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ECHO IN SLOPES 2012

LEFT ATRIUM : STRUCTURE AND FUNCTION

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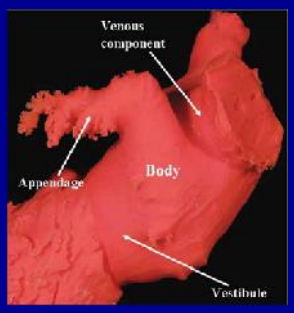
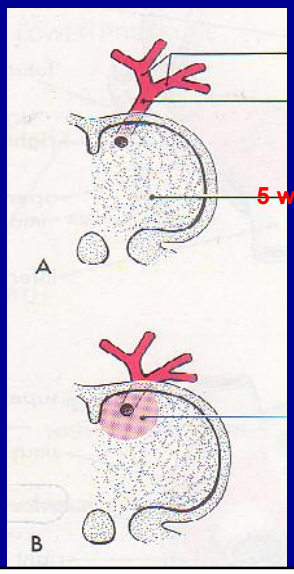
Morphology/Development of LA

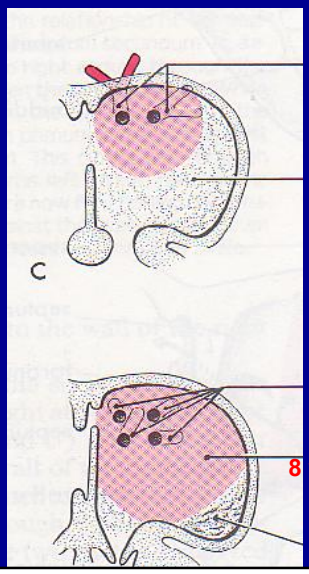
- Development of LA
- Appendage develops from primitive atria
- The body of the atria are incorporated from the venous blood vessels



As atrium expands, primitive pulmonary vein incorporated into left atrium, forming smooth-walled chamber. LAA is trabeculated and a remnant of the primitive left atrium *(Moore 1993)*



5 weeks



8 weeks

Why Bother About LA ?

- Modulates LV filling : reservoir, conduit and pump function capabilities
- Barometer of diastolic function
- Volume Sensor of the Left Heart
- Endocrine function of natriuretic peptide release
- Prognosticator in CAD , valve and nonvalvular conditions
- Important route for many diagnostic and therapeutic cardiac interventions

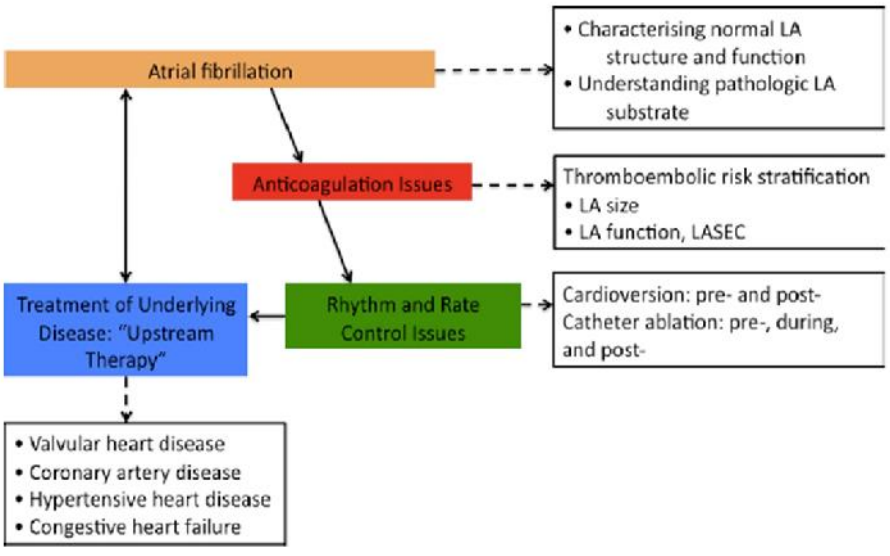
Increased LA size is associated with:

- Incidence of atrial fibrillation
- Incidence of ischemic stroke
- Poor CV outcome (MI, CHF, TIA/stroke and death) in older pts
- Risk of overall mortality after MI
- Risk of death and hospitalization in subjects with dilated cardiomyopathy

Left Atrium and Pathophysiology

Clinical settings	Echocardiographic technique	LA function involved	Parameters	Clinical role
Mild hypertension[9]	2D, TDI	Conduit	Decrease of conduit volume and early diastolic LA strain rate (ESr)	Early identification of LV diastolic dysfunction
Heart failure with normal LV ejection fraction[10]	TDI	Contractile	Lack of increase of late diastolic mitral annular velocity (A') during exercise	Identifies patients with heart failure and normal LV ejection fraction
LV systolic dysfunction[w18]	TDI	Contractile	Late diastolic mitral annulus velocity and LA strain during atrial contraction	Predict maximal workload or peak oxygen consumption during exercise
LV systolic dysfunction[11]	TDI	Contractile	Late diastolic mitral annular velocity (a') <5 cm/s	Predicts cardiac death and hospitalisation for worsening heart failure
Idiopathic dilated cardiomyopathy[12]	2D	Contractile	Increase in left atrial active emptying fraction after inotropic stimulation	Related to peak oxygen consumption
Hypertrophic cardiomyopathy[13]	TDI and STE	Reservoir	2D atrial strain <10.8%	Differentiates hypertrophic cardiomyopathy from other types of LV hypertrophy
Hypertrophic cardiomyopathy[14]	STE	Contractile	Late diastolic LA strain rate (ASr) < −0.92/s	Related to presence of heart failure symptoms
Mitral stenosis[w20]	TDI	Reservoir	LA systolic strain rate (SSr) < −1.69/s	Predictor of events
Mitral regurgitation[w22]	3D	Contractile	LA emptying fraction	Correlated with pulmonary artery pressure
Atrial fibrillation[15]	VVI	Reservoir	LA strain	Related to atrial fibrosis assessed by MRI
Atrial fibrillation[16]	TDI	Reservoir	LA systolic strain rate (SSr) >1.80/s	Predicts maintenance of sinus rhythm after cardioversion
General population[17]	TDI	Electrical	Total atrial conduction time >190 ms	Predicts new onset atrial fibrillation
Acute myocardial infarction[w23]	TDI	Electrical	Total atrial conduction time >127 ms	Predicts new onset atrial fibrillation

Importance of LA Assessment in Atrial Fibrillation

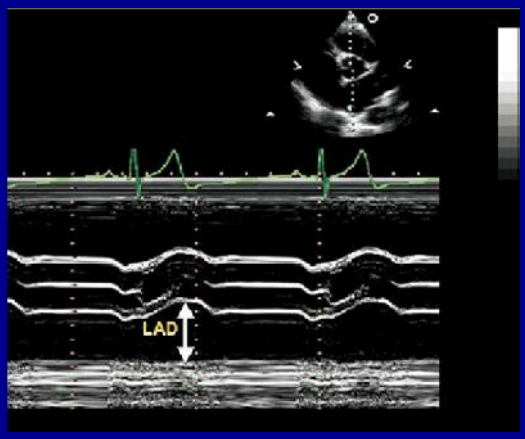


More Recently: Increase LA size

- Associated with adverse outcomes in HOCM
- Useful barometer for assessing reverse remodelling secondary to CRT
- Adverse prognosticator in aortic stenosis

M-mode : LA size

- Cursor should pass through aortic valve
- LA diameter measured from trailing edge of posterior aortic wall to leading edge of posterior LA wall
- This is against M-mode convention (leading to leading) but done to avoid variable extent of space between LA and aortic wall (ASE)

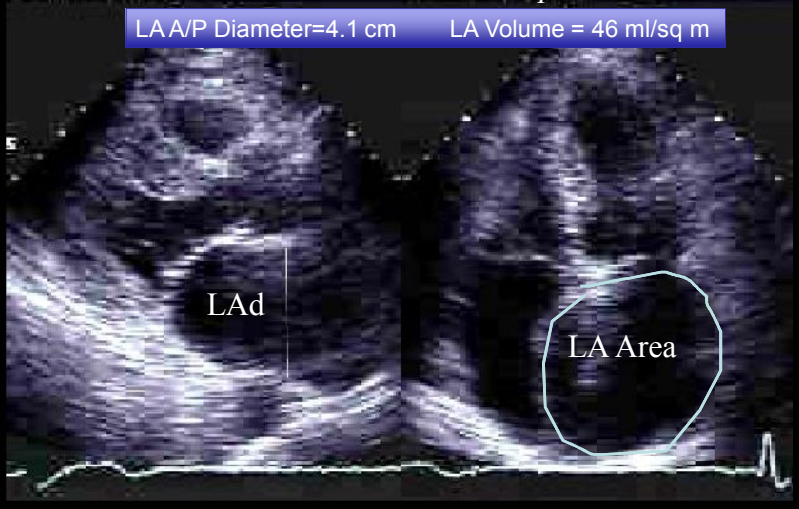


LA AP Diameter PLAX/ PSAX

- Simple to use : familiar to many non-imagers and non cardiologists
- has been widely accepted as a method of measuring LA size
- prognostic studies available for CHF, AF etc
- Problem : assymetric LA enlargement
- inability of LA to enlarge when limited by sternum and spine. Normal AP diameter can be a source of false sense of assurance on LA size

Assessment of Left Atrial Size: Why Volumes Better Than Size

Apical Area/Volumes are more accurate than parasternal dimension



Can We Use LA AP Diameter as A Screen ?

