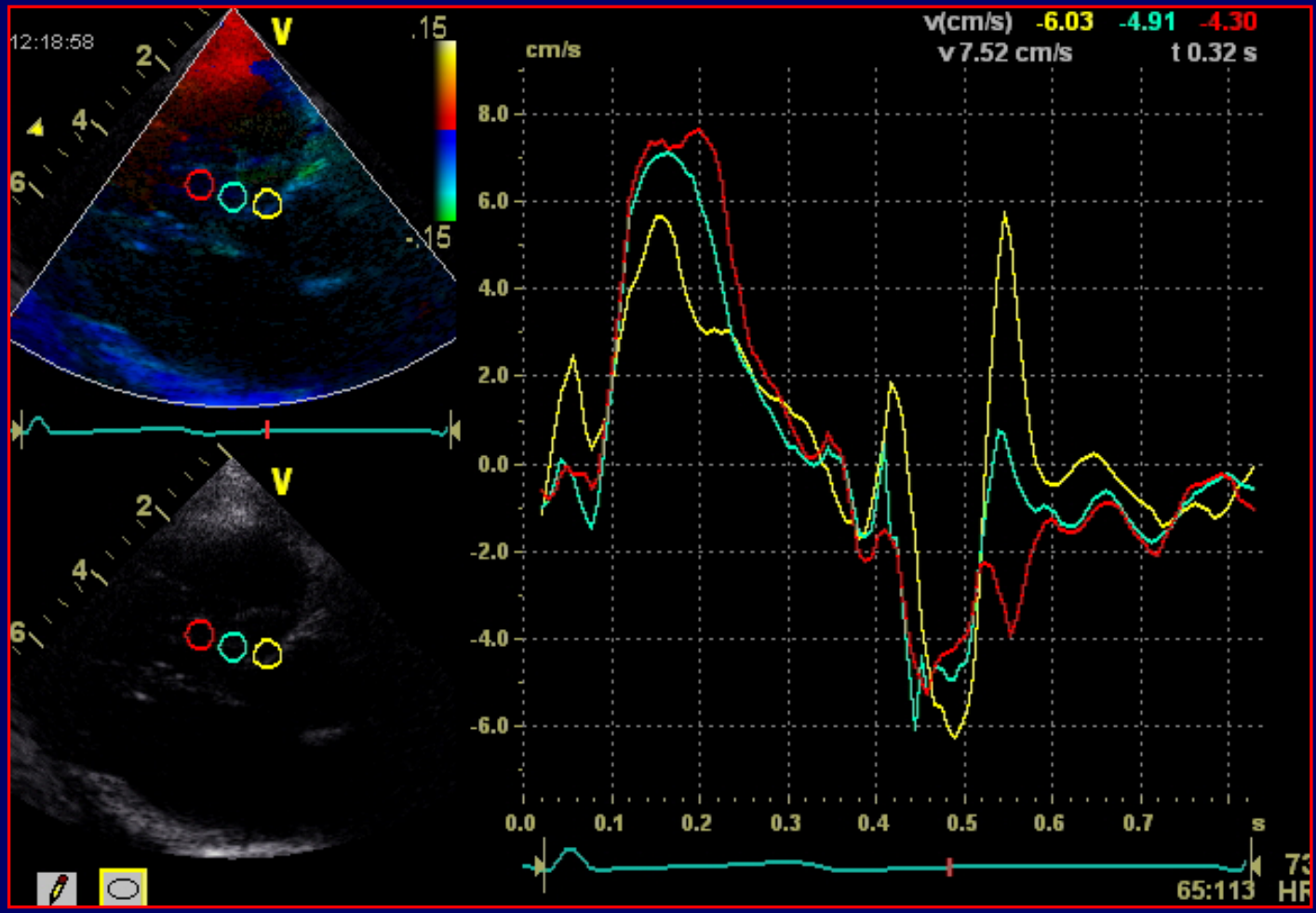
$$G = (V_{endocardium} - V_{epicardium}) / W \cos\theta$$

