Left ventricular twist in physiology and disease

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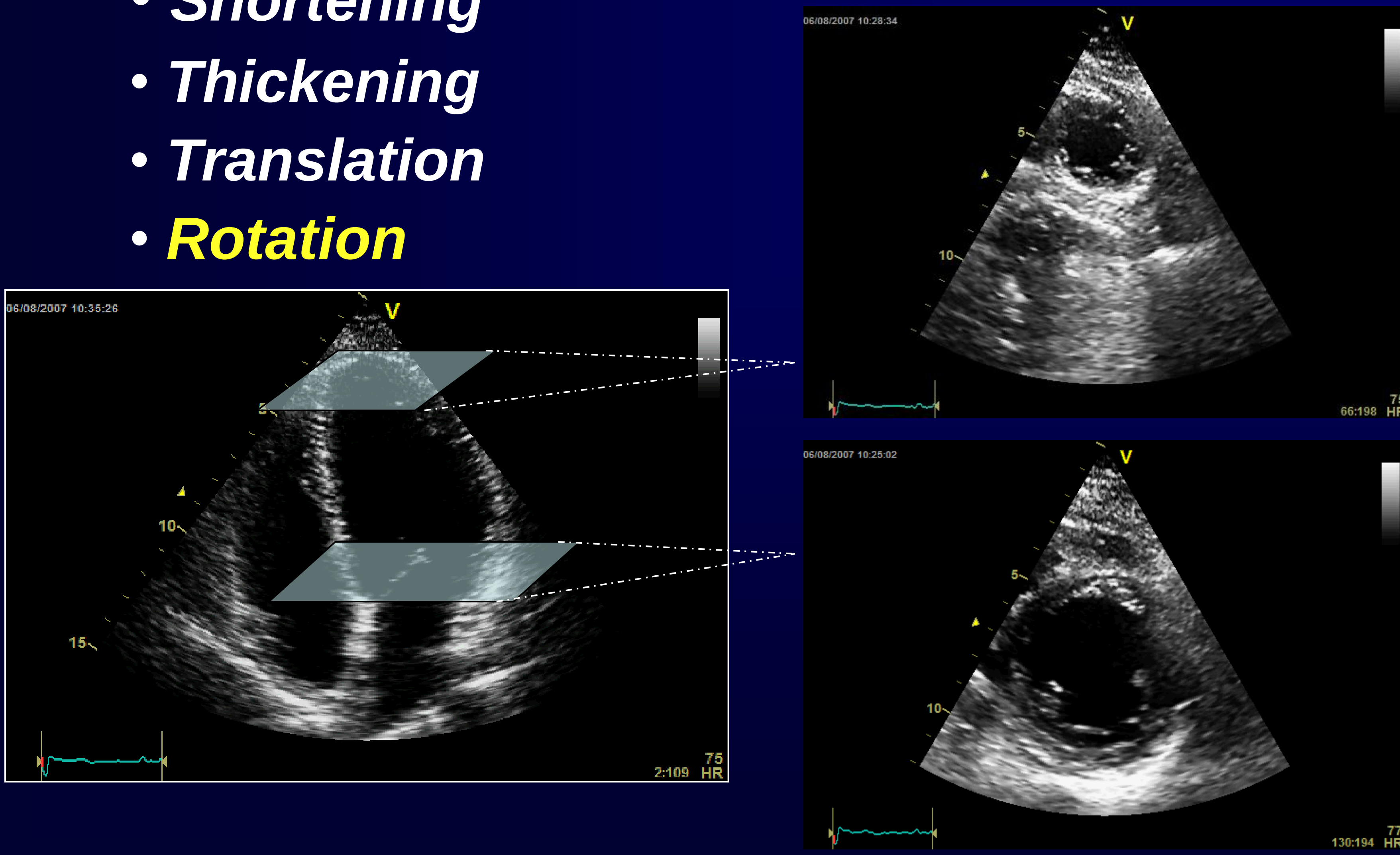
Agenda

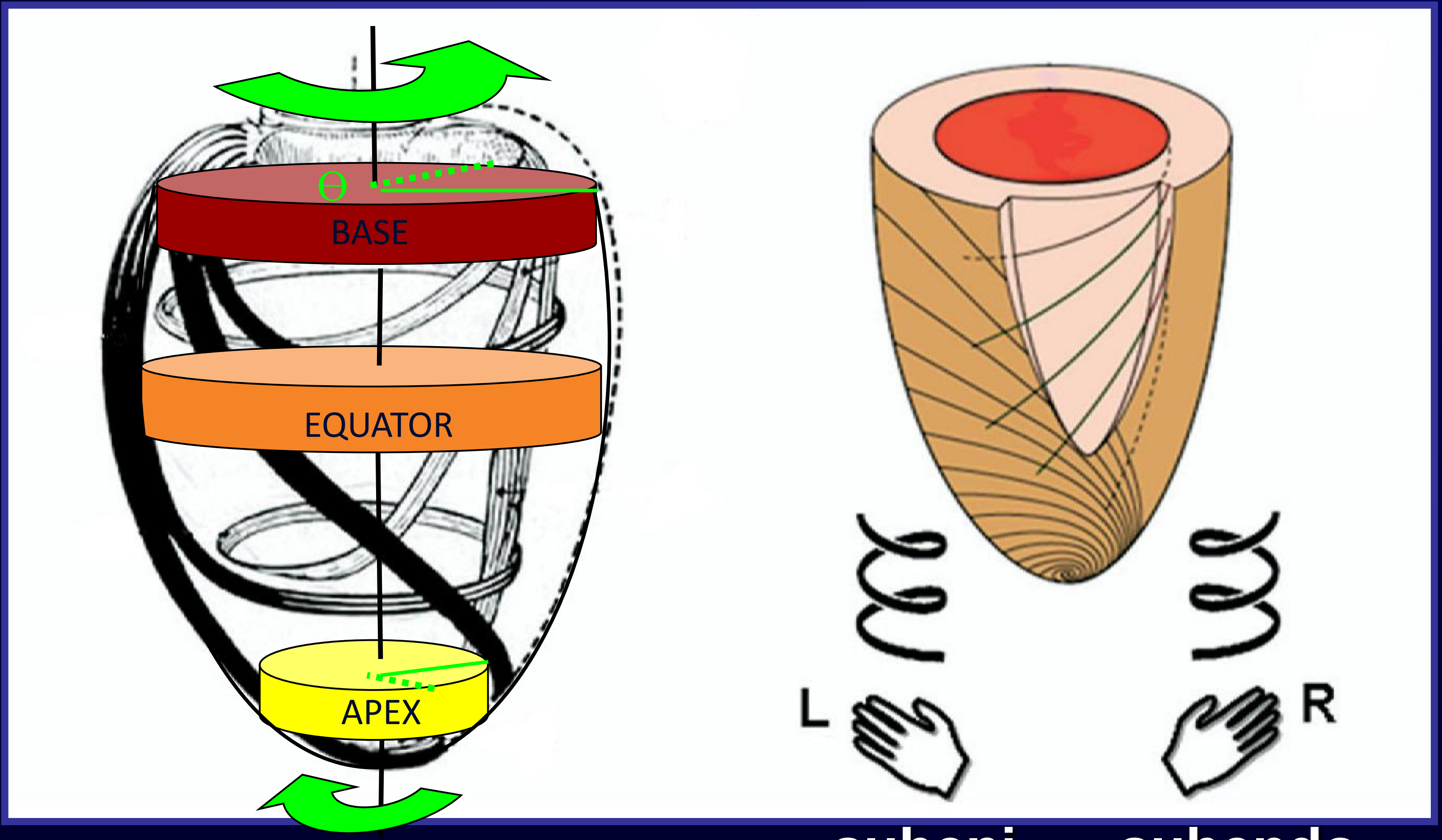
- Anatomical background
- Physiological implications
- Validation and technical issues
- Pathological implications

