Systolic ventricular function – how to assess the left ventricle

Mark K. Friedberg, MD

Hospital for Sick Children, Toronto

SickKids®
The Labatt Family
Heart Centre

Outline

- What is function
- Methods to assess LV function
  - Global function
  - Hemodynamics
  - Regional function

- Strain/ strain rate and dyssynchrony will be covered in other lectures

Defining cardiac function?

- “ability of the heart to fill at a low enough pressure not to cause pulmonary congestion, then deliver a sufficient quantity of blood to the vasculature at a high enough pressure to perfuse the tissue, and to augment this performance during exercise.”

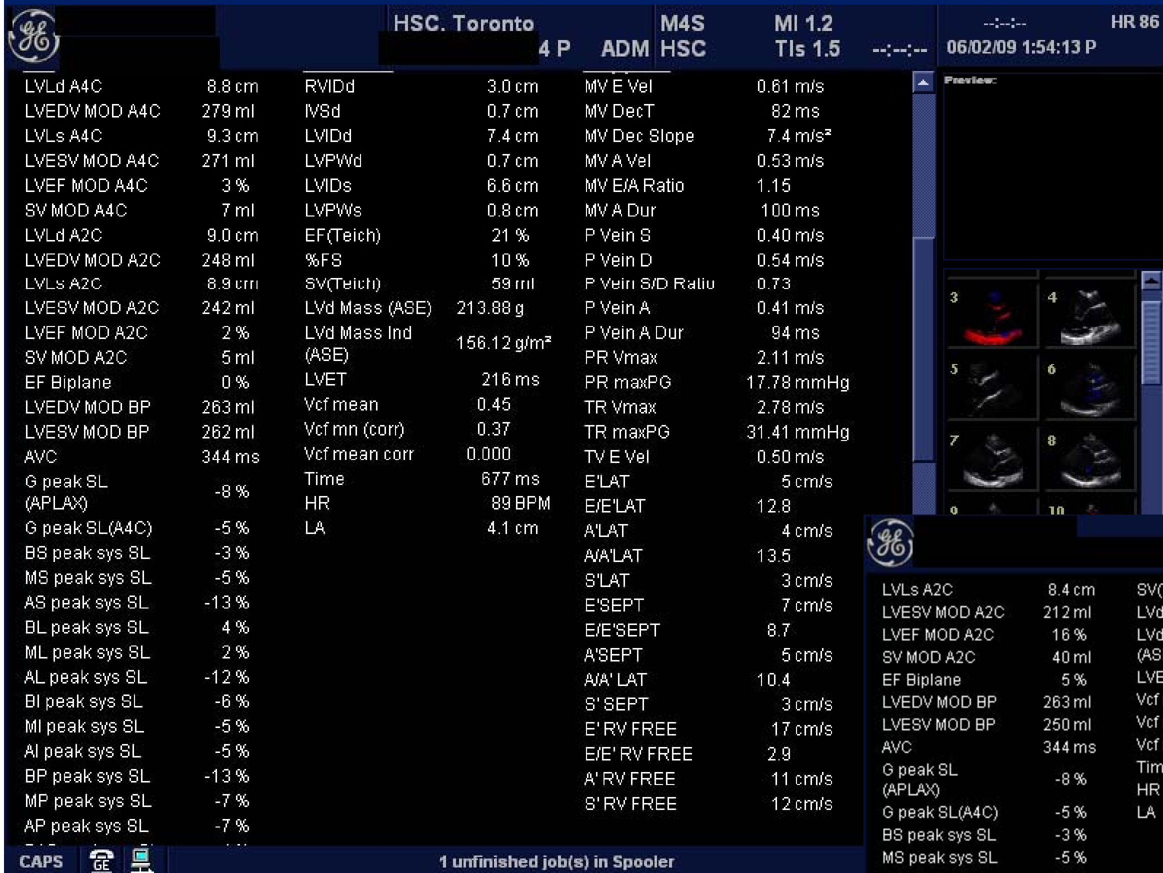
Thomas, JACC 2006;48;2012-2025;

Quantifying function

One of the biggest challenges is deciding how best to quantify cardiac function!

- No measurable quantity corresponds to integrated functional assessment
- Surrogates approximate individual aspects of cardiac function.
- It depends on what question you ask.

A routine echo report (partial list)….



HSC. Toronto [redacted] 4 P ADM M4S HSC MI 1.2 TIs 1.5 --:--:-- 06/02/09 1:54:13 P HR 86

LVLd A4C	8.8 cm	RVIDd	3.0 cm	MV E Vel	0.61 m/s
LVEDV MOD A4C	279 ml	IVSd	0.7 cm	MV DecT	82 ms
LVLs A4C	9.3 cm	LVIDd	7.4 cm	MV Dec Slope	7.4 m/s²
LVESV MOD A4C	271 ml	LVPWd	0.7 cm	MV A Vel	0.53 m/s
LVEF MOD A4C	3 %	LVIDs	6.6 cm	MV E/A Ratio	1.15
SV MOD A4C	7 ml	LVPWs	0.8 cm	MV A Dur	100 ms
LVLd A2C	9.0 cm	EF(Teich)	21 %	P Vein S	0.40 m/s
LVEDV MOD A2C	248 ml	%FS	10 %	P Vein D	0.54 m/s
LVLs A2C	8.9 cm	SV(Teich)	59 ml	P Vein S/D Ratio	0.73
LVESV MOD A2C	242 ml	LVd Mass (ASE)	213.88 g	P Vein A	0.41 m/s
LVEF MOD A2C	2 %	LVd Mass Ind (ASE)	156.12 g/m²	P Vein A Dur	94 ms
SV MOD A2C	5 ml			PR Vmax	2.11 m/s
EF Biplane	0 %	LVET	216 ms	PR maxPG	17.78 mmHg
LVEDV MOD BP	263 ml	Vcf mean	0.45	TR Vmax	2.78 m/s
LVESV MOD BP	262 ml	Vcf mn (corr)	0.37	TR maxPG	31.41 mmHg
AVC	344 ms	Vcf mean corr	0.000	TV E Vel	0.50 m/s
G peak SL (APLAX)	-8 %	Time	677 ms	E'LAT	5 cm/s
		HR	89 BPM	E/E'LAT	12.8
G peak SL(A4C)	-5 %	LA	4.1 cm	A'LAT	4 cm/s
BS peak sys SL	-3 %			A/A'LAT	13.5
MS peak sys SL	-5 %			S'LAT	3 cm/s
AS peak sys SL	-13 %			E'SEPT	7 cm/s
BL peak sys SL	4 %			E/E'SEPT	8.7
ML peak sys SL	2 %			A'SEPT	5 cm/s
AL peak sys SL	-12 %			A/A' LAT	10.4
BI peak sys SL	-6 %			S' SEPT	3 cm/s
MI peak sys SL	-5 %			E' RV FREE	17 cm/s
AI peak sys SL	-5 %			E/E' RV FREE	2.9
BP peak sys SL	-13 %			A' RV FREE	11 cm/s
MP peak sys SL	-7 %			S' RV FREE	12 cm/s
AP peak sys SL	-7 %				

CAPS 1 unfinished job(s) in Spooler

HSC. Toronto [redacted] 9 2:34:22 P ADM M4S HSC MI 1.2 TIs 0.5 --:--:-- 06/02/09 2:34:38 P HR 87

LVLs A2C	8.4 cm	SV(Teich)	59 ml	P Vein D	0.54 m/s
LVESV MOD A2C	212 ml	LVd Mass (ASE)	213.88 g	P Vein S/D Ratio	0.73
LVEF MOD A2C	16 %	LVd Mass Ind (ASE)	156.12 g/m²	P Vein A	0.41 m/s
SV MOD A2C	40 ml			P Vein A Dur	94 ms
EF Biplane	5 %	LVET	216 ms	PR Vmax	2.11 m/s
LVEDV MOD BP	263 ml	Vcf mean	0.45	PR maxPG	17.78 mmHg
LVESV MOD BP	250 ml	Vcf mn (corr)	0.37	TR Vmax	2.78 m/s
AVC	344 ms	Vcf mean corr	0.000	TR maxPG	31.41 mmHg
G peak SL (APLAX)	-8 %	Time	677 ms	TV E Vel	0.50 m/s
		HR	89 BPM	E'LAT	5 cm/s
G peak SL(A4C)	-5 %	LA	4.1 cm	E/E'LAT	12.8
BS peak sys SL	-3 %			A'LAT	4 cm/s
MS peak sys SL	-5 %			A/A'LAT	13.5
AS peak sys SL	-13 %			S'LAT	3 cm/s
BL peak sys SL	4 %			E'SEPT	7 cm/s
ML peak sys SL	2 %			E/E'SEPT	8.7
AL peak sys SL	-12 %			A'SEPT	5 cm/s
BI peak sys SL	-6 %			A/A' LAT	10.4
MI peak sys SL	-5 %			S' SEPT	3 cm/s
AI peak sys SL	-5 %			E' RV FREE	17 cm/s
BP peak sys SL	-13 %			E/E' RV FREE	2.9
MP peak sys SL	-7 %			A' RV FREE	11 cm/s
AP peak sys SL	-7 %			S' RV FREE	12 cm/s
BAS peak sys SL	-4 %			Systolic BP	60.58 mmHg
MAS peak sys SL	-6 %			Wall Stress	142.507 g/cm²
AAS peak sys SL	-10 %			Mean BP	49.29 mmHg
				Wall Stress	115.947 g/cm²

CAPS 1 unfinished job(s) in Spooler Scroll Ptr

Its like asking: what is the state of the global ecomomy?

Real GDP Growth (YoY)

Compare Multiple Indicators
Signup for a Trial

View Indicators for:
Pick Country

WORLD ECONOMY

- World Heatmap
- Exchange Rates
- Stock Market Indexes
- Government Bonds
- Commodity Futures
- Interest Rates
- Inflation Rates
- GDP Growth Rates
- GDP Billions/USD
- Unemployment Rates
- LIBOR Rates
- Indicators Table
- Special Reports
- Economic Calendar
- IMF Data & Forecasts

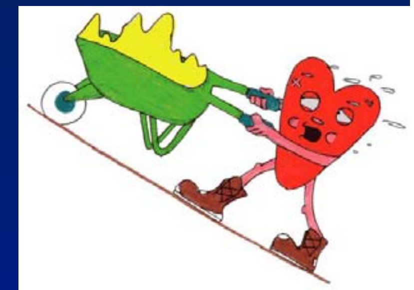
STOCK MARKET INDEXES

Country	Index	Yearly % Chg
Austria	WBI	4.29 %
Belgium	BEL20	9.04 %
Finland	HEX25	23.79 %
France	CAC	2.45 %
Germany	DAX	13.13 %
Greece	ASE	-30.00 %
Ireland	ISEQ	-4.21 %
Italy	MIB30	-39.19 %
Netherlands	AEX	11.69 %
Portugal	PSI20	-3.68 %
Luxembourg	LUXXX	17.38 %
Slovenia	SBITOP	-20.20 %
Spain	IBEX	-1.16 %
United States	INDU	9.63 %
Euro Area	SX5E	0.11 %
Japan	NKY	-12.02 %
United Kingdom	UKX	10.93 %
Canada	SPTSX	9.33 %
Australia	AS51	5.54 %
New Zealand	NZSE50FG	-3.63 %

Assessment of global LV function

- Chamber function
- Hemodynamics
- Myocardial function
- Interactions (ventricular-vascular; ventricular-ventricular)

Function and Performance



AFTERLOAD

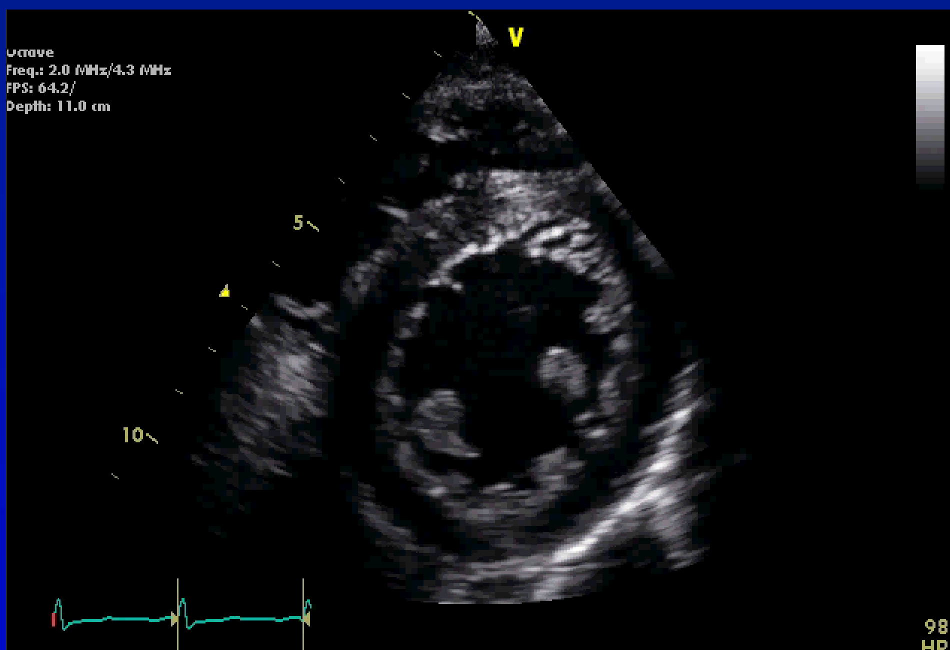
PRELOAD

CONTRACTILITY

Also need to consider…

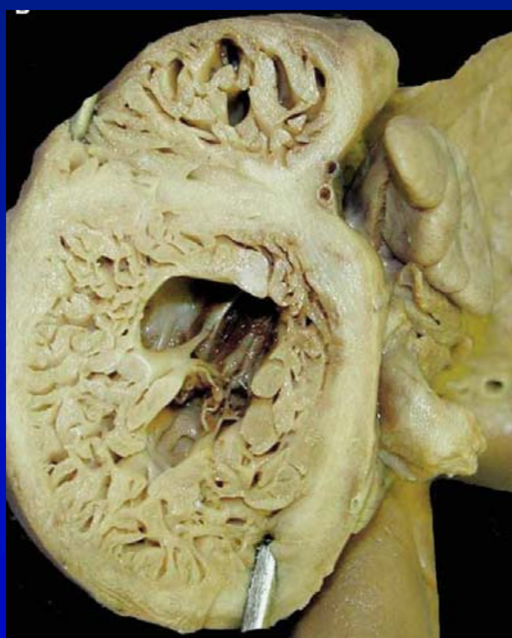
- Acute versus chronic changes
- Adaptation (hypertrophy)
- Heart rate

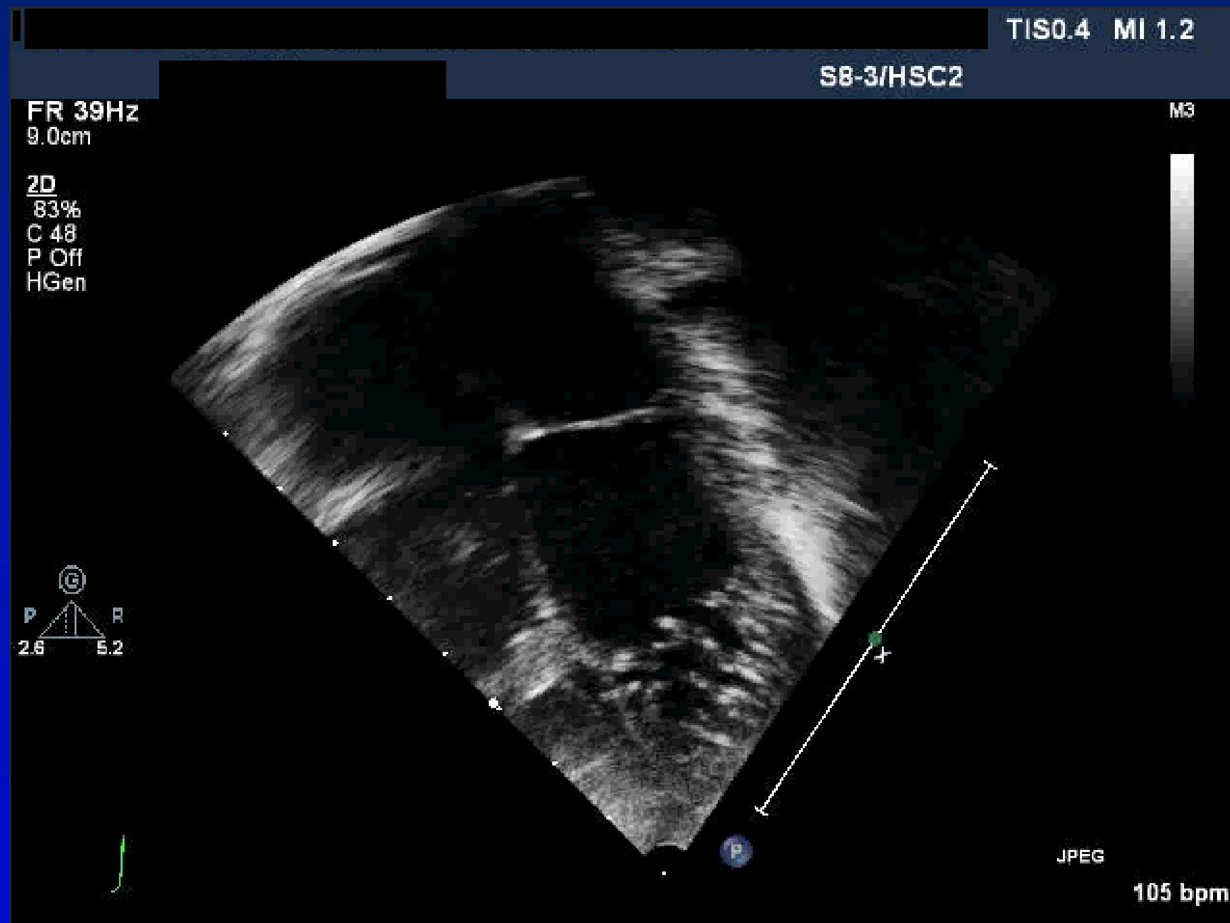
‘Eyeball’ assessment still a prevalent method