Myocardial Tissue Velocity

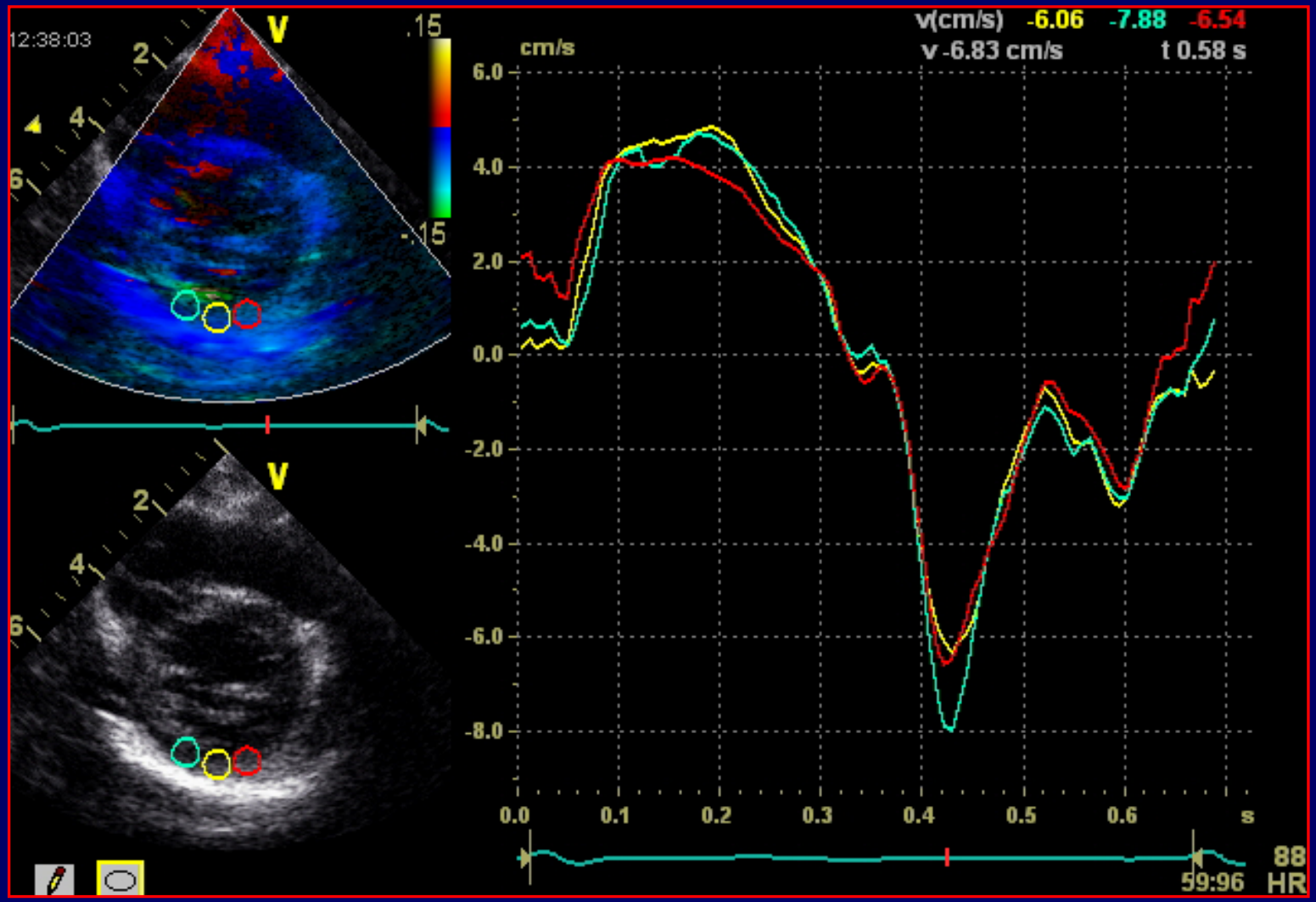


Myocardial Tissue Velocity

Parasternal long axis view

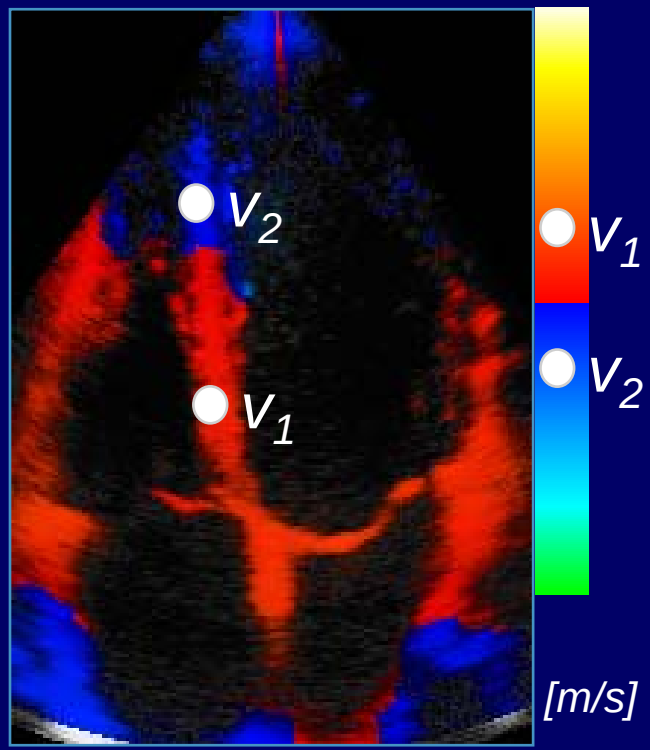


Myocardial Tissue Velocity

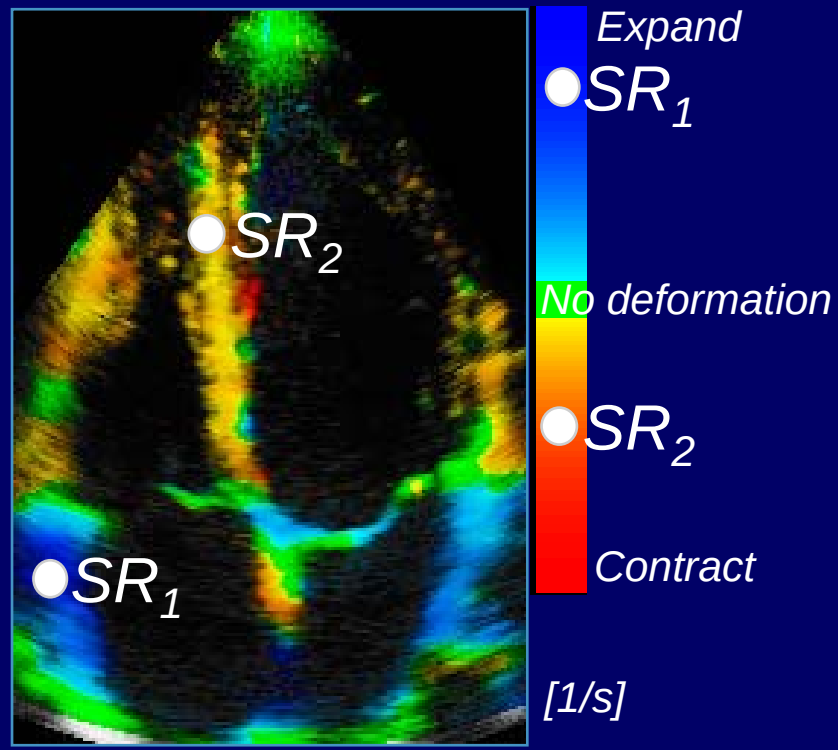


Tissue Doppler Velocity & Strain Rate

Tissue Velocity

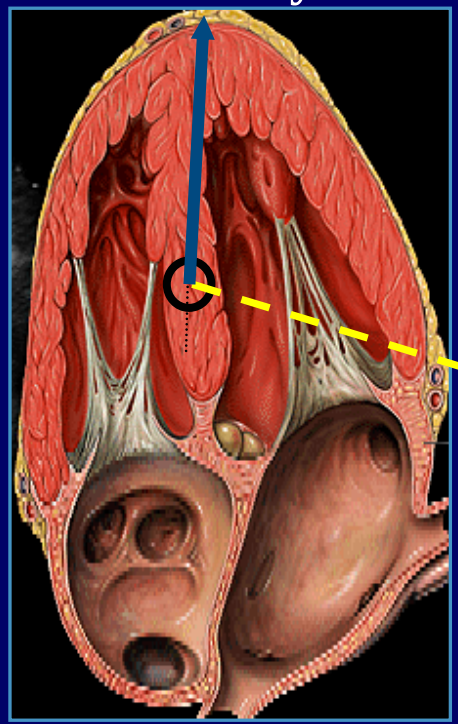


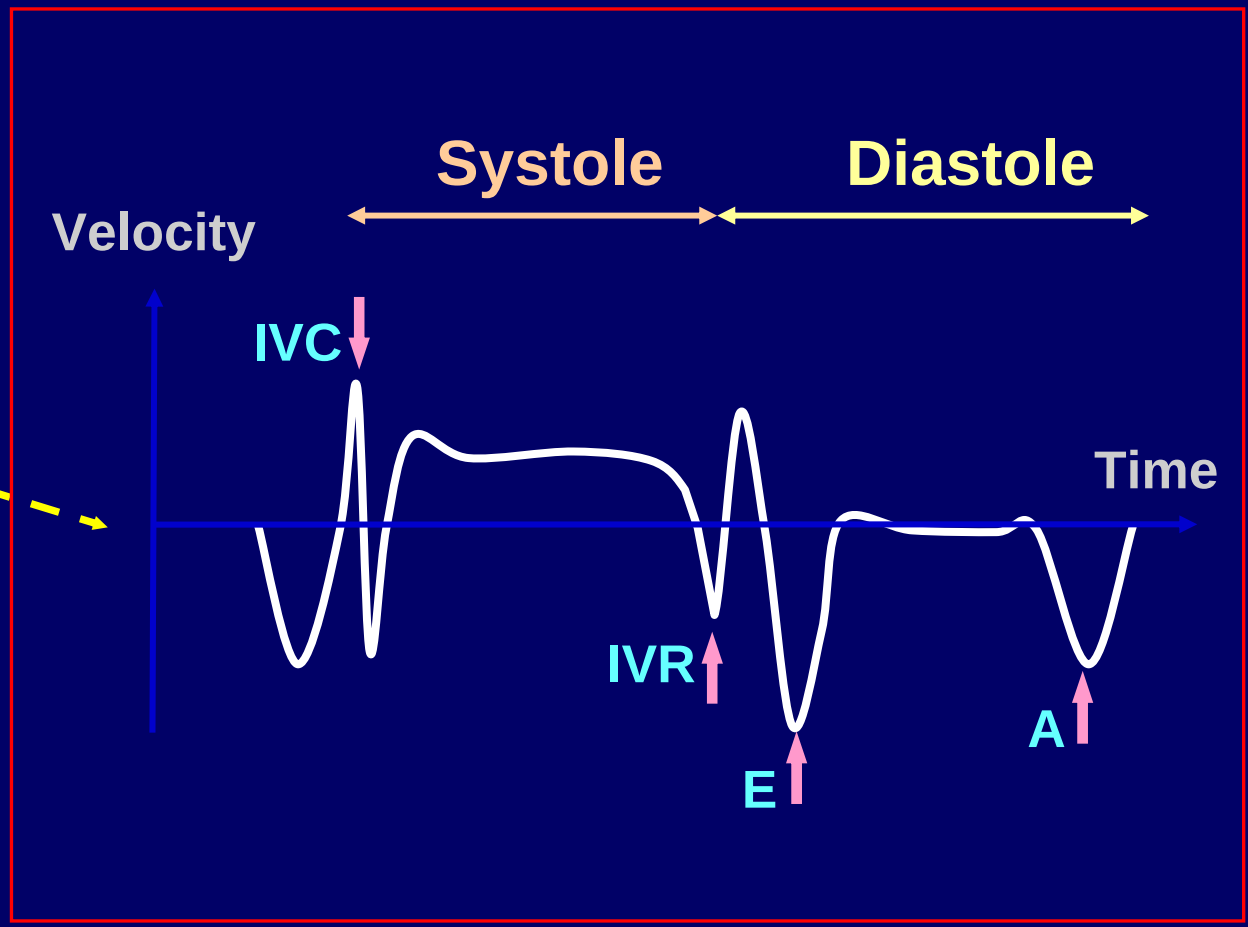
Strain Rate



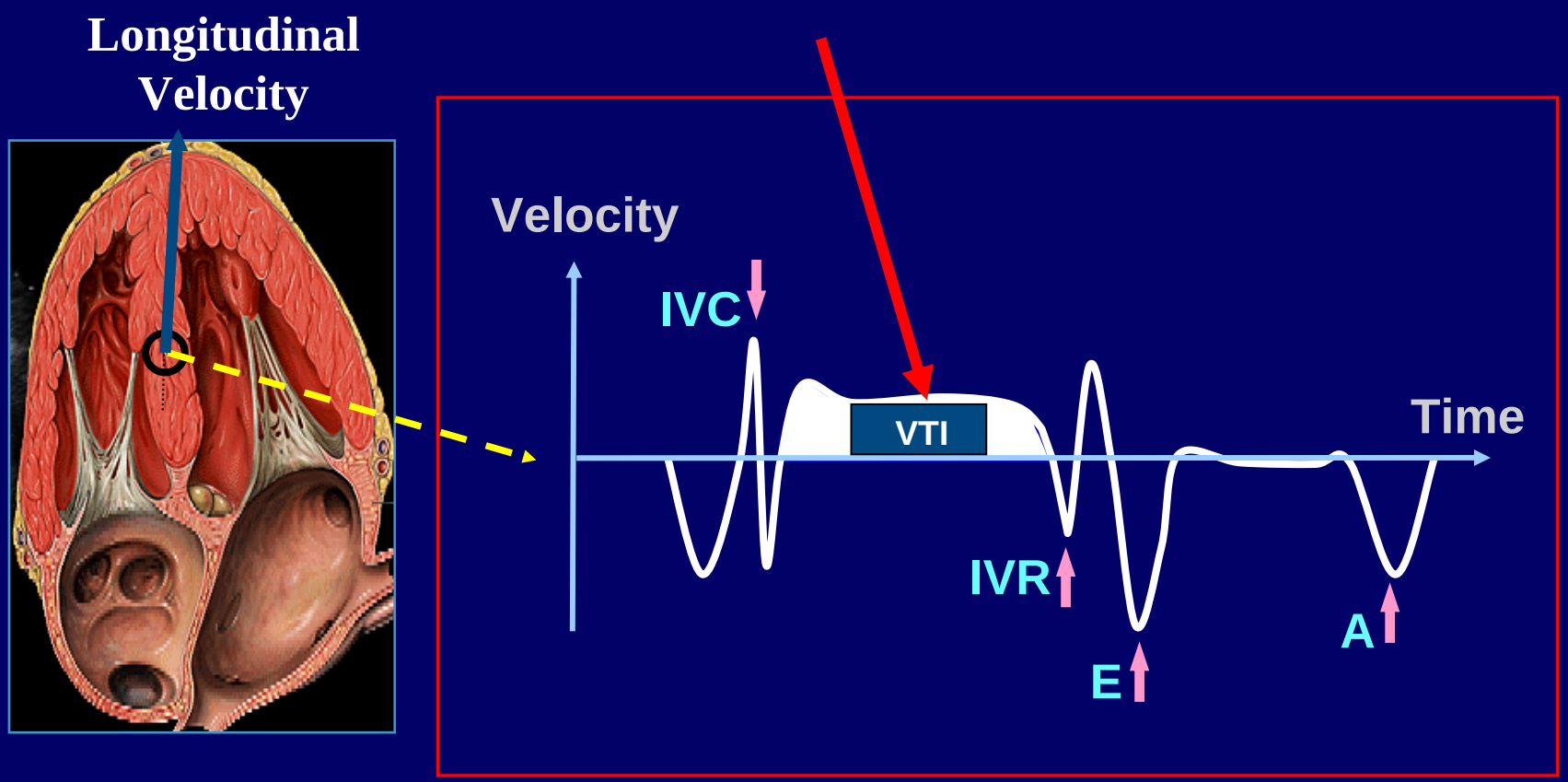
Tissue Doppler Velocity

Longitudinal Velocity



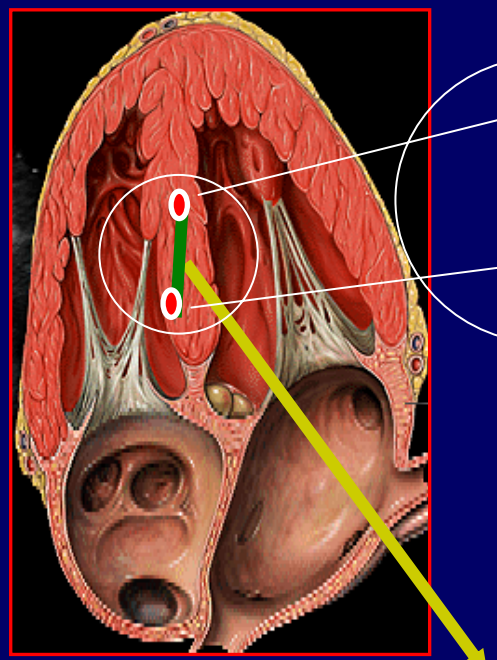


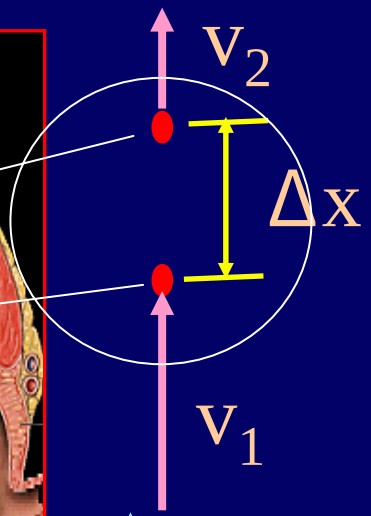
Tissue Tracking (Displacement)



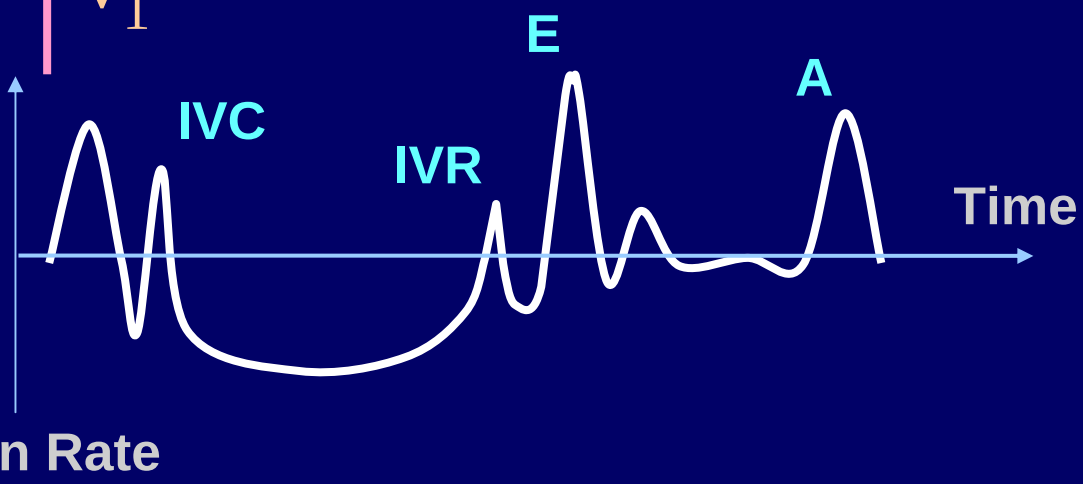
Velocity Time Integral (VTI) = Systolic Displacement
Tissue Tracking = Color Coded Systolic Displacement

Strain Rate : Rate of Deformation (Spatial velocity gradient)