LV: complex motion pattern

- ***Shortening***
- ***Thickening***
- ***Translation***
- ***Rotation***

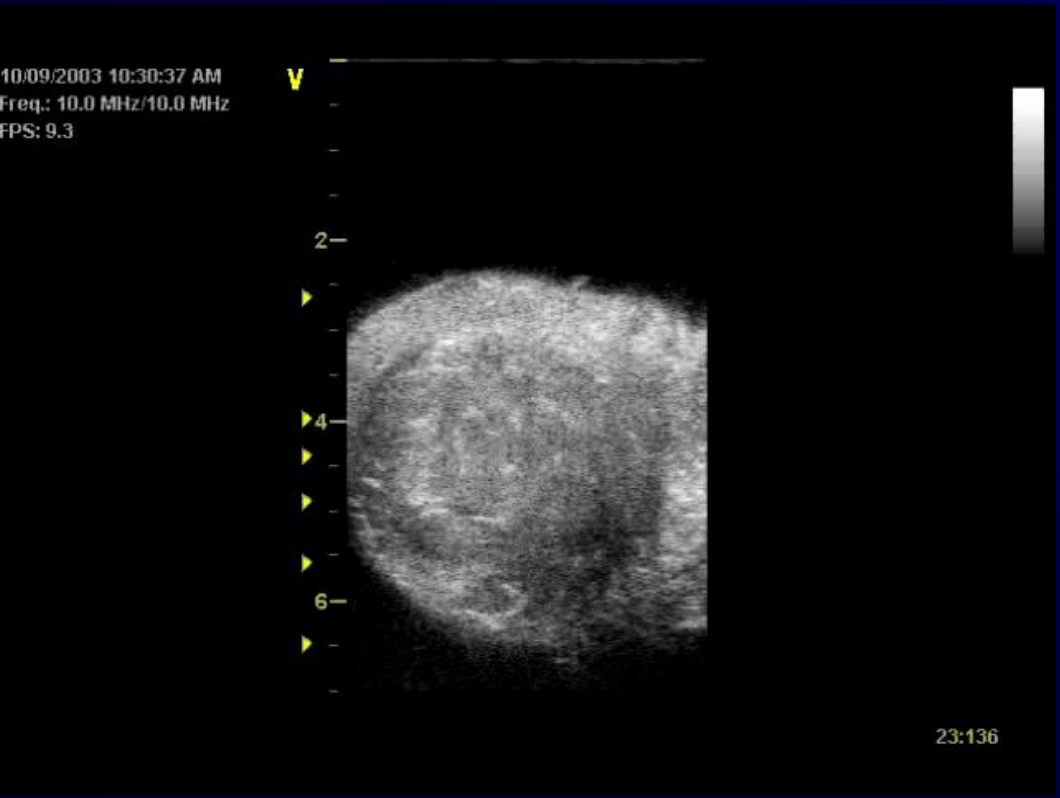


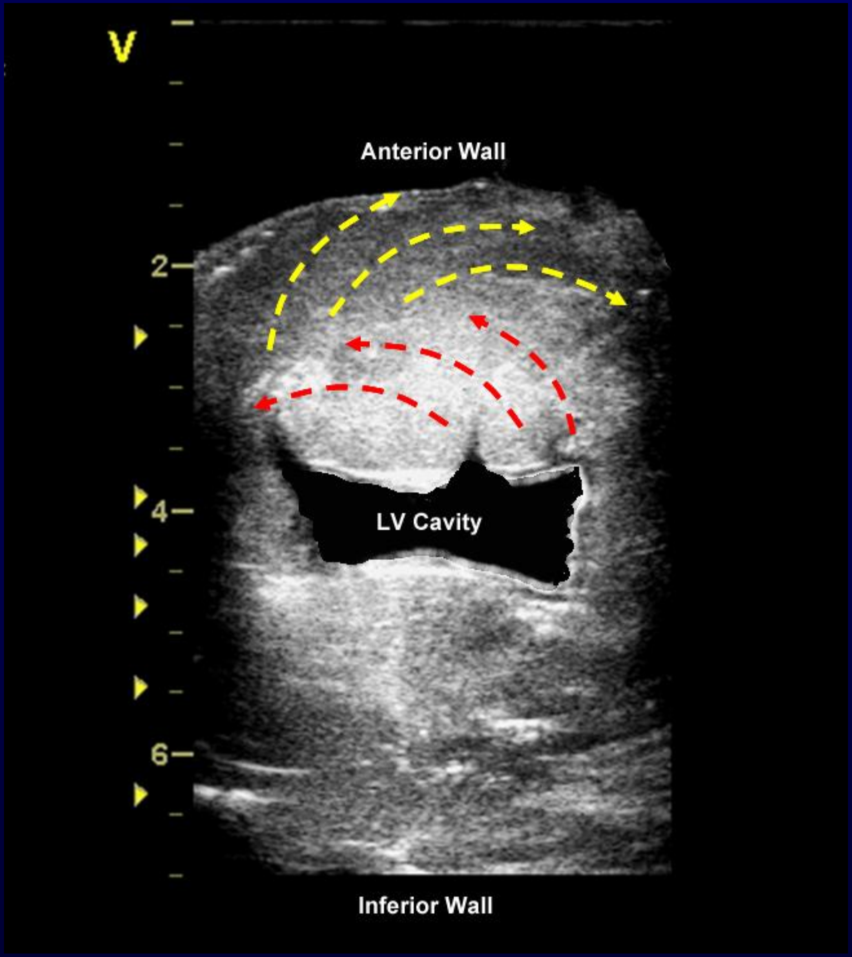
Left ventricular torsion



subepi subendo

Myocardial fiber arrangement





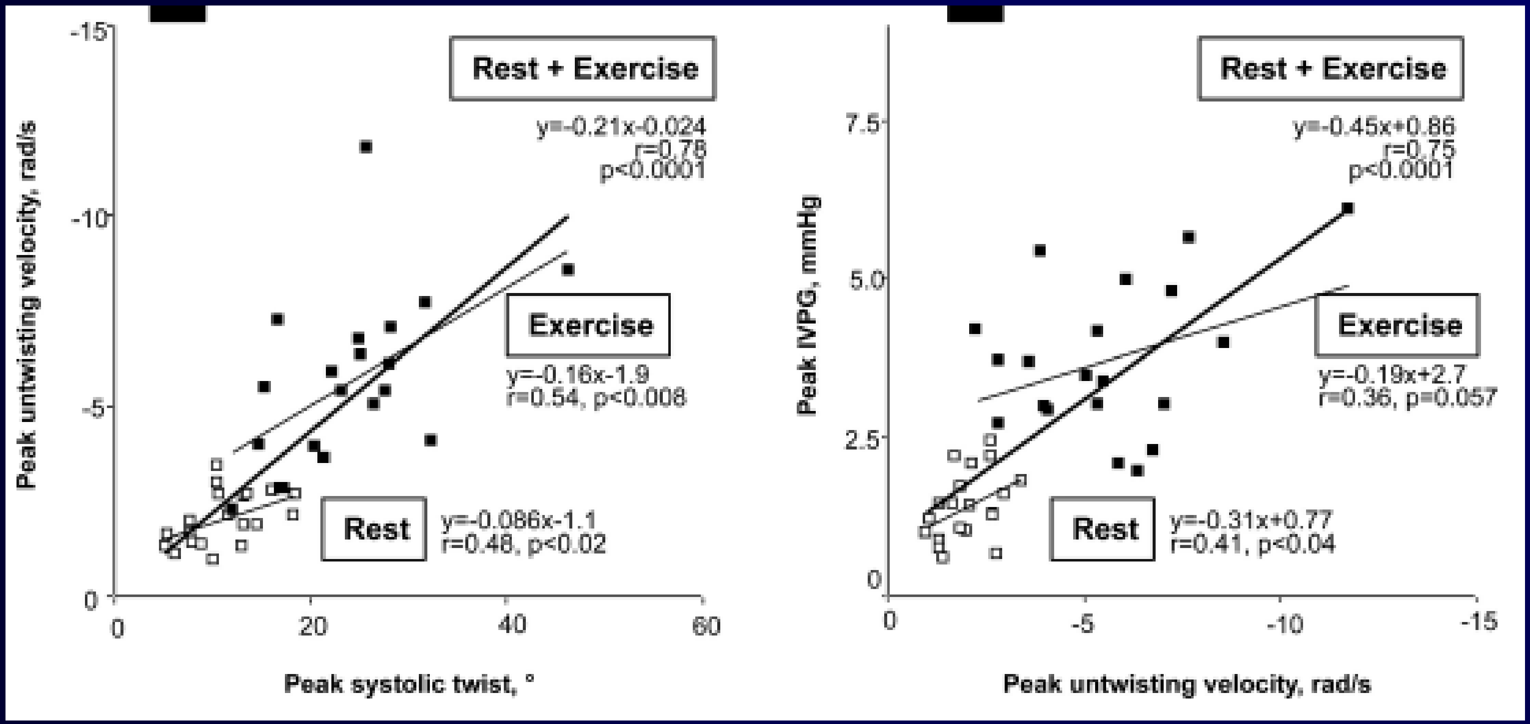
Sengupta PP *et al*. *J Am Coll Cardiol* 2006

Importance of cardiac torsion

- **Torsion helps bring a uniform distribution of LV fiber stress and fiber shortening across the wall, increasing the efficiency of LV contraction - *role in ejection***

- **Fiber twisting and shearing deform the matrix and result in storage of potential energy, which is subsequently utilized for diastolic recoil - *role in filling***