Experienced operator
Quick and easy
Subjective
Subtle findings overlooked

Sometimes we can see the abnormality





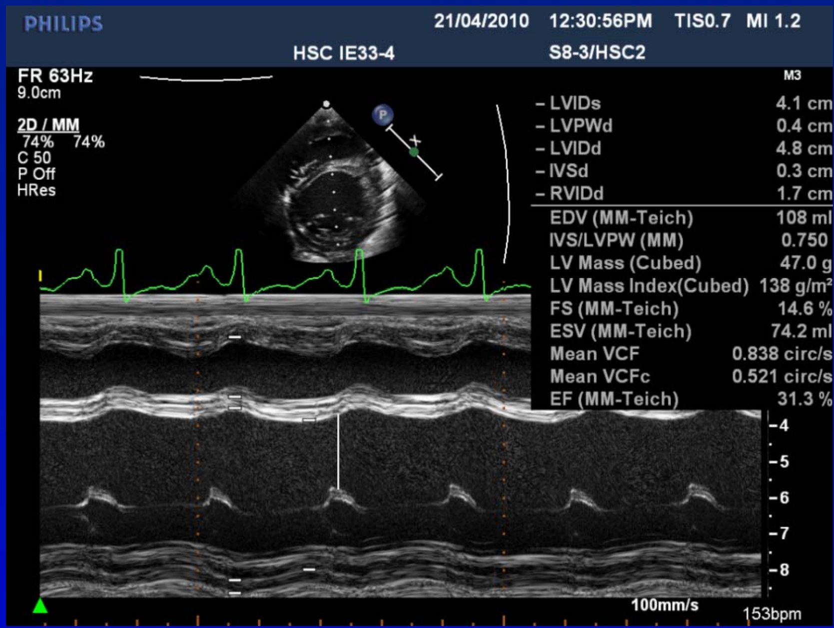
Ejection phase indices

- Most common functional surrogate is the chamber volume ejected in systole:
  - ejection fraction % = EDV - ESV/ EDV x 100
- M-mode
- 2-D
- 3-D

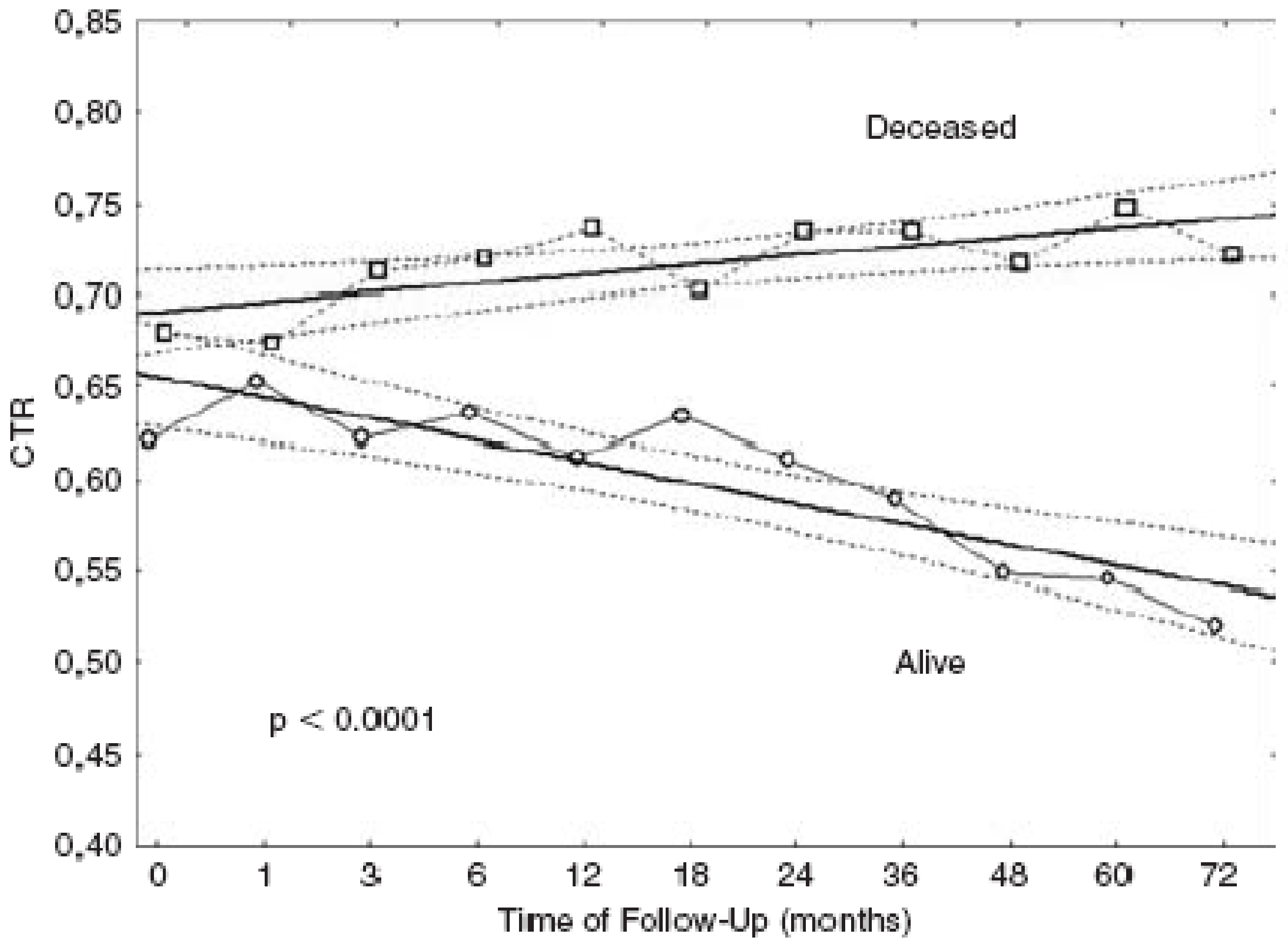
LV volumes themselves are important!

- End systolic volume
- End diastolic volume

- End systolic dimension
- End diastolic dimension

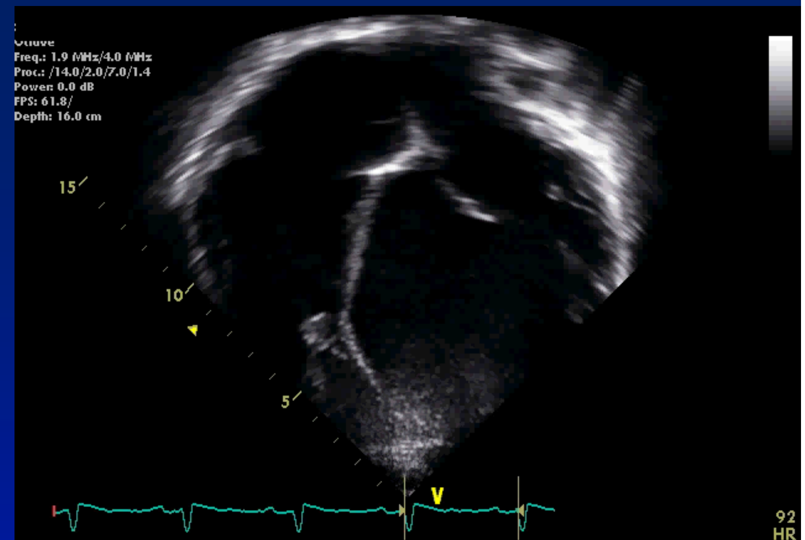


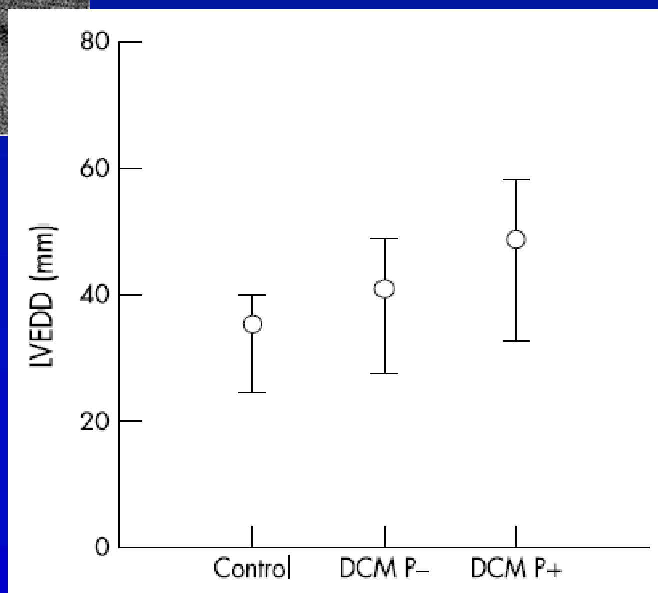
M-mode E point separation

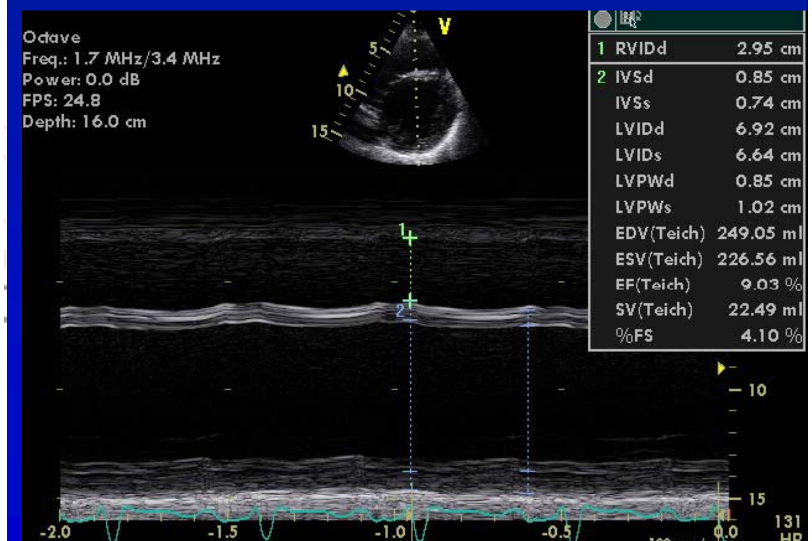


Azvedo, Cardiol Young 2007; 17: 175

Cardiomegaly

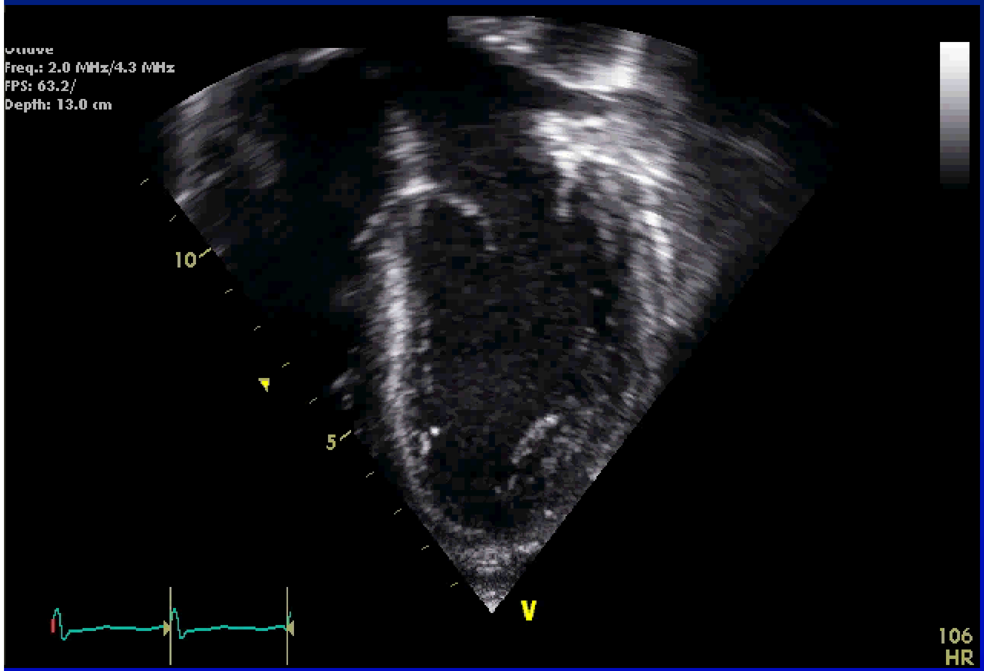


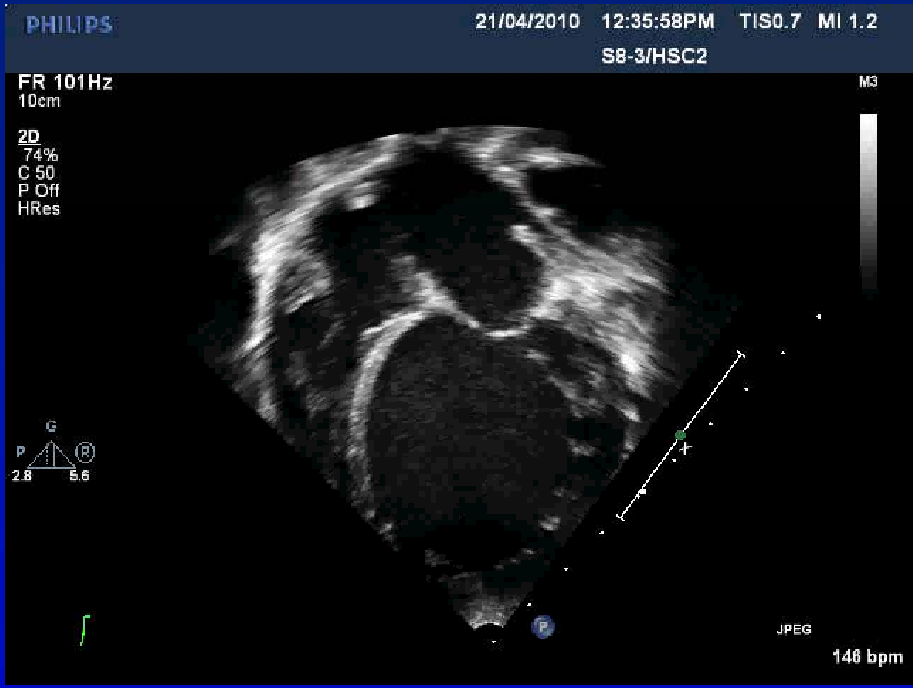




McMahon, Heart 2004;90:908

The shape of the ventricle is important!