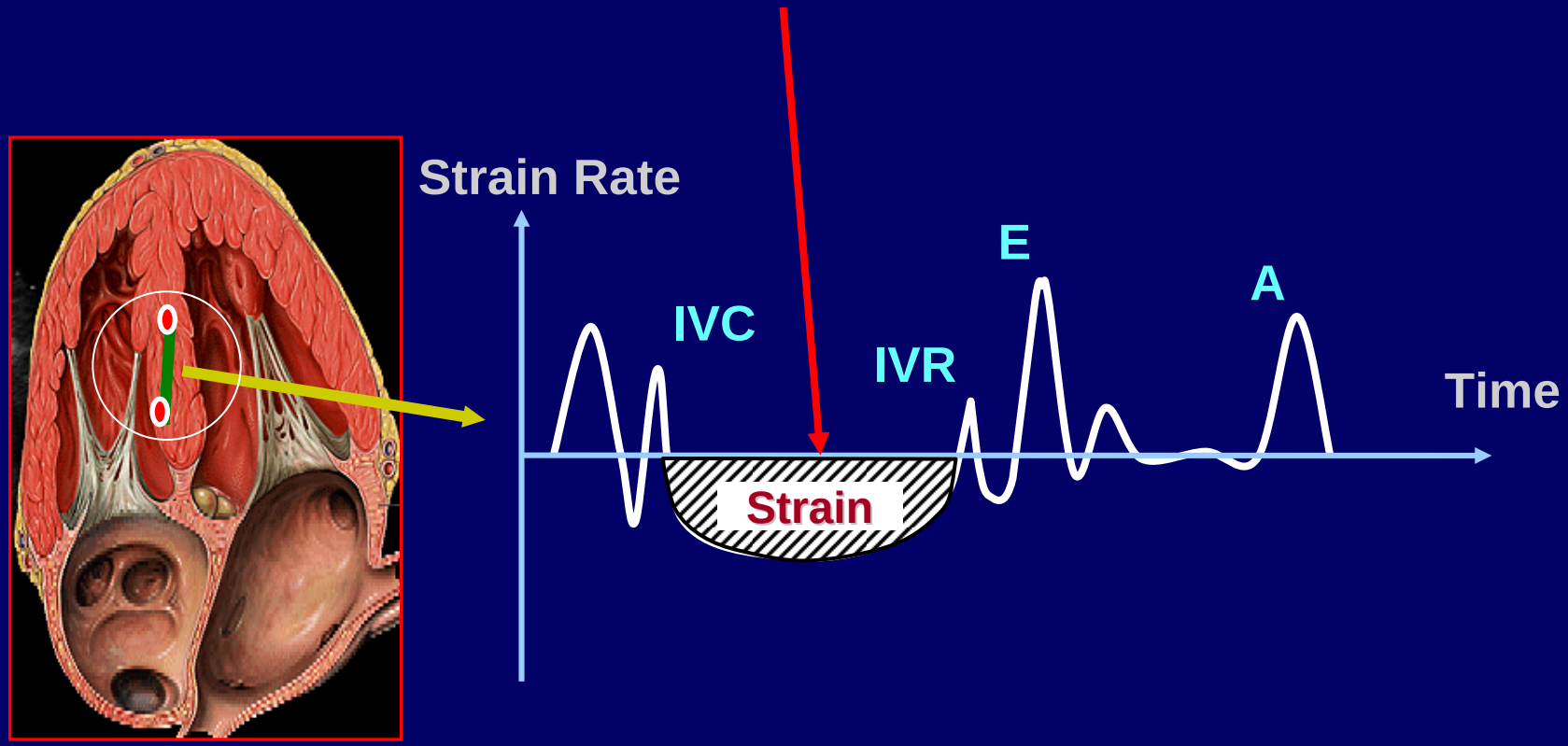




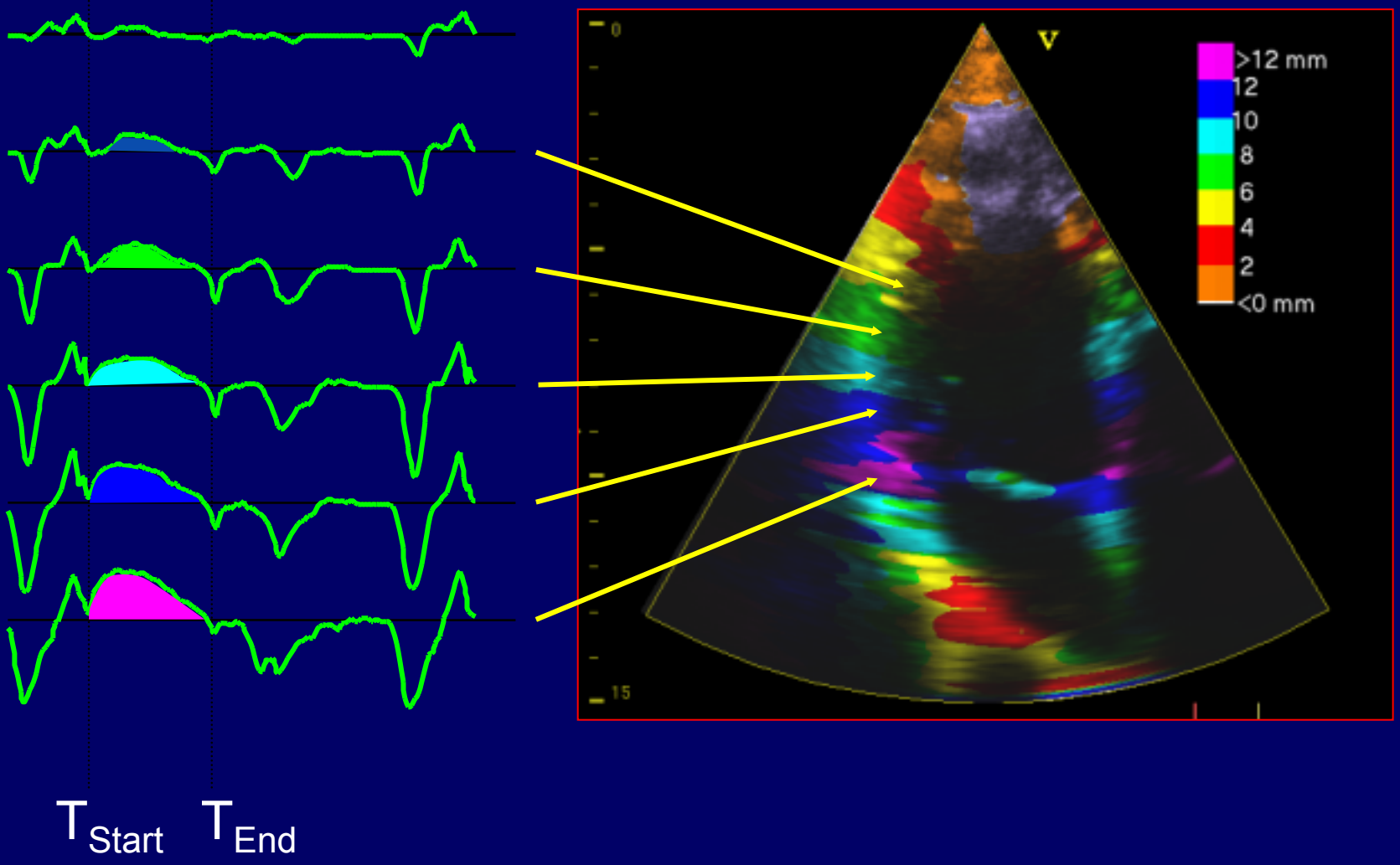
$$SR = \frac{v_2 - v_1}{\Delta x}$$



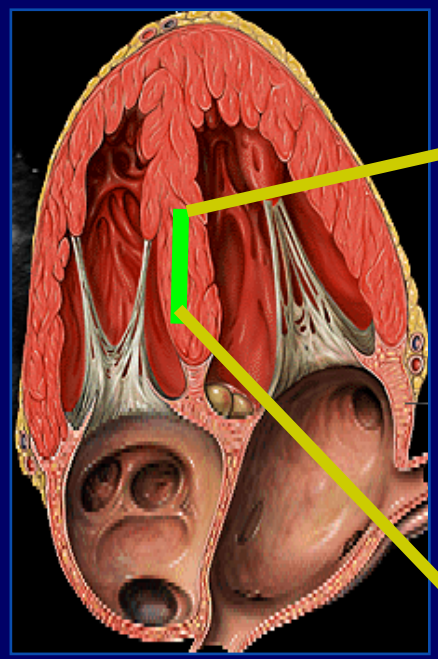
Strain - Local Deformation

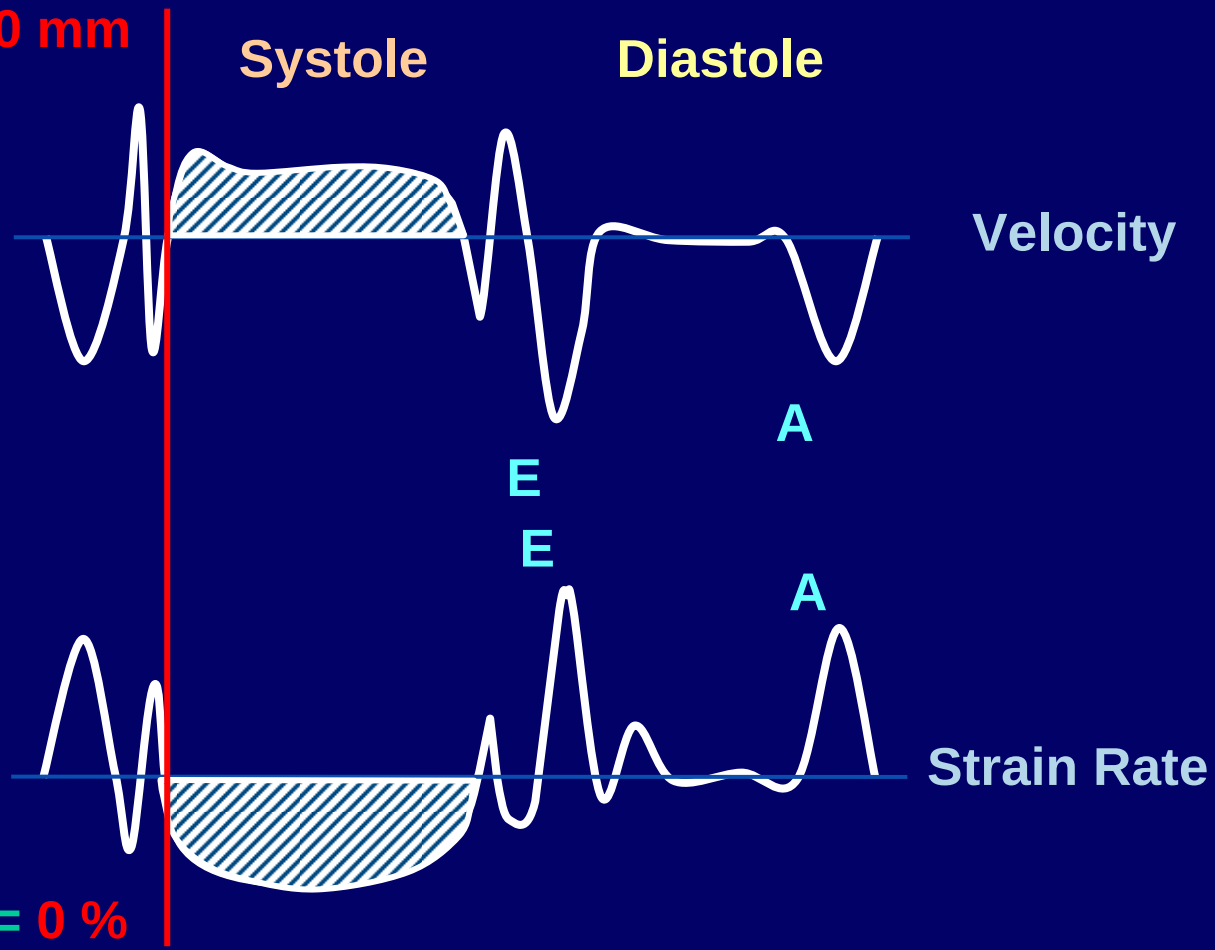


Color encoding based on tracked motion

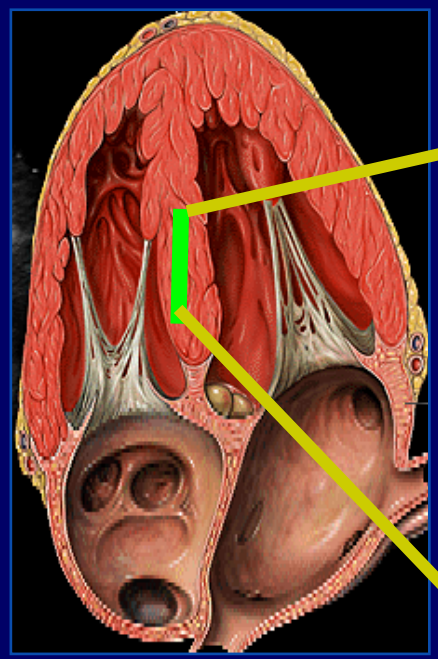


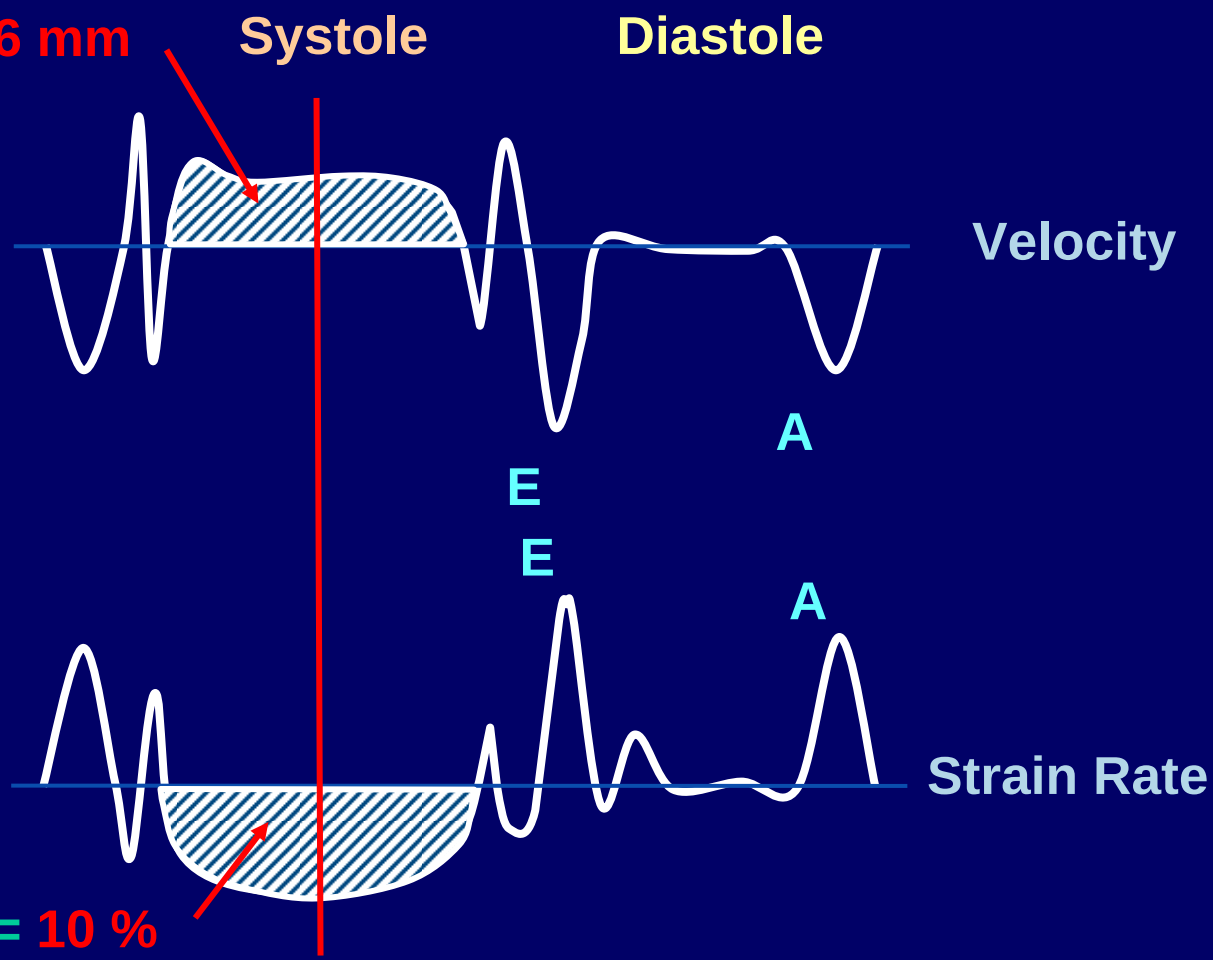
Longitudinal Displacement and Strain during the Systolic phase



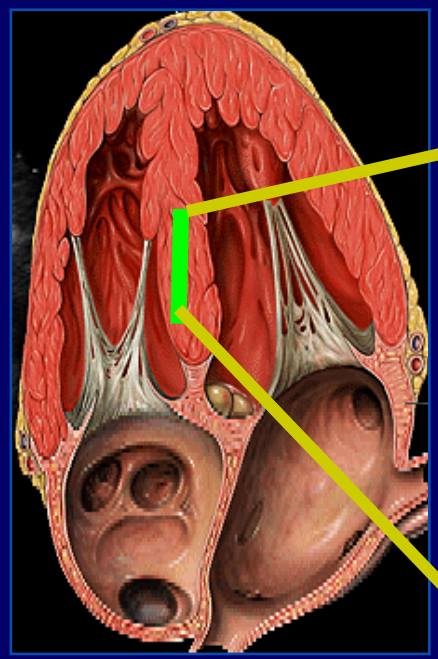


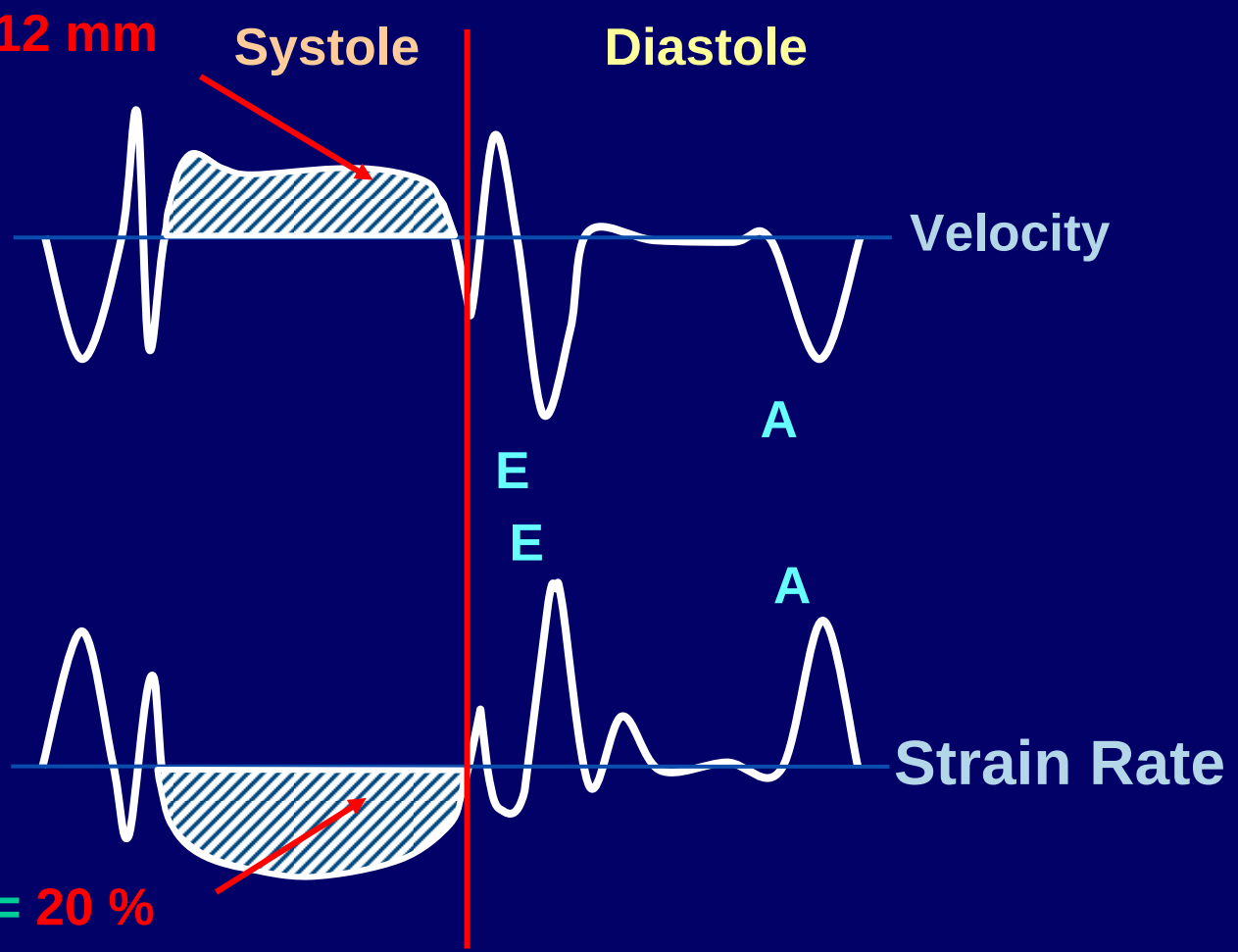
Longitudinal Displacement and Strain during the Systolic phase