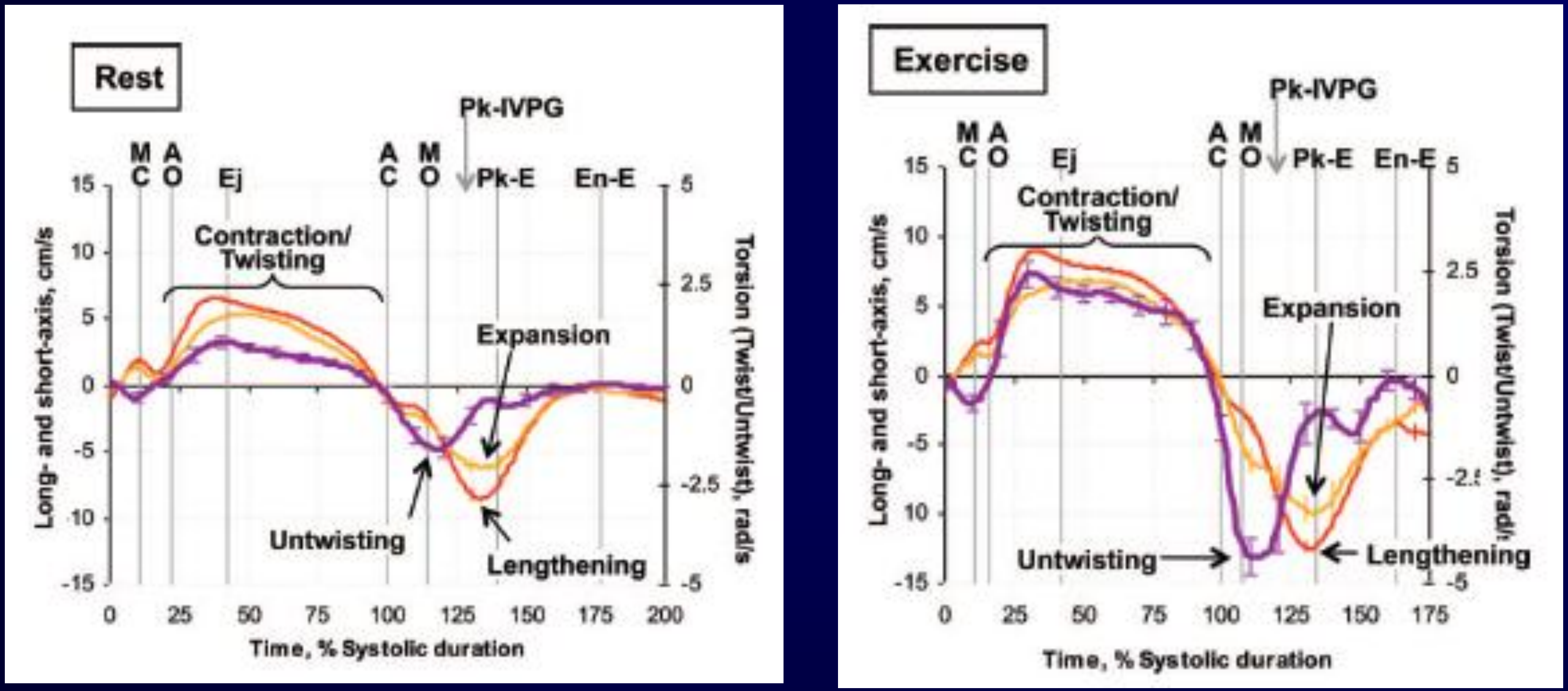
Arts T et al. *Am J Physiol* 1982
Sengupta PP et al. *J Am Coll Cardiol Imaging* 2008



- LV untwisting appears to be linked temporally with early diastolic base-to-apex pressure gradients, enhanced by exercise, which may assist efficient LV filling
- Thus, LV torsion and subsequent rapid untwisting appear to be manifestations of elastic recoil, critically linking systolic contraction to diastolic filling

Notomi Y et al. *Circulation* 2006

LV twist/untwist in normals

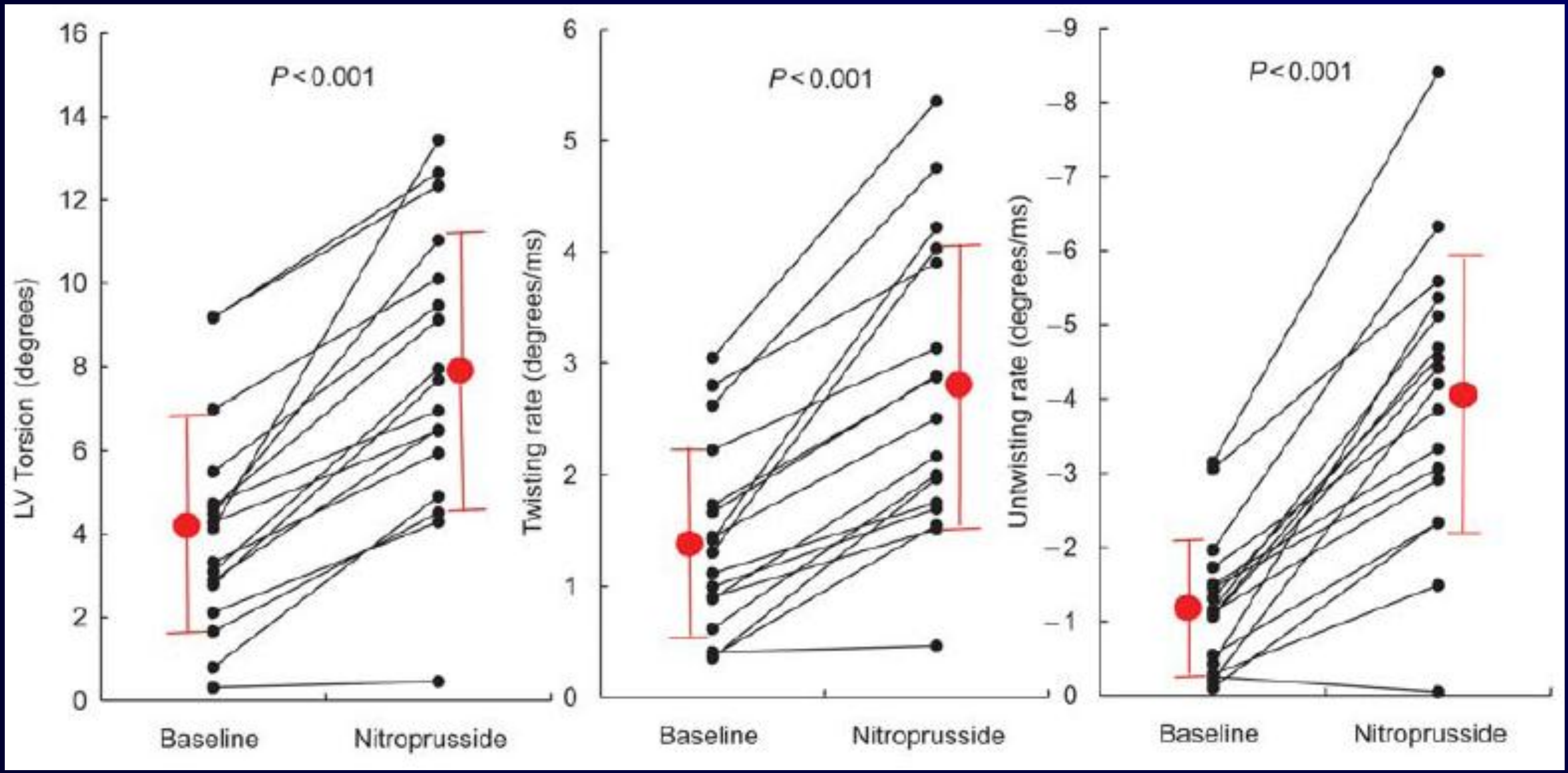


LV untwisting precedes both long-axis lengthening and short-axis expansion.

During exercise, the LV untwisting velocity was markedly enhanced, keeping the temporal sequence in early diastole.

Notomi Y et al. *Circulation* 2006

LV torsion – load dependence



- **LV torsion, TRs, and UTRs are all enhanced in the setting of drug-induced vasodilation, indicating substantial load dependence.**

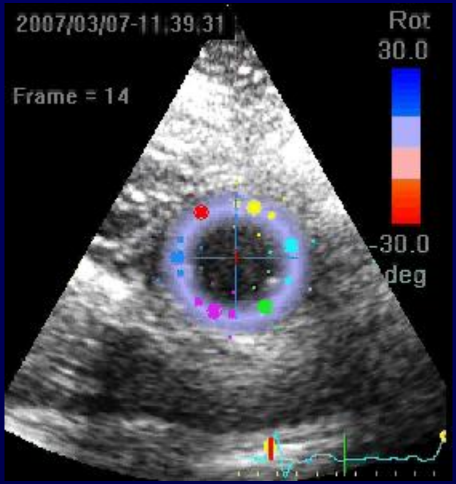
Park SJ et al. *Eur J Echocardiogr* 2010

How can LV rotation be assessed?

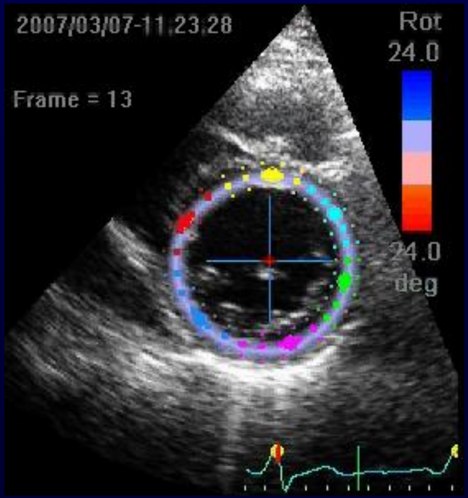
- **Sonomicrometry**
  - *invasive, epicardial radio-opaque markers*
- **Tagging MRI**
  - *limited availability*
- **Tissue Doppler**
  - *angle-dependency*
- **Speckle tracking**