Predictive Validity of LAD (N = 93)

	LAVI Normal	LAVI Abnormal (>32)
LAD Normal	52	8
LAD Abnormal (>4.7)	9	24

LAD >/= 4.7 cm Sens 75% Spec 85%

However if LAD is normal does not mean we will not have enlarged LA by volume

This along with numerous studies validating prognostic value of LA volume suggest that this is the preffered method of LA size assessment for echo labs

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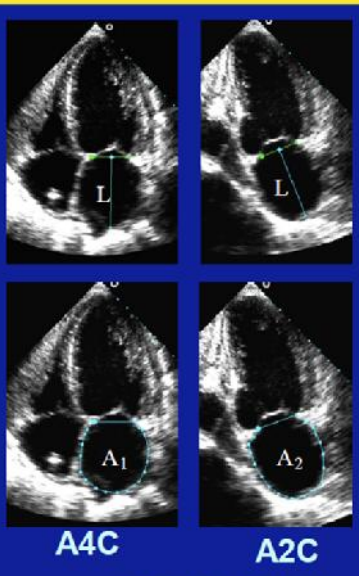
LA Volume: Area-Length Model



- where A_1 and A_2 represent the maximal planimetered LA area acquired from the apical 4- and 2-chamber-views.
- The area-length formula can be computed from a single plane, typically the apical 4-chamber, by assuming $A_1=A_2$,

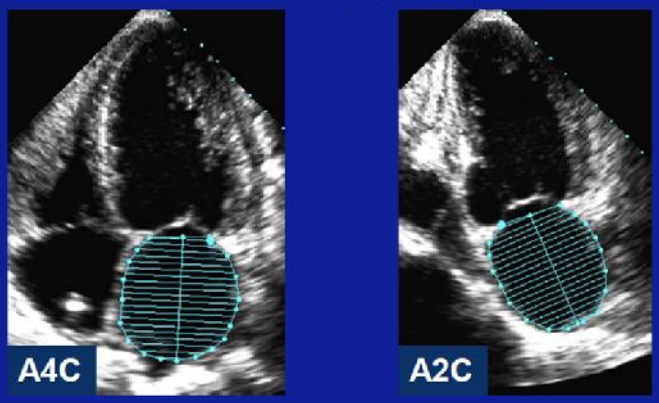
Left Atrial Volume = $8/3\pi[(A_1)(A_2)/(L)]$.

LA Volume: Simpson's Rule

•The volume of a geometrical figure can be calculated from the sum of the volumes of smaller figures of similar shape, most commonly, a series of stacked oval disks whose height is h and whose orthogonal minor and major axes are D1 and D2 (method of disks).

•Volume = $\pi/4(h)\sum(D1)(D2)$.

Biplane MOD



- A single plane MOD disks could be used to estimated LA volume by assuming the stacked disks are circular $V=\pi/4(h)\sum(D_1)$.[2]

LA Volume: Technical Aspects

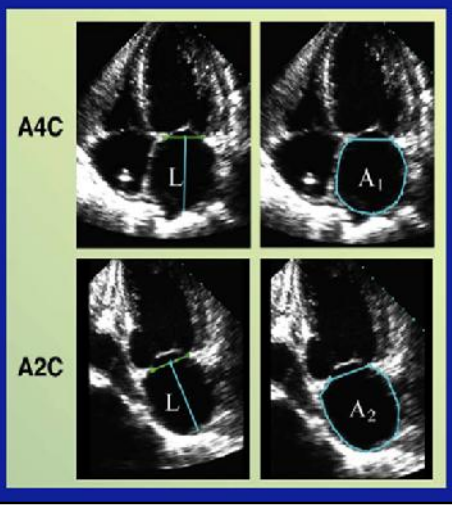
- Measure at end-ventricular systole when the LA chamber is largest (frame before MV opens)
- The inferior border should be represented by the plane of the mitral annulus.
- Avoid foreshortening of the LA.
- Base of the LA should be at its largest size indicating that the imaging plane passes through the maximal short-axis area.
- LA length should be maximized ensuring alignment along the true long-axis of the LA.
- Confluences of the pulmonary veins and LA appendage should be excluded.

LA Volumes

Left Atrial Volume = $8/3\pi [(A_1)(A_2)/(L)]$ *

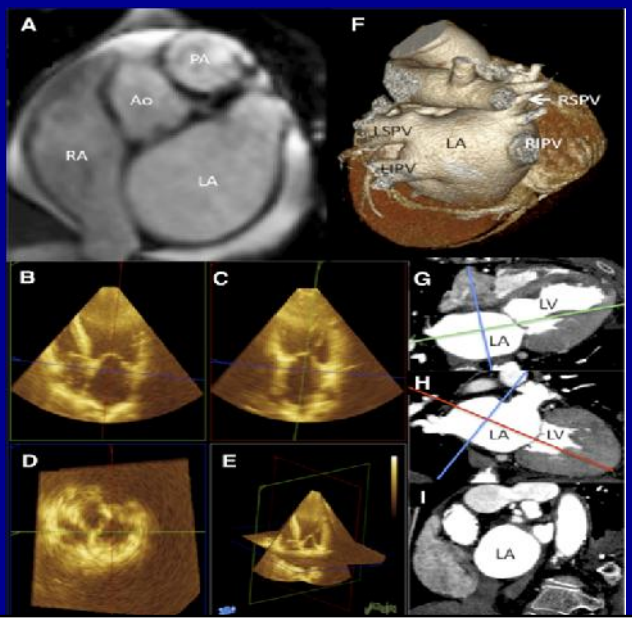
WOMEN and MEN

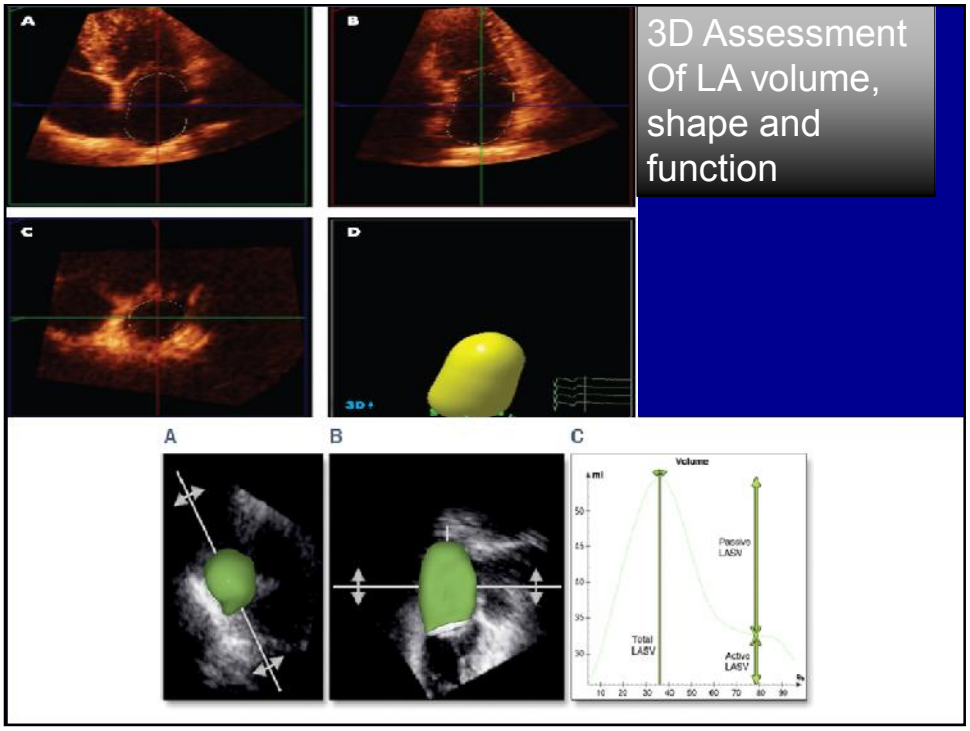
	Reference Range	Mildly Abnormal	Moderately Abnormal	Severely Abnormal
LA volume/ BSA (ml/m²)	22 ±6	29 - 33	34 - 39	≥ 40



JASE chamber quantifcation gudielines

3D Techniques of LA Assessment





Use of Real-time Three-dimensional Echocardiography to Measure Left Atrial Volume: Comparison with Other Echocardiographic Techniques

Carly Jenkins, BS, Kristen Bricknell, BS, MS, and
Thomas H. Marwick, MD, PhD, FACC, *Brisbane, Australia*

Table 3 Interobserver agreement with 2-dimensional echocardiography and real-time 3-dimensional echocardiography (n = 20) showing correlation and mean difference between the studies

	PLN	AMoV	PE	Simpson's	Area-length	3DE
R value	0.93*	0.89*	0.98*	0.95*	0.97*	0.99*
Z value (R value compared with 3D)	9.7*	6.01*	1.44 $P = .17$	3.30*	2.29 $P < .05$	N/A
Mean difference, mL	0 ± 1	−2 ± 5	−1 ± 3	0 ± 5	0 ± 4	0 ± 2
F value, comparison of variance	0.24*	4.76*	2.3 $P = .04$	4.05*	2.56 $P = .02$	N/A

N/A, not applicable; *PE*, prolate ellipsoid; *PLN*, left atrial planimetry; *3D*, 3-dimensional; *3DE*, 3D echocardiography.