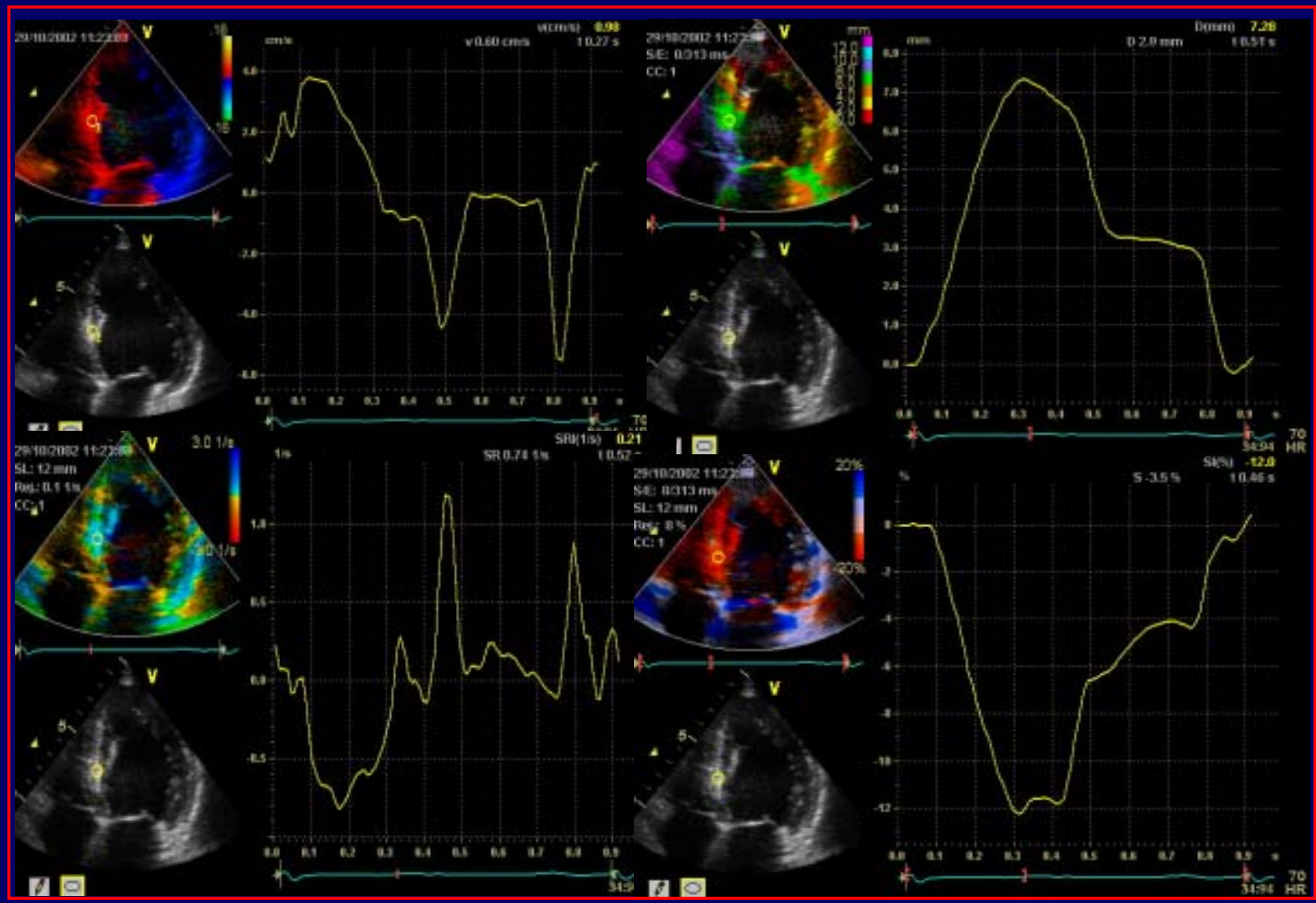


Longitudinal Displacement and Strain during the Systolic phase

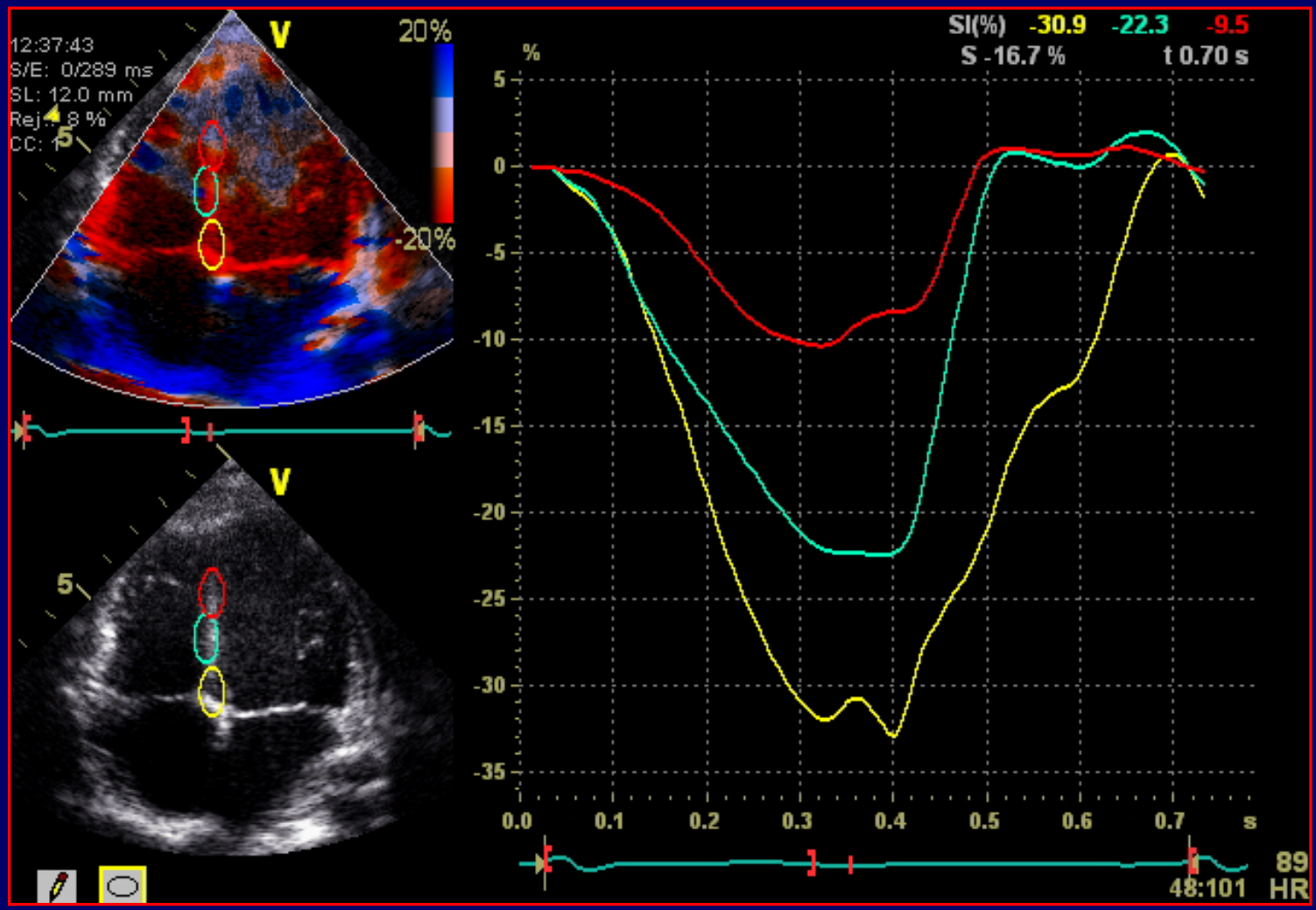




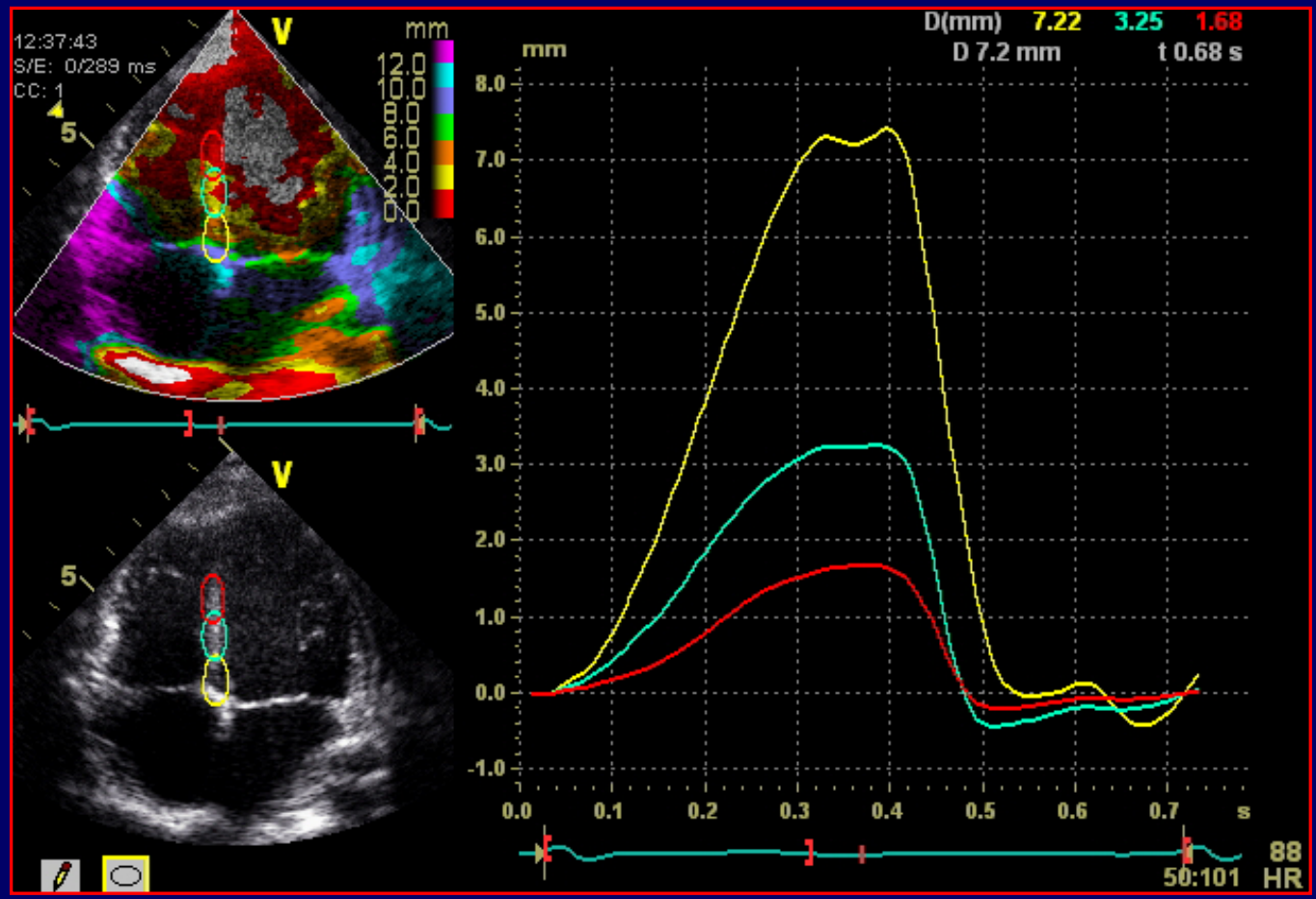
TDI, TT, SRI, Strain imaging & Profile



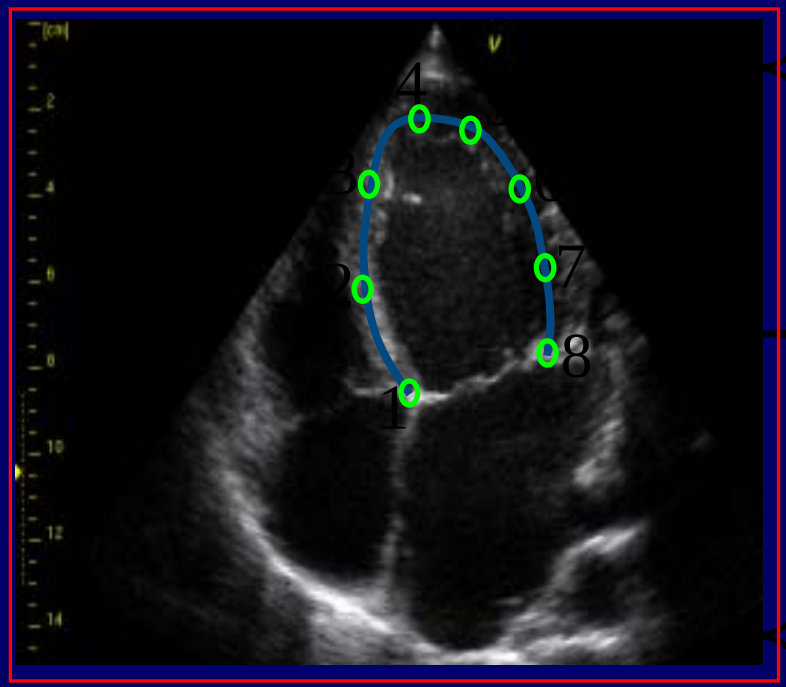
TDI, Strain imaging



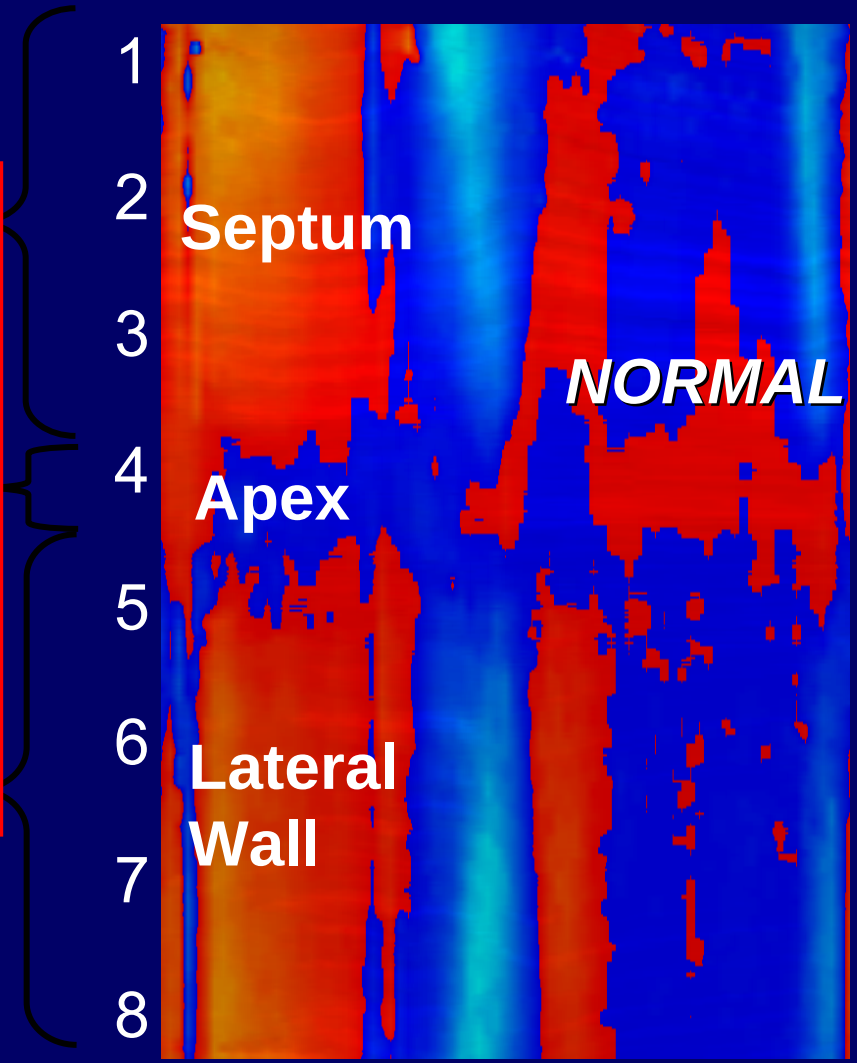
TDI, Tissue tracking imaging Displacement



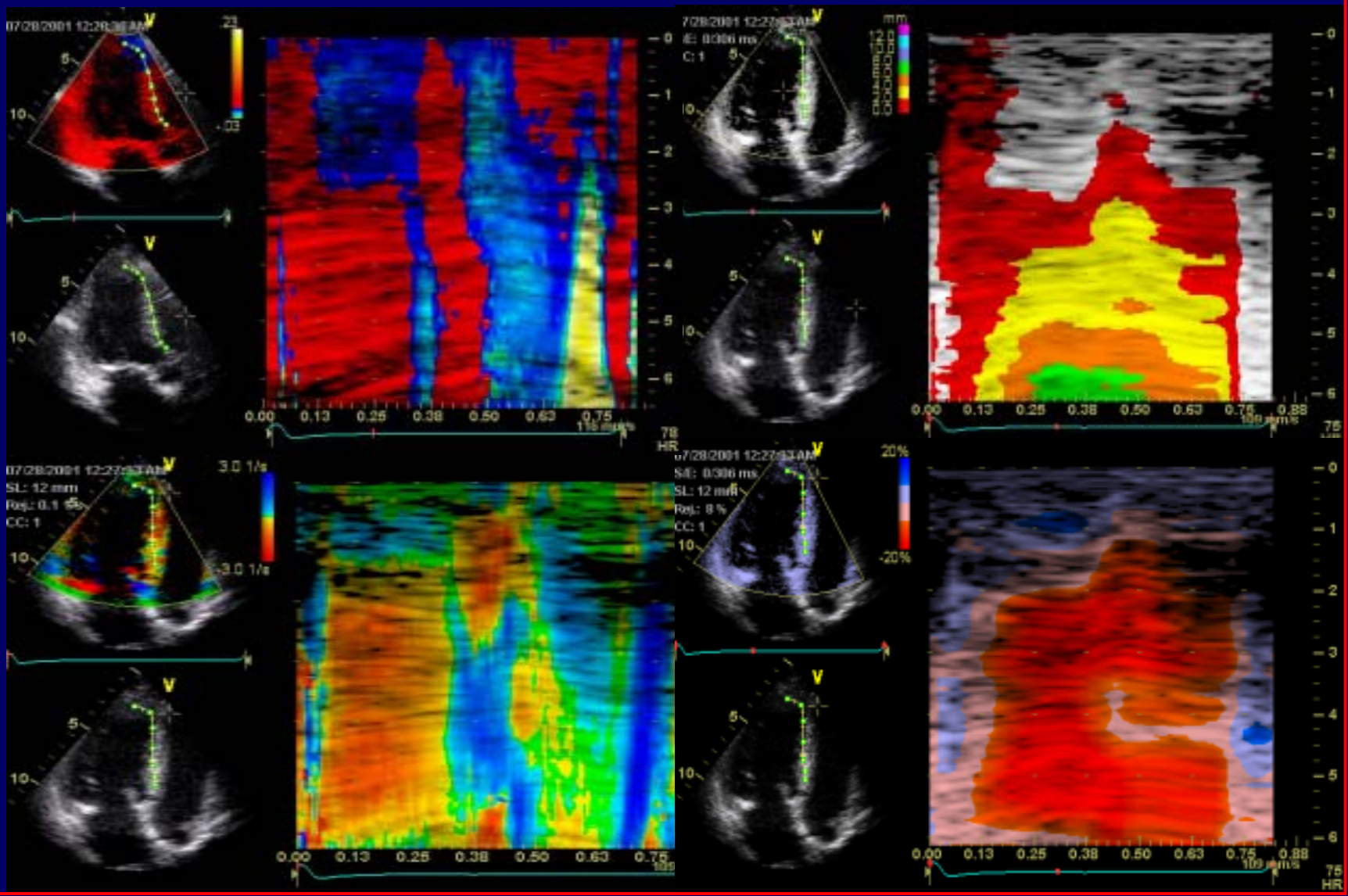
TDI Curved Anatomical M-mode



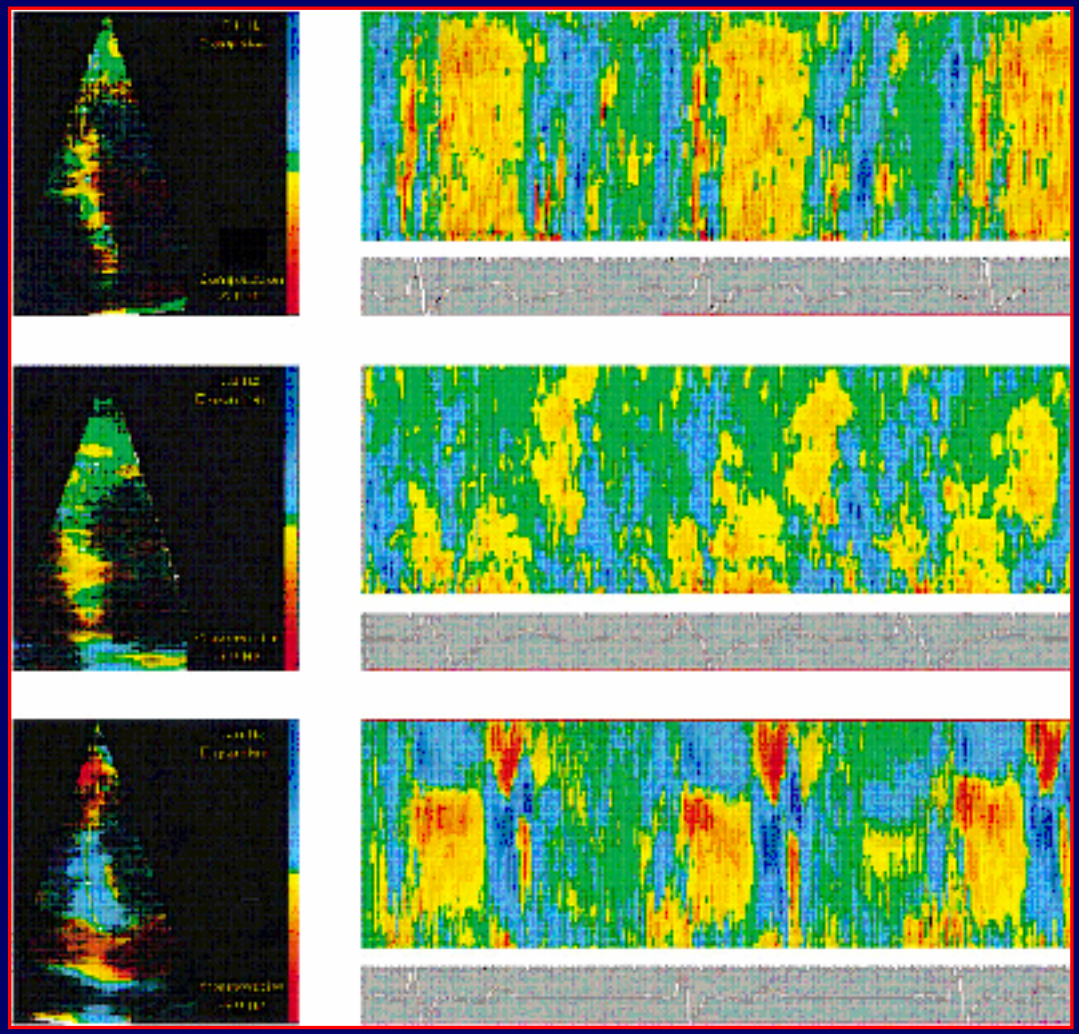
Curved Anatomical M-Mode



CAMM : Apex Post systolic thickenig



CAMM : Strain rate imaging



Normal

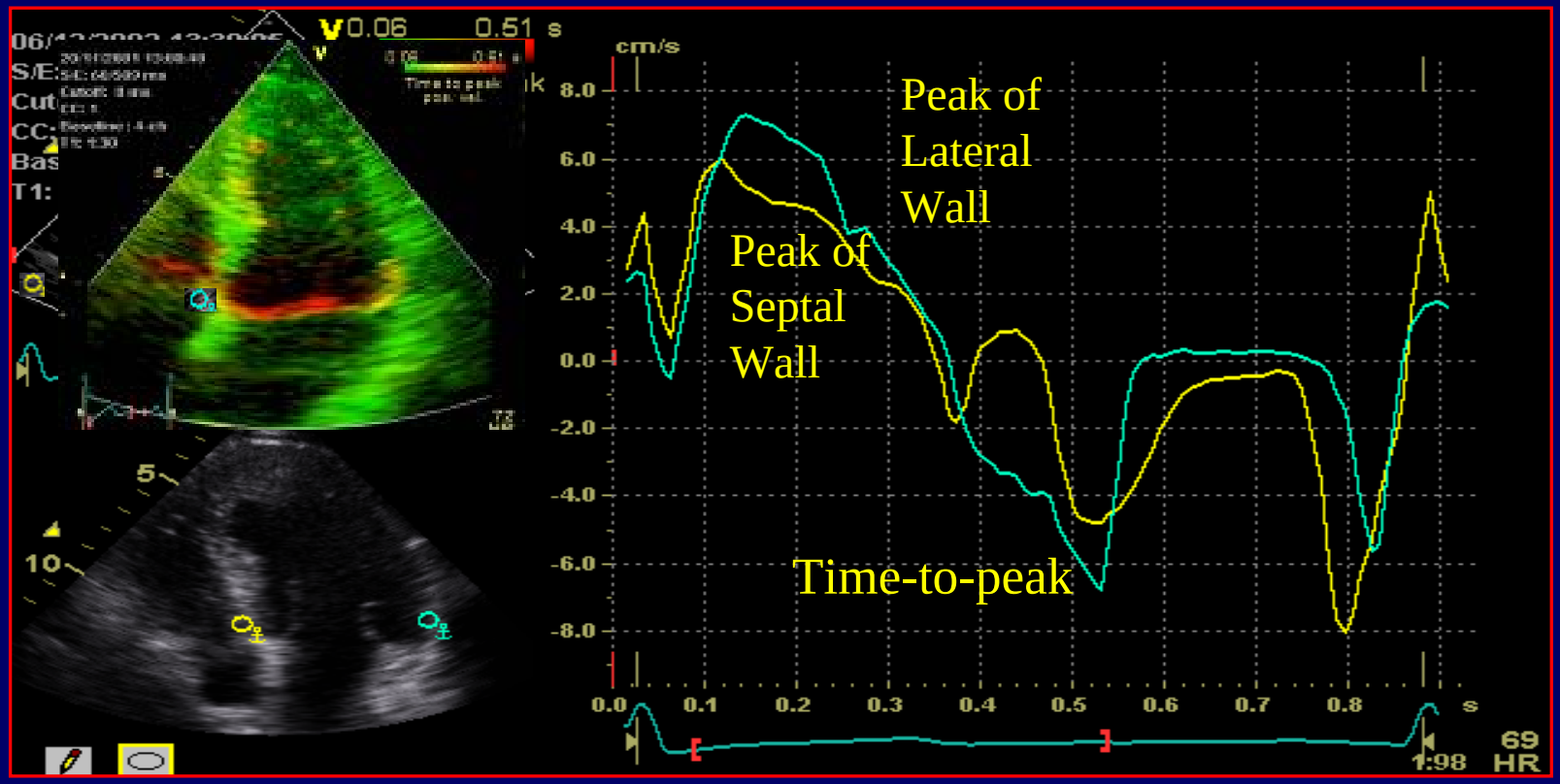
Apical akinesia

Apical dyskinesia

Voigt JU et al. J Am Soc Echocardiogr. 2000

Tissue Synchronization Imaging

Using Tissue Doppler to Map Synchrony

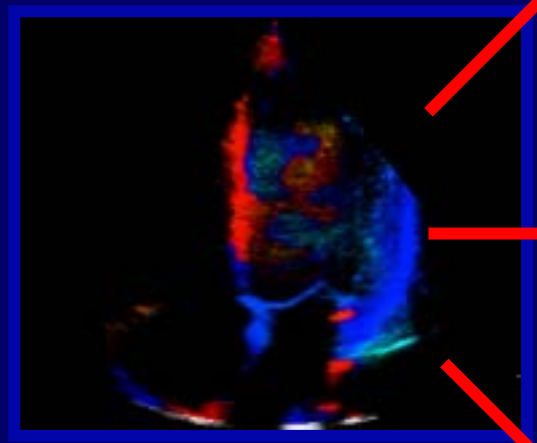


TSI does this calculation for *every* piece of myocardium and displays time-to-peak

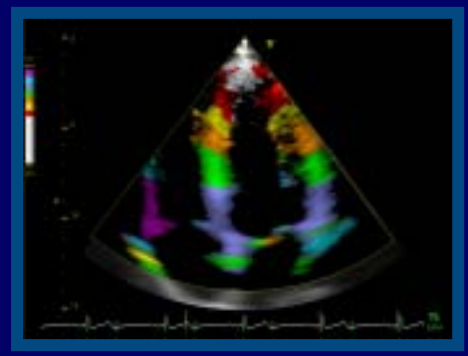
Parametric Imaging

Advance Applications

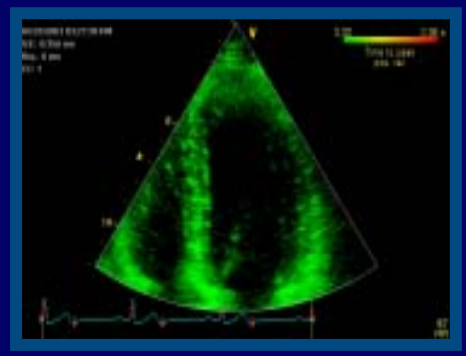
TVI, TTI, TSI, Strain…



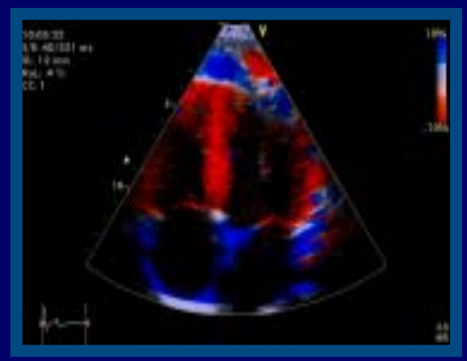
TVI
Tissue Velocity Imaging
Measures Myocardial
Long. Velocity [m/sec]