Left ventricular torsion

= rotation (rot) of the apex relative to the base



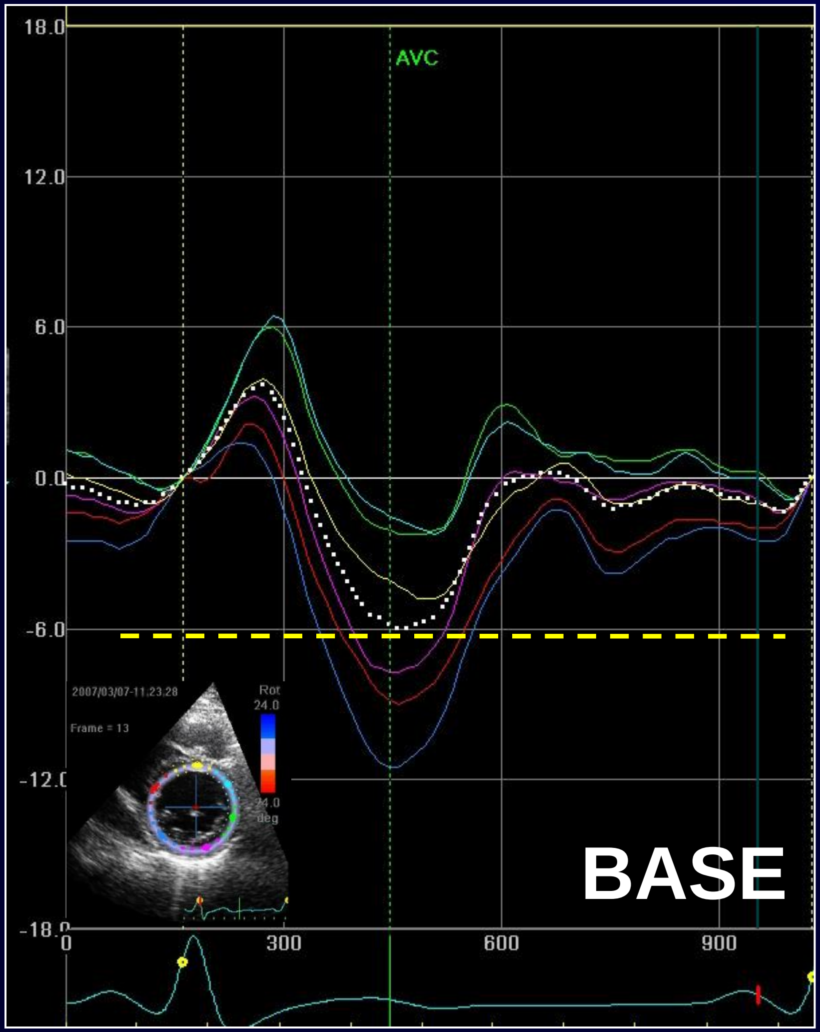
- *Apex:* counterclockwise (+)
- *Base:* clockwise (-)

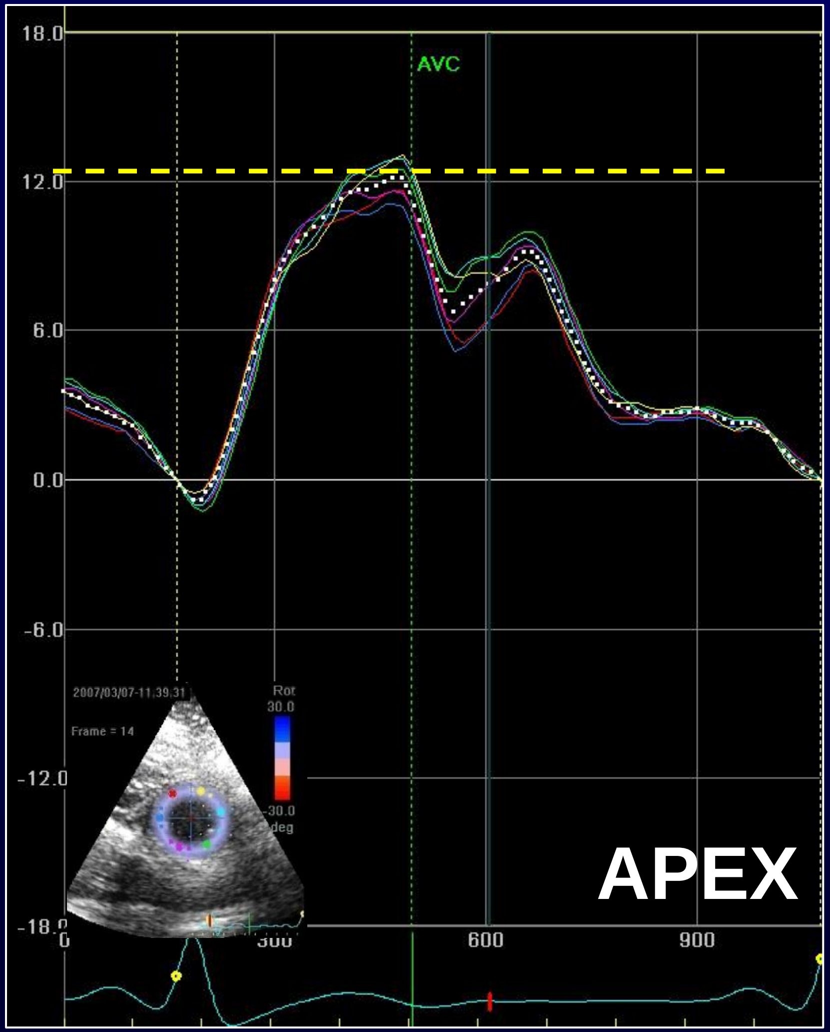


Twist (º) = apical rot – basal rot

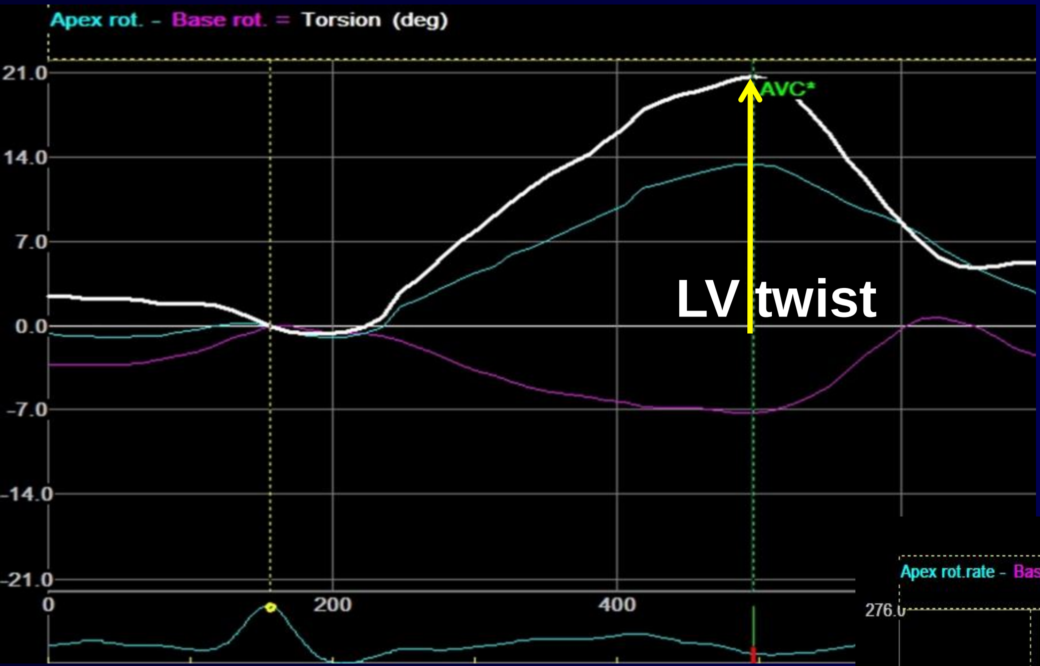
$$\textbf{Torsion (º/cm)} = \frac{\text{Twist}}{\text{Apex-to-base length}}$$

