The Strain of Mitral Regurgitation and LV Remodeling

Karen G. Zimmerman, BS, ACS, RDCS, RVT, FASE

ASE

HAWAII
2020

1

The Strain of Mitral Regurgitation and LV Remodeling

Karen G. Zimmerman, BS, ACS, RDCS, RVT, FASE

DISCLOSURES: THE GIANTS OF STRAIN! I AM NOT WORTHY BUT WILL DO MY BEST!

ASE

HAWAII
2020

2

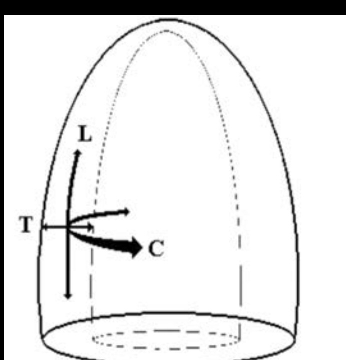
The Strain of Mitral Regurgitation and LV Remodeling

I. **Introduction**
II. **Myocardial Structure and Rotation**
III. **Strain Concepts**
  A. Basic Concepts
  B. Principles of Speckle Tracking
  C. Strain and Strain Rate by Speckle Tracking
IV. **Loading Conditions**
V. **Cellular Response**
VI. **Mitral Valve Regurgitation**
VII. **Mitral Valve Repair**
VIII. **Summary**

3

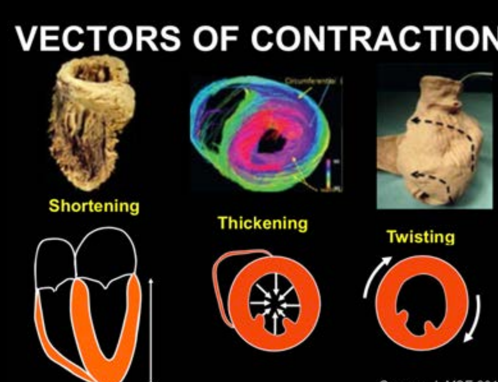
3 Dimensional heart moves in 3 directions

- **Longitudinal**
- **Circumferential**
- **Radial (transverse)**



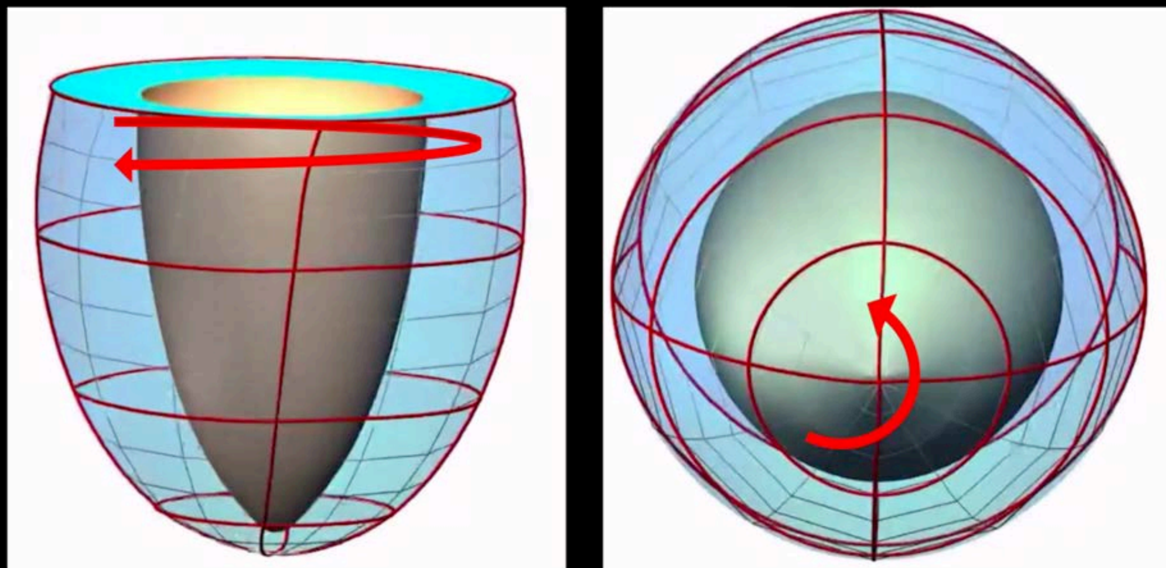
Orientation of cardiac strain along Longitudinal (L), Circumferential, and Radial (transverse, T) axes