TTI – Tissue Tracking
Measures Myocardial
Longitudinal
Displacement [mm]



TSI – Tissue Synchronization Imaging
Measures **Timing**;
Time-to-Peak Systolic
Velocity [msec]

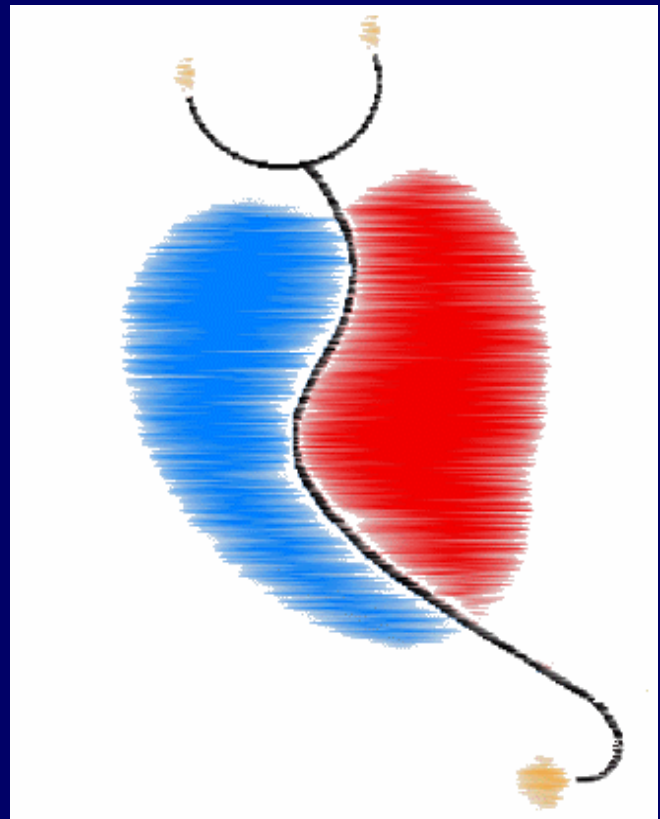


SI – Strain Imaging
Measures Myocardial
Longitudinal
Deformation [%]

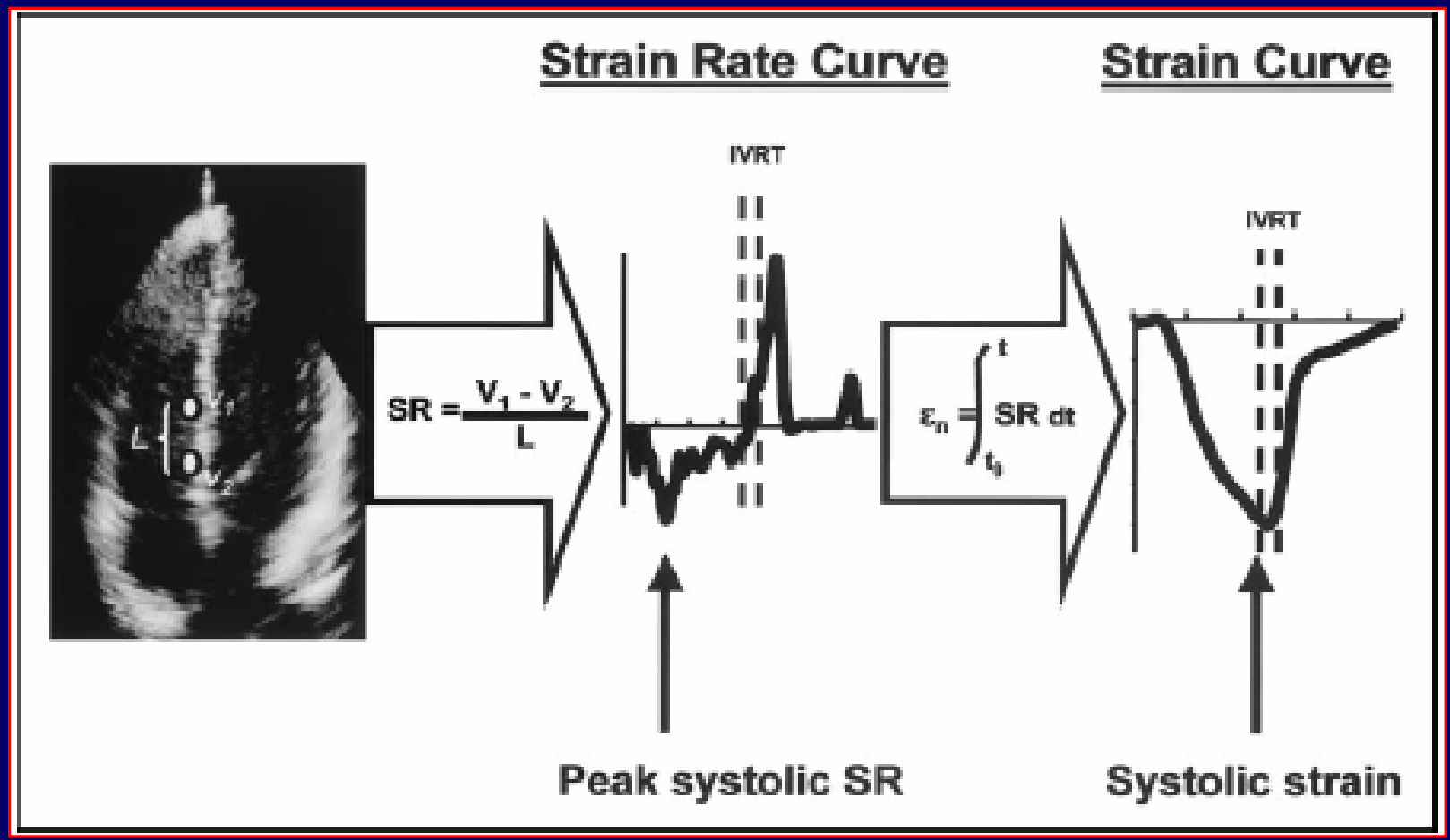
Clinical Application

Functional assessment
in Congenital Heart disease

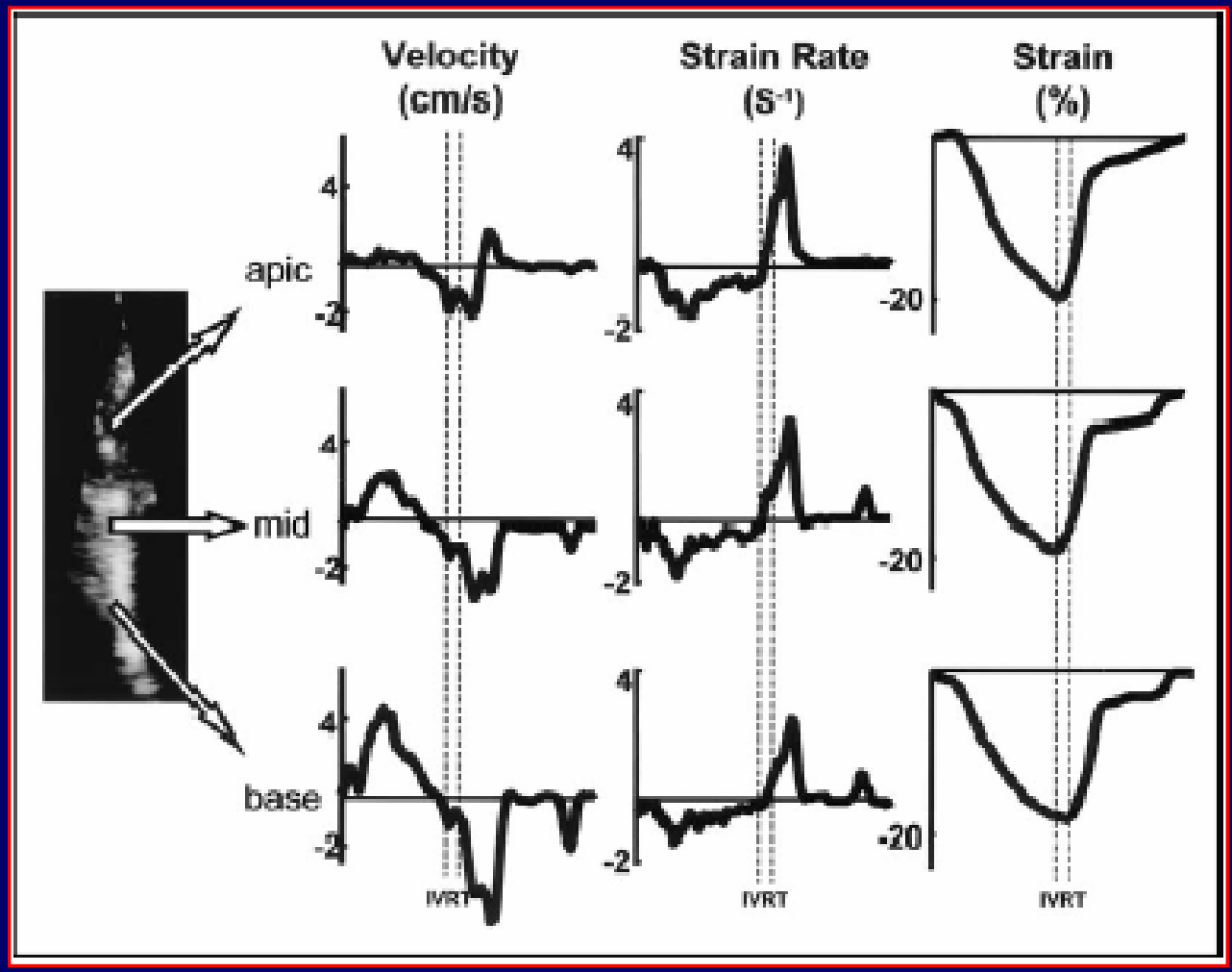
- s/p ASD device closure
- Aortic Stenosis
- RV function in TOF
- Diastolic dysfunction
- Ventricular function in
  Fontan physiology
- Etc.



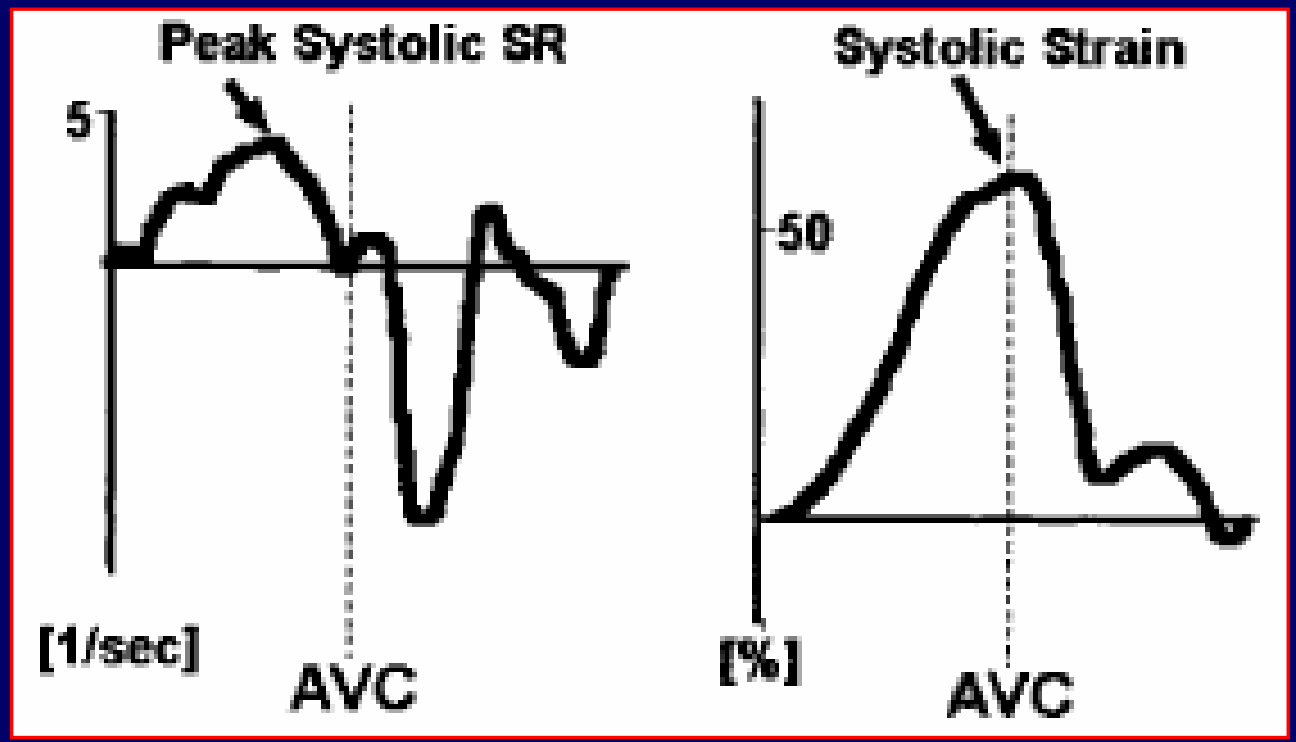
Strain Rate vs Strain - longitudinal



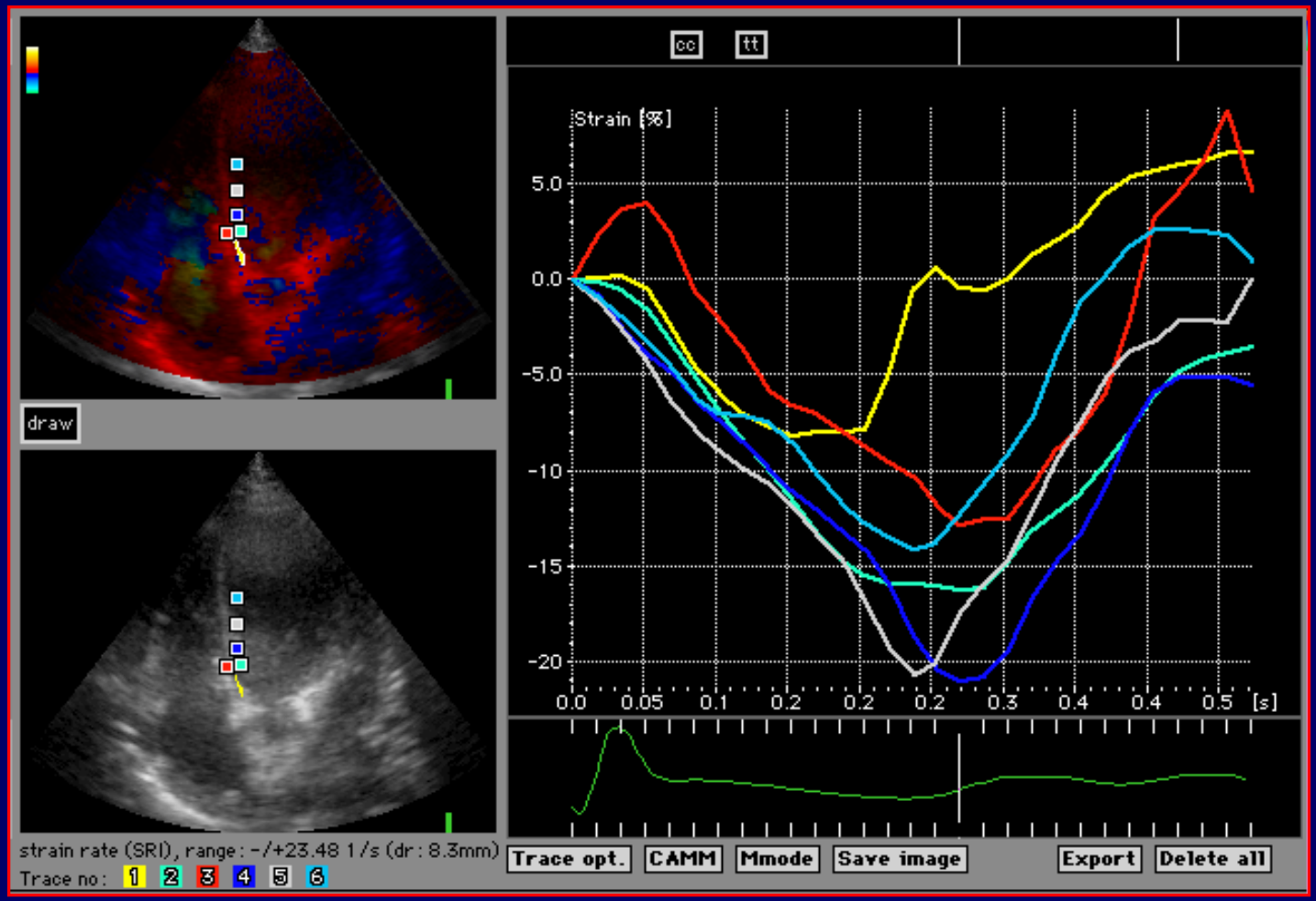
Longitudinal motion and deformation in RV with TOF