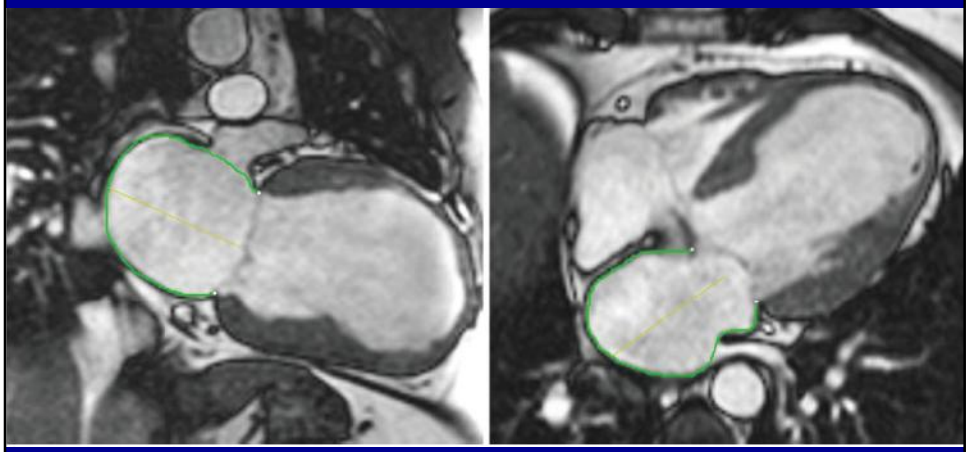
Conclusions: **The 2D measurements correlate closely with 3DE. Follow-up assessment in daily practice appears feasible and reliable with both 2D and 3D approaches.** (J Am Soc Echocardiogr 2005;18: 991-997.)

3D echo estimation on LA volume is feasible and accurate but does not represent a major advantage over current 2D techniques which compare favorably

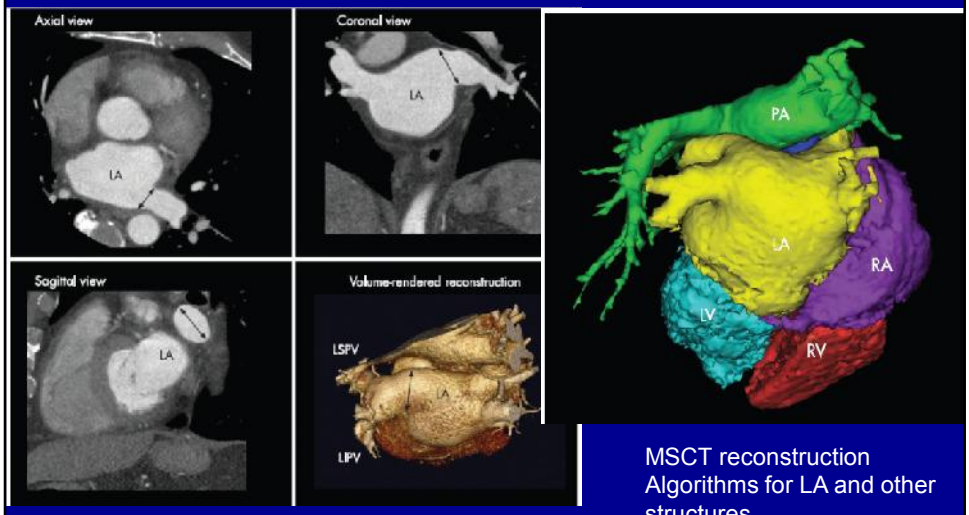
So current 2D LA volume assessment remains the method of choice in echo labs

To date no studies exist showing incremental diagnostic and prognostic valve if 3D LA assessment

LA Volume by MRI



CT of LA and Pulmonary Veins



MSCT reconstruction Algorithms for LA and other structures

Comparison of Echo CT and MR for LA Assessment

	Echocardiography	Cardiac CT	CMR
Technical considerations			
Temporal resolution*	2D = 10–20 ms 3D = 50–75 ms TDI = 5–10 ms Speckle = 10–20 ms	75–250 ms	25–50 ms
Spatial resolution*	2D = 0.5–1 mm 3D = 1–2 mm	0.5–2 mm	1–2 mm
Limitation with imaging window	Yes	No	No
True 3D dataset	Only with 3D	Yes	Selected sequences only
Real-time imaging	+++	–	+
Tissue characterization	+	+	+++
Availability	+++	++	+
Typical scan duration, min	30	10	30–50
Cost	Low	Moderate	High
Safety	Contrast	Radiation risk Iodinated contrast	Gadolinium contrast and renal failure Contraindications with pacemaker and defibrillators Hemodynamically stable patients only

Comparison of Echo CT and MR for LA Assessment

	Echocardiography	Cardiac CT	CMR
Usefulness in the assessment of the left atrium			
LA size			
Static	+++	+++	+++
Phasic	+++	+	++
LA mechanics	+++	–	+
LA structure	+	+	+++
Current indications	First-line diagnostic evaluation and follow-up	Accurate 3D dataset for electroanatomic mapping Diagnosis and follow-up of pulmonary vein stenosis	Diagnostic evaluation and follow-up for patients with poor echocardiographic windows Accurate 3D dataset for electroanatomic mapping in patients with concern over radiation risk Diagnosis and follow-up of pulmonary vein stenosis in patients with concern over radiation risk
Potential indications	Serial monitoring of LA phasic volumes Detailed functional assessment of LA phasic function		Characterization of post atrial fibrillation ablation scarring Serial monitoring of LA phasic volumes

Comparison of Imaging Methods LA Assessment

	Imaging modality				
Role	TTE	TEE	CMR	MDCT	Nuclear imaging
Assessment of LA size	++	++	+++	+++	—
Assessment of LA function	+++	+++	++	++	—

COMMENTS ON TEE AND LA STRUCTURE:

1. Near field accquisition prevents visualization of all borders reliably
2. LA volume assessment cannot be assessed reliably
3. Mediolateral, superio-inferior and AP dimensions of LA can be obtained and midesophageal 4, 2 and 3 chamber views to get an assessment of LA size
4. Recommend adjunct accquistion of focussed parasternal and apical windows in patients presenting directly for TEE without prior TTE

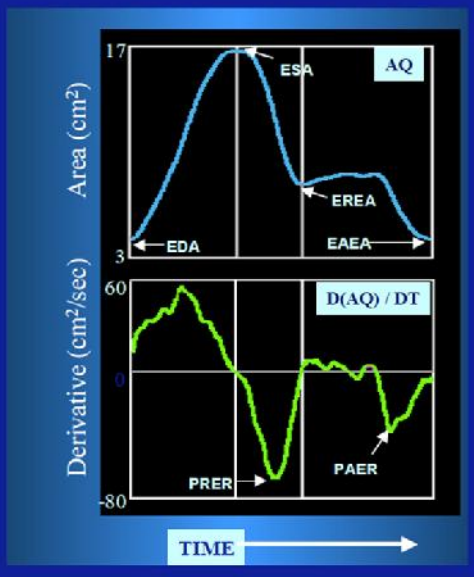
Pubished Reference Ranges

	Women				Men			
	Reference range	Mildly abnormal	Moderately abnormal	Severely abnormal	Reference range	Mildly abnormal	Moderately abnormal	Severely abnormal
Atrial dimensions								
LA diameter, cm	2.7–3.8	3.9–4.2	4.3–4.6	≥4.7	3.0–4.0	4.1–4.6	4.7–5.2	≥5.2
LA diameter/BSA, cm/m^2	1.5–2.3	2.4–2.6	2.7–2.9	≥3.0	1.5–2.3	2.4–2.6	2.7–2.9	≥3.0
RA minor-axis dimension, cm	2.9–4.5	4.6–4.9	5.0–5.4	≥5.5	2.9–4.5	4.6–4.9	5.0–5.4	≥5.5
RA minor-axis dimension/BSA, cm/m^2	1.7–2.5	2.6–2.8	2.9–3.1	≥3.2	1.7–2.5	2.6–2.8	2.9–3.1	≥3.2
Atrial area								
LA area, cm^2	≤20	20–30	30–40	>40	≤20	20–30	30–40	>40
Atrial volumes								
LA volume, mL	22–52	53–62	63–72	≥73	18–58	59–68	69–78	≥79
LA volume/BSA, mL/m^2	*22 ± 6*	*29–33*	*34–39*	*≥40*	*22 ± 6*	*29–33*	*34–39*	*≥40*