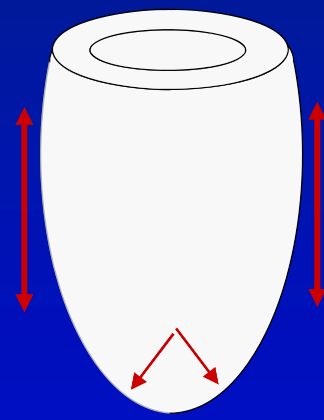




Influence of geometry on function

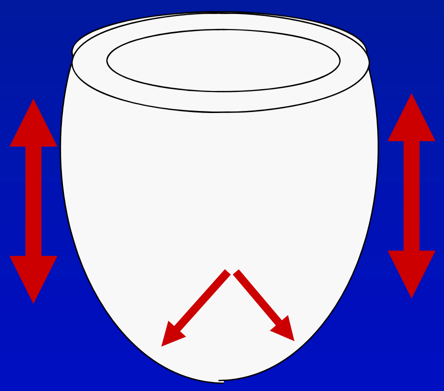
- Ellipsoid is more efficient for ejecting blood compared to sphere
- Remodelling into spherical configuration is mechanically unfavourable

Normal LV



Low stress at apex
Thin apical wall
Long axis shortening ++

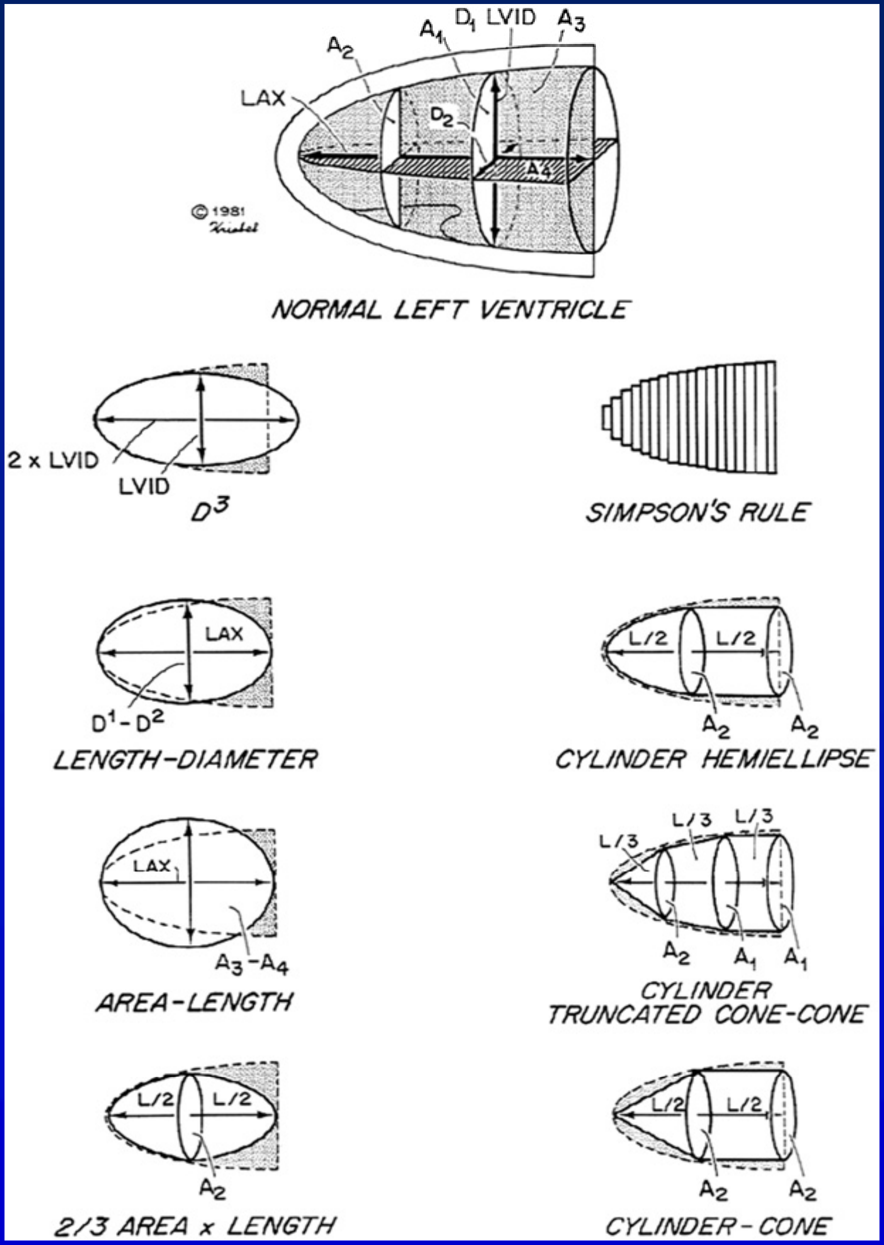
Remodeled LV(increased pressure)