Strain Rate vs Strain - radial

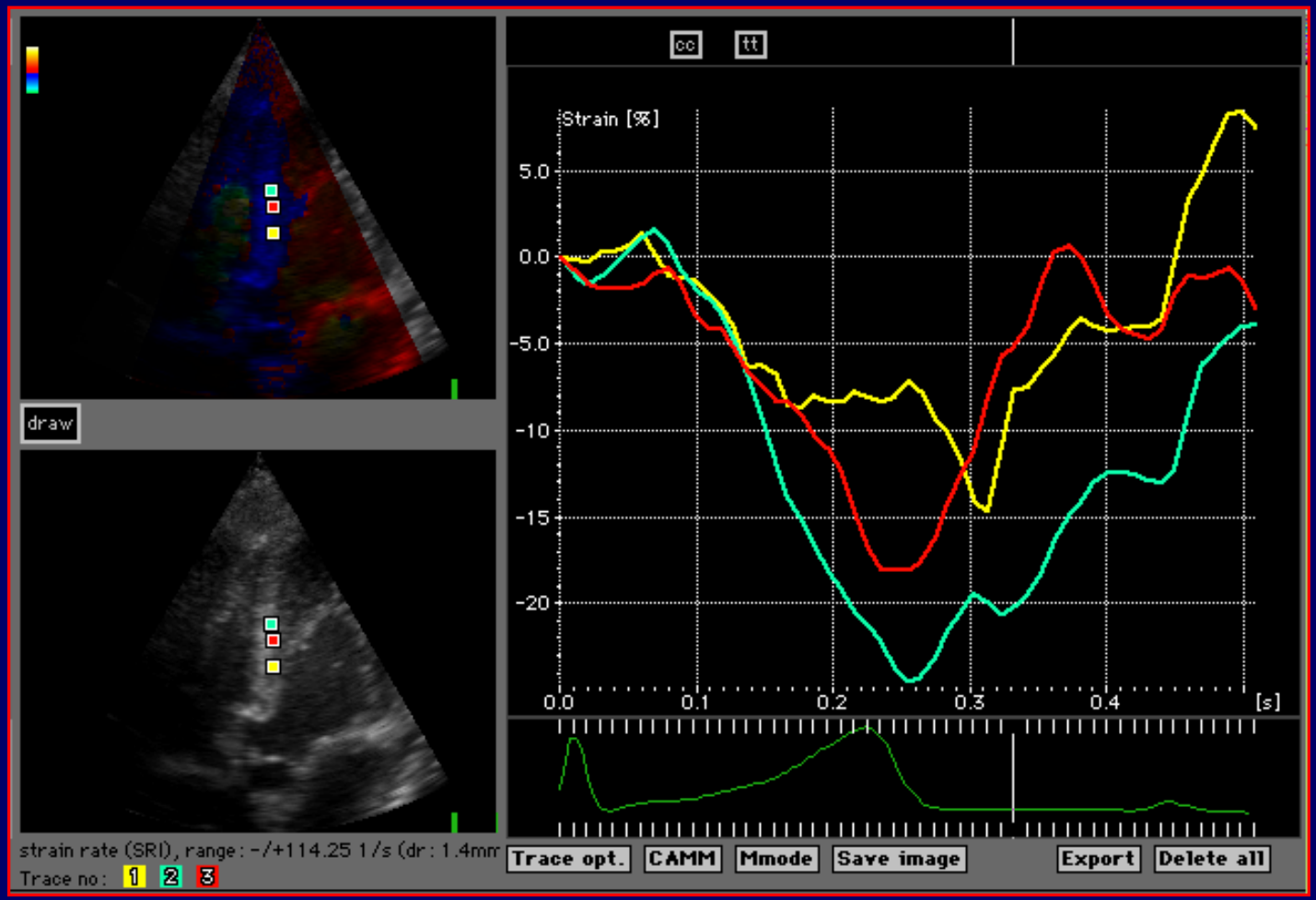


Peri-patch regional myocardial function in VSD repair



Eun, AHA 2002

Peri-patch regional myocardial function in VSD repair



Eun, AHA 2002

Table 1. The Strain parameters in VSD repain patients

	Peripatch	Remote region	*p*-value
Longitudinal			
SR_{ES}	-3.79 ± 3.19	-5.33 ± 4.17	< 0.05
SR_{ED}	4.05 ± 1.62	5.63 ± 3.66	< 0.05
SR_{LD}	3.96 ± 2.34	3.42 ± 1.95	NS
ε			
ε peak	-24.69 ± 11.08	-30.71 ± 11.12	< 0.01
Radial			
SR_{ES}	3.31 ± 1.85	3.77 ± 1.61	NS
SR_{ED}	-4.02 ± 3.09	-7.02 ± 3.09	< 0.01
SR_{LD}	-3.63 ± 3.36	-5.67 ± 5.49	< 0.05
ε			
ε peak	19.02 ± 16.36	37.27 ± 28.37	< 0.0001

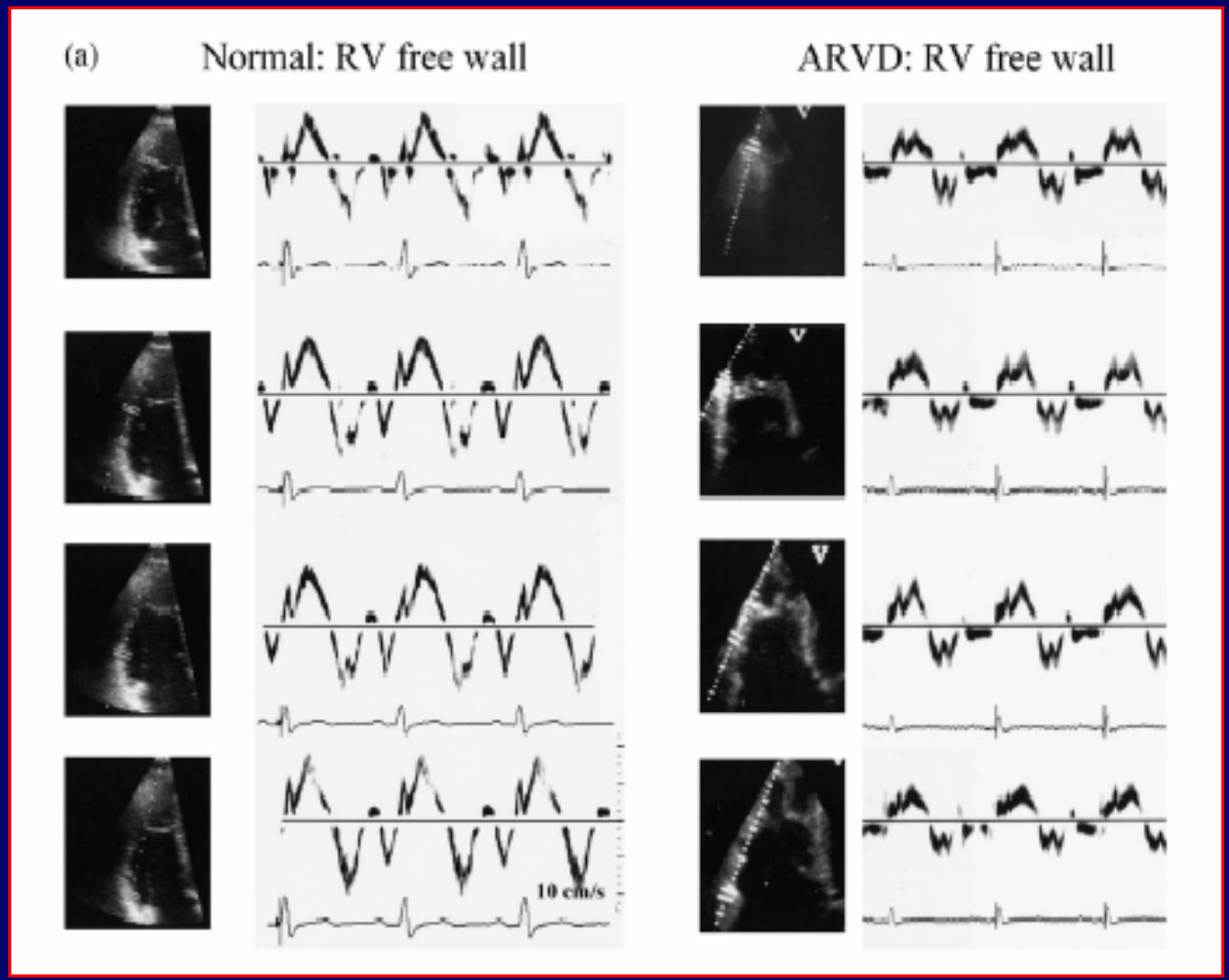
Eun et al. AHA 2002

Table 2. Time to Strain parameters in VSD patients

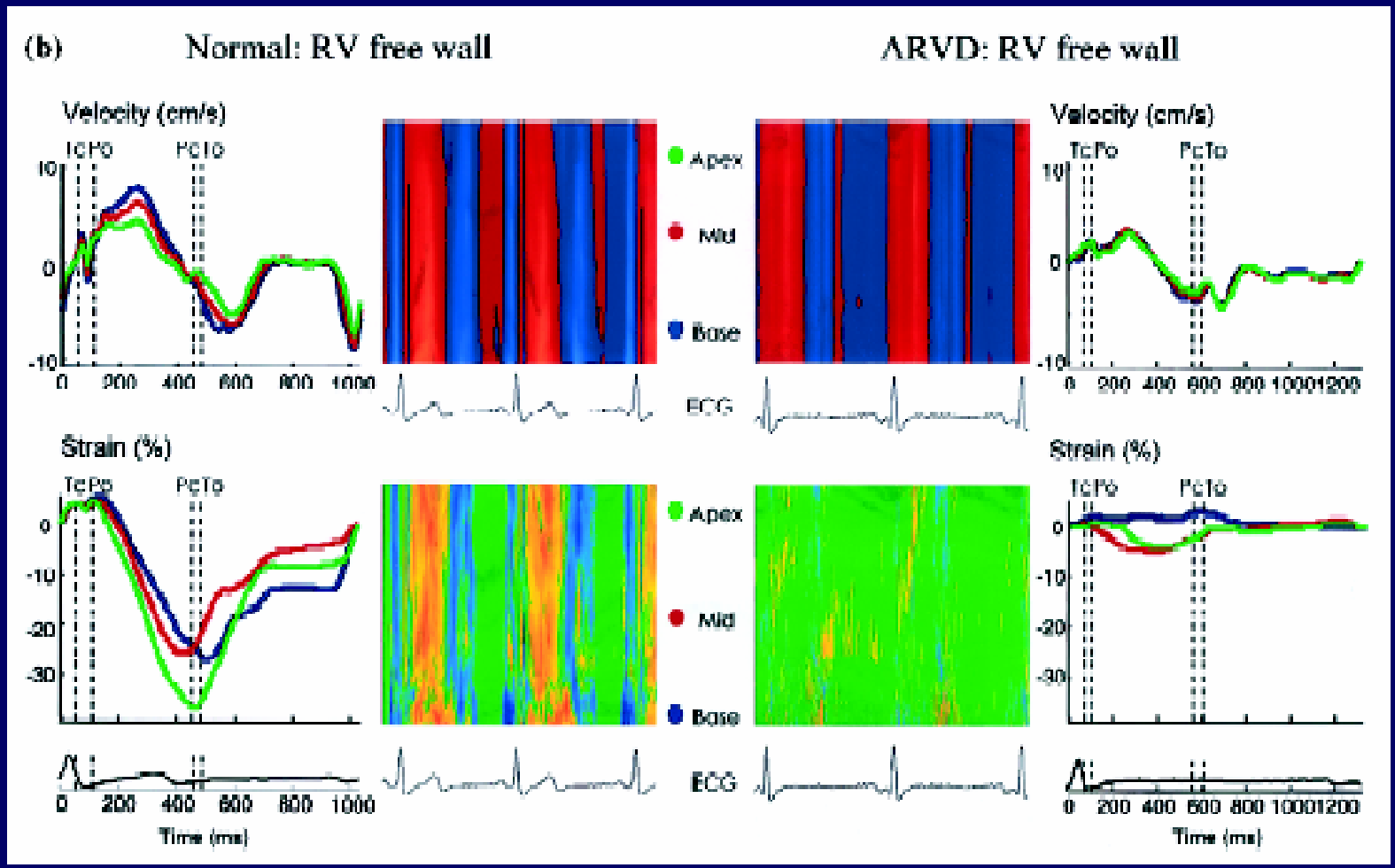
	Peripatch	Remote region	*p*-value
Longitudinal			
SR_{ES}	0.144 ± 0.059	0.110 ± 0.046	< 0.01
SR_{ED}	0.371 ± 0.087	0.357 ± 0.082	< 0.05
SR_{LD}	0.497 ± 0.148	0.486 ± 0.145	NS
ε			
ε peak	0.313 ± 0.080	0.241 ± 0.062	< 0.0001
Radial			
SR_{ES}	0.147 ± 0.049	0.164 ± 0.199	NS
SR_{ED}	0.347 ± 0.097	0.347 ± 0.113	NS
SR_{LD}	0.464 ± 0.136	0.460 ± 0.139	NS
ε			
ε peak	0.329 ± 0.099	0.265 ± 0.079	< 0.0001

Eun et al. AHA 2002

Tissue velocity in Normal vs RV dysplasia

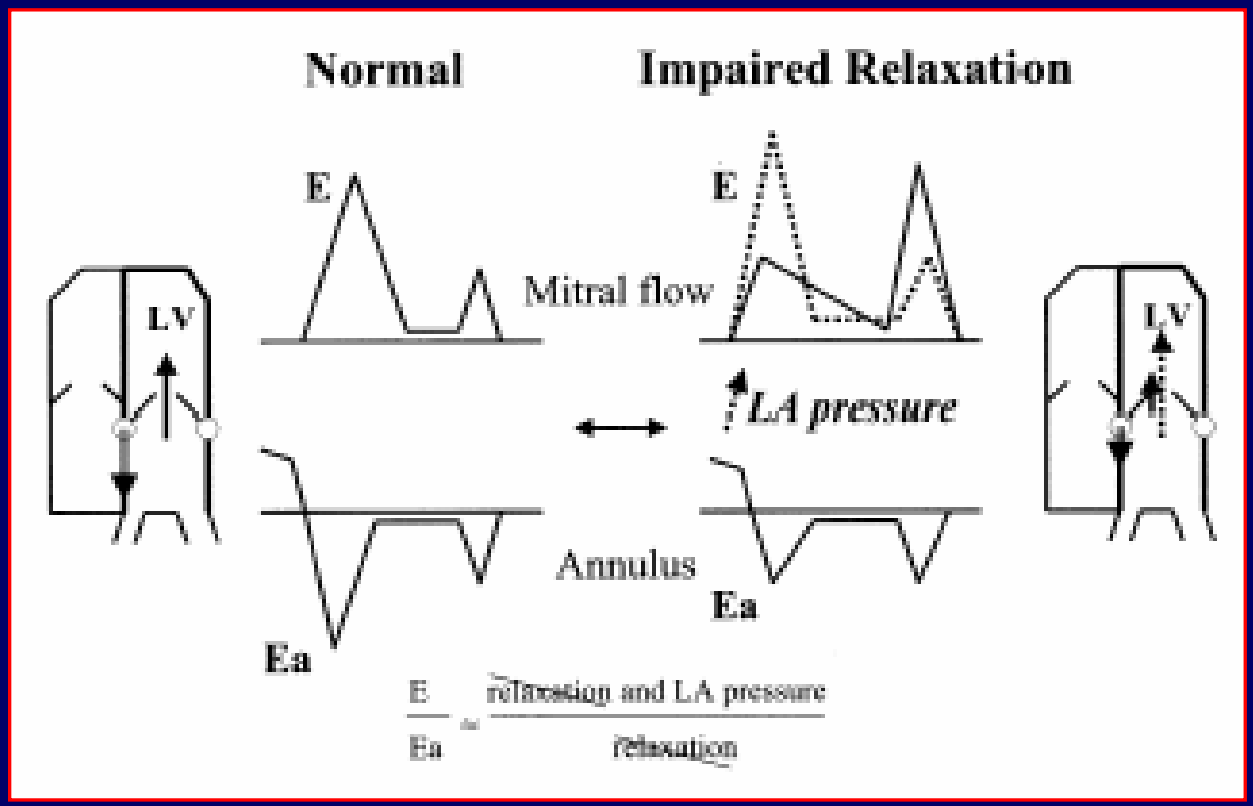


Tissue velocity in Normal vs RV dysplasia



Herbots et al. Eur J Echocardiography 2003; 4: 101–107

Conventional and TDI velocity



E / Ea : strong relation to invasively measured PCWP

By Paelinck et al. J Am Coll Cardiol 2005;45:1109–16.

Tissue Velocities in normal children by age group

Table 2 Pulse wave Doppler tissue velocities and time intervals in healthy children by age group

Age group	N	E'-wave velocity	A'-wave velocity	S'-wave velocity	ICT	IRT	E/E' ratio
Mitral annular							
<1 y	63	9.7 ± 3.3 (8.8–10.5)	5.7 ± 1.8 (5.3–6.2)	5.7 ± 1.6 (5.3–6.1)	77.4 ± 18.4 (72.7–82.0)	57.0 ± 14.8 (53.1–60.8)	8.8 ± 2.7 (8.1–9.5)
1–5 y	68	15.1 ± 3.4† (14.3–15.4)	6.5 ± 1.9 (6.1–7.0)	7.7 ± 2.1† (7.2–8.2)	76.9 ± 15.9 (72.8–80.9)	62.1 ± 13.2 (58.9–65.4)	6.5 ± 2.0† (6.0–7.0)
6–9 y	55	17.2 ± 3.7† (16.2–18.3)	6.7 ± 1.9 (6.2–7.3)	9.5 ± 2.1† (8.9–10.1)	77.9 ± 18.9 (72.4–83.4)	62.9 ± 11.9 (59.5–66.3)	5.8 ± 1.9 (5.3–6.4)
10–13 y	58	19.6 ± 3.4† (18.7–20.5)	6.4 ± 1.8 (5.9–6.9)	10.8 ± 2.9* (10.0–11.5)	76.6 ± 16.2 (72.4–80.9)	62.6 ± 12.4 (59.4–65.9)	4.9 ± 1.3 (4.6–5.2)
14–18 y	81	20.6 ± 3.8 (19.7–21.4)	6.7 ± 1.6 (6.3–7.1)	12.3 ± 2.9† (11.6–12.9)	78.9 ± 15.4 (75.4–82.3)	69.5 ± 15.5* (66.1–73.0)	4.7 ± 1.3 (4.4–5.0)
Total	325	16.5 ± 5.3 (16.0–17.1)	6.4 ± 1.9 (6.2–6.6)	9.3 ± 3.4 (8.9–9.7)	77.5 ± 16.7 (75.7–79.5)	63.2 ± 14.4 (61.7–64.9)	6.1 ± 2.4 (5.9–6.4)
Septal							
<1 y	63	8.1 ± 2.5 (7.5–8.7)	6.1 ± 1.5 (5.7–6.4)	5.4 ± 1.2 (5.1–5.7)	77.5 ± 17.5 (73.0–82.0)	53.0 ± 11.7 (50.0–56.0)	10.3 ± 2.7 (9.7–11.0)
1–5 y	68	11.8 ± 2.0† (11.3–12.3)	6.0 ± 1.3 (5.7–6.4)	7.1 ± 1.5† (6.8–7.5)	80.1 ± 15.5 (76.3–83.9)	59.8 ± 12.0 (56.9–62.7)	8.1 ± 1.8† (7.7–8.5)
6–9 y	55	13.4 ± 1.9† (12.8–13.9)	5.9 ± 1.3 (5.5–6.3)	8.0 ± 1.3 (7.6–8.4)	82.8 ± 15.3 (78.4–87.2)	65.6 ± 10.7 (62.5–68.7)	7.2 ± 1.6 (6.8–7.7)
10–13 y	58	14.5 ± 2.6 (13.8–15.2)	6.1 ± 2.3 (5.6–6.7)	8.2 ± 1.3 (7.9–8.5)	87.9 ± 16.4* (83.6–92.2)	72.5 ± 12.3 (69.3–75.8)	6.6 ± 1.4 (6.3–7.0)
14–18 y	81	14.9 ± 2.4 (14.3–15.4)	6.2 ± 1.5 (5.9–6.6)	9.0 ± 1.5 (8.7–9.3)	88.4 ± 15.6 (84.9–91.9)	77.5 ± 14.5 (74.3–80.8)	6.4 ± 1.5 (6.1–6.8)
Total	325	12.6 ± 3.4 (12.2–13.0)	6.1 ± 1.6 (5.9–6.3)	7.6 ± 1.9 (7.4–7.8)	83.5 ± 16.5 (81.7–85.4)	66.1 ± 15.3 (64.4–67.9)	7.7 ± 2.3 (7.5–8.0)

Eidem et al, J Am Soc Echocardiogr. 2004, Vol 17 (3) 212 – 221.