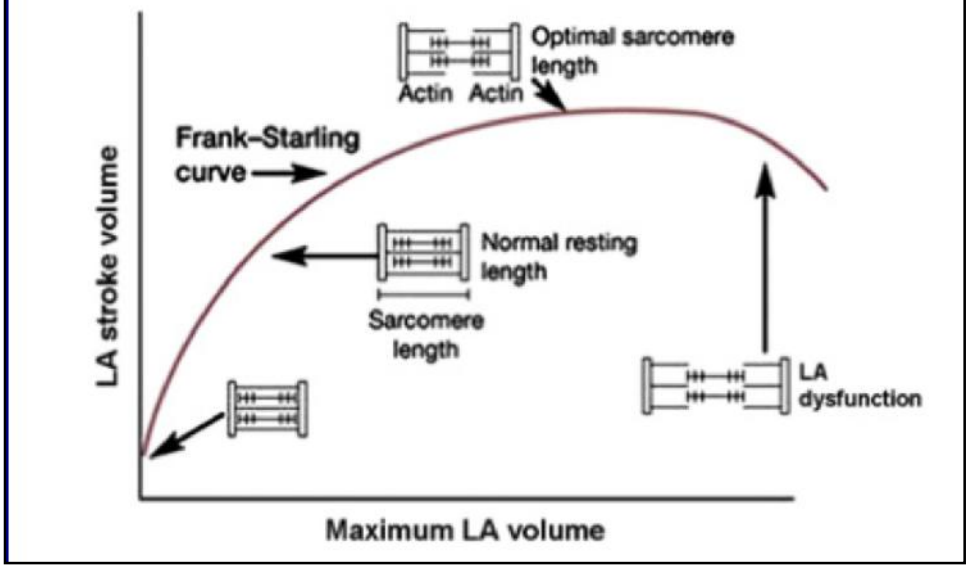
JASE 2005

LA FUNCTION

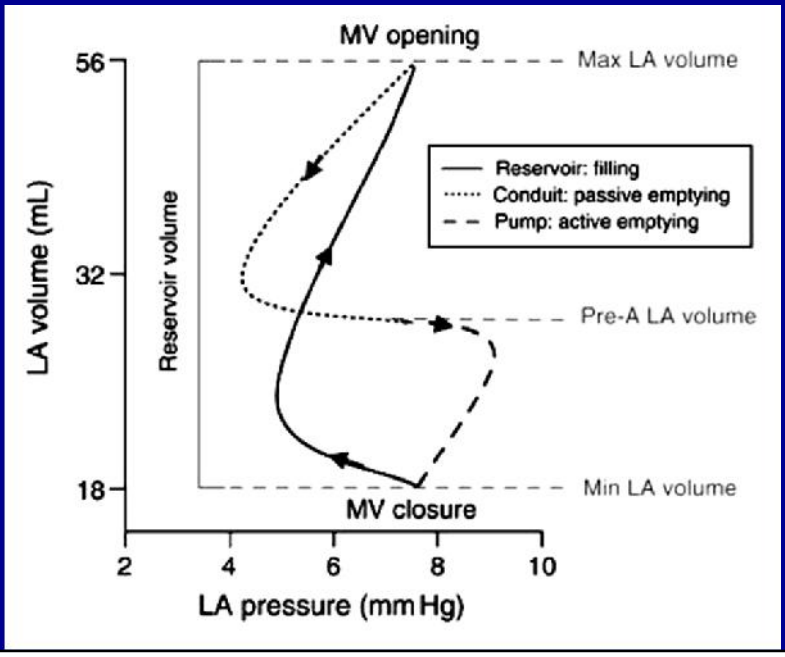
- Contractile pump that delivers 15-30% of the LV filling
- Reservoir that collects pulmonary venous return during ventricular systole
- Conduit for the passage of stored blood from the LA to the LV during early ventricular diastole



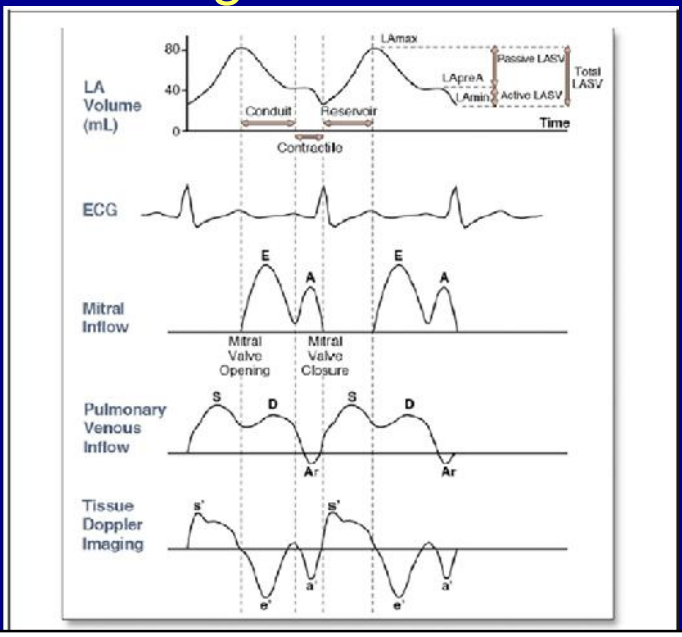
Frank-Starling Law of Left Atrium



Phasic LA Function



Understanding LA Phasic Function



Phasic LA Function : Formulas

Phasic function	Formula
LA reservoir function	
LA total emptying volume	$V_{max} - V_{min}$
LA total emptying fraction	$(V_{max} - V_{min})/V_{max}$
LA conduit function	
LA passive emptying volume	$V_{max} - V_{pre\ A}$
LA passive emptying fraction	$(V_{max} - V_{pre\ A})/V_{max}$
Conduit volume	LV stroke volume $-(V_{max} - V_{min})$
LA pump function	
LA active emptying volume	$V_{pre\ A} - V_{min}$
LA active emptying fraction	$(V_{pre\ A} - V_{min})/V_{pre\ A}$

LA Max Volume :measured before MV opening ; at end of T wave on EKG
LA minimum volume : before MV closure : at QRS complex
LA Pre "A" volume : ar start of P wave on EKG

European Journal of Echocardiography (2011) **12**, 421–430

LA volume Index and Diastolic Dysfunction Grade

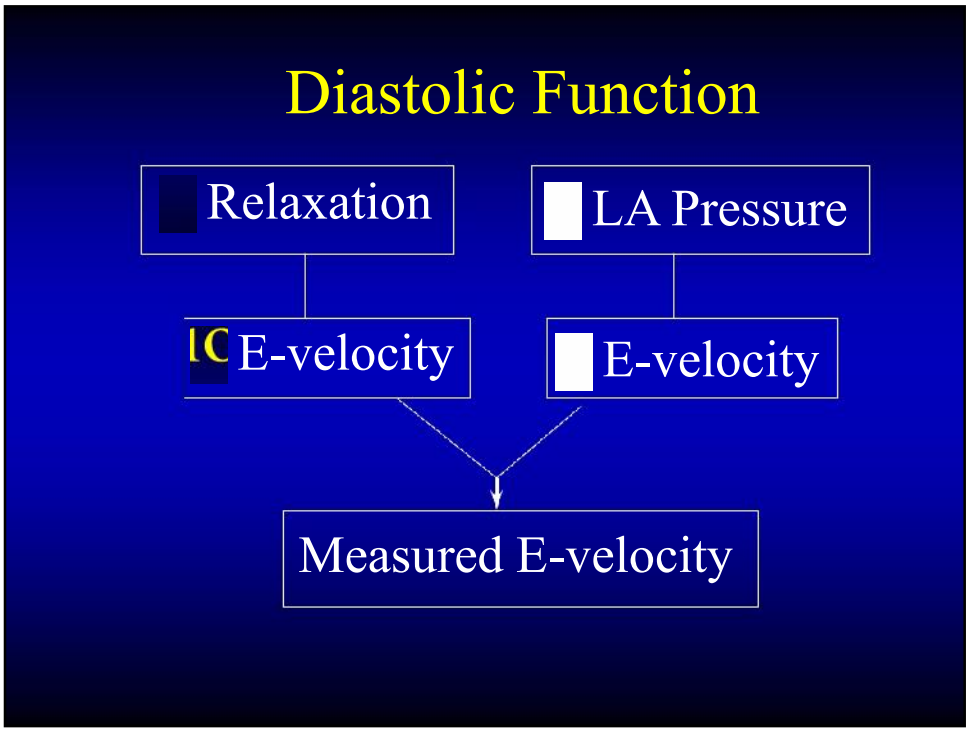
Diastolic grade	n	% of cohort	LA vol index ml/sq m	% meeting criteria for LA dilation
Normal	1212	73	23+/-6	9
Grade 1	315	19	25+/-8	17
Grade 2	118	7	31+/-8	48
Grade 3/4	12	1	48+/- 12	100

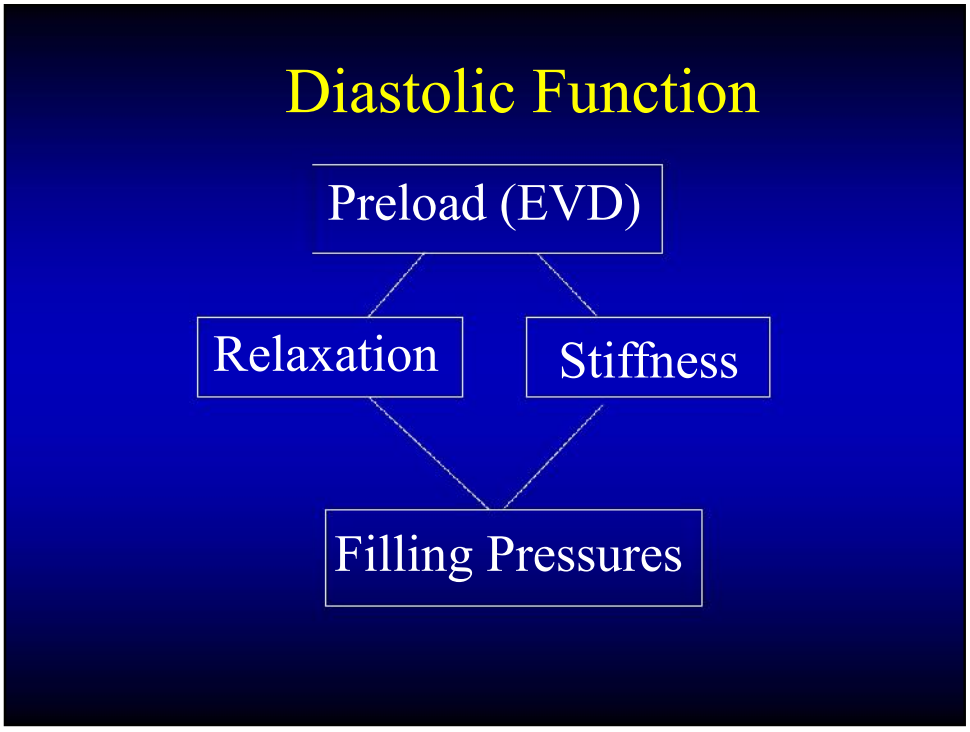
Pritchett AM et al JACC 2005;45;87-92

Estimation Of Filling Pressures

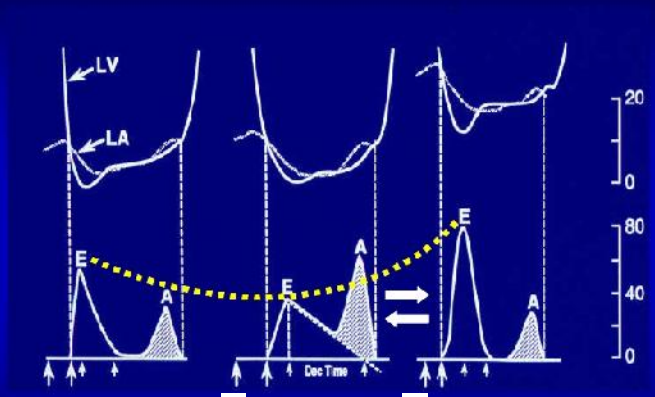
- Transmitral velocity directly relates to LA Pressure
- Transmitral velocity inversely relates to Tau (time constant of relaxation)
- Definitions for filling pressures :