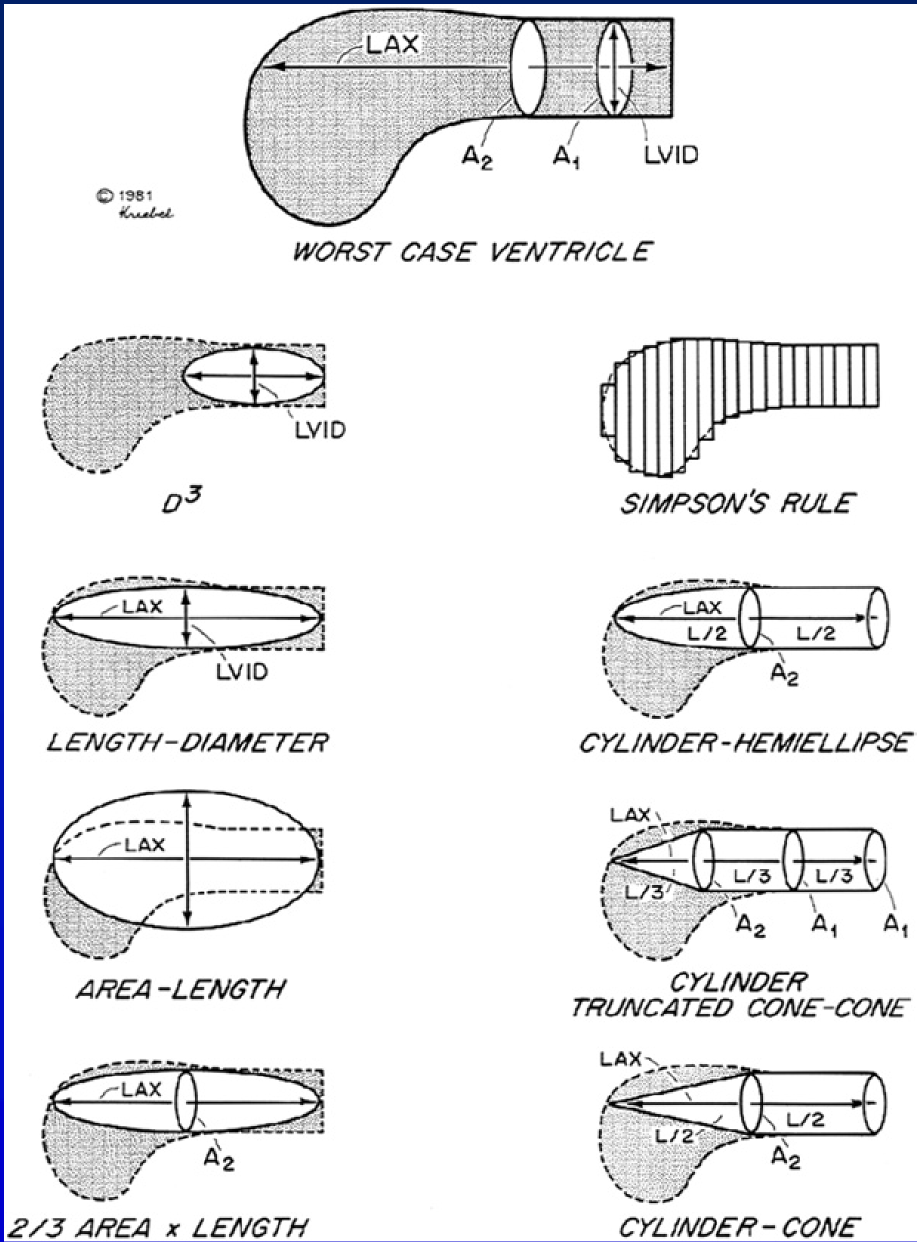


High stress at apex
Thick apical wall
Long axis shortening -

Slide courtesy of Luc Mertens, MD

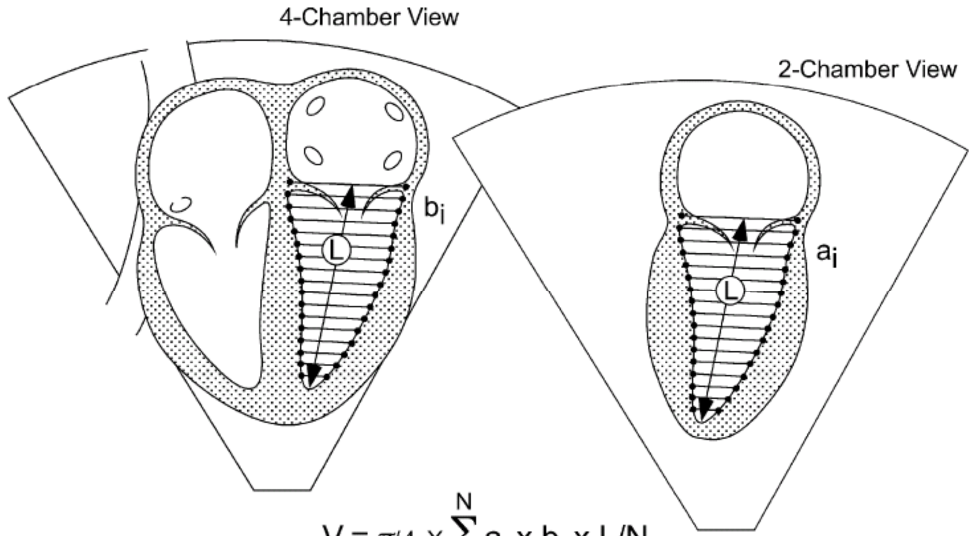
Geometrical assumptions



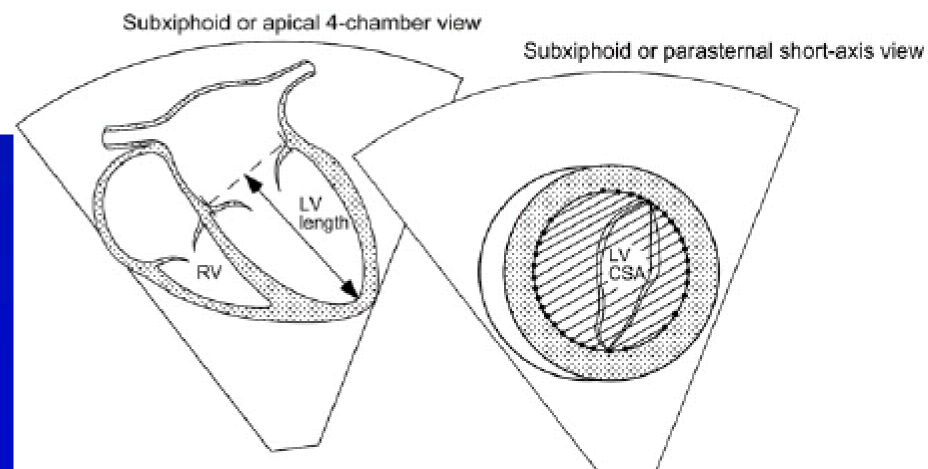


Picard, JASE, 2008

EF by Simpsons method and area length - method



$$V = \pi/4 \times \sum_{i=1}^{N} a_i \times b_i \times L/N$$

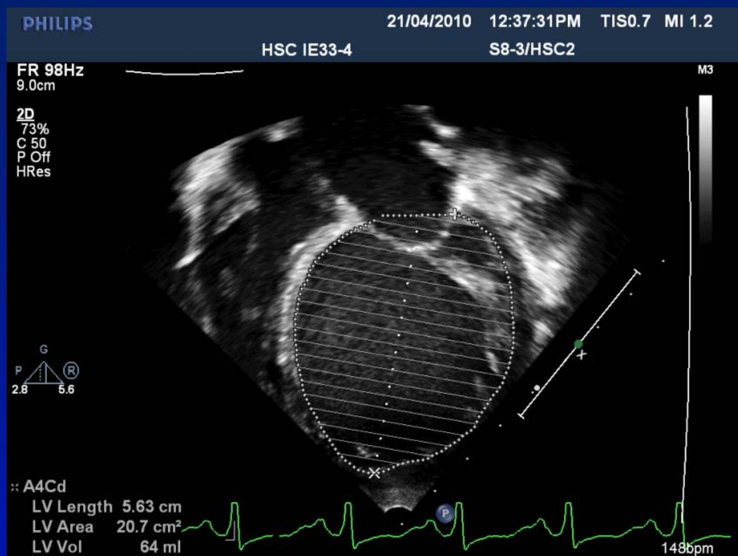


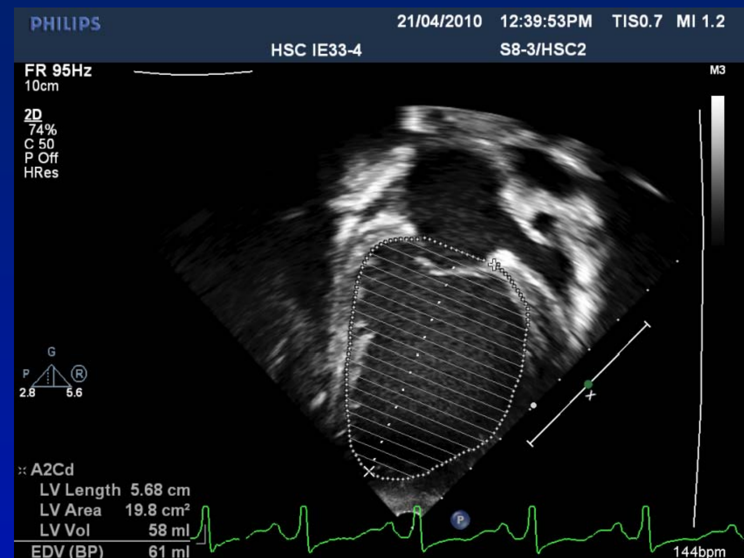
A

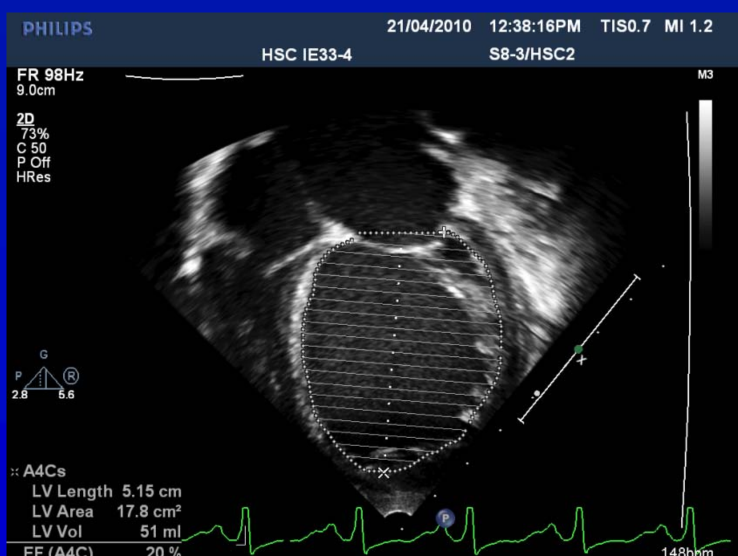
$$V = 5/6 \times CSA \times Length$$

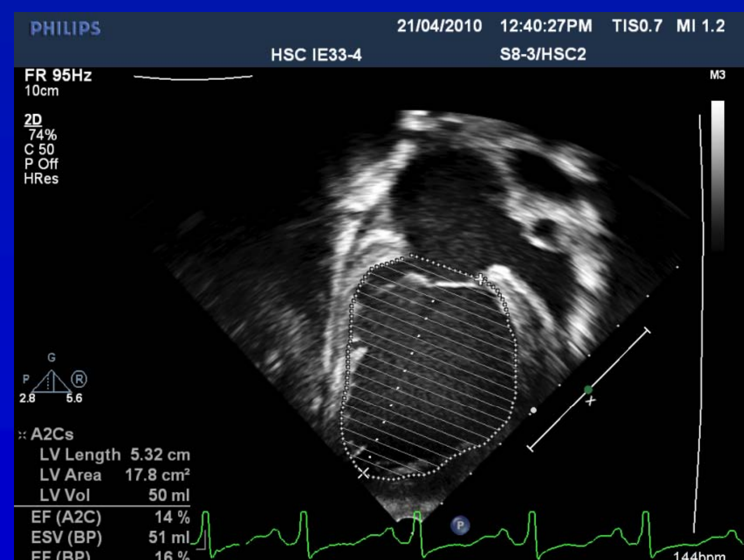
Lopez, JASE 2010;23:465

Volumes and EF by biplane Simpson's

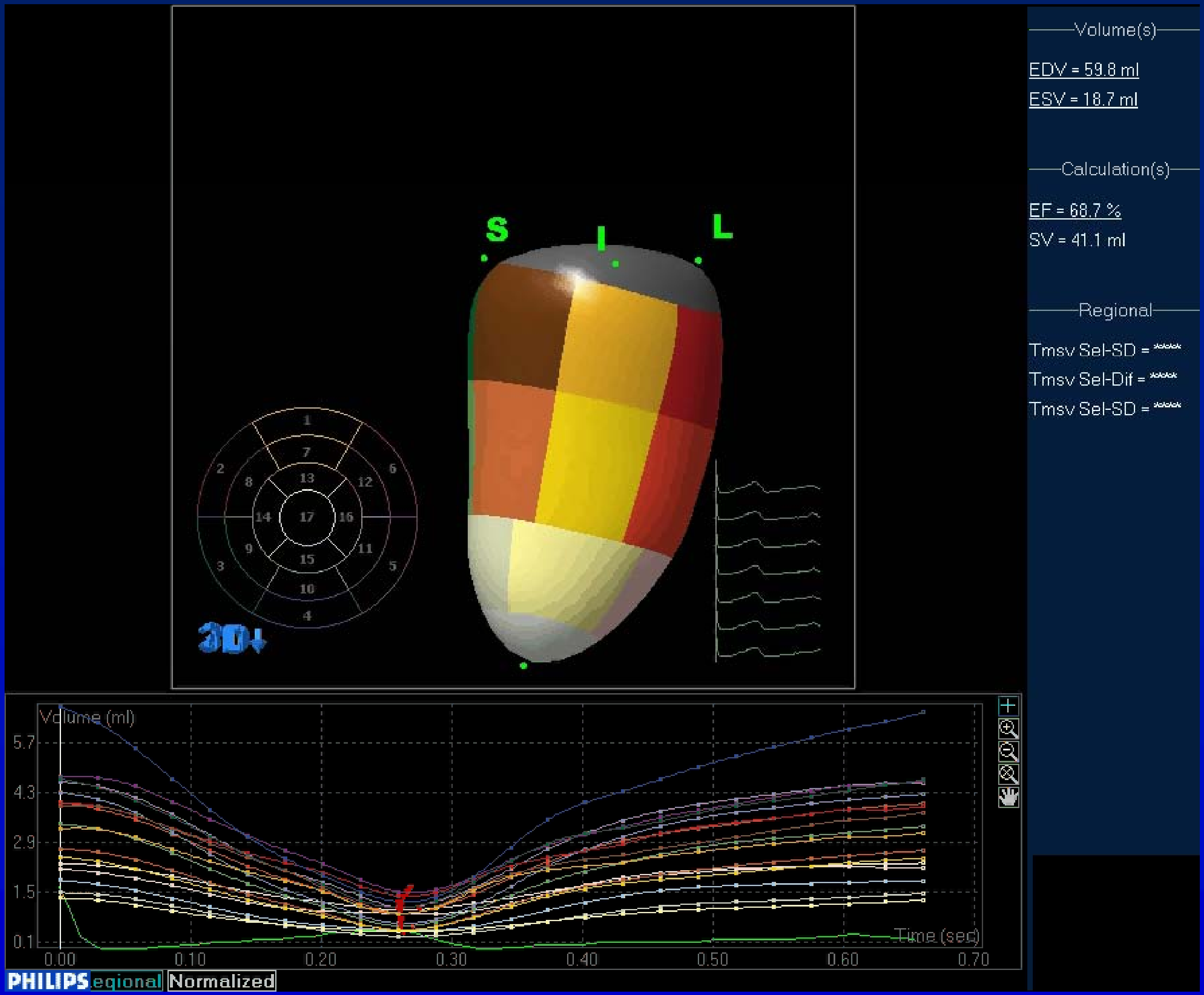




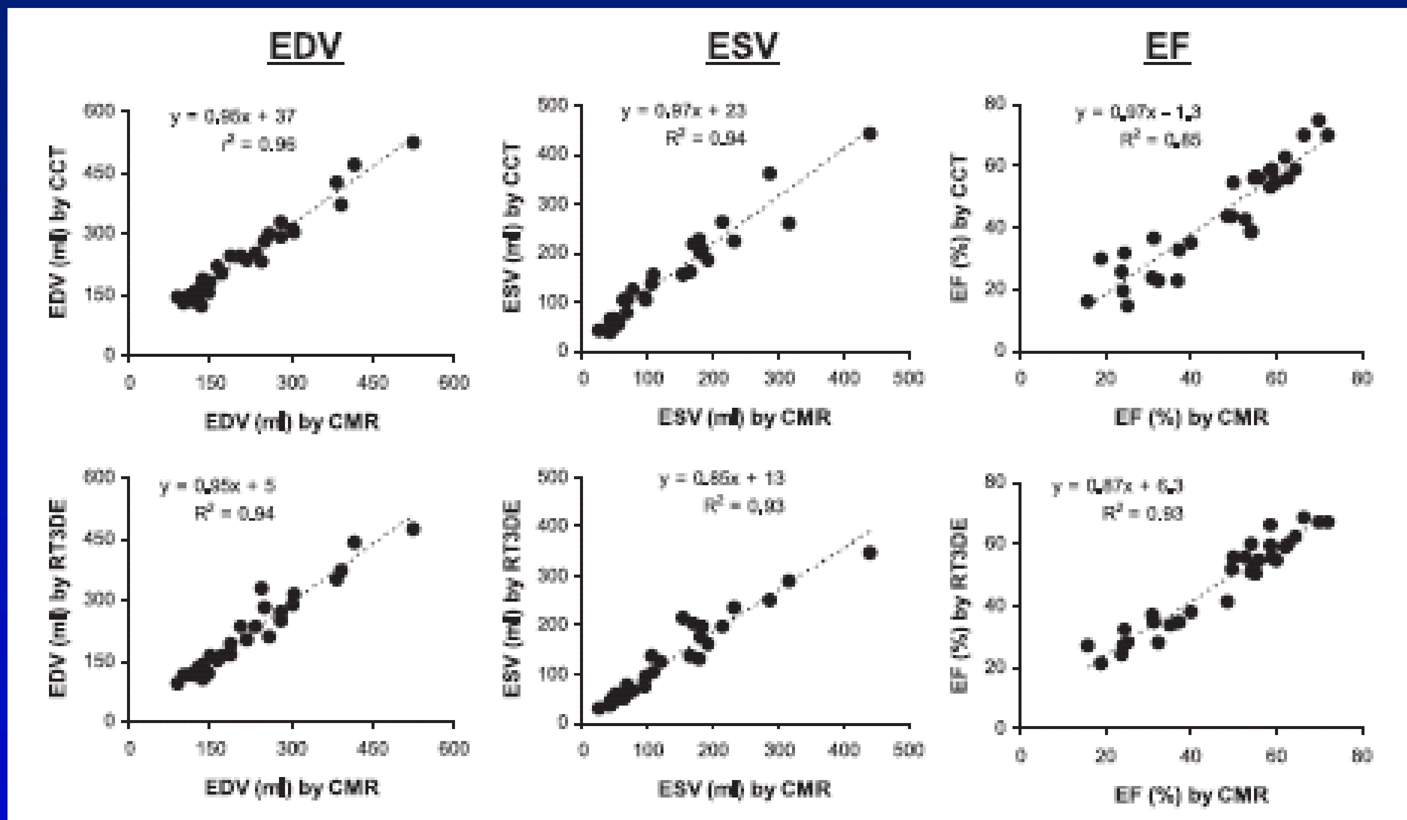




Ejection fraction by 3-D



3D volume measurements are comparable to MRI



Sugeng, Circ. 2006;114:654

M-mode/ 2D/ 3D vs MRI in children

Table II. Correlation between MM, 2DE, 3DE, and CMR for measurements of LV indices

	LVEDV			LVESV			LVEF			LV mass		
	r	SEE	*P*	*r*	SEE	*P*	*r*	SEE	*P*	*r*	SEE	*P*
MM	0.87	15.28	<.001	0.90	6.75	<.001	0.81	8.92	<.001	0.89	1.67	<.001
2D biplane	0.89	12.11	<.001	0.90	5.88	<.001	0.83	6.87	<.001	0.92	1.10	<.001
3D (4-plane)	0.96	10.30	<.001	0.95	3.83	<.001	0.85	5.48	<.001	0.96	0.56	<.001
3D (8-plane)	0.97	9.36	<.001	0.97	3.36	<.001	0.86	5.33	<.001	0.97	0.47	<.001
3D (auto)	0.96	9.25	<.001	0.93	3.52	<.001	0.88	5.45	<.001	0.98	0.48	<.001

SEE, Standard estimation error.

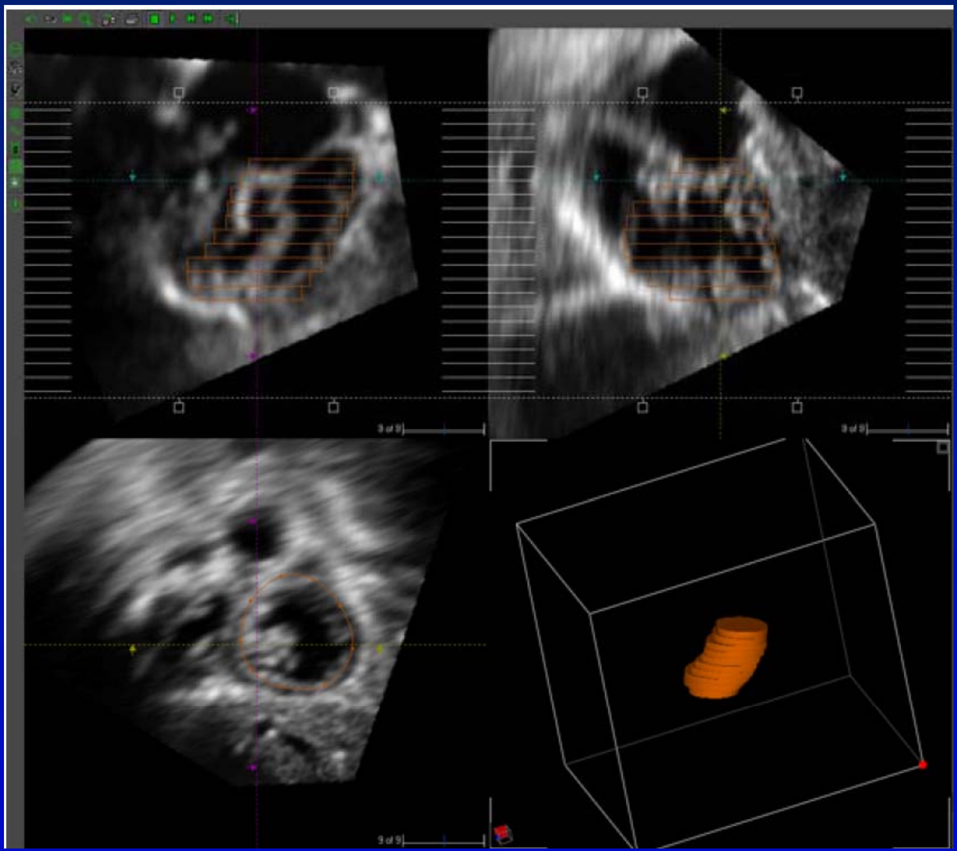
Table III. Agreement between MM, 2DE, 3DE, and CMR for measurements of LV indices

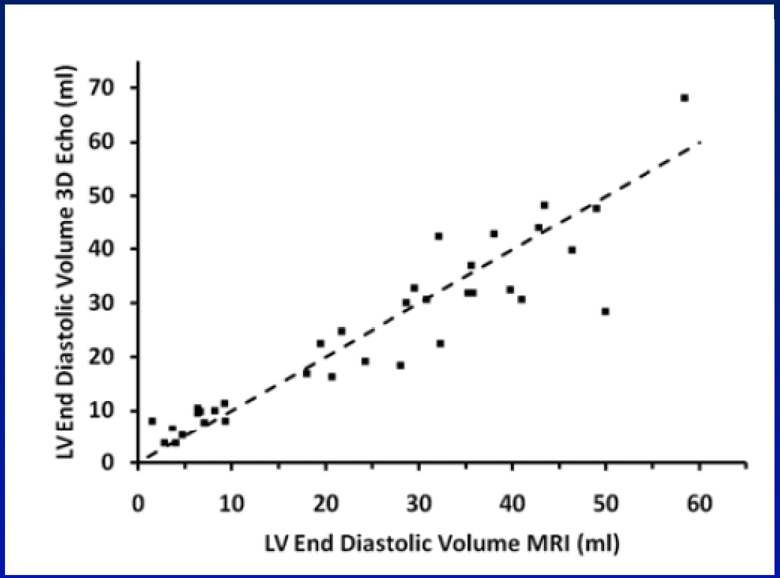
	LVEDV		LVESV		LVEF		LV mass	
	MD	*P*	MD	*P*	MD	*P*	MD	*P*
MM	4.78 ± 14.14	*P* = .07	2.4 ± 6.5	*P* = .13	-2.32 ± 4.55	*P* = .14	3.2 ± 13.21	*P* = .07
2D biplane	-7.87 ± 12.11	*P* < .05	-2.2 ± 4.8	*P* = .15	-1.87 ± 3.50	*P* = .35	2.8 ± 12.51	*P* = .11
3D (4-plane)	-6.88 ± 10.01	*P* < .05	-2.4 ± 3.45	*P* = .13	-1.45 ± 3.30	*P* = .30	1.1 ± 11.28	*P* = .17
3D (8-plane)	-6.83 ± 9.66	*P* < .05	-1.84 ± 3.29	*P* = .17	-0.45 ± 2.17	*P* = .42	1.58 ± 10.38	*P* = .25
3D (auto)	-6.93 ± 9.71	*P* < .05	-1.6 ± 3.87	*P* = .31	-1.55 ± 2.81	*P* = .28	0.8 ± 11.30	*P* = .38

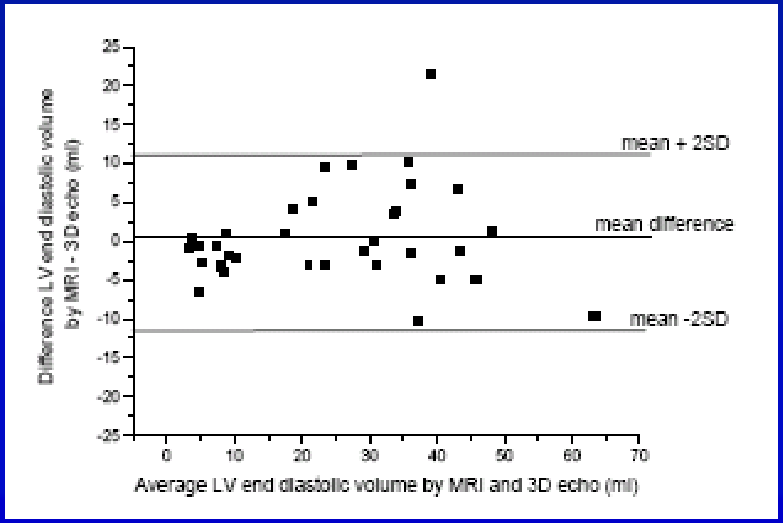
MD, Mean difference.

Ge, AHJ 2008;155:946

3D summation of discs in small LVs and CHD







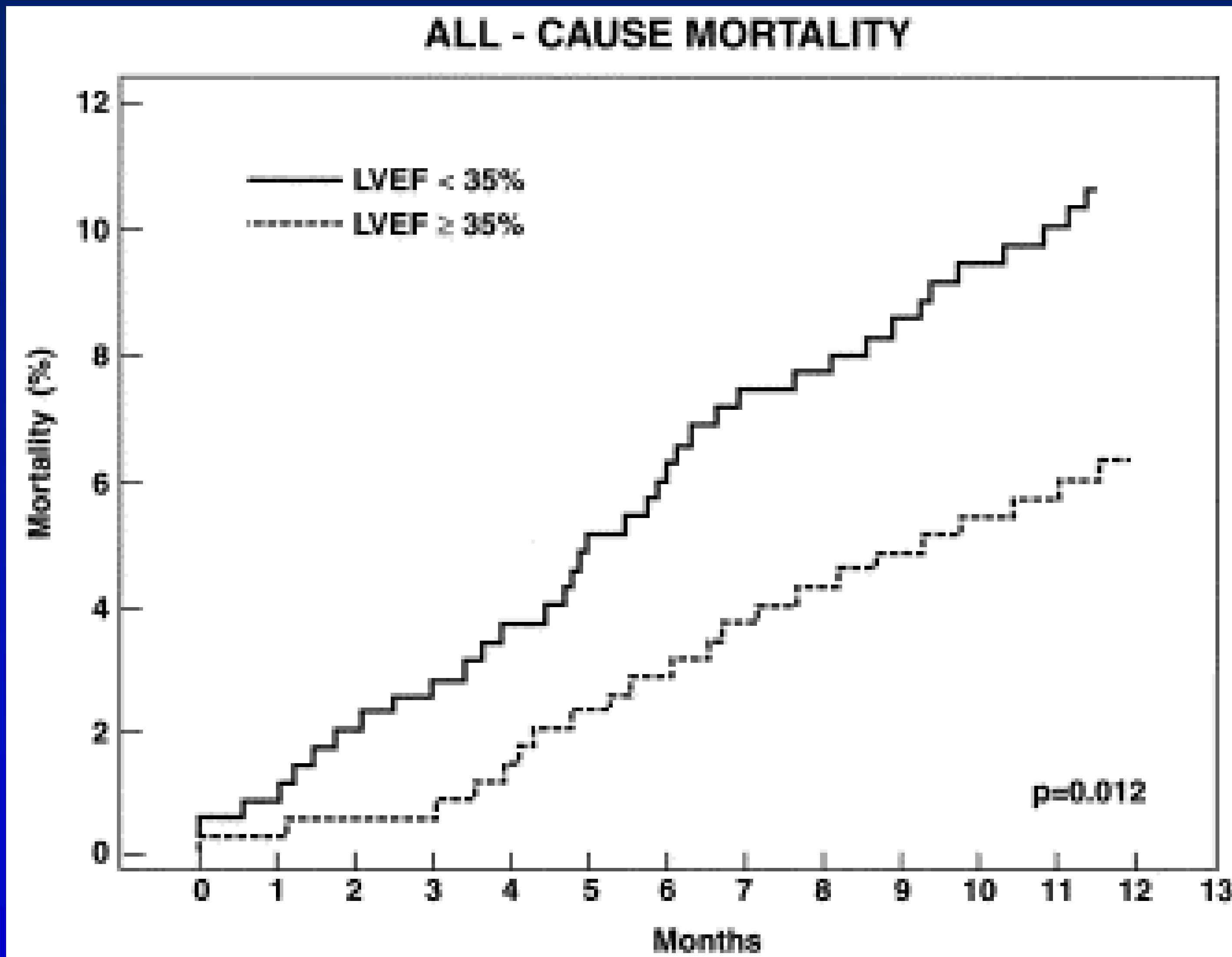
Friedberg, Circ Cardiovasc Imaging. 2010 Sep 20.