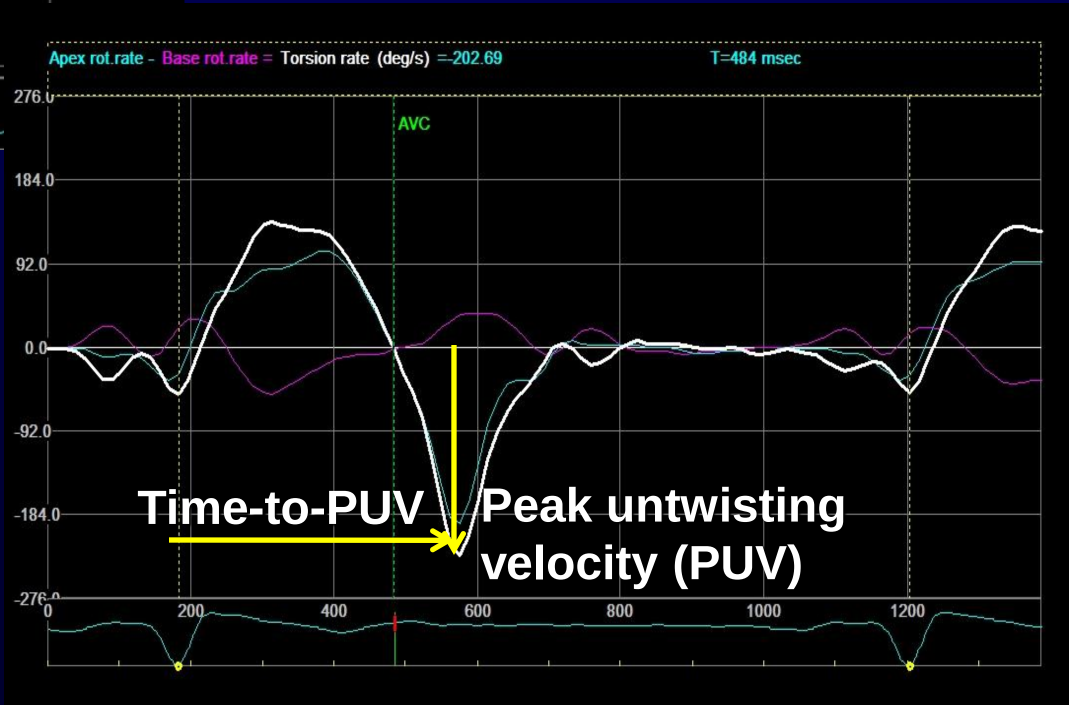
Rotation vs time plots





Temporal sequence of LV twist / untwist



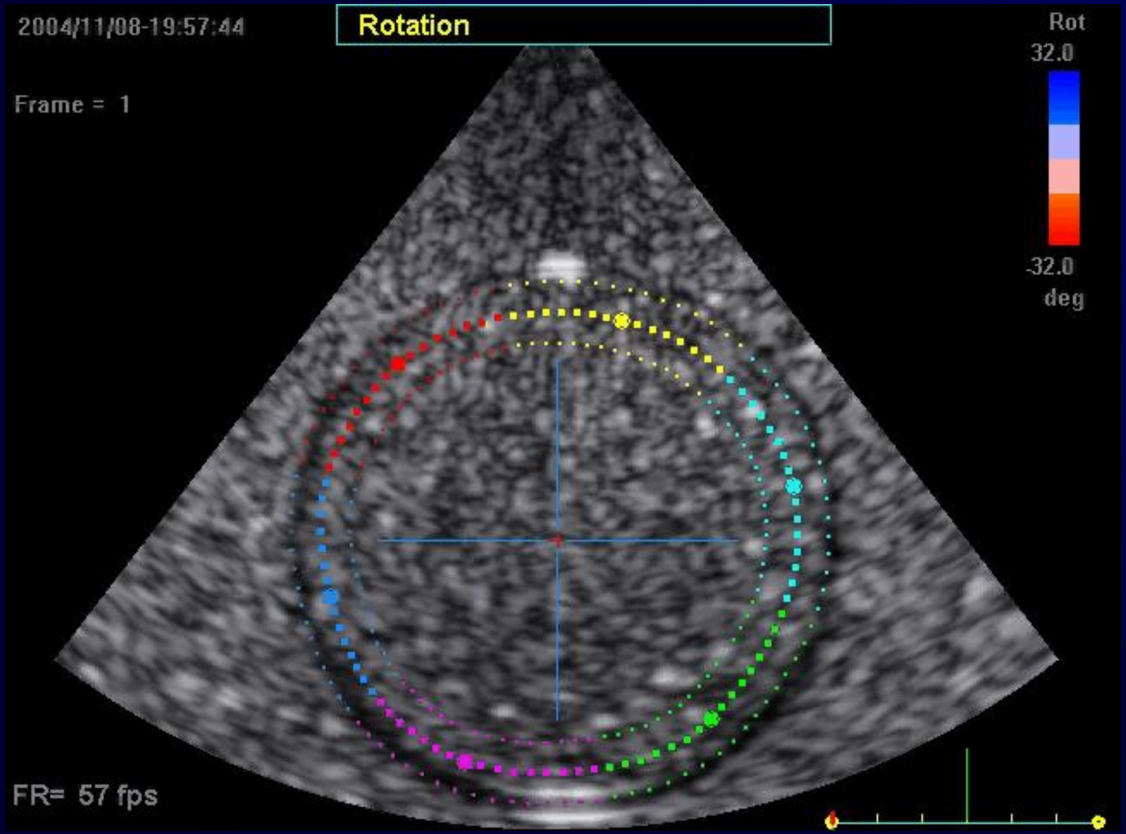


Base

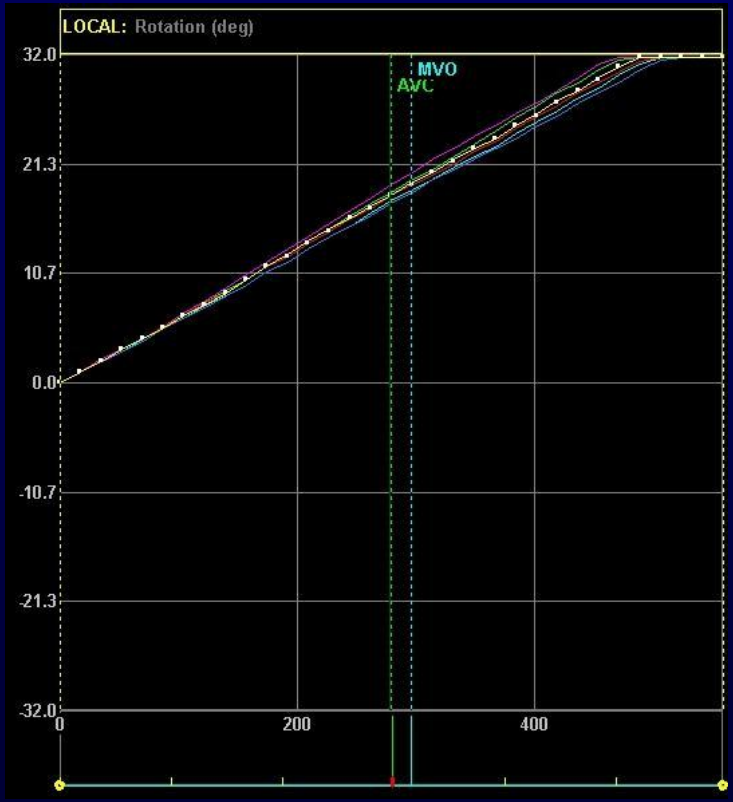
Apex

Apex-Base = Twist

Speckle Imaging Rotation Validation vs Rotating Phantom



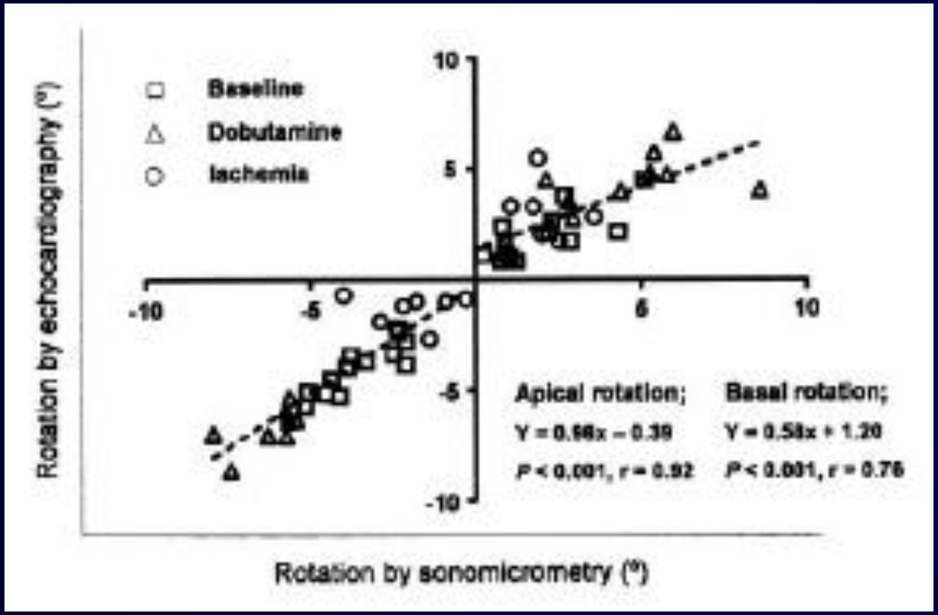
Technical validation

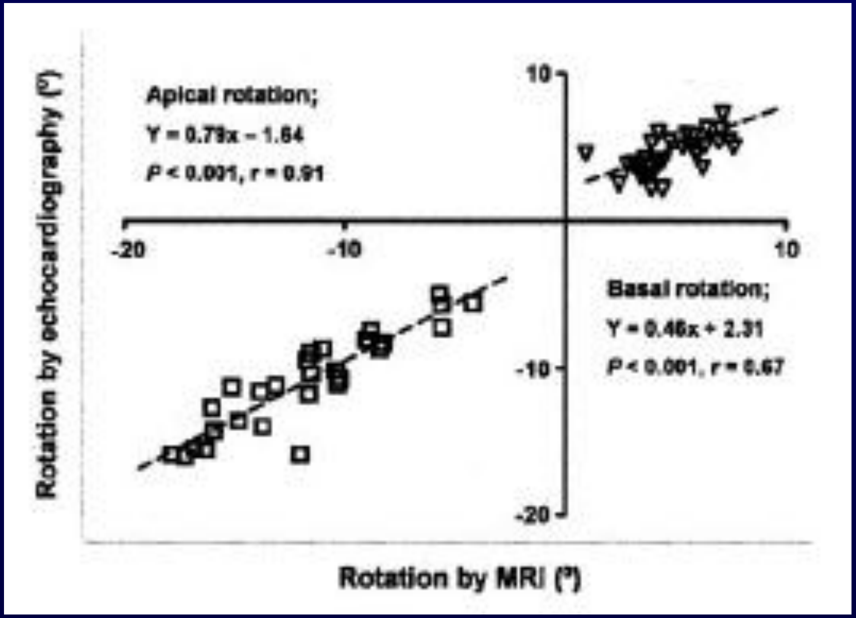


Courtesy of P. Lysyansky

LV rotation by STE : validation

Clinical validation





Experimental data (13 dogs)

Clinical data (29 normal subjects)

Helle-Valle T et al. *Circulation* 2006.