1. Left atrial pressure (mean)
2. Pulmonary capillary wedge pressure (PCWP: corollary for LAP)
3. LV pre-a diastolic pressure : correlates with LAP
4. LVEDP : LV end diastolic pressure post a : does not always correlate with LAP: LAP many times


Diastolic Function
Relaxation
LA Pressure
E-velocity
E-velocity
Measured E-velocity


Diastolic Function
Preload (EVD)
Relaxation
Stiffness
Filling Pressures

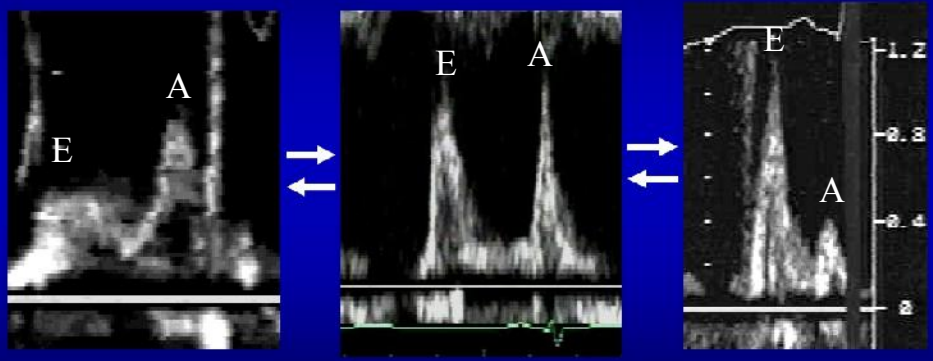
Relation of Transmitral Velocity to LV Pressure



Normal | Relaxation Normal LAP | Relaxation High LAP

Transmitral Velocity in CHF With Low EF

LV relaxation is always impaired



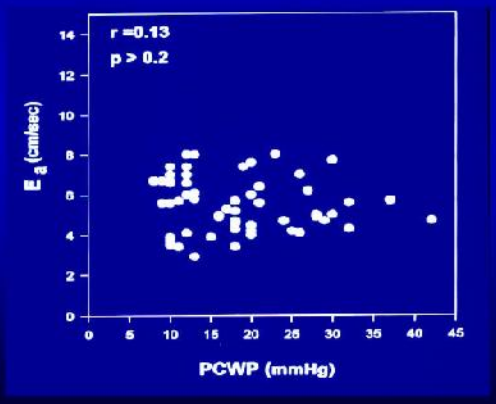
Impaired Relaxation
LAP <15mmHg

Pseudo-normal
LAP ~15-25mmHg

Restrictive
LAP >25mmHg

Ea - An Index of Myocardial Relaxation

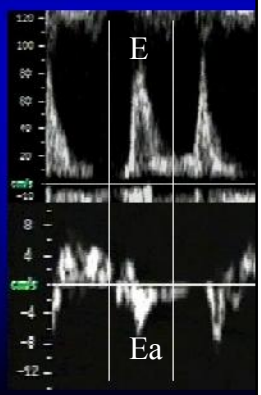
- Ea (or Em) relates poorly with LAP or LVEDP (i.e., relatively insensitive to preload)



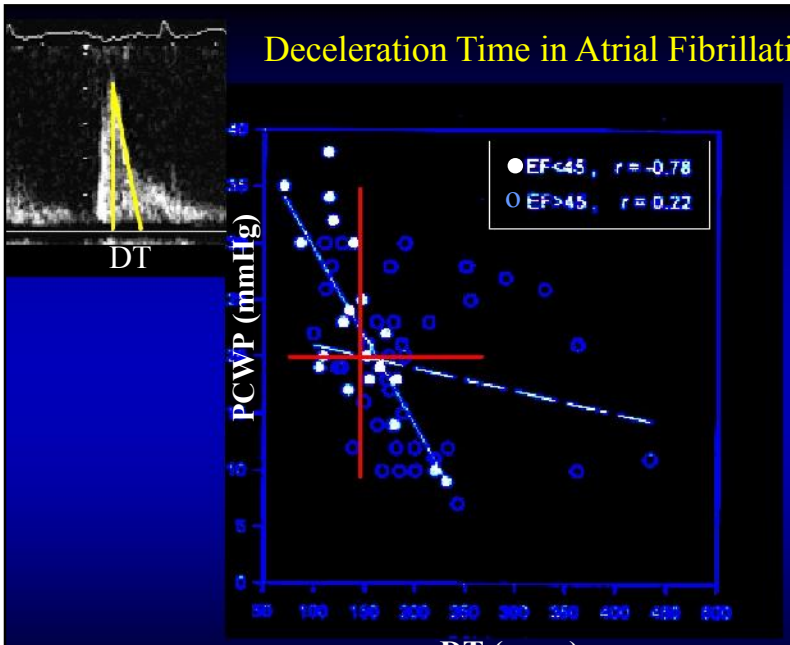
Nagueh et al, JACC 1997;30:1527-1533

Ea - An Index of Myocardial Relaxation

- The early diastolic velocity of the mitral annulus is an index of LV relaxation
- Ea (or Em) relates poorly with LAP or LVEDP
- The ratio of transmitral E-vel to Ea relates well with mean LAP



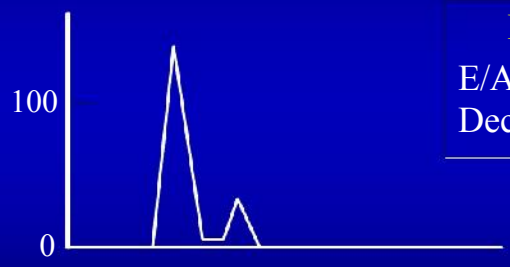
Deceleration Time in Atrial Fibrillation



Nagueh SF et al, Circulation 94: 2138 ,1996

Restrictive Mitral Inflow Pattern in Patients With Depressed LV Function

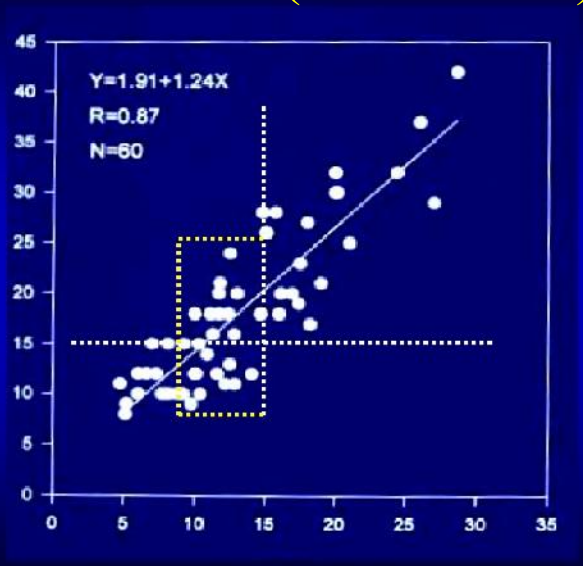
RELATION TO PROGNOSIS



Restrictive inflow
E/A ratio ε 2 and/or
Deceleration time <140ms

This pattern is associated with high LAP, increased LV stiffness and worse clinical outcome

PCWP or LAP = (E/Ea x 1.25) + 1.9

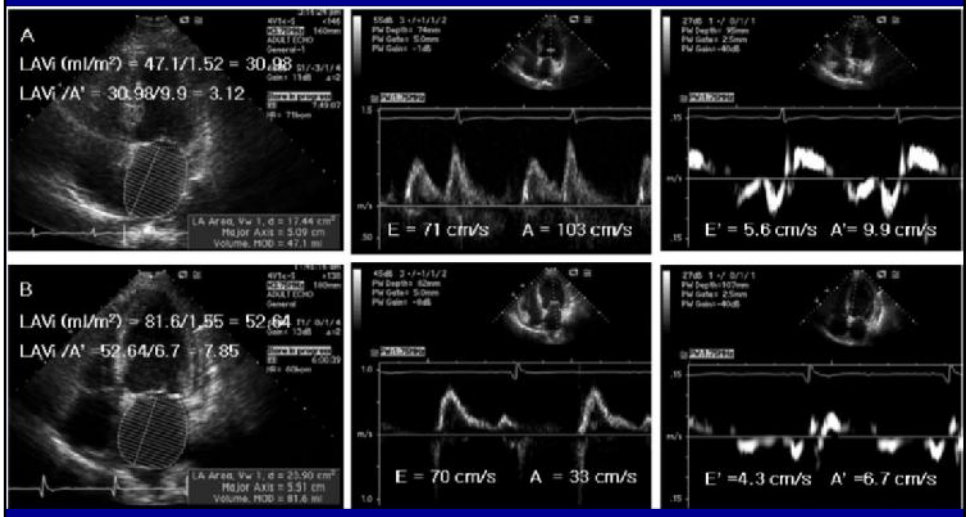


Relation of Mean PCWP to E/Ea Ratio

E/Ea

Nagueh et al, J ACC 1997;30:1527-1533

LA volume Index and Tissue Doppler A' in Diastolic Dysfunction



LAvolume index/A': A ratio incorporating filling pressure and LV compliance

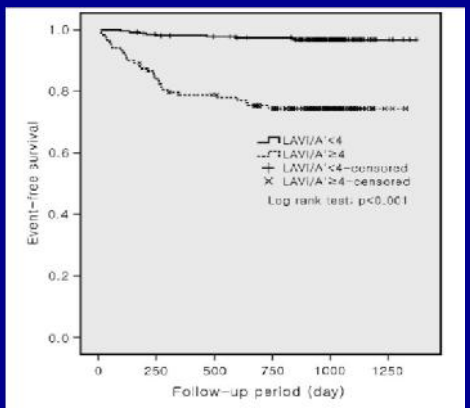
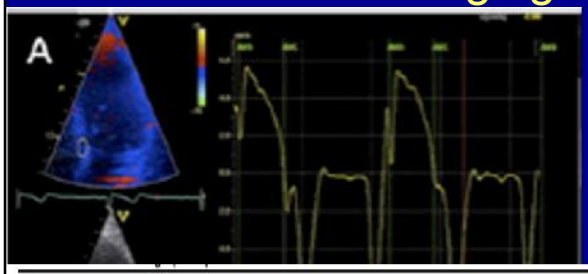


Figure 3. Kaplan-Meier and log-rank comparisons of the incidence of cardiac death and/or rehospitalization for congestive heart failure according to the LAVi/A' cutoff value.