Ejection fraction limitations

- Technique limitations
  - Visualization of endocardial borders (contrast)
  - LV is 3-dimensional; most models for calculation based on 2 dimensions (3D echo)

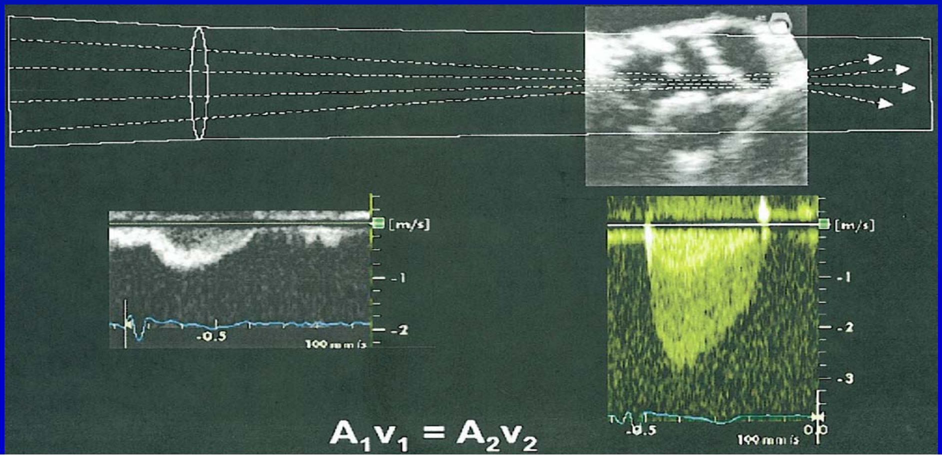
- Physiologic limitations
  - Preload dependency
  - Afterload dependency
  - Heart rate

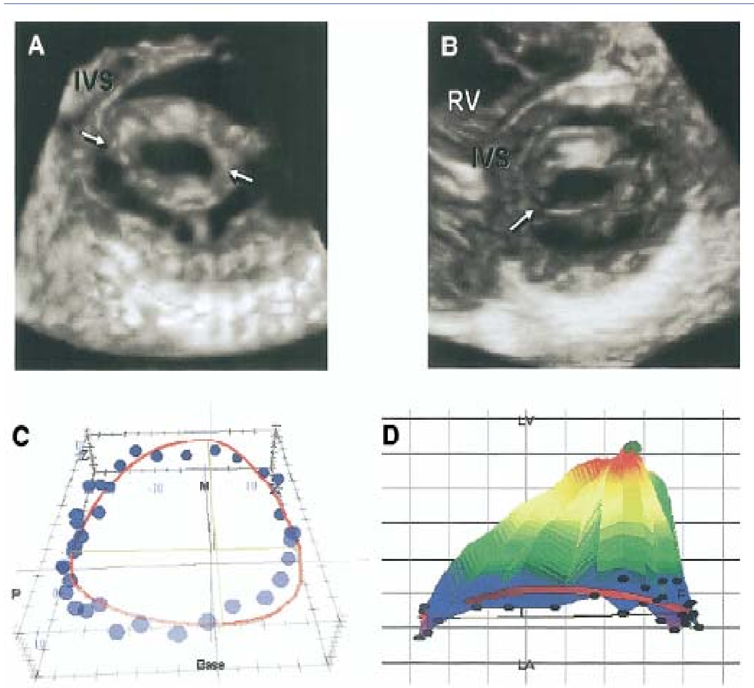
Why do we still use EF?

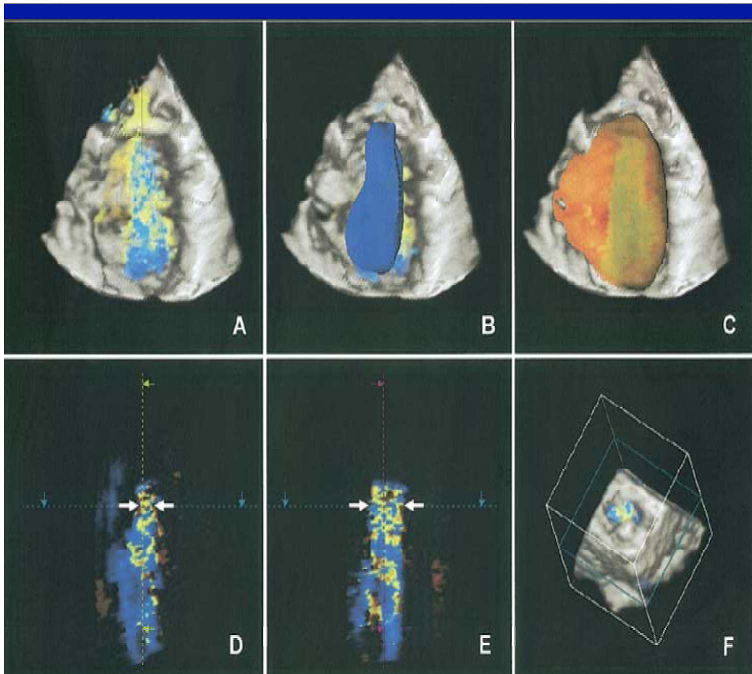


Hemodynamics

- Blood flow is governed by conservation of:
  - Mass
  - Momentum
  - Energy.
- Blood is incompressible:
  - flow into a region = flow out of that region
  - continuity equation for measuring stroke volume & cardiac output.







Lang, JACC 2006; 48:2053– 69

Mitral Valve Function

Functional MR is common and associated with outcome

New interventional devices and CRT to control LV remodeling increase importance of MR assessment.

Evaluate severity and mechanism.

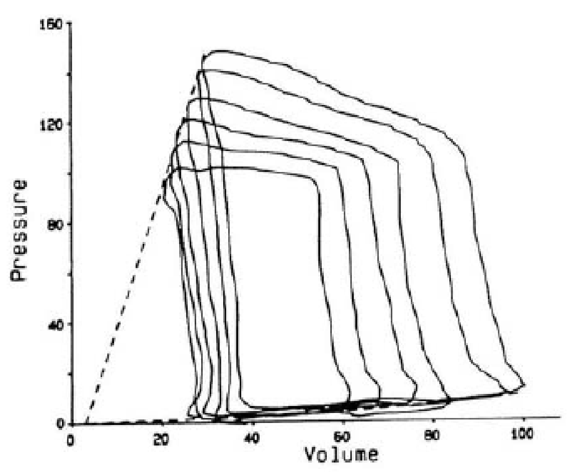
Functional MR severity is difficult to assess (change during systole; variability, complex jet morphology).

Most severe in early systole. Reduced as LV volume decreases and MV leaflets are pushed back to annular plane.

Volumetric methods may be useful to

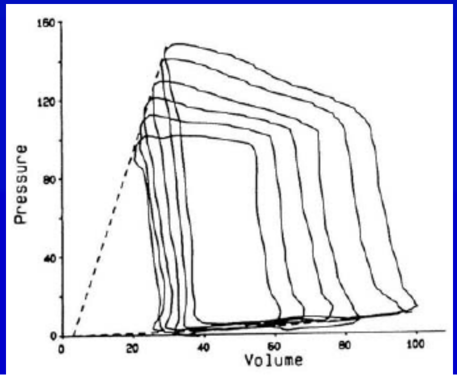
Assessment of myocardial contractility

- continuous acquisition of ventricular pressure and volume data during sudden preload change.
- end-systolic elastance and preload recruitable stroke work most popular.



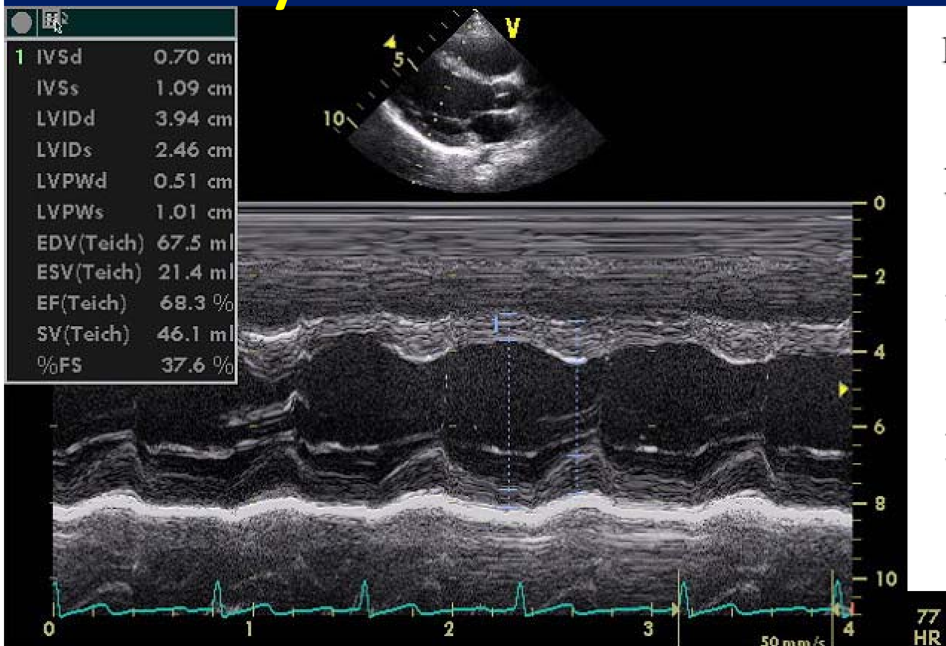
Assessment of myocardial 'global' contractility

- Many studies have investigated non-invasive estimates of contractility without need for preload intervention.
- end-systolic elastance (from single beat)- complex combination of non-invasive BP, diastolic and systolic LV volumes, pre-ejection and ejection times, and EF.
- LV power (peak systolic flow x pressure/(EDV)^2
  - *later work suggested that this type of correction is inadequate*.



Kass DA, Circulation 1991;84:1698 –708.
Nakayama M, Am Heart J 1998;136:281– 8.
Segers P, Am J Physiol Heart Circ Physiol 2003;284:H2295
Chen CH, JACC 2001;38:2028 –34.

Myocardial contractility from M-mode?

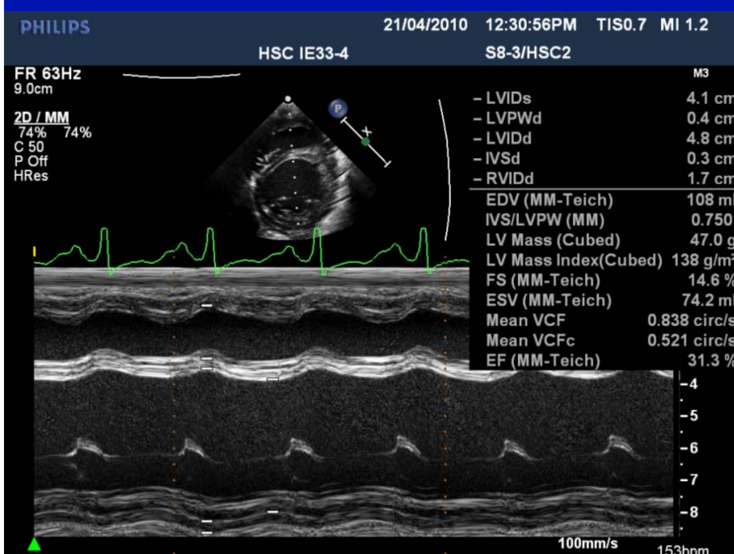


$$EDV = EDVd^3;$$

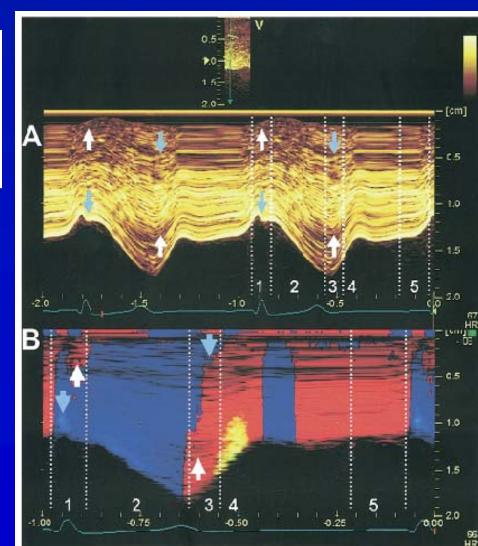
$$ESV = LVIDs^3;$$

$$EF = (EDV - ESV)/EDV \times 100\%;$$

$$\text{LV mass (in grams)} = 0.8^*[1.04\{(PWTd + LVIDd + SWTd)^3 - LVID^3\}] + 0.6.$$



$$SF = 100\frac{EDD - ESD}{EDD}$$



Sengupta, JACC, 2006;48:1988 –2001

Myocardial contractility from M-mode?

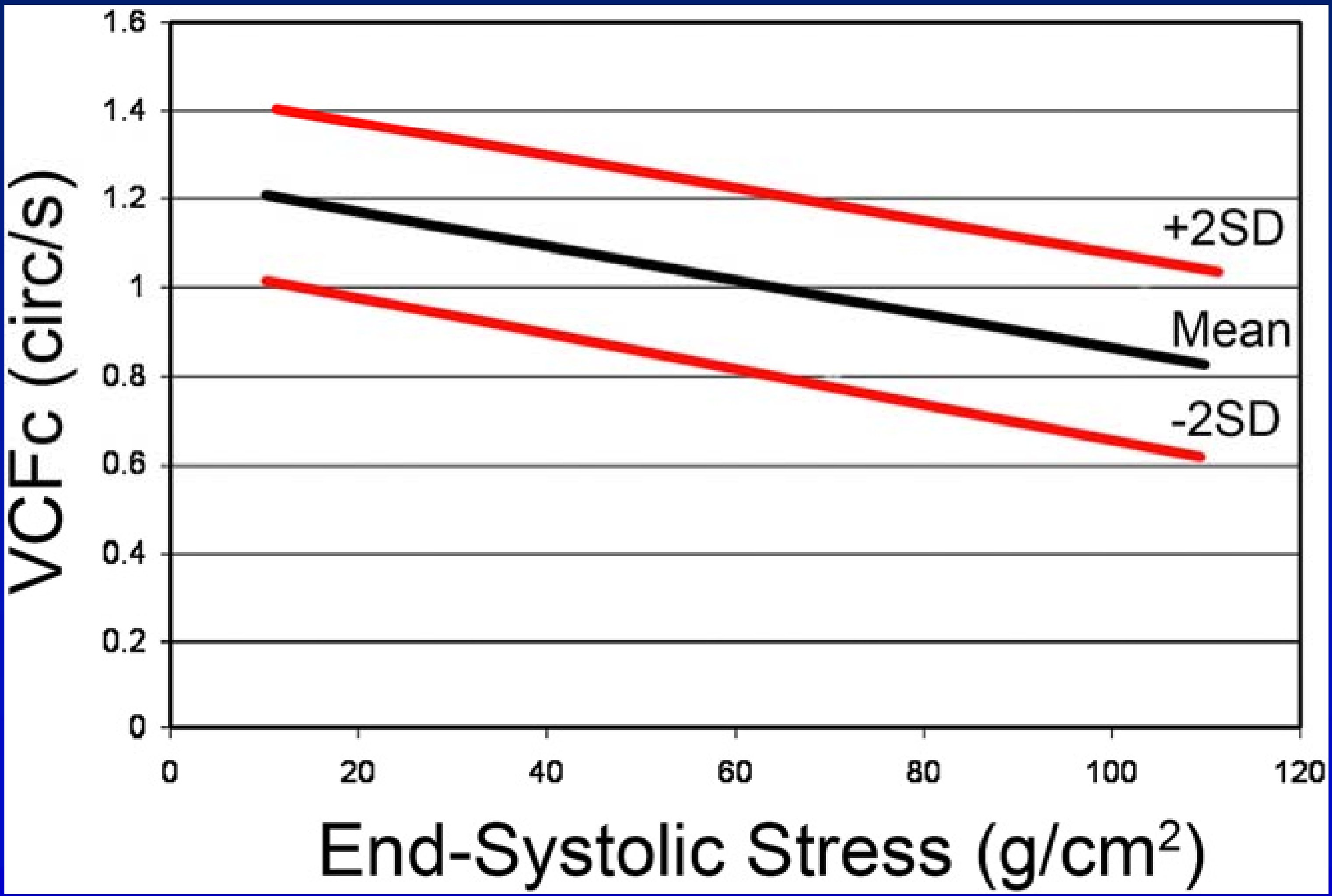
- Corrected Velocity Circumferential Fiber Shortening (VCFc) = shortening fraction / heart rate-adjusted ejection time

$$ET_C = \frac{\text{ejection time}}{\sqrt{\text{ECG R-R interval}}}$$

- VCFc is evaluated in relation to afterload (end-systolic wall stress):

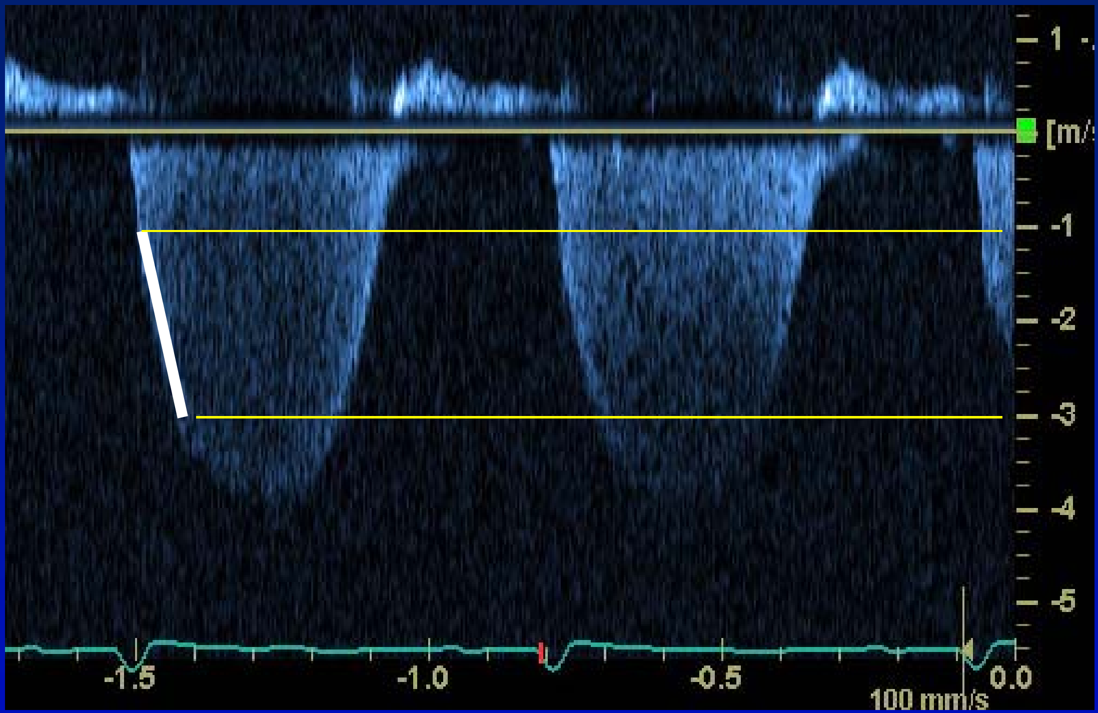
$$ESWS = \frac{1.35 D_{ES} \, P_{ES}}{4h\left[1 + \frac{h}{D_{ES}}\right]}$$