STE vs MR: Impact of missing the true apex

- 43 pts with various pathologies, 56±14 years (22–84)
- 2D-STE vs tagging MR

Apical rotation measured by 2D-STE significantly underestimated that measured by tagging MR

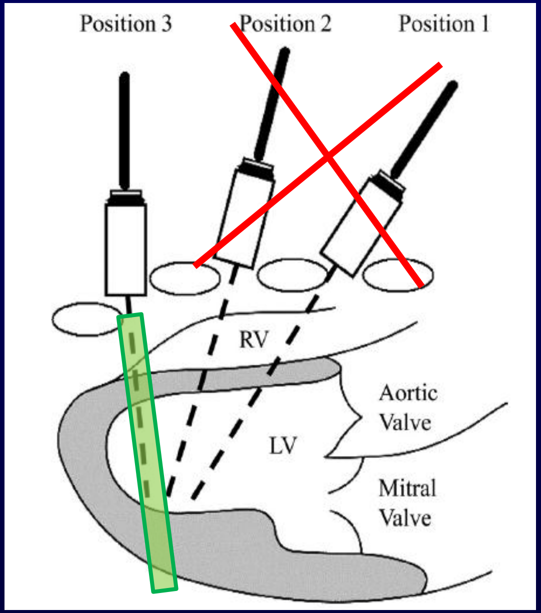
Underestimation of apical rotation by 2D-STE is probably not related to intrinsic inaccuracies of this technique, but rather to its inability to image the true LV apex *(achieved in only 10% pts in this study!)*

Goffinet C et al. *Eur Heart J* 2009

LV torsion and its correlates in normals

N = 100	
Age (years)	r = 0.4, p < 0.0001
LVESD (mm)	r = -0.3, p = 0.004
EF (%)	r = 0.3, p = 0.002
LAVi (ml/m²)	r = 0.3, p = 0.003
Vp (cm/s)	r = 0.3, p = 0.003
E/Vp	r = -0.4, p = 0.003

Popescu BA et al.



Van Dalen BM, et al. *JASE* 2008

LV torsion by STE: clinical studies

Although conceptually simple,
torsion is more complex in practice

Table 1 Reported Values for Torsion in Normals of Similar Age

Author	Method	Subjects (n)	Age (yrs)	Torsion
Takeuchi et al. (9)	Speckle tracking	57	29 ± 6	6.7 ± 2.9°
Notomi et al. (8)	DTI	10	28 ± 3	8.7 ± 2.7°
Neilan et al. (10)	Speckle tracking	17	37 ± 9	10 ± 4°
Notomi et al. (3)	DTI	20	34 ± 7	11 ± 4°
Halle-Valle et al. (11)	Speckle tracking	29	33 ± 6	14.5 ± 3.2°

DTI = Doppler tissue imaging.

Wide variability in the reported values
for resting systolic torsion

Weyman AE. *J Am Coll Cardiol* 2007

Physiological variables affecting LV twist/untwist

Table 1. Physiological Variables Influencing Left Ventricular Twist Mechanics

Physiological Variables	Twist	E_r
Increasing preload (35–37)	↑	↓
Increasing afterload (35–37)	↓	↓*
Increasing contractility (9,36,38,39)	↑	↑
Exercise (40)	↑	↑
Increasing age (33,34)	↑	↓*

Numbers in parentheses correspond to the reference number in the References list. *Delayed onset of untwisting.
↓ = reduced; ↑ = increased; E_r = early diastolic untwisting velocity.

Sengupta PP et al. *J Am Coll Cardiol Imaging* 2008

Exercise

- Short-term exercise can almost double LV twisting and untwisting (by augmented rotation that stores additional potential energy released for improving diastolic suction)

- Long-term exercise training may reduce the values of resting LV twist (and increased torsional reserves are being used in high-demand situations)

- With advancing age, the higher resting torsion is associated with attenuation of torsional reserve at peak exercise

Neilan TG et al. *J Am Soc Echocardiogr* 2006
Notomi Y et al. *Circulation* 2006
Notomi Y et al. *Am J Physiol Heart Circ Physiol* 2008
Zocalo Y et al. *Conf Proc IEEE Eng Med Biol Soc* 2007
Burns AT et al. *J Am Soc Echocardiogr* 2007

Apical rotation and LV function

- Both LV twist and apical rotation are more closely related to LV dP/dt_{max} than LV EF after ligation of either LAD or LCx artery

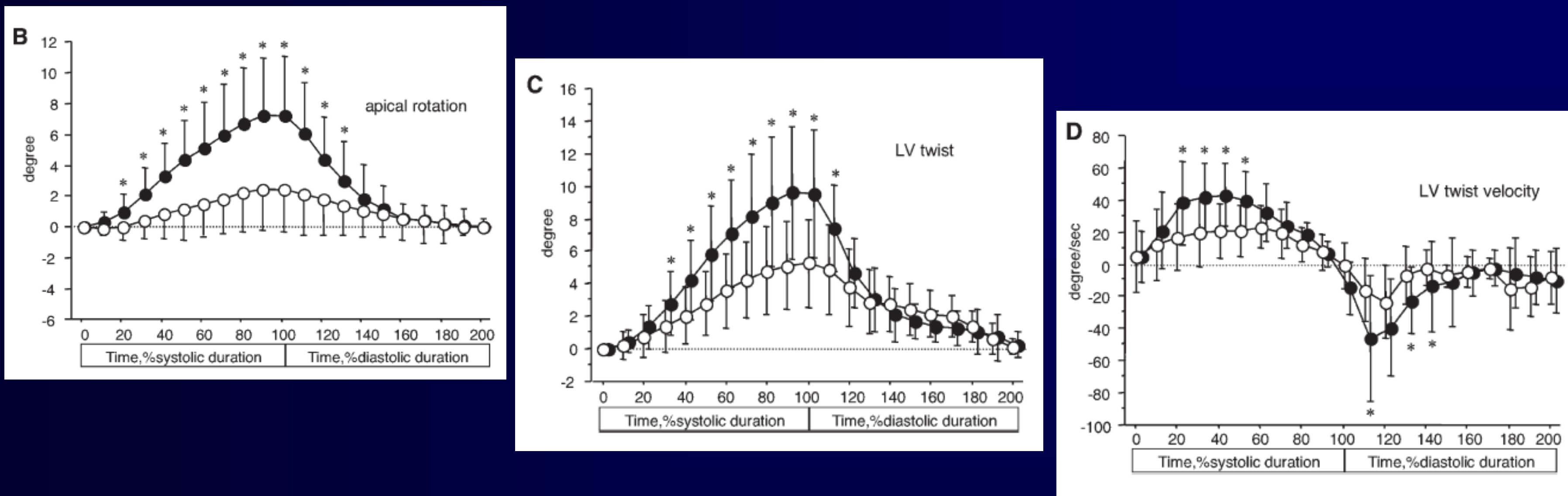
- Apical rotation by STE correlated well with LV twist over a wide range of loading conditions and inotropic states, and during myocardial ischemia

- Apical rotation measurement by STE is an effective noninvasive index of global LV contractility

Opdahl A et al. *J Am Soc Echocardiogr* 2008
Kim WJ et al. *Circ Cardiovasc Imaging* 2009

Anterior myocardial infarction

30 pts with old anterior MI (>1 mo): 2 groups (LVEF ≥ 45%; < 45%)



LV apex is the main determinant of LV torsion and untwisting both in normal and diseased hearts

Takeuchi M et al. ***J Am Soc Echocardiogr*** **2007**

Exercise echo in HFNEF

In HFNEF - widespread abnormalities of both LV systolic and diastolic function that become more apparent on exercise:

- **At rest *lower values* of**
  - **Longitudinal and radial strain**
  - **Apical rotation**
  - **Reduced and delayed untwisting**
  - **Mitral annular velocities**

Correlated with peak VO_{2max}

- **At exercise, all parameters failed to normalize**

HFNEF is not an isolated disorder of diastole

Tan YT. *J Am Coll Cardiol* 2009

Aortic stenosis

	Controls (n=40)	AS (n=61)	p value
Peak apical rotation (°)	15.7±5.9	21.0±7.6	<0.001
Peak basal rotation (°)	-6.2±2.9	-6.7±3.2	0.4
Twist (°)	20.8±6.8	26.5±9.1	0.001
LV twist rate (°/s)	118±35	137±55	0.006
Peak systolic torsion (°/cm)	2.7±0.9	3.4±1.3	0.002
LV peak untwisting rate (°/s)	-143±48	-158±59	0.18
Time to peak untwisting rate	1.23±0.09	1.21±0.08	0.2
LV peak apical back rotation rate (°/s)	-93±47	-115±55	0.04
Time to peak apical back rotation rate	1.19±0.12	1.25±0.1	0.015
LV peak basal back rotation rate (°/s)	64±20	70±23	0.18
Time to peak basal back rotation rate	1.21±0.09	1.20±0.11	0.8

Popescu BA et al. *Eur J Echocardiogr* 2010

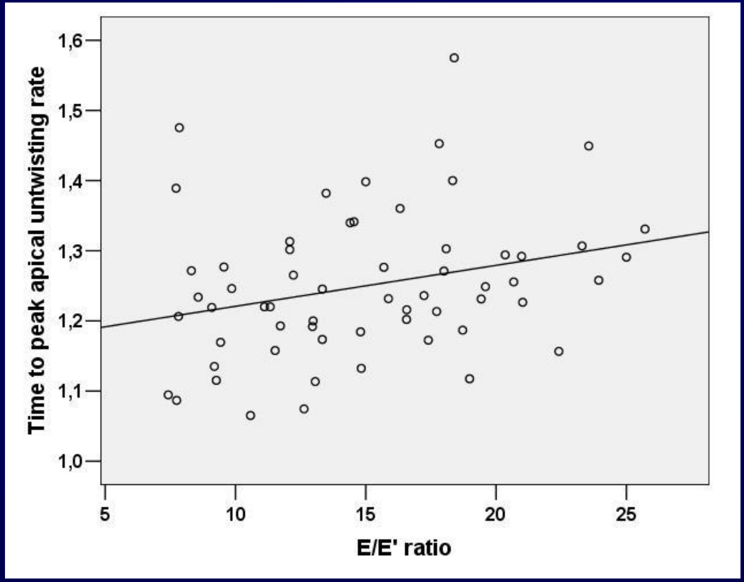
Aortic stenosis

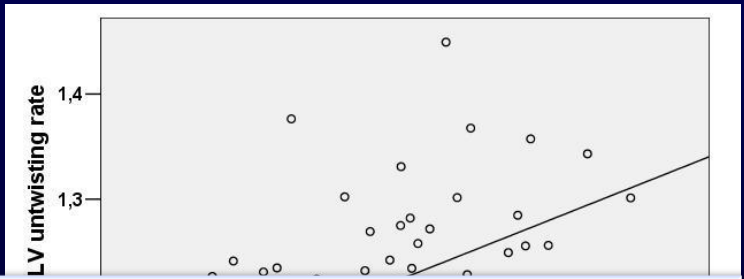
Time to peak LV untwisting rate and time to peak apical back rotation rate were significantly related to:

- E/E' ratio

- Indexed LA volume

- BNP levels (p<0.04 for all)





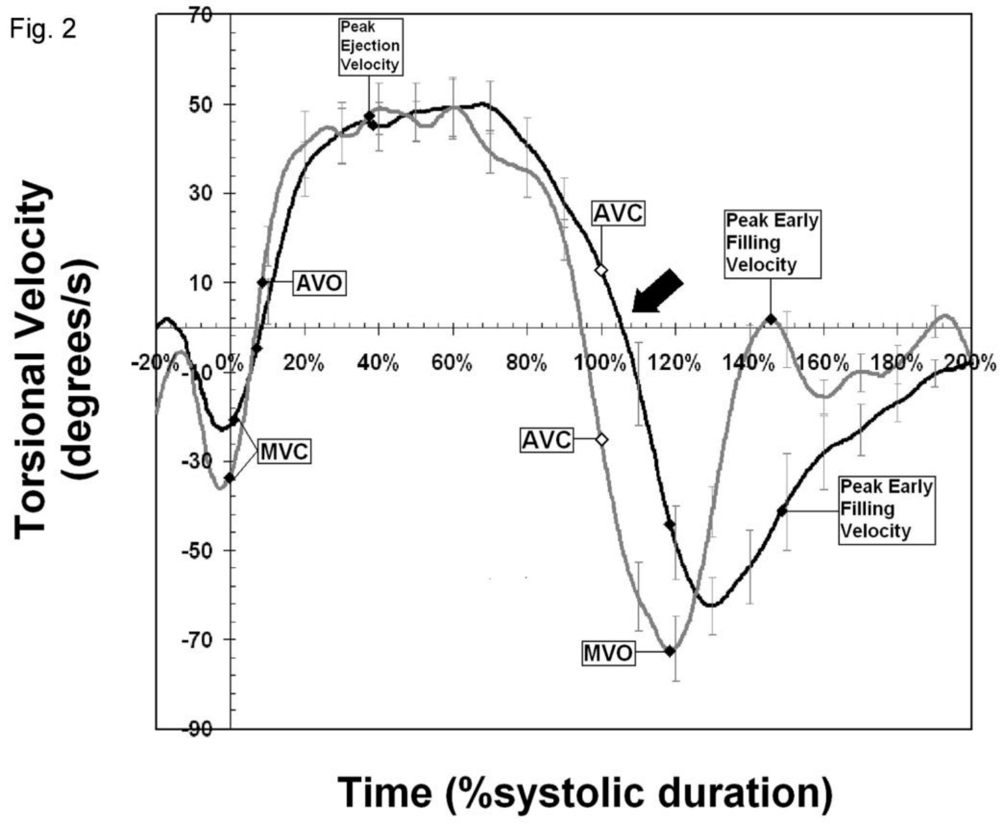
In patients with severe AS and preserved LVEF there is a significant relationship between delayed LV untwisting and increased filling pressures, suggesting a role for impaired LV untwisting in the pathophysiology of diastolic dysfunction in AS

Popescu BA et al. *Eur J Echocardiogr* 2010

LV torsion by STE in mitral regurgitation

- 38 pts with mod–severe MR (MVP) vs 30 controls
- LV remodeling and MR degree correlated with:

Fig. 2



- reduced LV torsion
- reduced untwisting velocity
- delayed onset of untwisting

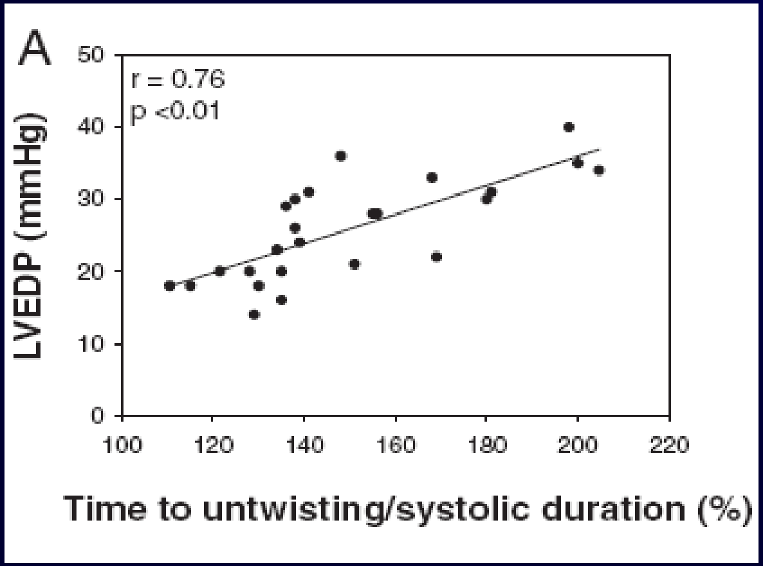
Borg A, et al. *Heart* 2008

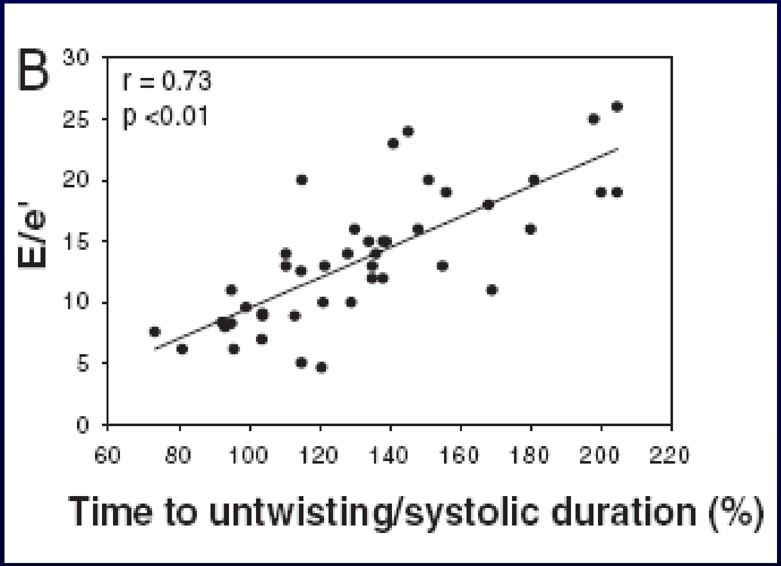
Obstructive HCM (HOCM)

- **Twist and untwisting rate not different from controls**

- **Untwisting was delayed in HCM (*in HOCM more than in HCM*) and correlated with LVFP, reduced LV volumes and V02$_{max}$**

- **Septal reduction improved the LV untwisting, increased LVEDV and V02$_{max}$**

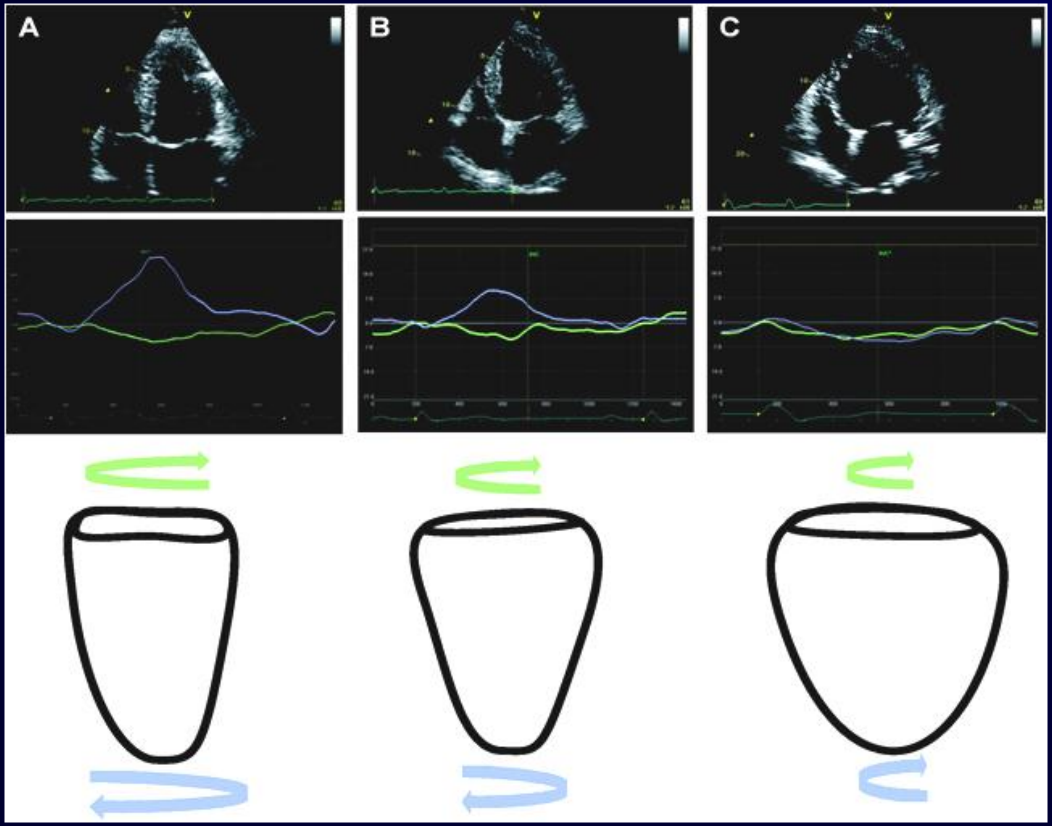




Wang J et al. *J Am Coll Cardiol* 2009

Dilated cardiomyopathy

• **LV systolic rotation at both basal and apical levels and LV torsion are significantly reduced in pts, compared to controls (A)**