Tissue Doppler Based Techniques of LA function : Emerging Applications



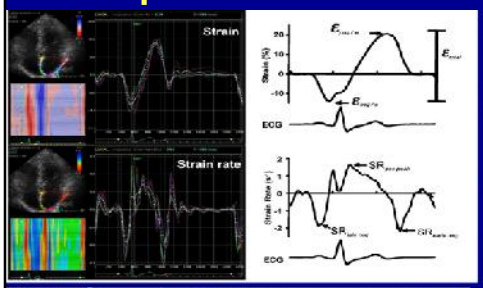
Echocardiographic technique	Echocardiographic parameters	LA function assessed	Limitations
TDI	Late diastolic mitral annular velocity (a')	Contractile	Angle dependent
	LA segmental velocities (S, e', a')	Reservoir/conduit/contractile	Influenced by translation/tethering
			Time consuming
		actile	Low reproducibility
			Influenced by image quality
		actile	No validation of the software

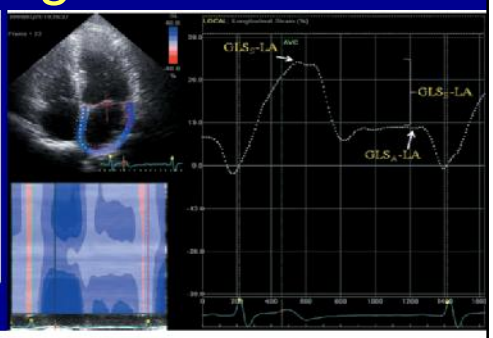
Challenges with DTI in LA
1. thin walled LA : no definitive model of shape similar to LV
2. Many areas of drop out (septum, Lpul Vein etc 0
3. Different studies have different regions of interest
4. Noisy accquistions
5. Regional representation of global function

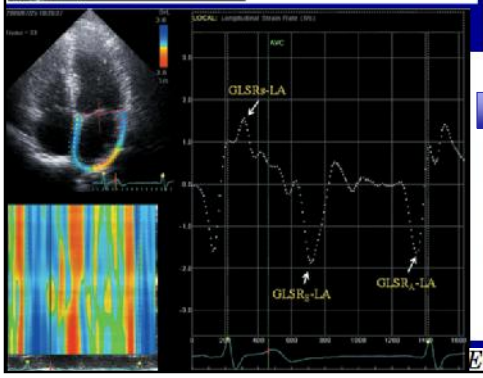
Parameters of LA Function by Tissue Doppler Assessment

	LA Reservoir Function	LA Conduit Function	LA Contractile Function
Preferred Nomenclature			
Events in the LA	Atrial Filling	Passive Atrial Emptying	Active Atrial Systole
V	V_{pos}	$V_{early\ neg}$	$V_{late\ neg}$
SR	SR_{pos}	$SR_{early\ neg}$	$SR_{late\ neg}$
ε	ε_{total}	ε_{pos}	ε_{neg}
Alternative Nomenclature, Named After Events in the LV			
Events in the LV	Ventricular Systole	Ventricular Early Diastole	Ventricular Late Diastole
V	V_s	V_e	V_a
SR	SR_s	SR_e	SR_a
ε	ε_s	ε_e	ε_a

Speckle Tracking Strain of LA





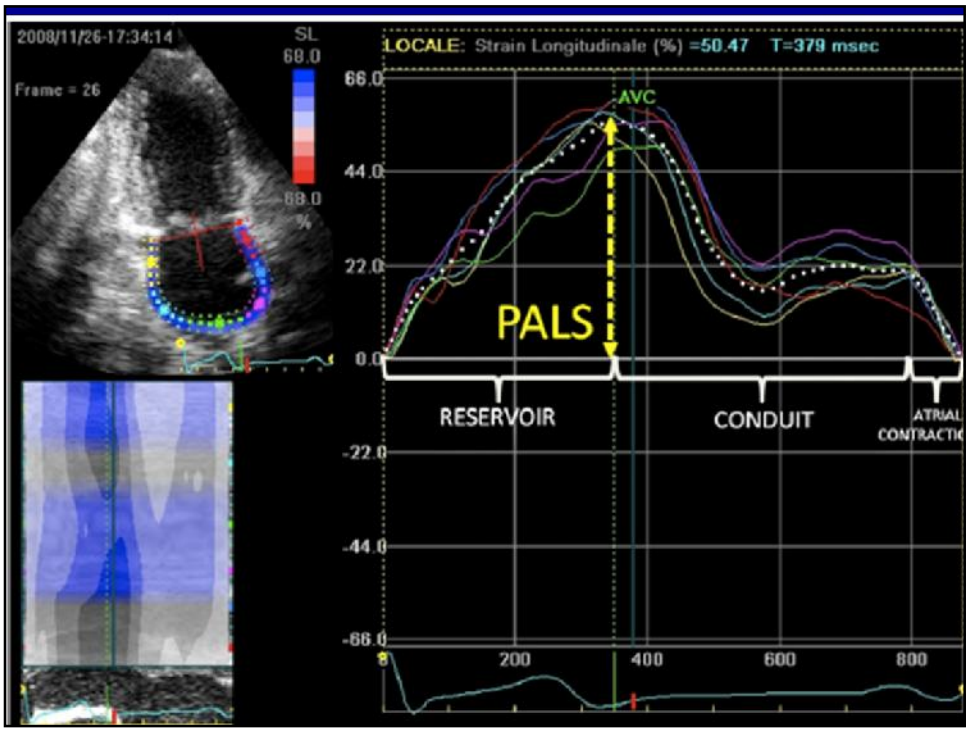


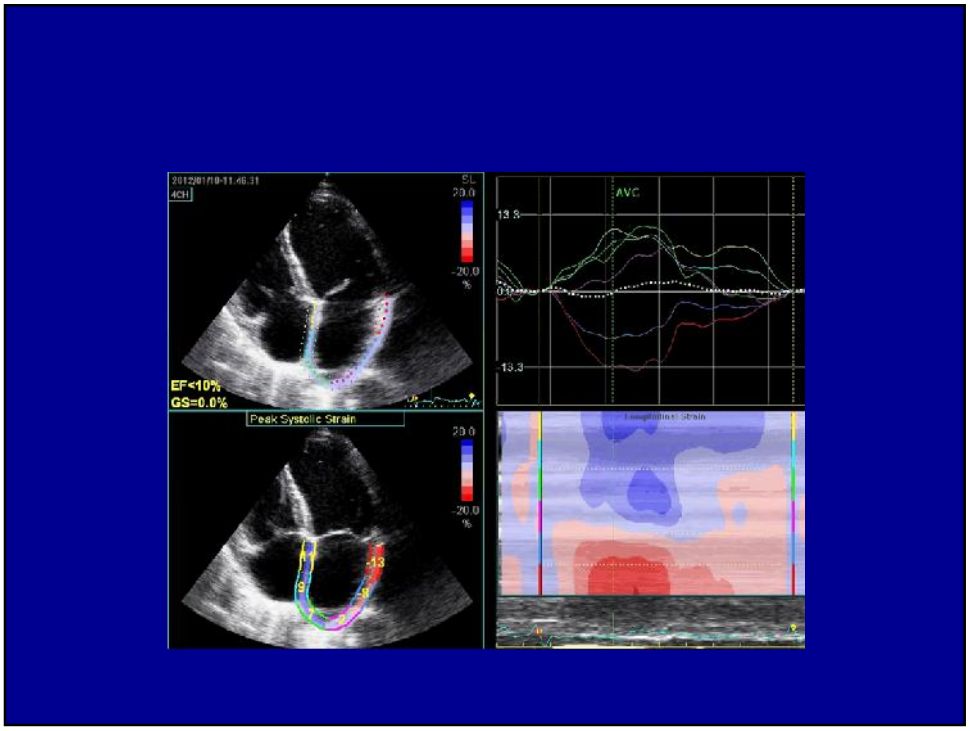
Global Longitudinal Strain/Strain Rate of Left Atrium