Tissue Velocities in normal children by age group

Table 2 Pulse wave Doppler tissue velocities and time intervals in healthy children by age group

Age group	N	E'-wave velocity	A'-wave velocity	S'-wave velocity	ICT	IRT	E/E' ratio
Tricuspid annular							
<1 y	63	13.8 ± 8.2 (11.7–15.9)	9.8 ± 2.4 (9.1–10.5)	10.2 ± 5.5 (8.8–11.7)	68.7 ± 18.2 (63.9–73.5)	52.0 ± 12.9 (48.5–55.4)	4.4 ± 2.3 (3.8–5.0)
1–5 y	68	17.1 ± 4.0† (16.1–18.1)	10.9 ± 2.7 (10.2–11.6)	13.2 ± 2.0† (12.7–13.7)	77.7 ± 15.0 (73.9–81.5)	59.0 ± 13.9 (55.4–62.5)	3.8 ± 1.1 (3.5–4.1)
6–9 y	55	16.5 ± 3.0 (15.7–17.4)	9.8 ± 2.7 (9.0–10.6)	13.4 ± 2.0 (12.8–14.0)	91.8 ± 21.5† (85.5–98.0)	58.5 ± 17.5 (53.4–63.6)	3.6 ± 0.8 (3.4–3.9)
10–13 y	58	16.5 ± 3.1 (15.7–17.4)	10.3 ± 3.4 (9.3–11.2)	13.9 ± 2.4 (13.2–14.5)	98.1 ± 21.7 (92.2–103.9)	61.7 ± 19.9 (56.4–67.1)	3.5 ± 1.4 (3.2–3.9)
14–18 y	81	16.7 ± 2.8 (16.0–17.3)	10.1 ± 2.6 (9.5–10.7)	14.2 ± 2.3 (13.7–14.7)	101.9 ± 20.4 (97.2–106.6)	62.9 ± 18.9 (58.5–67.3)	3.7 ± 1.0 (3.5–3.9)
Total	325	16.1 ± 4.7 (15.6–16.7)	10.2 ± 2.8 (9.9–10.5)	13.0 ± 3.4 (12.6–13.4)	88.2 ± 23.1 (85.6–90.8)	59.0 ± 17.2 (57.0–60.9)	3.8 ± 1.4 (3.6–4.0)

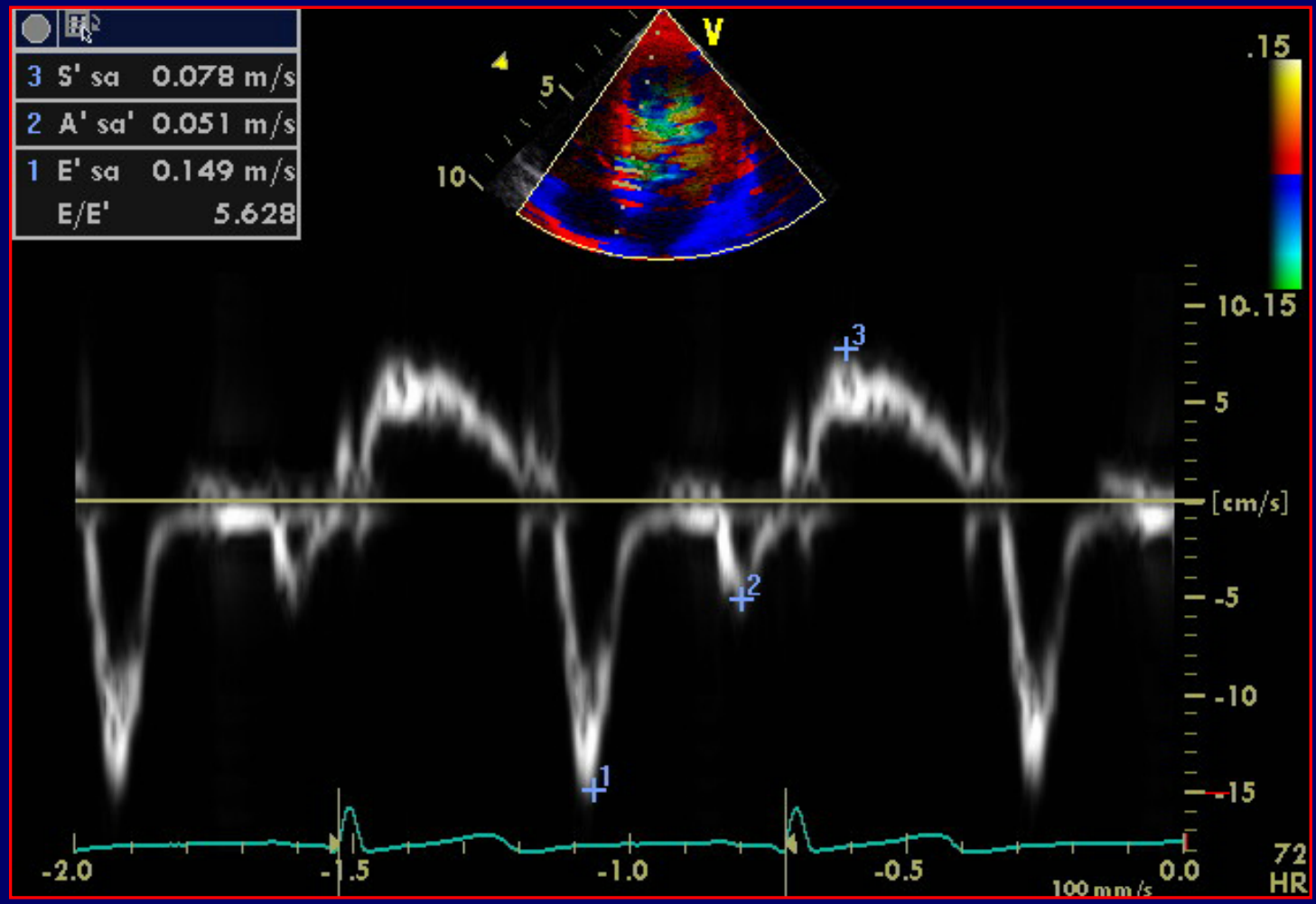
A, Late diastolic velocity; *A'*, late diastolic annular velocity; *ICT*, isovolumic contraction time; *E*, early diastolic inflow Doppler velocity; *E'*, early diastolic annular velocity; *IRT*, isovolumic relaxation time; *S*, systolic velocity; *S'*, systolic annular velocity.

*$P < .05$; †$P < .01$ compared with preceeding age group.

Data expressed as mean ± SD (95% confidence interval). Doppler tissue imaging velocities are expressed in cm/s. Time intervals are expressed in milliseconds.

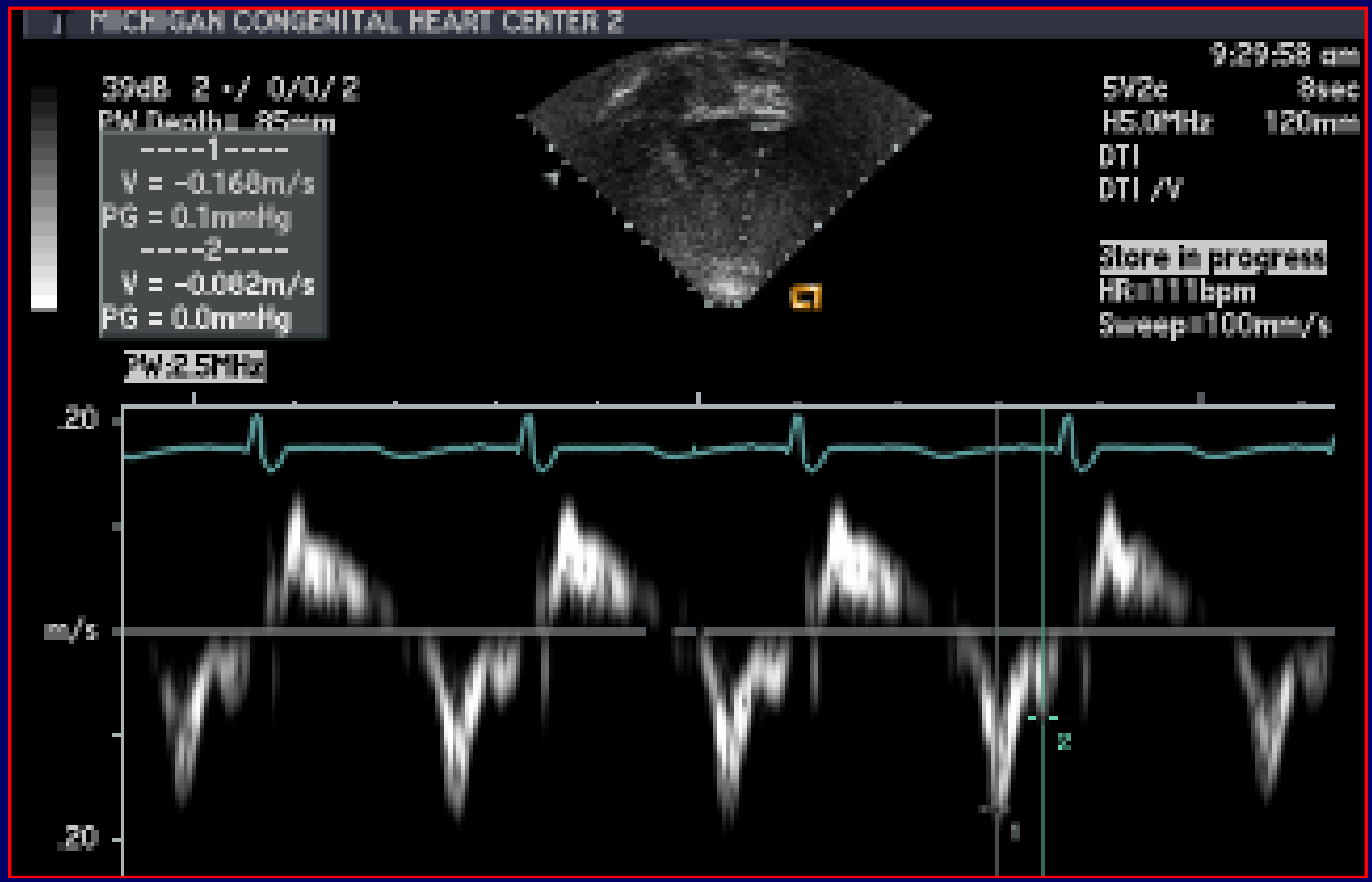
Eidem et al, J Am Soc Echocardiogr. 2004, Vol 17 (3) 212 – 221.