http://folk.ntnu.no/stoylen/strainrate



4

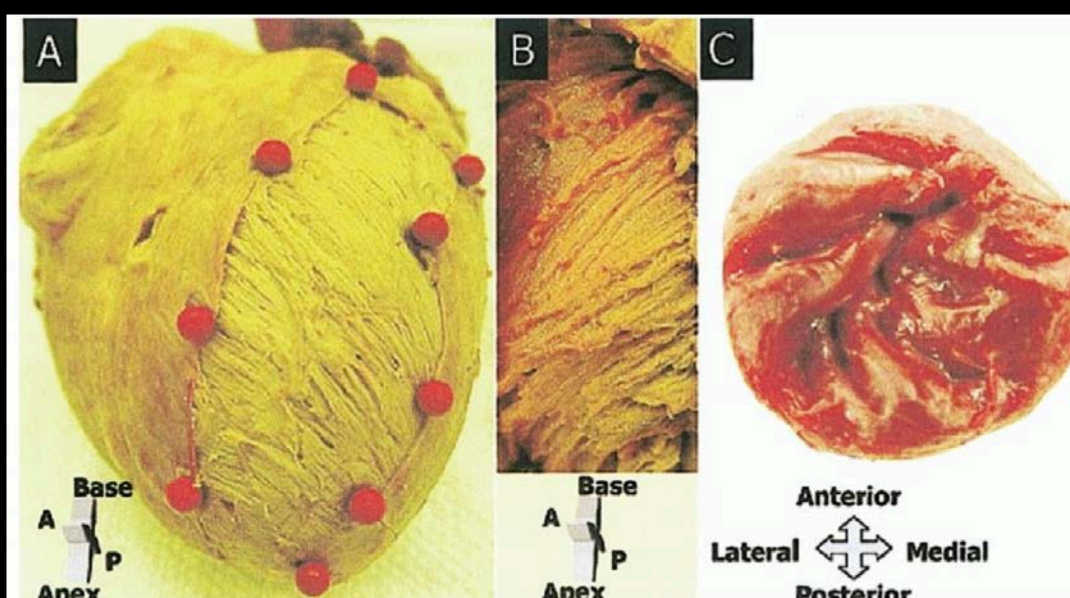
Basal clockwise rotation and apical counterclockwise



Otto CM, ed. *The Practice of Clinical Echocardiography, 5th edition.* Elsevier Saunders, Philadelphia, Pennsylvania 2016

5

3 Different fiber arrangements



Senguptka et al. Left Ventricular Structure and Function. J Am Coll Cardiol 2006;48:1988-2001

6

The Strain of Mitral Regurgitation and LV Remodeling

- I. **Introduction**
- II. **Myocardial Structure and Rotation**
- III. **Strain Concepts**
  - A. Basic Concepts
  - B. Principles of Speckle Tracking
  - C. Strain and Strain Rate by Speckle Tracking
- IV. **Loading Conditions**
- V. **Cellular Response**
- VI. **Mitral Valve Regurgitation**
- VII. **Mitral Valve Repair**
- VIII. **Summary**