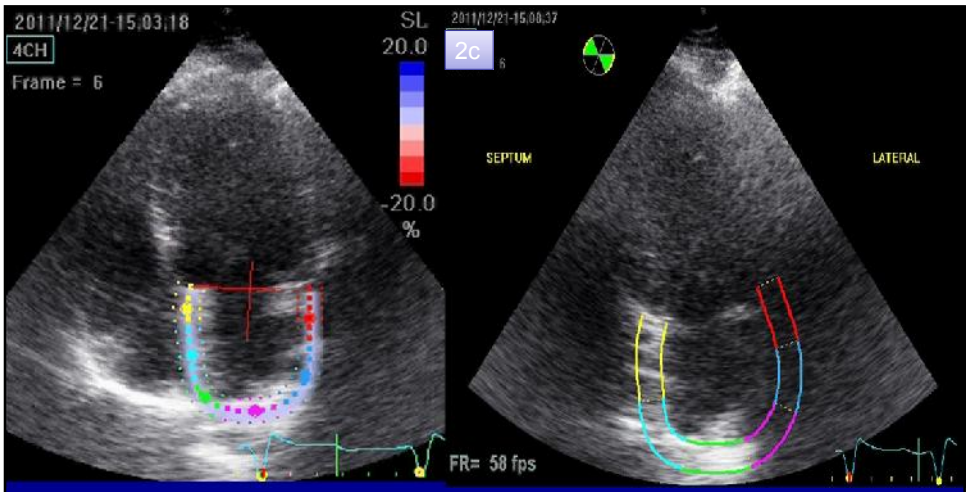
n-54 normals	4C View	2C View	Biplane
GLS_S-LA (%)	33.8 ± 6.3	37.6 ± 7.8	35.7 ± 5.8
GLS_E-LA (%)	20.3 ± 5.1	20.7 ± 6.3	20.4 ± 5.0
GLS_A-LA (%)	13.6 ± 3.4	16.9 ± 4.3	15.3 ± 2.9
$GLSR_S$-LA (s^{-1})	1.38 ± 0.25	1.48 ± 0.36	1.43 ± 0.24
$GLSR_E$-LA (s^{-1})	−1.69 ± 0.44	−1.61 ± 0.42	−1.65 ± 0.37
$GLSR_A$-LA (s^{-1})	−1.71 ± 0.34	−2.19 ± 0.53	−1.95 ± 0.33

November 2009

ECHOCARDIOGRAPHY, Volume 26


2008/11/26-17:34:14
Frame = 26
SL
68.0
-68.0
%
LOCALE: Strain Longitudinale (%) =50.47 T=379 msec
66.0
44.0
22.0
0.0
-22.0
-44.0
-66.0
AVC
PALS
RESERVOIR
CONDUIT
ATRIAL
CONTRACTI
200
400
600
800


4CH
SL
20.0
-20.0
%
EF<10%
GS=0.0%
AVC
13.3
-13.3
Peak Systolic Strain
20.0
-20.0
%



CHALLENGES OF SPECKLE TRACKING FOR LA

1. thin walls
2. poor definition

Emerging Applications of LA Speckle Tracking: Prediction of Increased PCWP /LAP

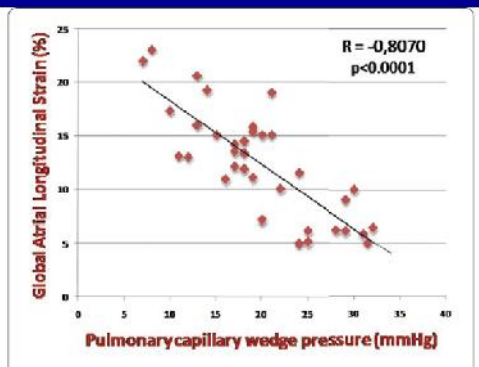


Figure 2 Correlation between global peak atrial longitudinal strain (PALS) and pulmonary capillary wedge pressure. R = -0.8070; p < 0.0001 (PALS, peak atrial longitudinal strain).

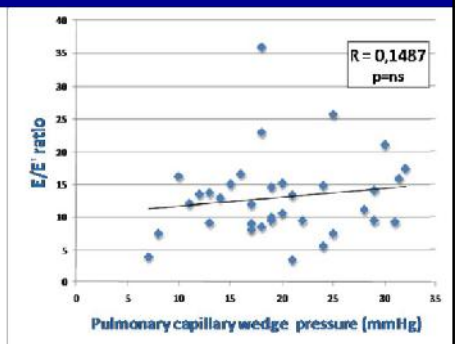


Figure 3 Correlation between global peak atrial longitudinal strain (PALS) and mean E/Em ratio. R = 0.1487; p = ns. (PALS, peak atrial longitudinal strain; E, early transmitral flow velocity; Em, early diastolic mitral annular velocity).

Cameli *et al. Cardiovascular Ultrasound* 2010, **8**:14
http://www.cardiovascularultrasound.com/content/8/1/14

Predictors of Increased PCWP

	Cutoff value	Sensitivity (95% CI)(%)	Specificity (95% CI)(%)	AUC
Two-dimensional Echo				
LV EDV	>278 ml	50.0 (15.6-85.6)	88.2 (46.3-99.6)	0.60
LA area	>36.5 cm^2	60.0 (32.4-84.1)	50.0 (16.1-85.3)	0.68
LA volume indexed	>37.8 ml/m^2	67.9 (53.9-96.8)	87.5 (56.9-95.7)	0.78
Mitral flow Doppler				
Mitral E wave	> 94.2 cm/s	90.1 (66.8-99.7)	66.8 (26.3-93.2)	0.72
E/A ratio	>2.6	89.4 (65.1-97.2)	65.2 (24.3-92.9)	0.70
Tissue Doppler				
Mean E/Em ratio	>16.8	67.9 (27.8-91.5)	93.1 (76.9-99.8)	0.69
Speckle tracking				
Global PALS	<15.1%	100 (83.9-100)	93.2 (78.1-99.8)	0.93

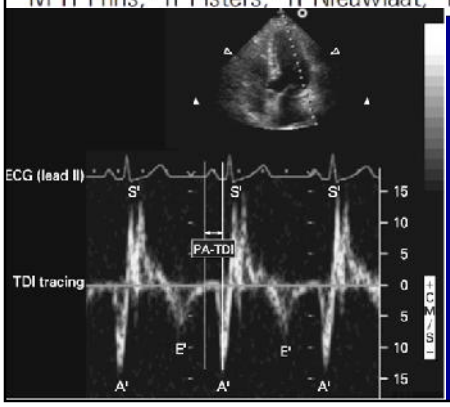
Cameli *et al. Cardiovascular Ultrasound* 2010, **8**:14
http://www.cardiovascularultrasound.com/content/8/1/14

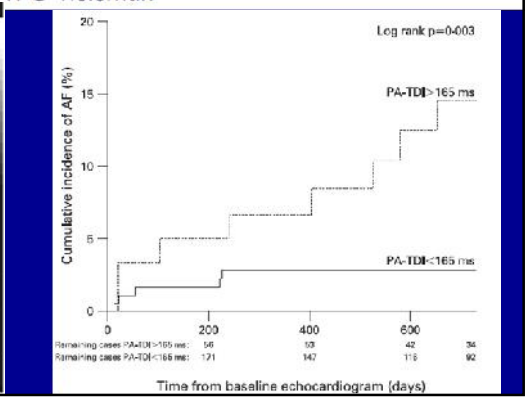
LA Tissue Doppler to Predict New Onset Atrial Fibrillation

Atrial tissue Doppler imaging for prediction of new-onset atrial fibrillation

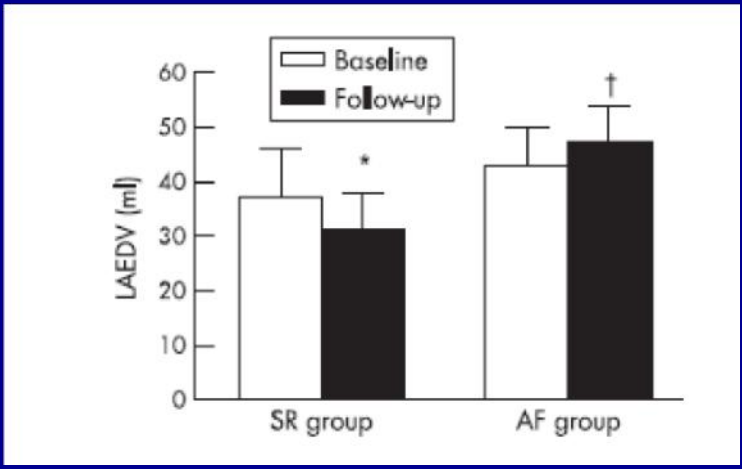
Heart 2008

C B De Vos,[1] B Weijs,[1] H J G M Crijns,[1] E C Cheriex,[1] A Palmans,[1] J Habets,[1] M H Prins,[1] R Pisters,[1] R Nieuwlaat,[1] R G Tieleman[1,2]

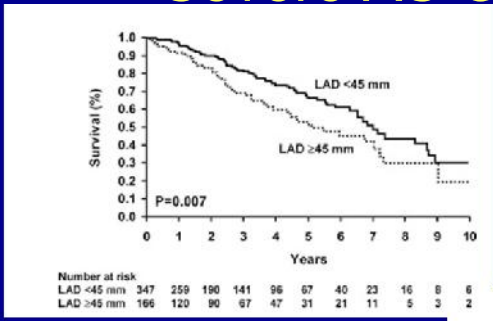


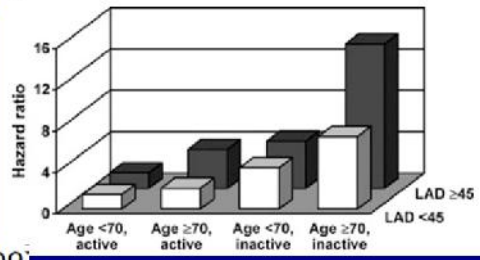


LA remodeling after AF Ablation



LA Size and Asymptomatic Severe AS Outcomes



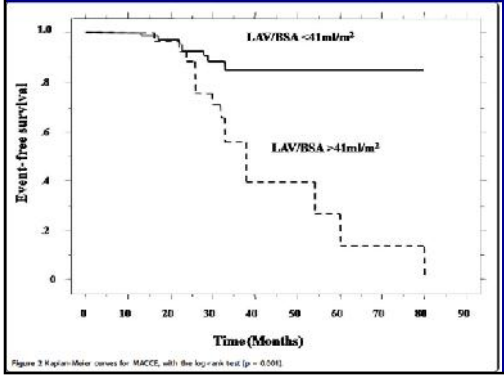


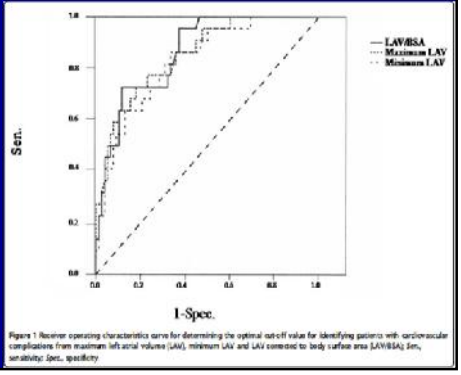
Casaclang-Verzosa, et al.
Echocardiography 2010;27:105-109