VCFc-wall stress relation



Lopez, JASE 2010, adapted from Colan

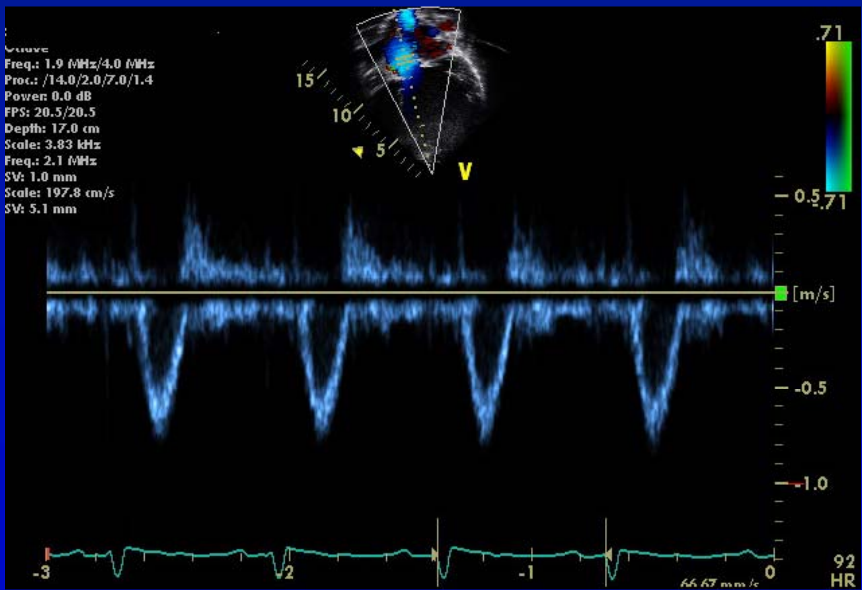
Echo Doppler measures that correlate with contractility: dP/ dT from mitral regurgitation

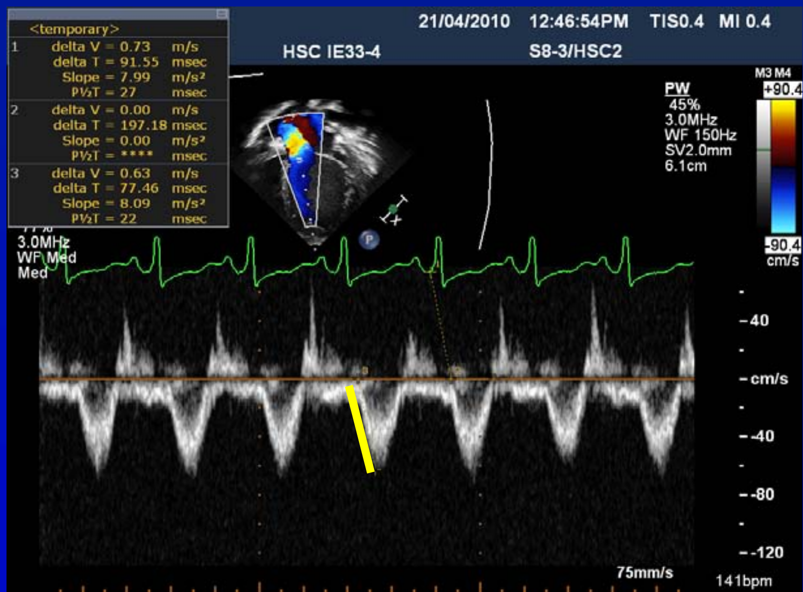


- Sensitive to loading conditions
- Measurements of slope are very variable

Doppler measures that correlate with contractility

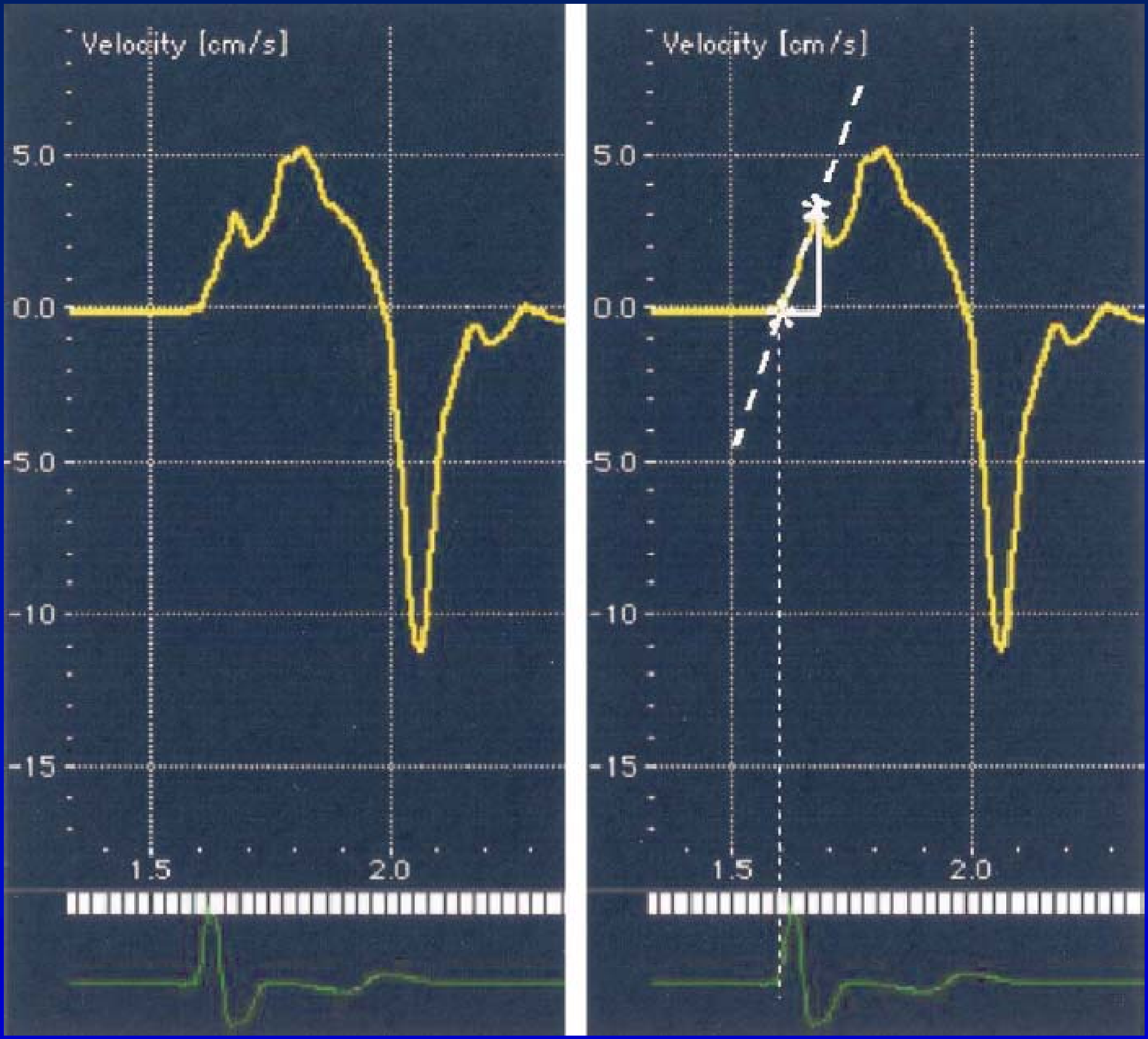
- systolic velocity acceleration in the LVOT
- early systolic intraventricular pressure drop along LVOT
- Isovolumic acceleration
- systolic strain rate



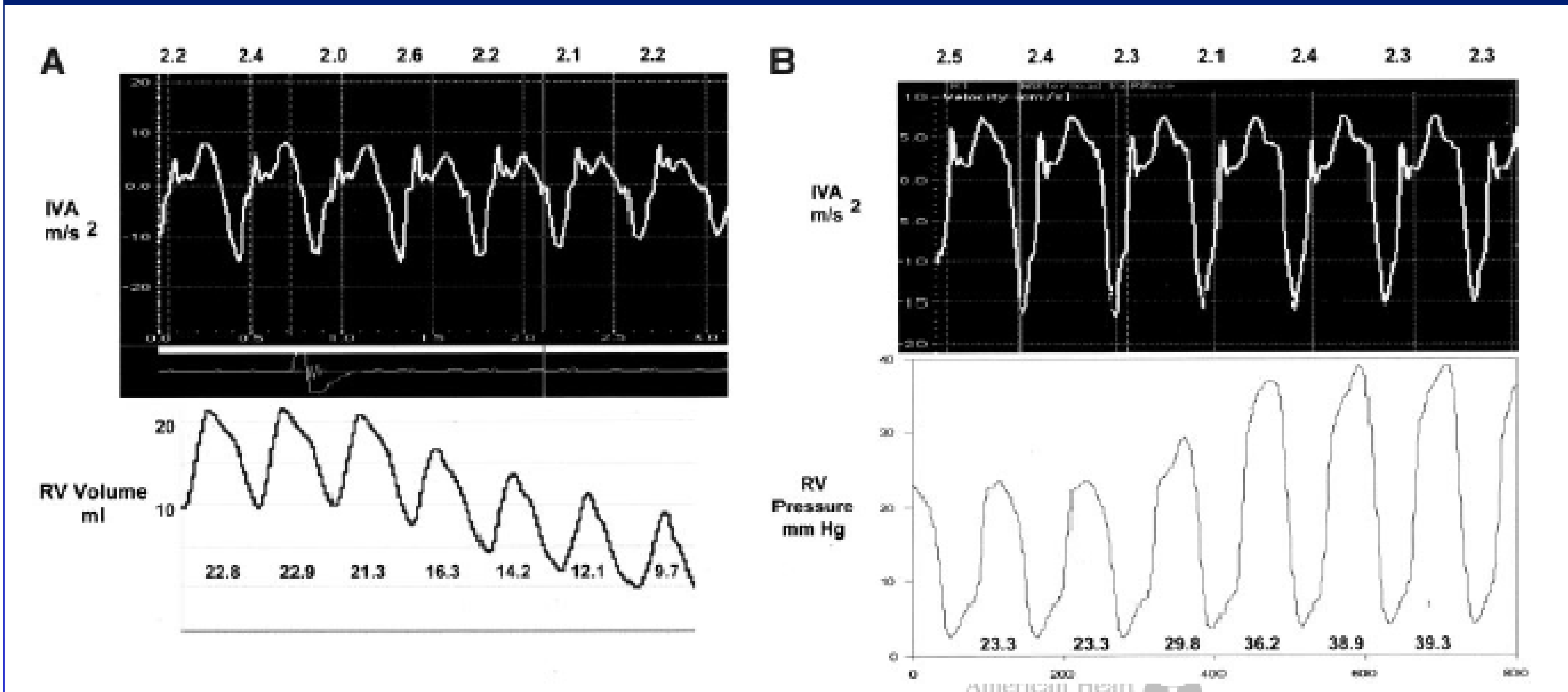


Bauer F,. JACC 2002; 40:1320 –7.
Greenberg NL, Circulation 2002;105:99.
Yotti R, Circulation 2005;112:1771–9.

Isovolumic acceleration



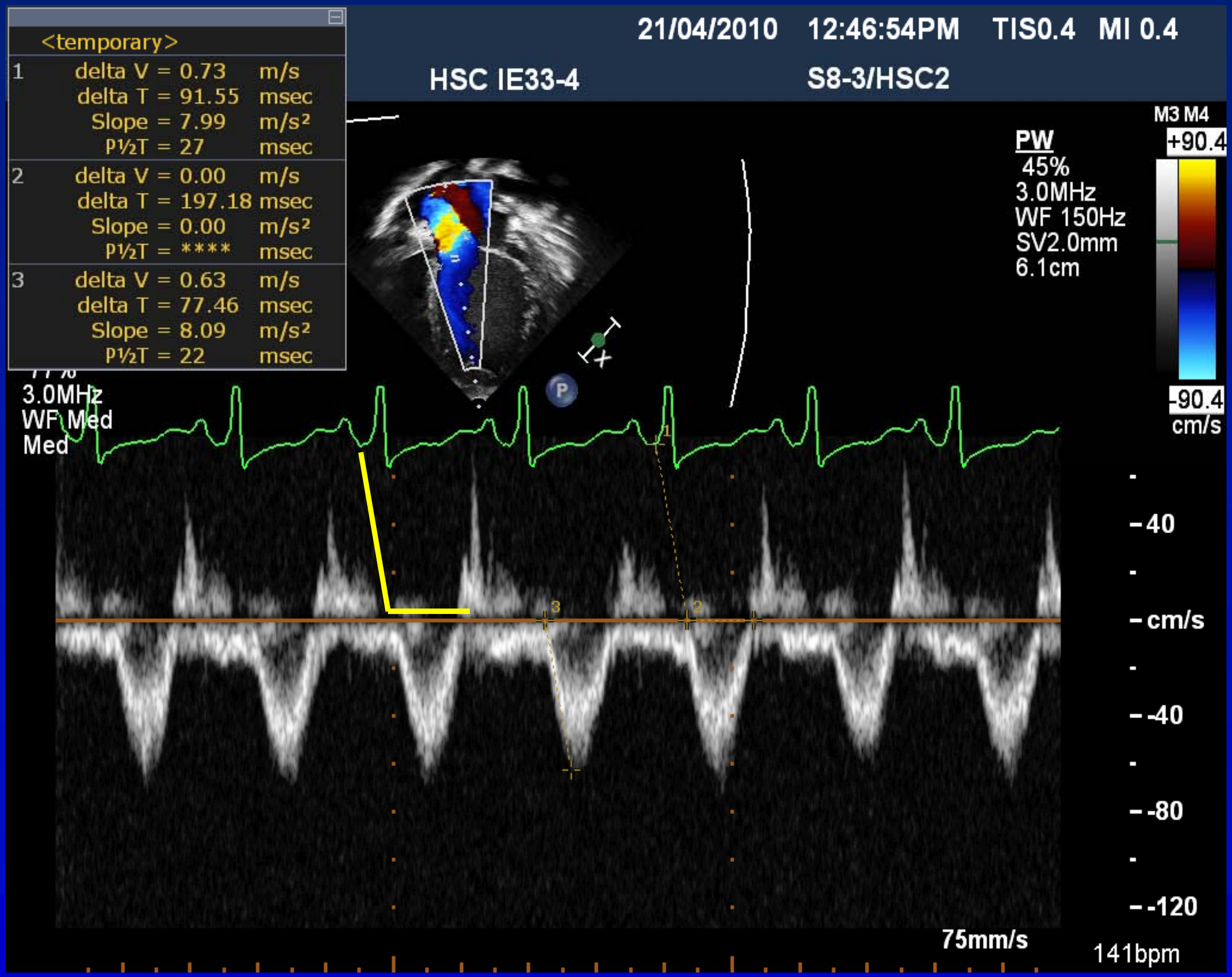
Isovolumic acceleration is relatively load independent