TDI in Normal children



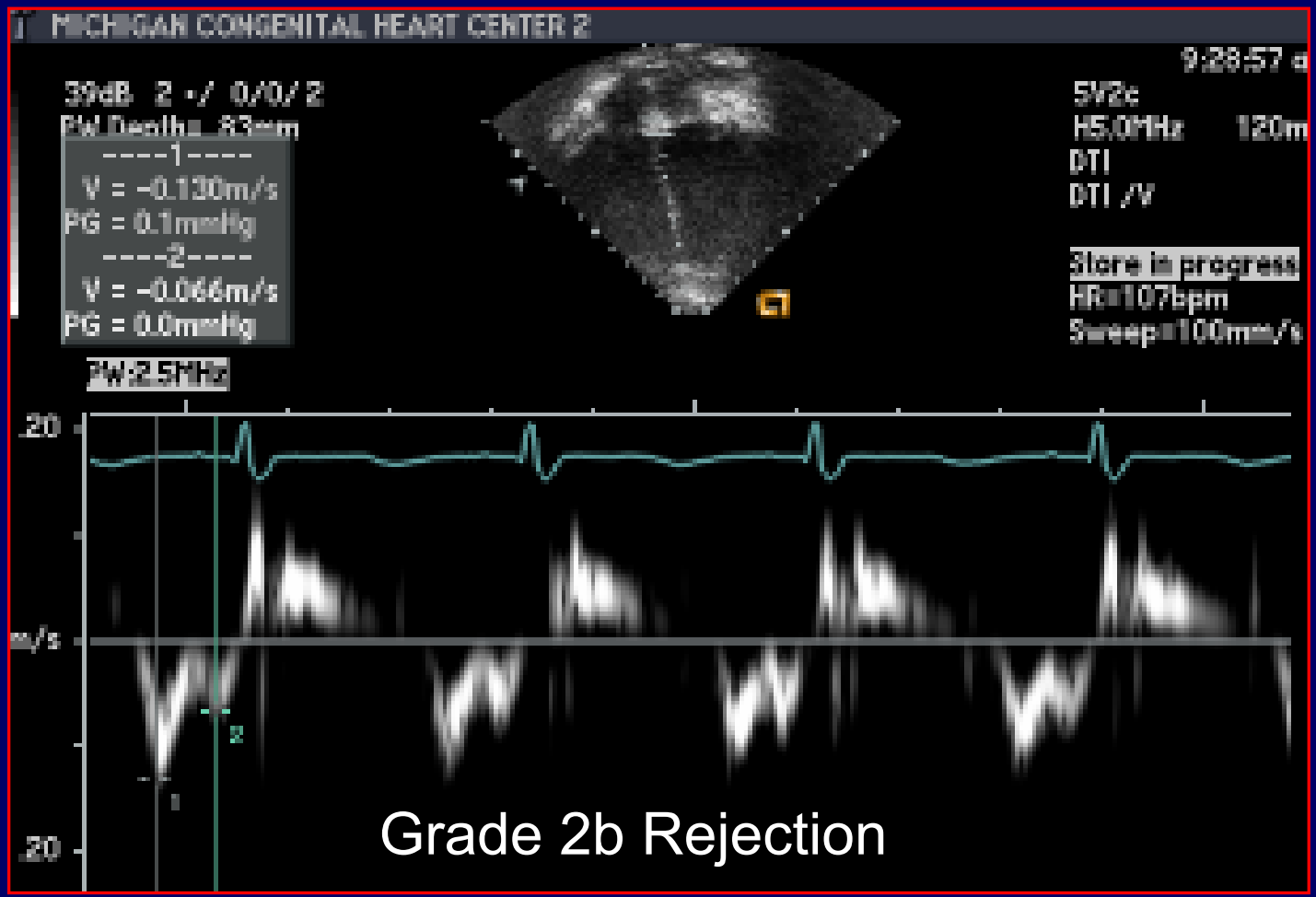
Eun, ACC 2004

TDI in Heart Transplant patient



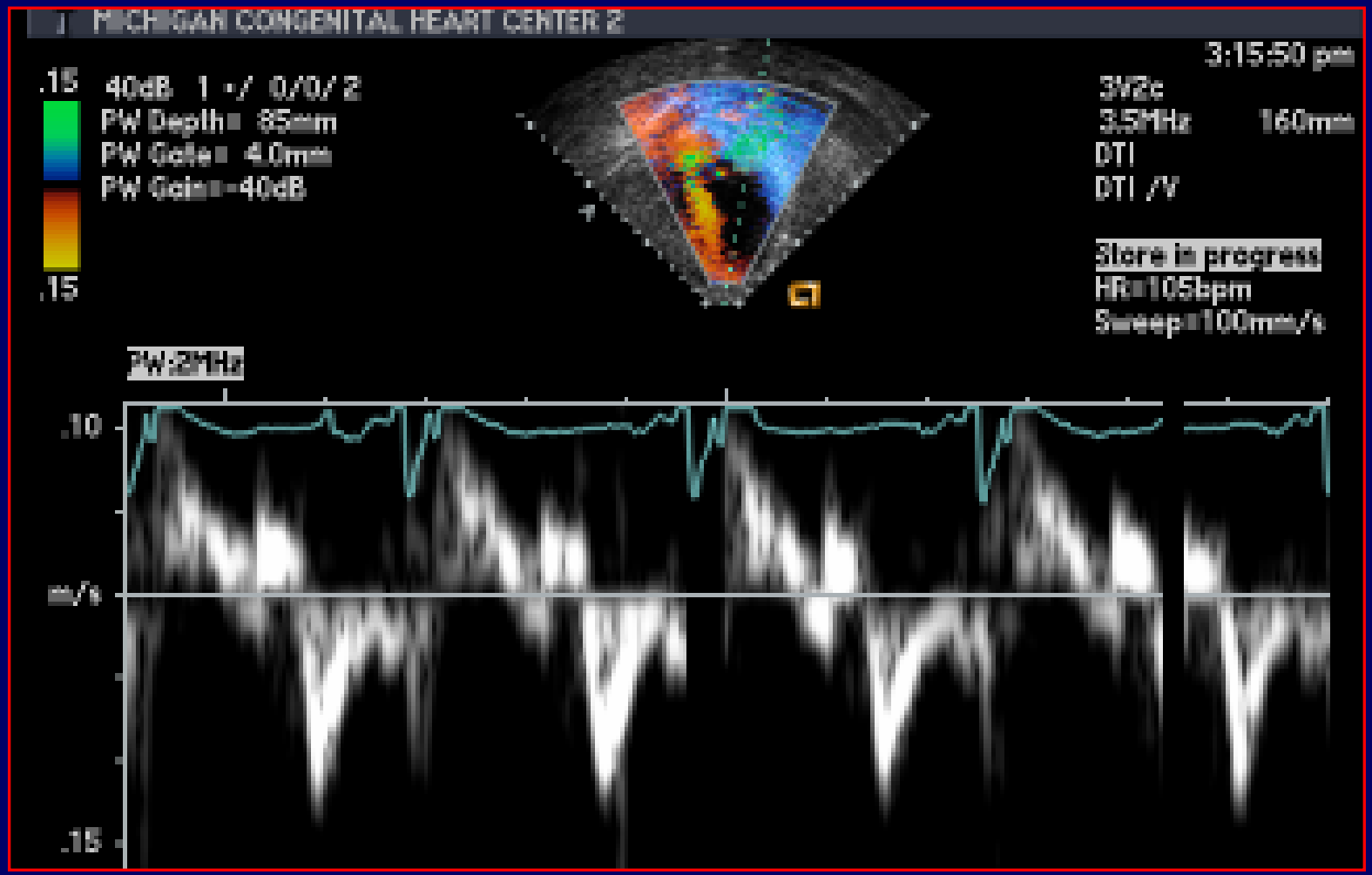
Eun, ACC 2004

TDI in Heart Transplant patient



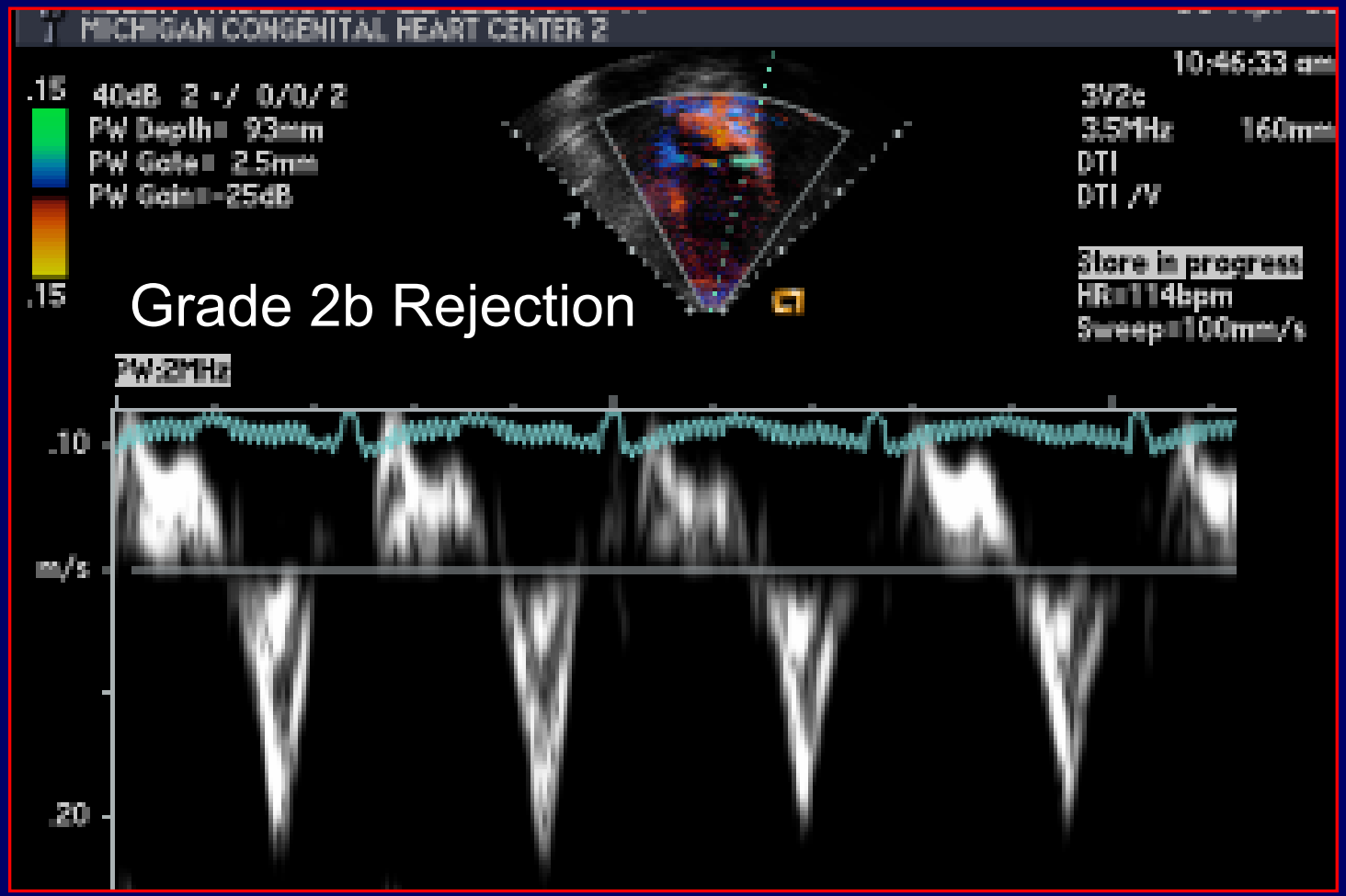
Eun, ACC 2004

TDI in Heart Transplant patient



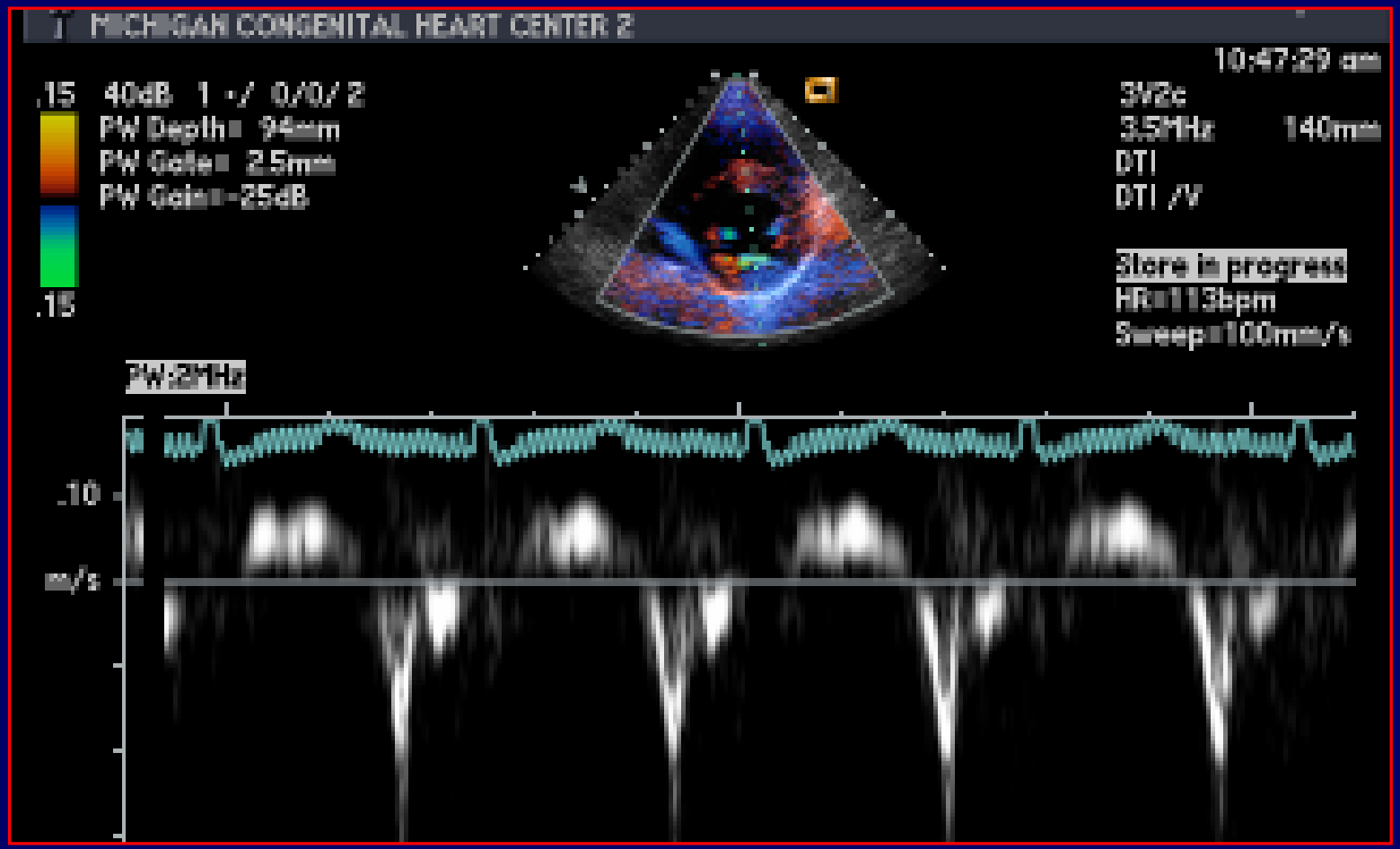
Eun, ACC 2004

TDI in Heart Transplant patient



Eun, ACC 2004

TDI in Heart Transplant patient



Eun, ACC 2004

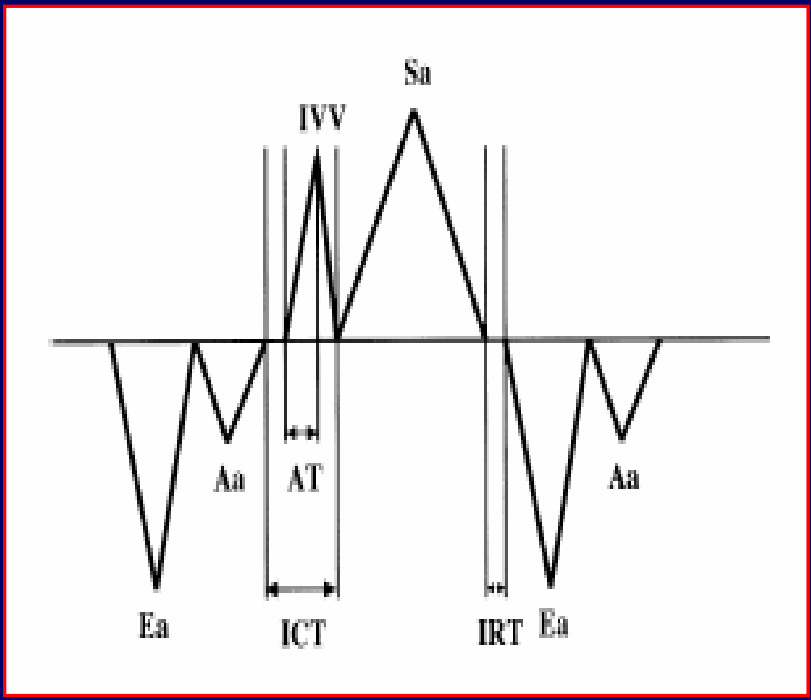
The myocardial performance index (Tei index) by TDI

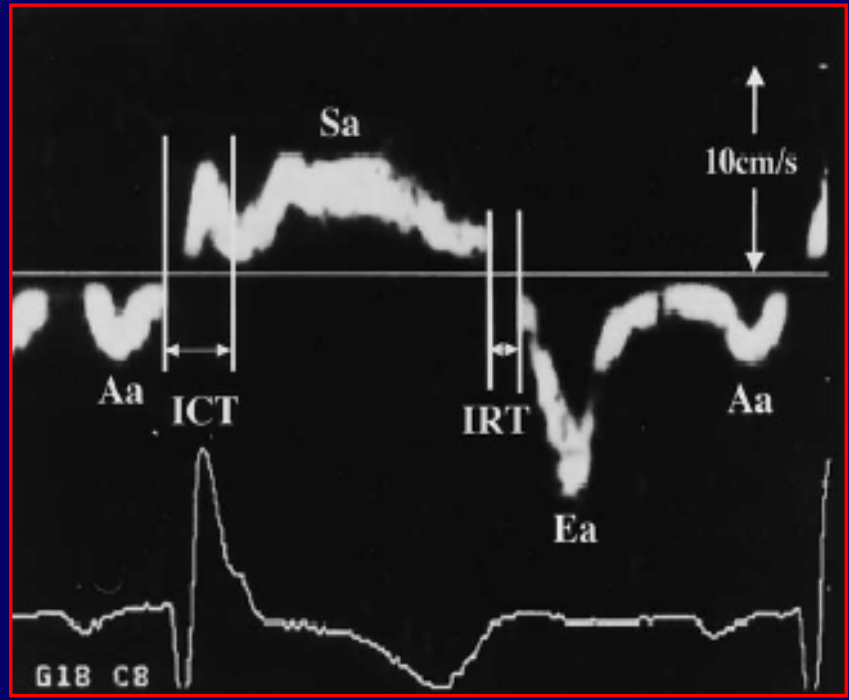
--- > ***Tei*** can also be obtained by TDI.

- Simple and noninvasive measurement for assessing global right ventricular (RV) function
- Sensitive indicator of RV function promising new means - global RV function with PR

By Yasuoka et al. Pediatr Cardiol. 2004 ; 25(2):131-6.

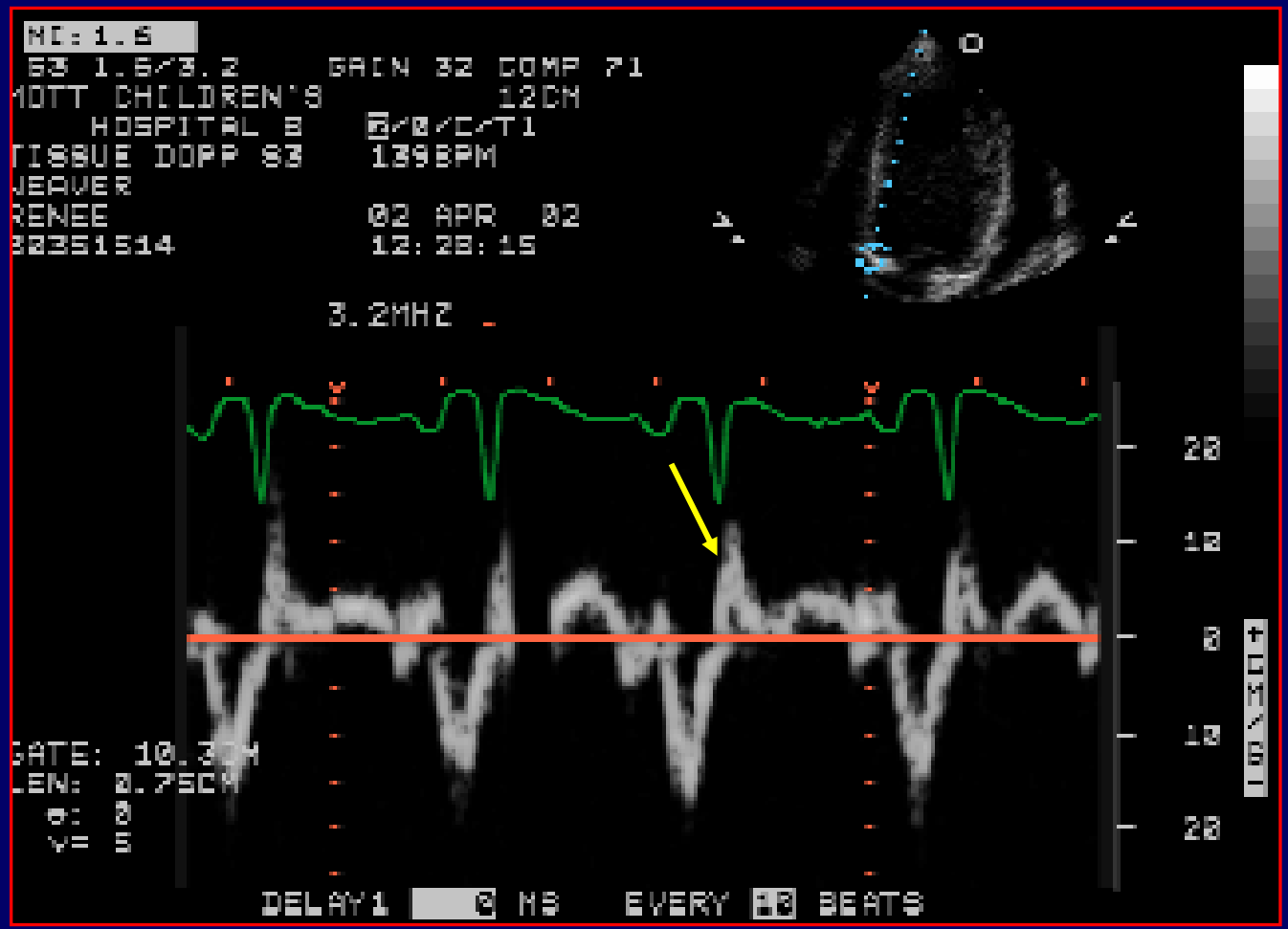
Myocardial Acceleration during Isovolumic Contraction (IVA)





AT : Acceleration time of myocardial velocity during isovolumic contraction
IVV : peak myocardial velocity during isovolumic contraction

Myocardial Acceleration during isovolumic contraction (IVA)



Myocardial Acceleration during isovolumic contraction (IVA)

a new index of right ventricular contractile function

--- unaffected by ventricular shape
or loading conditions

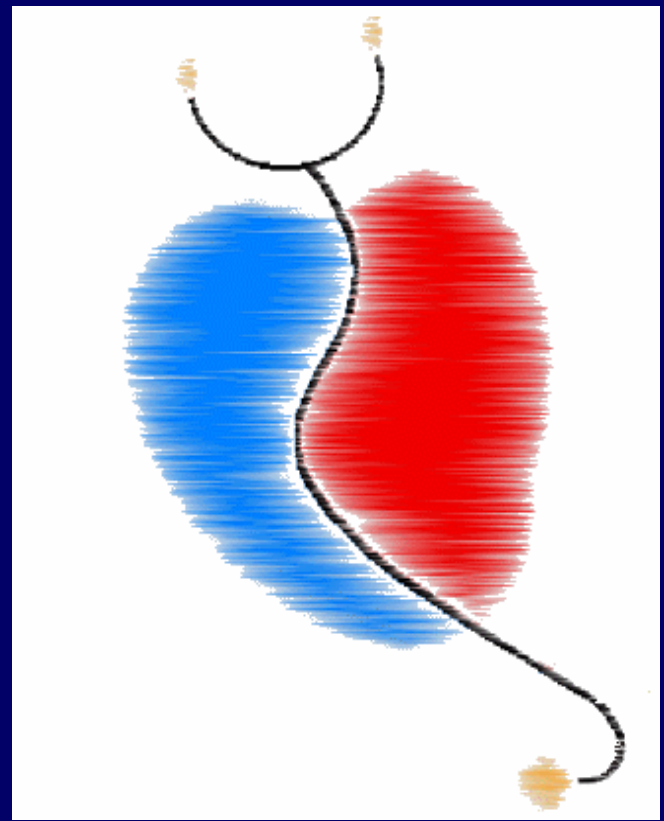
--- assess RV contractile function for patients
with repaired TOF and various degrees of PR

J Am Soc Echocardiogr. 2004 Apr;17(4):332-7.

Clinical Application

Congenital Heart disease
- pre- operative assessment
- post- operative assessment

Acquired Heart disease
- **Myocarditis**
- **Other infection**
- **Kawasaki disease**
- **Diastolic dysfunction**
- **Systolic dysfunction**
- **Heart failure**



*THANK YOU~**