Left atrial volume predicts adverse cardiac and cerebrovascular events in patients with hypertrophic cardiomyopathy

Tani *et al. Cardiovascular Ultrasound* 2011, **9**:34
http://www.cardiovascularultrasound.com/content/9/1/34

LAV/BSA for MACE
sens 75% spec 88%





Thank you

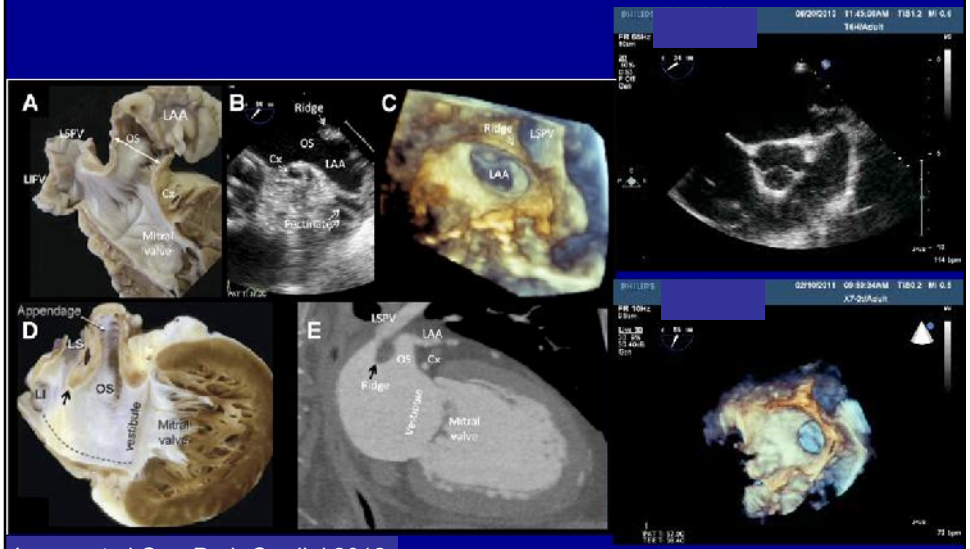
	Decade 3	Decade 4	Decade 5	Decade 6	Decade 7	Decade 8
Systolic strain (%)						
Septal	93±18	85±18	80±20	76±22*	69±20*†	63±21*†
Lateral	73±23	70±20	65±25	57±19*	54±20*	43±22*†‡
Inferior	64±21	67±21	62±20	50±22†	56±39	45±21†
Anterior	73±20	65±23	62±20	54±21*	44±16*†‡	46±20*
Global	77±15	72±15	67±14	59±15*†	55±14*†	49±16*†‡
Left atrial stiffness index	0.08±0.03	0.10±0.04	0.11±0.04	0.15±0.06*†‡	0.18±0.07*†‡	0.21±0.8*†‡§
Systolic strain rate (s^{-1})						
Septal	3.8±0.7	3.6±0.9	2.9±0.9*†	2.9±0.8*†	2.6±0.8*†	2.3±0.8*†
Lateral	3.3±0.9	3.3±0.9	2.8±0.8	2.6±0.8*†	2.5±0.7*†	2.2±0.7*†
Inferior	3.0±0.9	3.3±1.0	2.6±1.1	2.2±0.8*†	2.2±0.7*†	1.8±0.7*†
Anterior	2.9±0.7	2.9±0.9	2.6±0.8	2.3±0.6*†	2.2±1.0*†	1.9±0.8*†
Global	3.3±0.6	3.3±0.7	2.7±0.6*†	2.5±0.5*†	2.4±0.6*†	2.1±0.6*†‡
Early diastolic strain rate (s^{-1})						
Septal	4.3±1.4	3.7±1.1	3.5±1.4	3.1±1.2*	2.6±0.9*†	1.8±0.7*†‡§
Lateral	4.4±1.9	3.3±1.4	2.8±1.4*	2.4±1.0*	1.9±0.7*†	1.4±0.7*†‡
Inferior	3.2±1.6	3.2 ±1.6	2.8±1.3	2.4±1.0	1.9±0.7*†	1.5±0.6*†‡
Anterior	3.9±1.3	3.4±1.5	3.1±1.4	2.5±0.9*†	1.8±1.1*†‡	1.1±0.6*†‡§
Global	4.0±1.1	3.4±1.1	3.0±1.1*	2.6±0.7*†	2.1±0.6*†‡	1.5±0.4*†‡§
Late diastolic strain rate (s^{-1})						
Septal	2.4±0.7	2.8±1.2	2.9±0.7	3.1±0.8*	3.2±1.0*	3.4±1.2*
Lateral	2.8±1.1	2.8±1.3	3.2±1.2	3.4±0.7	3.8±1.5	3.9±0.8*†
Inferior	2.2±0.9	2.4±0.9	2.6±0.8	3.0±0.9*	3.2±1.0*†	3.2±0.6*
Anterior	3.1±1.2	3.2±1.1	3.7±1.2	3.3±0.8	3.2±1.4	3.7±1.0
Global	2.6±0.7	2.7±0.7	3.1±0.6*	3.2±0.5*†	3.3±0.8*†	3.5±0.5*†

*p<0.05 compared with decade 3.
†p<0.05 compared with decade 4.
‡p<0.05 compared with decade 5.
§p<0.05 compared with decade 6.

Normal values of color tissue doppler strain and strain rate of LA by age

Boyd AC, Richards DAB, Marwick T, *et al. Heart* [2011]. doi:10.1136/heartjnl-2011-300134 5 of 7

LA Appendage



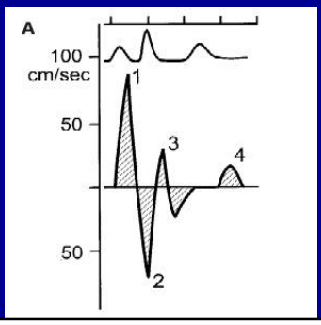
Leong et al Curr Prob Cardiol 2012

Flow Pattern Classification

- 3 types (Garcia *AHJ* 1992)
  - Type I: SR & regular pattern
  - Type II: Afib with active "sawtooth" pattern
  - Type III: Afib with no identifiable flow waves
    - III with higher rate of "smoke"/thrombi
    - mobile thrombi >1.5cm higher rate of emboli

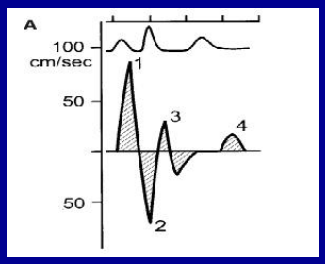
Sinus Rhythm

- 1) LAA Contraction (outflow)
  - late diastolic, positive (toward TEE transducer) outflow signal shortly after P-wave (atrial systole)
  - related temporally to mitral A wave
  - correlate with 2D measurements of LAA-ejection fraction



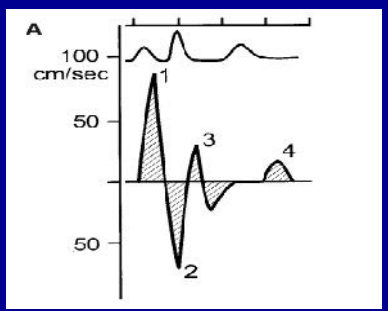
Sinus Rhythm

- 2) LAA filling
  - early systolic, negative (away from transducer) doppler inflow signal
  - physiologic process not studied as well, and relative role of active (LAA relaxation) versus passive (elastic recoil) resulting in filling are poorly defined



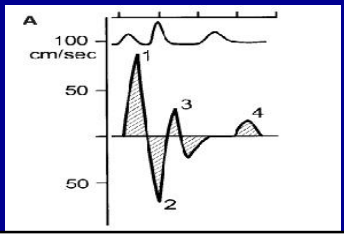
Sinus Rhythm

- 3) Systolic reflection waves
  - variable number of alternating LAA outflow and inflow of contraction/filling
    - reflects importance of LV function on LAA function/stroke risk



Sinus Rhythm

- 4) Early diastolic LAA flow
  - low velocity outward signal following mitral E wave
  - initially thought to be due to compression of LAA medial wall by superior motion of base of the LV during diastole
    - more plausible explanation is passive emptying of LAA, paralleling LA emptying during rapid ventricular filling in early diastole
  - undetermined significance, perhaps important in LAA-dysfxn



Normal flow velocities

Study	Study Group	Contraction Velocities, cm/s	Filling Velocities, cm/s	Early Diastolic Forwar Velocities, cm/s
Kortz et al. (28)	46 healthy volunteers; age, 22–41 yr	64 ± 19	46 ± 12	38 ± 11
Müggе et al. (26)	30 patients with structurally normal hearts (clinically indicated TEE)	Transverse view, 50 ± 6 Longitudinal view, 52 ± 15	Transverse view, 52 ± 13 Longitudinal view, 58 ± 18	NA*
Tabata et al. (15)	50 patients with structurally normal hearts (clinically indicated TEE)	60 ± 14	52 ± 13	20 ± 11

NA = data not available. TEE = transesophageal echocardiography.

LA APPENDAGE FUNCTION AFFECTED IN

1.CHF
2.MS/MR
3.ATRIAL FIBRILLATION/FLUTTER