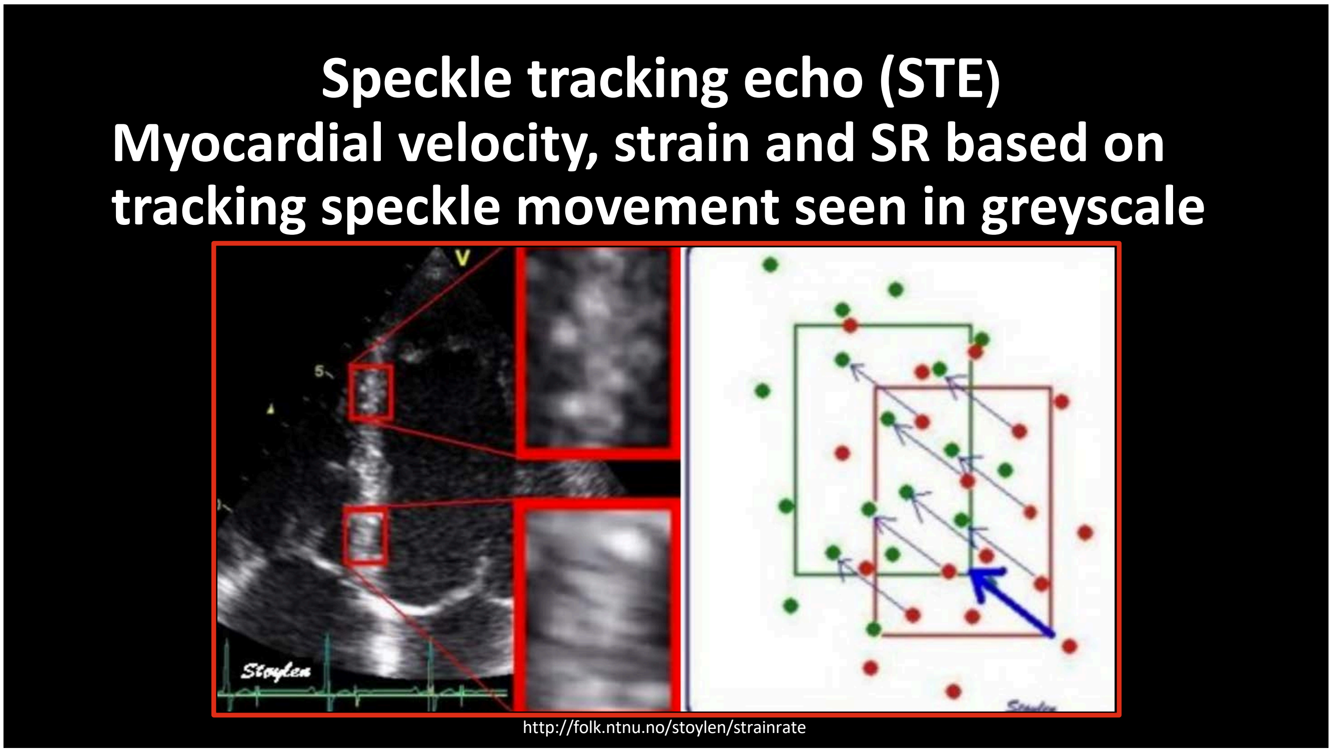
7

Strain = Deformation

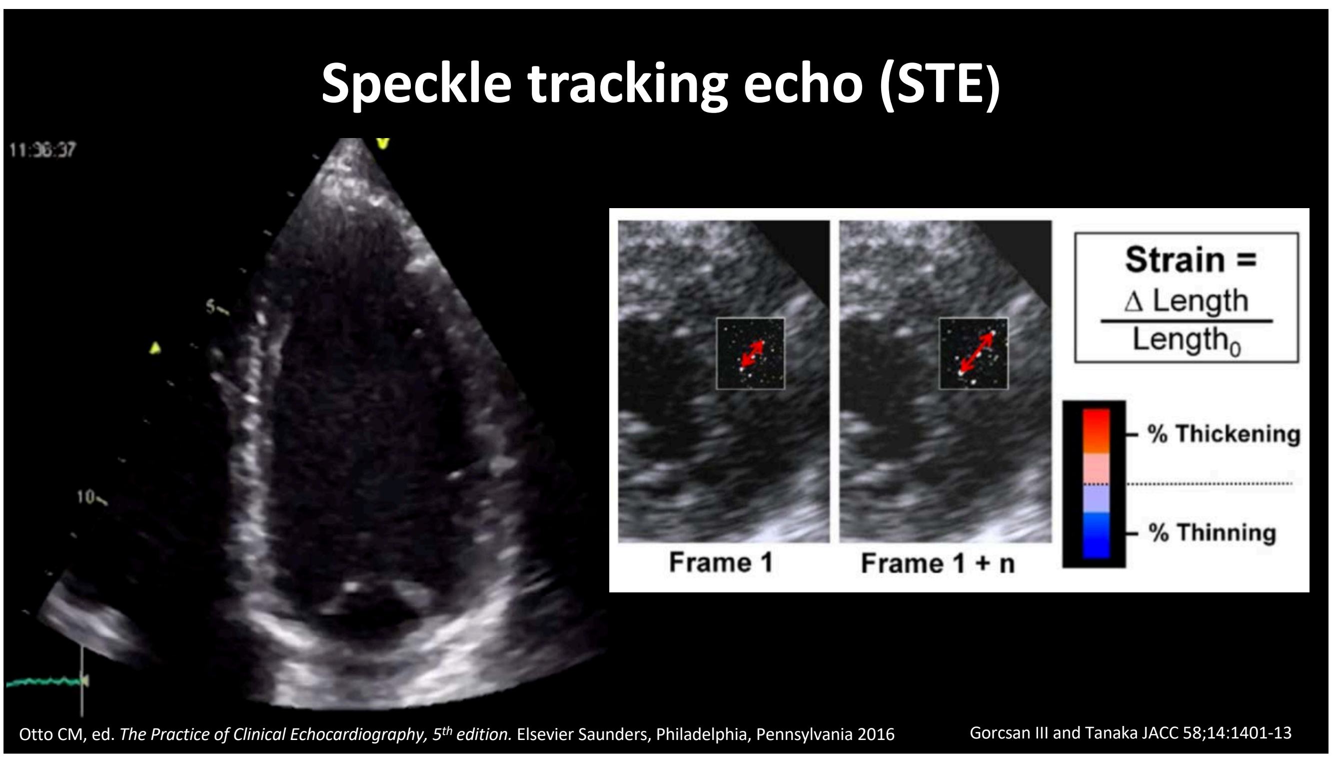
- **Along a single linear axis (stretching or lengthening)**
- **Strain is change in length *in-comparison to* initial length**
- **Strain =** $\frac{(new\ length - initial\ length)}{initial\ length}$ **or** $\frac{L-Lo}{Lo}$
- **Dimensionless**
- **Expressed as *percentage of change***
- **Angle dependent**