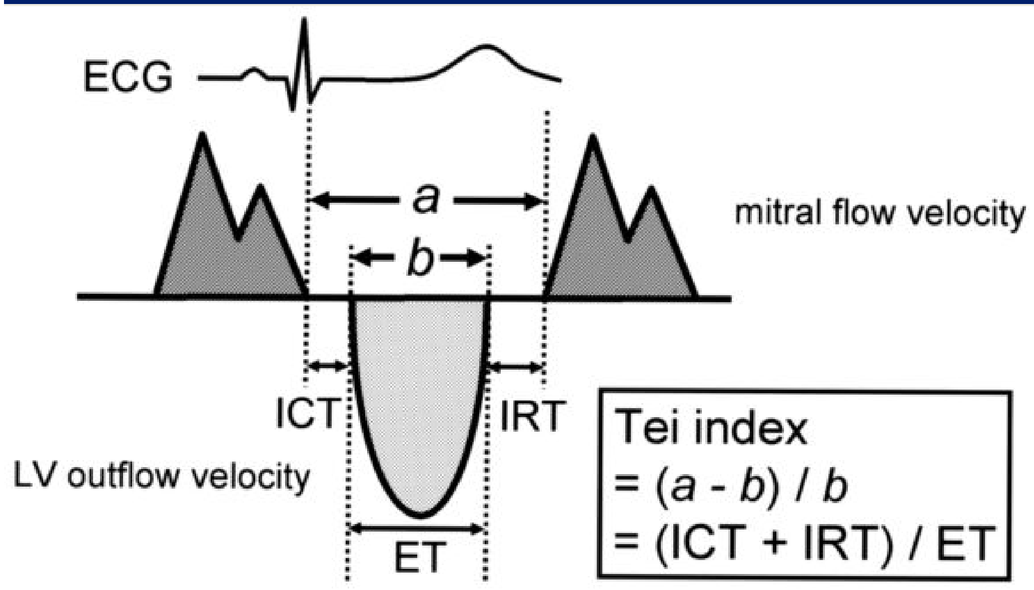
Vogel, Circ 2002;105:1693

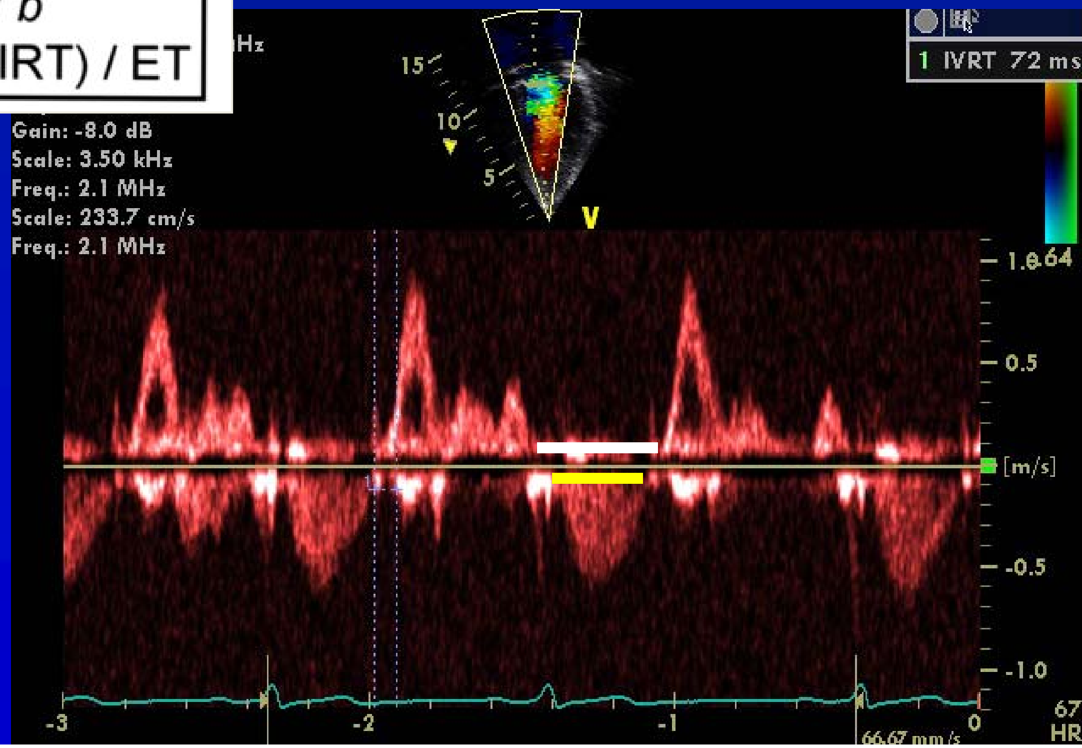
Other Doppler Indices

- Systolic time intervals



The myocardial performance index





MPI as contractility parameter is debatable

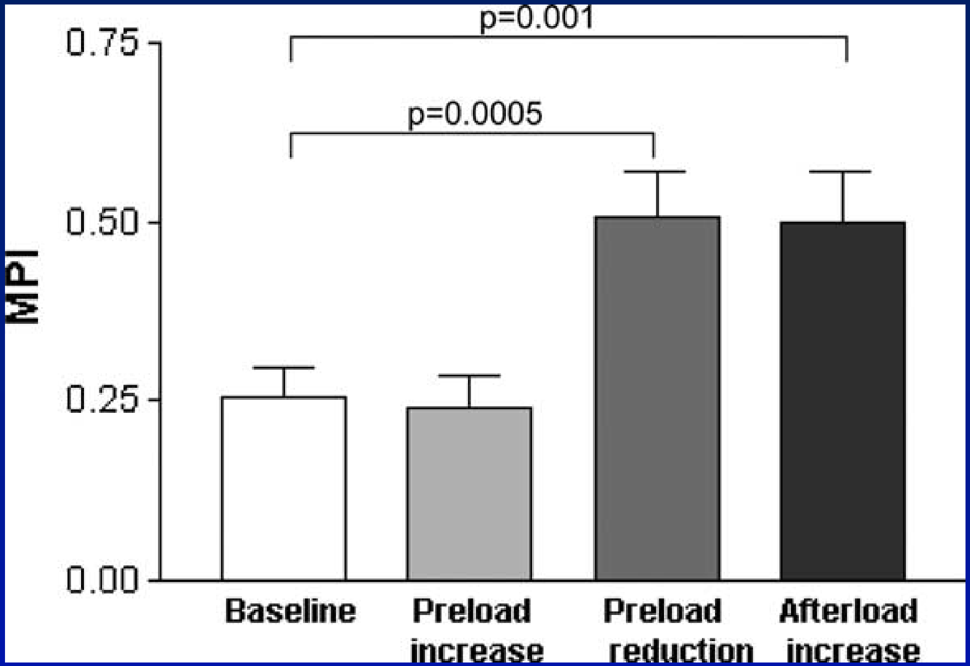
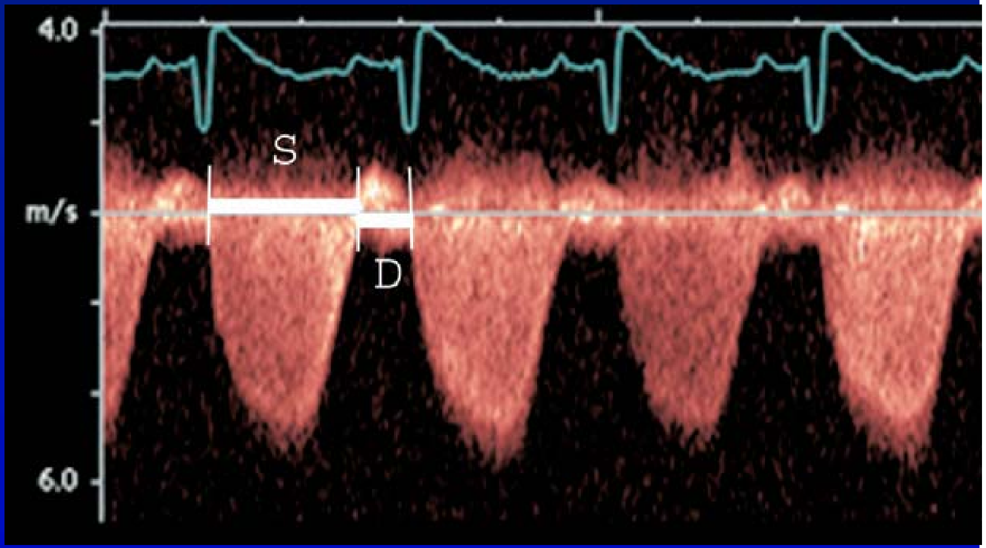


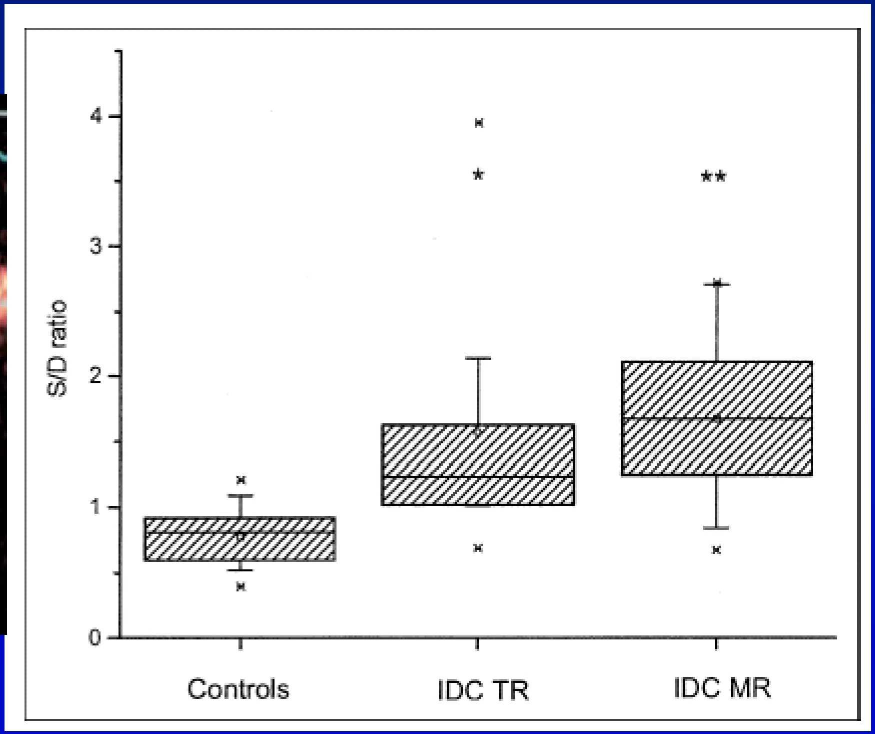
Table 1 Absolute and percentage changes in contractile indices compared with baseline values during modulation of inotropy	Baseline	Esmolol (1 mg/kg/min)	Dobutamine (10 μg/kg/min)
MPI	0.26 ± 0.13	0.31 ± 0.18	0.22 ± 0.11
Total isovolumic time (ms)	47 ± 22	54 ± 30	39 ± 20
Ejection time (ms)	183 ± 15	181 ± 16	175 ± 17*
dP/dt_{max} (mm Hg/s)	1001 ± 240	966 ± 205	1569 ± 532***
Ees (mm Hg/ml)	2.38 ± 1.22	2.11 ± 1.10	3.71 ± 2.24*
dP/dt_{min} (mm Hg/s)	−1027 ± 2.81	−988 ± 251	−1397 ± 338***
% change MPI		16.6 ± 27.4	−4.4 ± 49
% change dP/dt_{max}		−3.0 ± 5.8	55.6 ± 27***
% change Ees		−14.8 ± 28.0	60.7 ± 63.5*

*$p < 0.05$, ***$p \leqslant 0.001$ as compared with baseline value.

Cheung MM, Eur Heart J 2004;25:2238

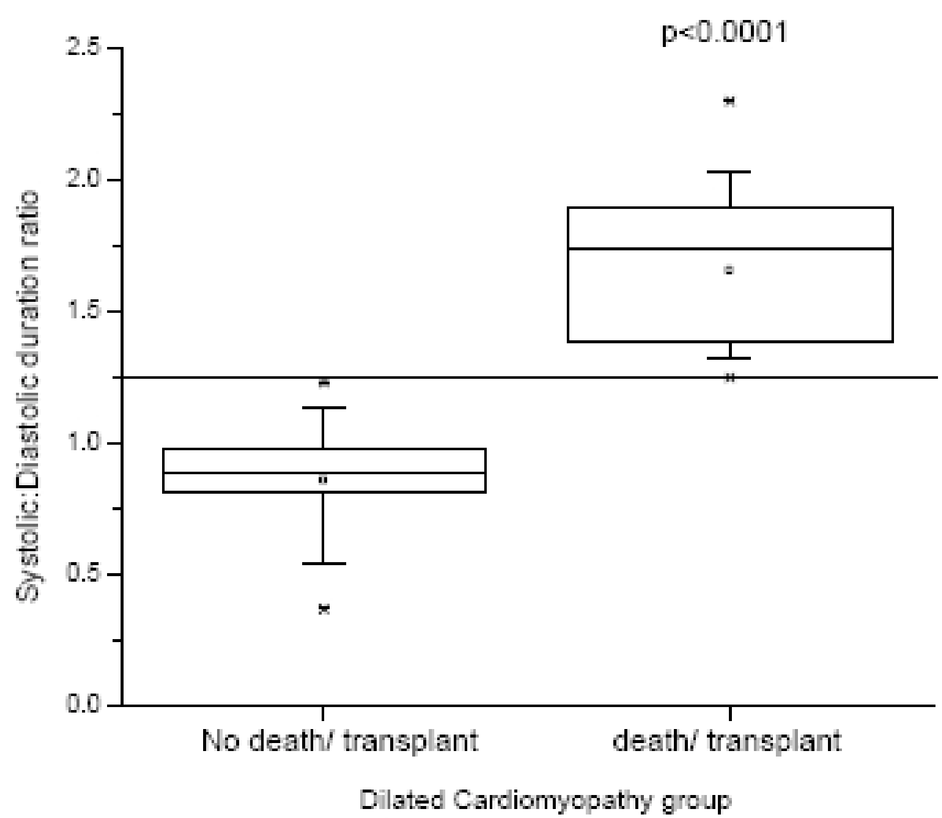
The systolic to diastolic duration ratio





Friedberg, AJC 2006;97:101

S:D ratio (by TDI) and outcome



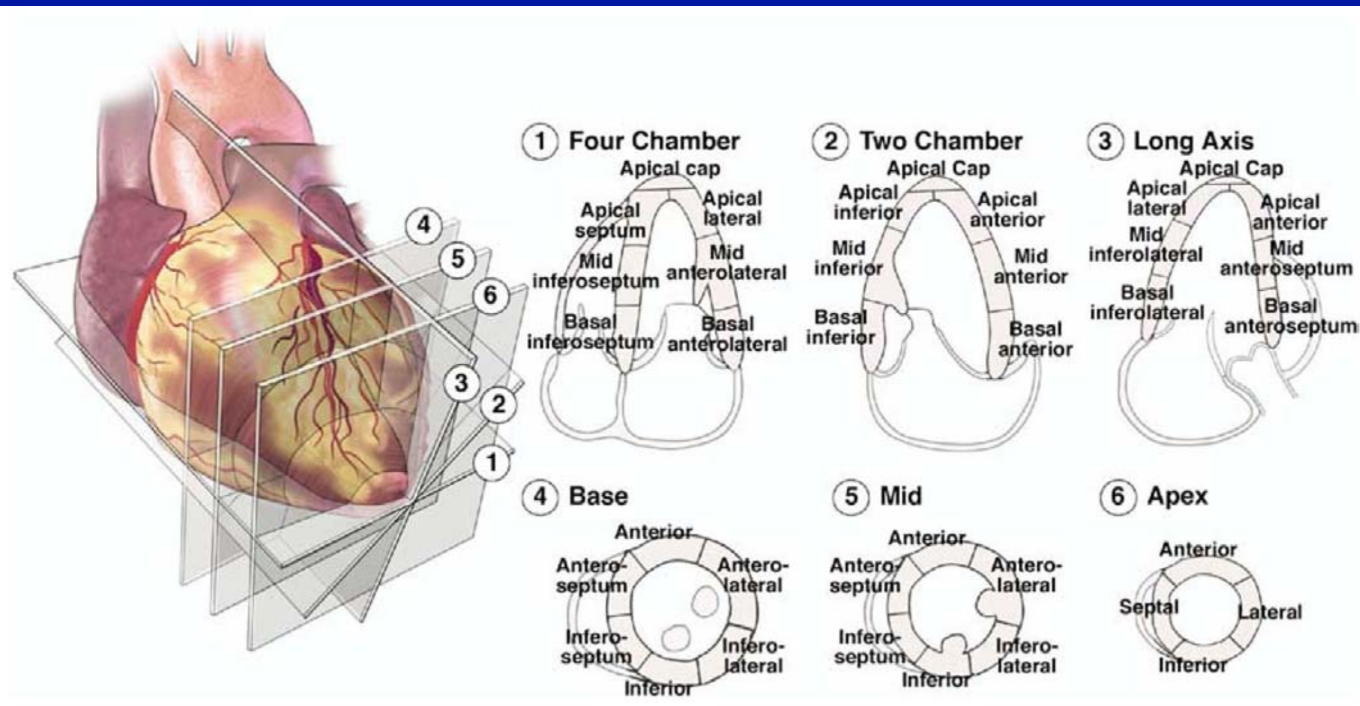
Mondal, AHA, 2010

Contractile Reserve

- Systolic dysfunction more likely under stress.
- Regional dysfunction during stress can identify ischemic and nonischemic cardiomyopathy.
- In HF, contractile reserve, (dP/dt, EF%, cardiac output response) is related to outcome.
- Contractile reserve mirrors sympathetic dysfunction,which makes this an inexpensive surrogate for tests of sympathetic status.