• **2 different patterns of apical rotation:**

- **normally directed**

(B - counterclockwise)

- **reversed**

(C - clockwise)

Popescu BA et al. *Eur J Heart Failure* 2009

Dilated cardiomyopathy

	DCM (+) (n=24)	DCM (-) (n=26)	p value
Men, n (%)	18 (75)	23 (88)	0.2
Age (years)	51 (13)	48 (13)	0.4
QRS duration (ms)	114 (33)	147 (38)	0.004
Mitral regurgitation degree (0-3)	1.3 (0.8)	1.8 (0.8)	0.03
LVEDV (ml/m^2)	107 (44)	148 (66)	0.01
LVESV (ml/m^2)	75 (40)	110 (51)	0.01
LV sphericity index	1.64 (0.19)	1.51 (0.20)	0.02
LV mass (g/m^2)	173 (48)	213 (72)	0.02
LVFS (%)	18 (6)	14 (5)	0.01
LVEF (%)	33 (12)	26 (7)	0.02
Peak E' (cm/s)	5.6 (1.9)	4.4 (1.7)	0.04
E/E' ratio	14 (6)	19 (10)	0.04

Dilated cardiomyopathy

Reversed apical rotation and loss of LV torsion in pts with DCM is associated with:

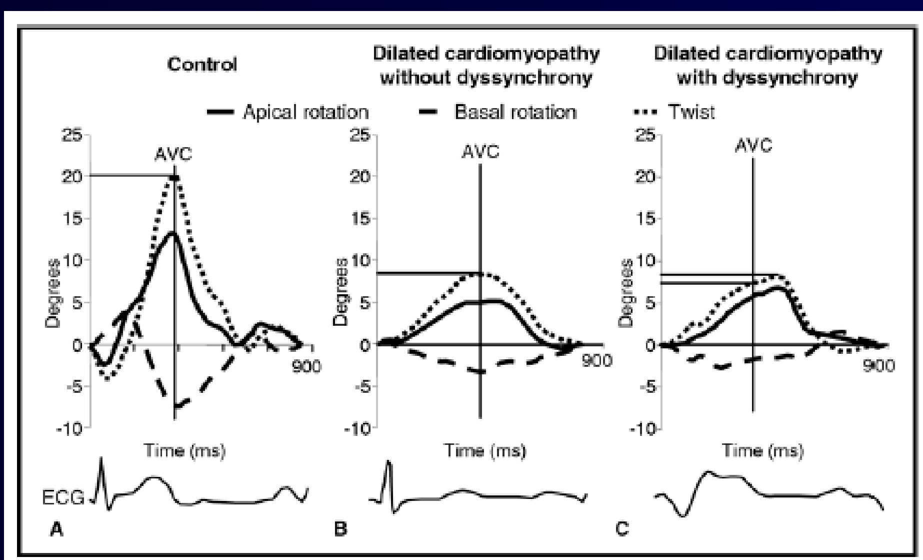
- **significant LV remodeling**
- **increased electrical dyssynchrony**
- **reduced systolic function**
- **increased filling pressures**

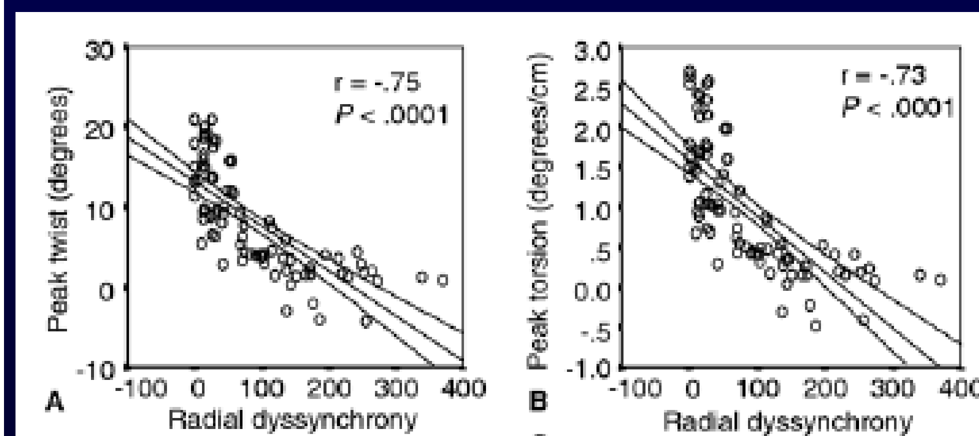
Indicating a more advanced disease stage

Effect of Mechanical Dyssynchrony and Cardiac Resynchronization Therapy on Left Ventricular Rotational Mechanics

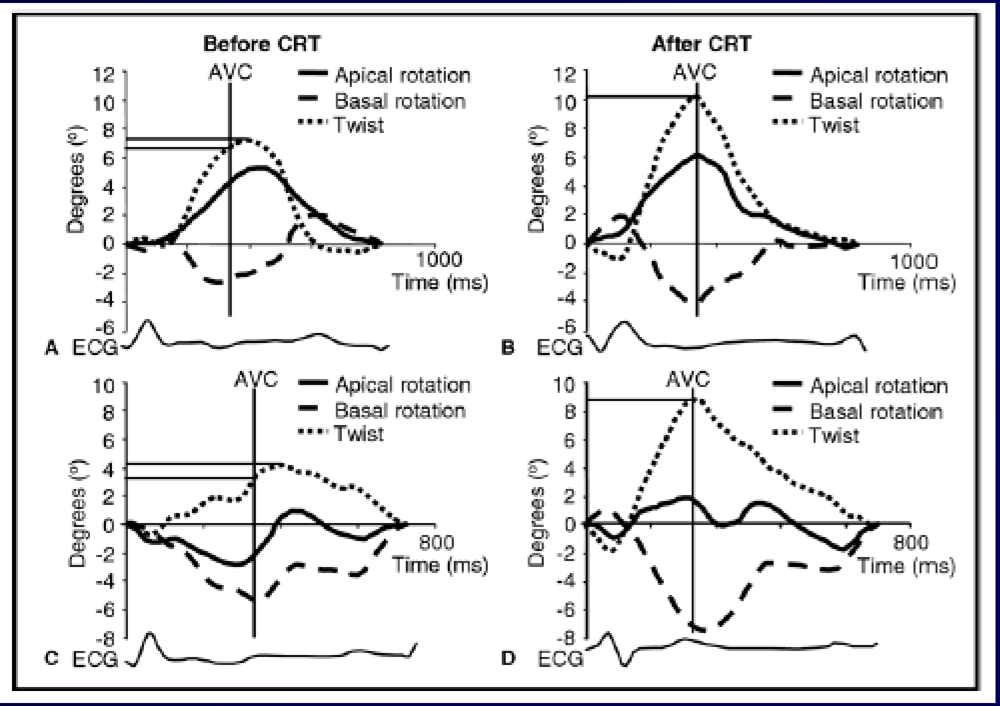
Leyla Elif Sade, MD*, Özlem Demir, MD, Ilyas Atar, MD, Haldun Müderrisoglu, MD, and Bülent Özin, MD

- **54 pts with HF; 33 underwent CRT**
- **33 control subjects**
- **Radial & Long dyssynchrony by STE**
- **Apical & Basal rotation, twist & torsion by STE**





Am J Cardiol **2008;101:1163-9.**



- **LV dyssynchrony is associated with discoordinate rotation of the apical and basal regions, which in turn significantly decreases peak LV twist and torsion.**
- **LV torsion and twist at AVC had the highest Sv (90%) and Sp (77%) to predict CRT responders among all other parameters, including radial and longitudinal dyssynchrony**

Sade LE et al. *Am J Cardiol* 2008

Current and Evolving Echocardiographic Techniques for the Quantitative Evaluation of Cardiac Mechanics: ASE/EAE Consensus Statement on Methodology and Indications Endorsed by the Japanese Society of Echocardiography

3.3. LV Rotation

Summary and Recommended Indications: Despite the growing evidence in support of clinical implications of LV twist measurements using 2D STE, routine clinical use of this methodology is not recommended at this time.

Eur J Echocardiogr **2011;12:167-205.**

Conclusions

- LV twist/untwist play an important role in LV function, in both ejection and filling
- Speckle tracking echocardiography allows the assessment of LV rotation, twist/untwist
- Standardization of acquisition and processing is essential for proper use of this technique
- Careful selection of the apical LV cut is mandatory, or else underestimation of apical rotation/twist may result
- The incremental role of these parameters in clinical decision-making needs further studies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