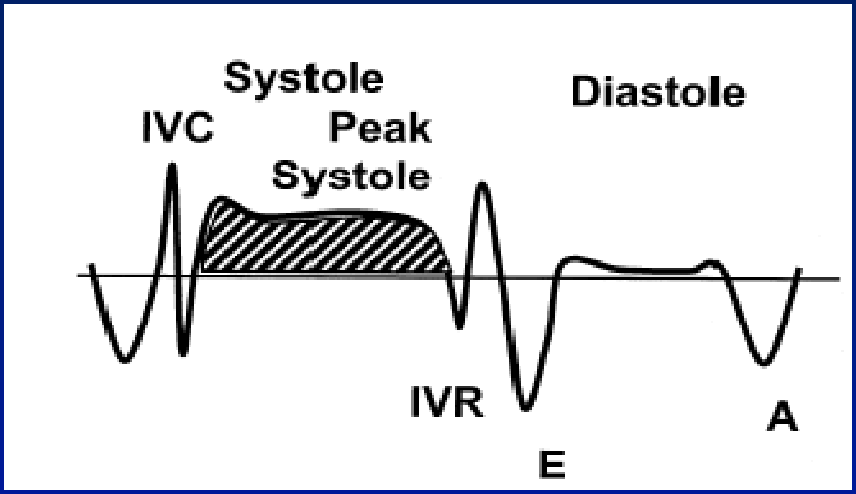
Assessment of regional function

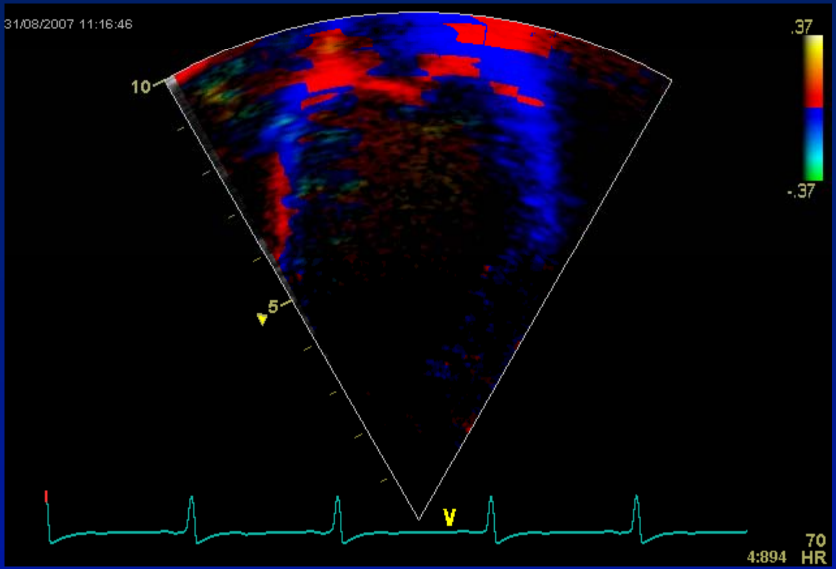
- Commonly assessed by LV 17-segment model
- Qualitative grade assigned to each segment (1-5).
- Method changed little from initial descriptions of wall motion abnormalities and is observer-dependent.

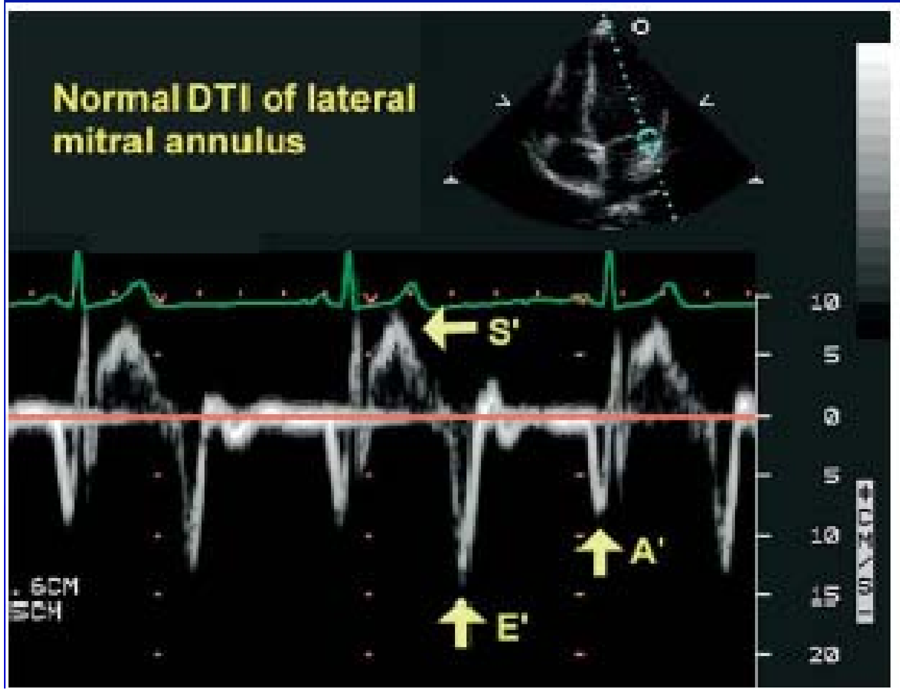


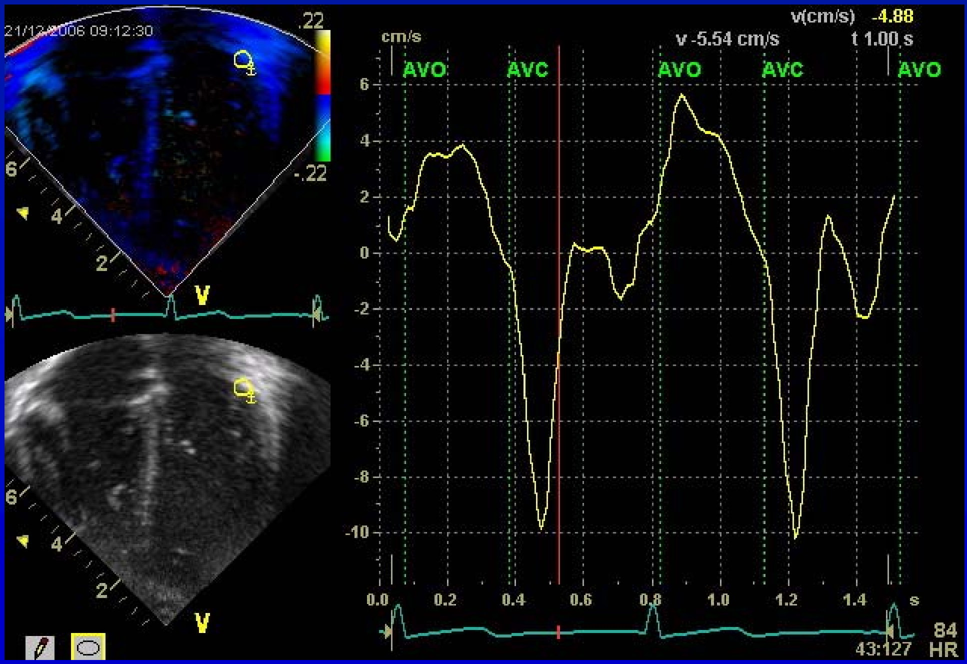
Lang JASE 2005;18: 1440
Heger, Circ 1979;60:531

Tissue Doppler Imaging



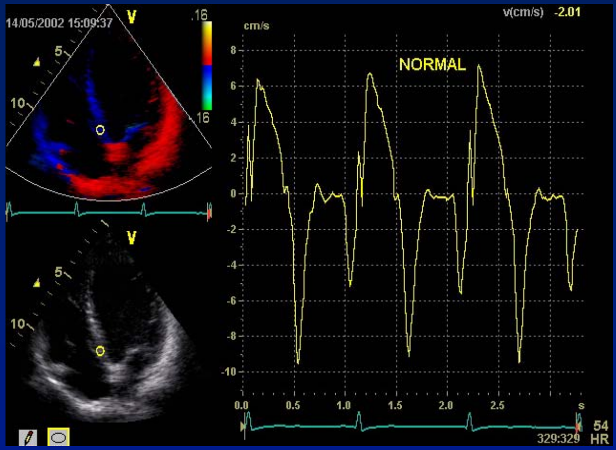


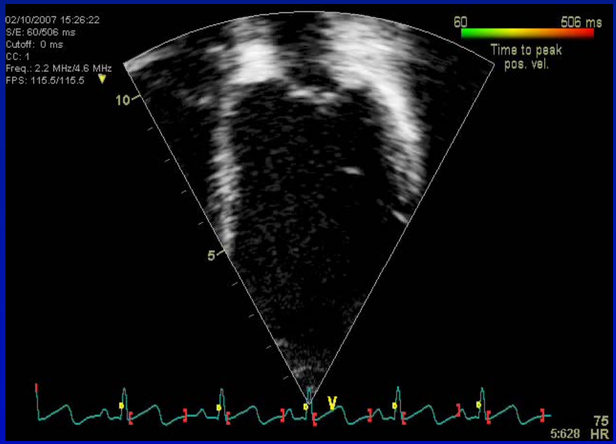


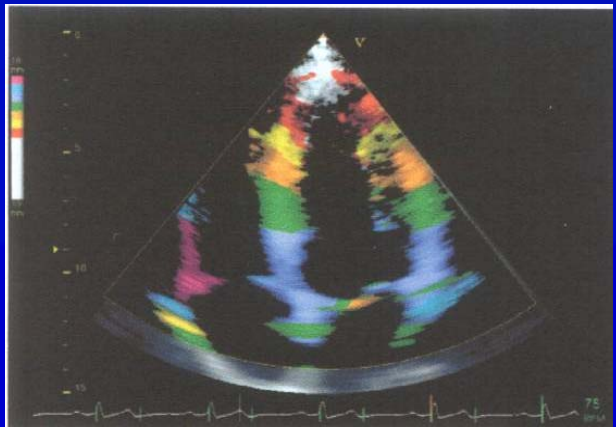


Why is tissue Doppler useful to study function?

- excellent temporal resolution (4 ms)
- instantaneous velocity of myocardial motion.
- velocity data can be post-processed for displacement, strain rate, and strain.
- interrogates function in 3-dimensions
- relatively load-independent
- information on timing contraction/relaxation.







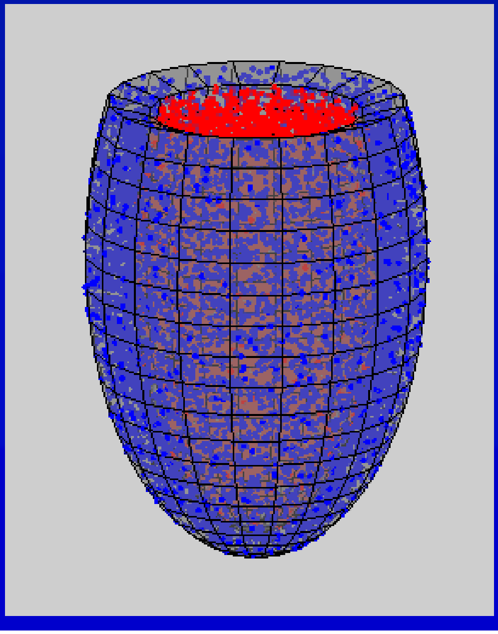
Limitations of TDI

- only measure component of motion parallel to ultrasound beam
- velocity may reflect translation rather than actual local contraction
- motion due to tethering of adjacent normally contracting segments.

Coutsesy Piet Claus

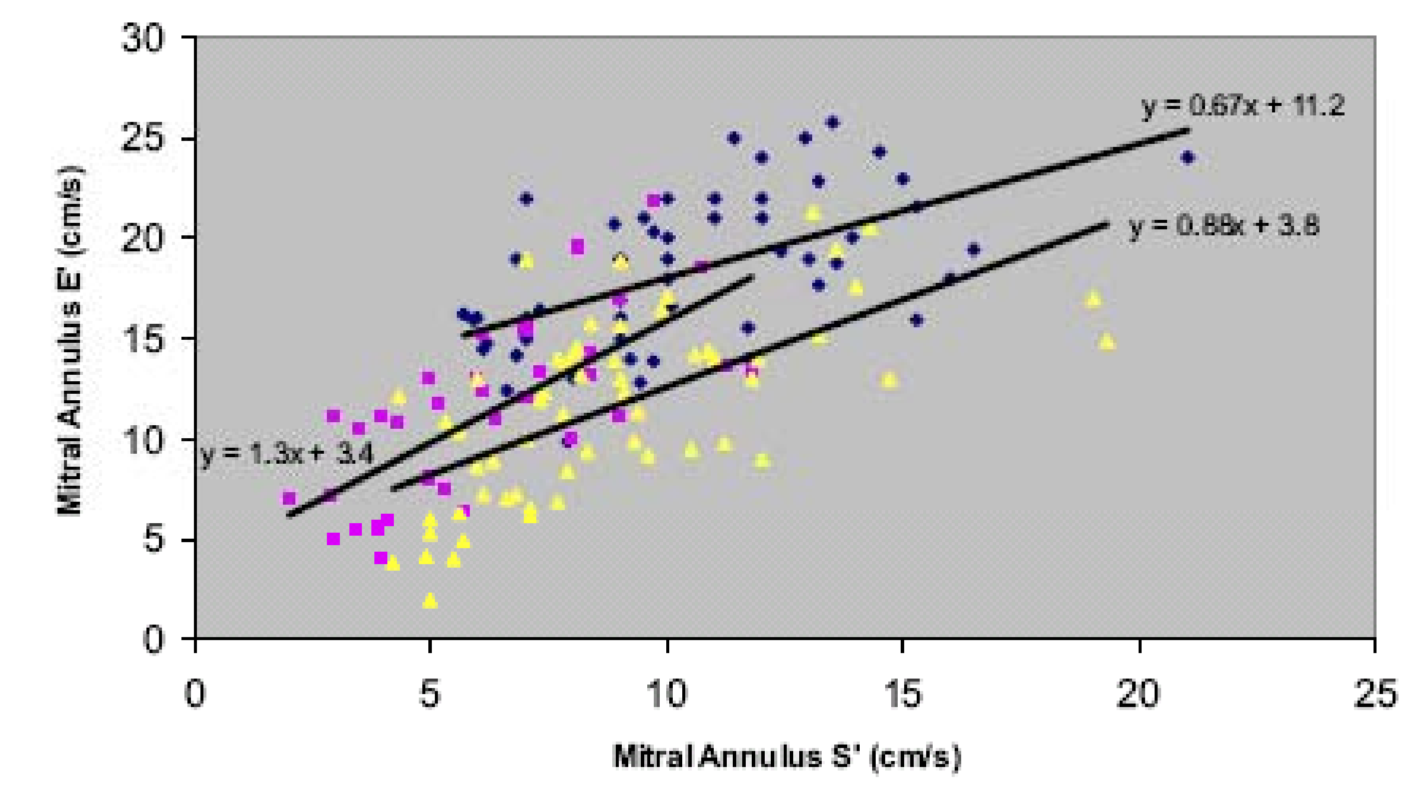
Links between systolic and diastolic function

- Torsion links between systole and diastole.
- Elastic energy stored during systole is released with sudden untwisting during isovolumic relaxation (Titin)
- Intraventricular pressure gradients are generated - filling proceeds at low pressure.
- Important in exercise when diastole shortened



Courtesy Piet Claus

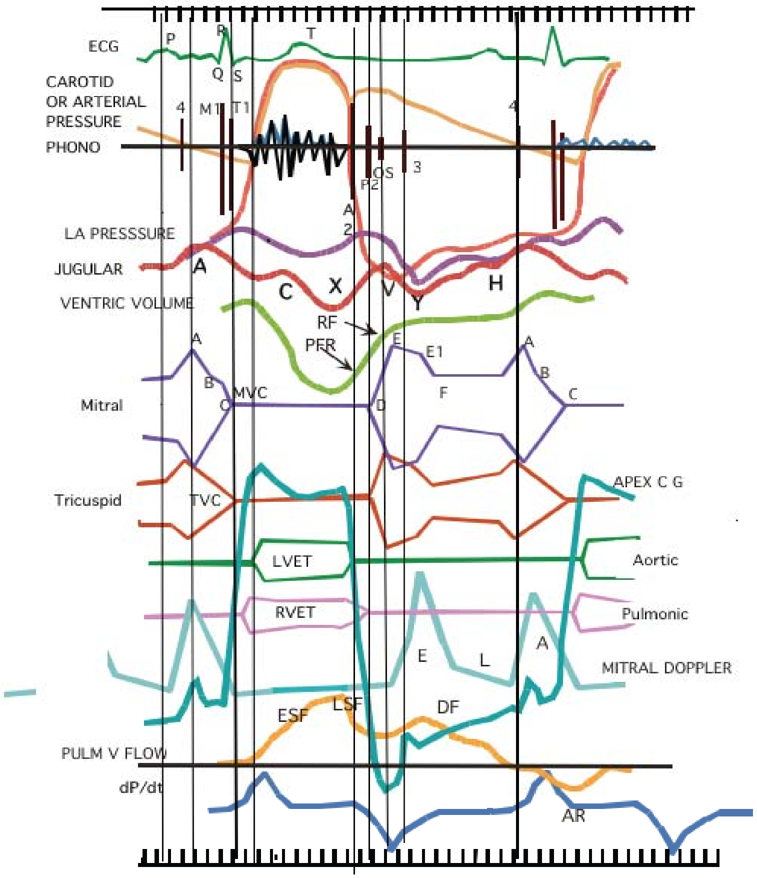
Links between systolic and diastolic function



Controls - *blue diamonds*
DCM - pink squares
HCM - *yellow triangles.*

Mohammed, JASE 2009;22:145

LV contraction needs to be synchronous



Assessment of ventricular synchrony

- Separate lecture!

So which indices do we use for LV functional assessment?

- Ventricular volumes
- Ejection fraction
- Mitral regurgitation
- Tissue velocities
- Strain (AFI)
- Formal dyssynchrony assessment in certain patients

- We record VCFc/ wall stress-but don't routinely use it in clinical decision making.

- The philosopher Arthur Schopenhauer believed that the most common folly of humans was to lose track of their original intent.

- So , as my original intent was to end the talk…!

Thank you