Ho, J Cardiac Kinetics: Taking the stress out of strain

8

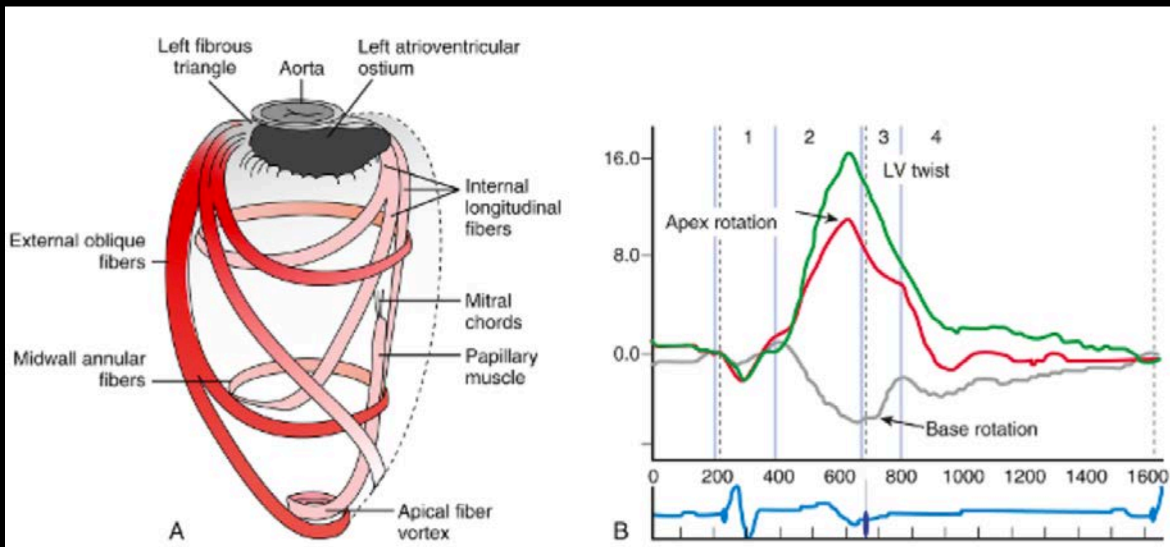

Speckle tracking echo (STE)
Myocardial velocity, strain and SR based on tracking speckle movement seen in greyscale
http://folk.ntnu.no/stoylen/strainrate

9


Speckle tracking echo (STE)
Strain = Δ Length / Length0
% Thickening
% Thinning
Frame 1
Frame 1 + n
Otto CM, ed. The Practice of Clinical Echocardiography, 5th edition. Elsevier Saunders, Philadelphia, Pennsylvania 2016
Gorcsan III and Tanaka JACC 58;14:1401-13

10

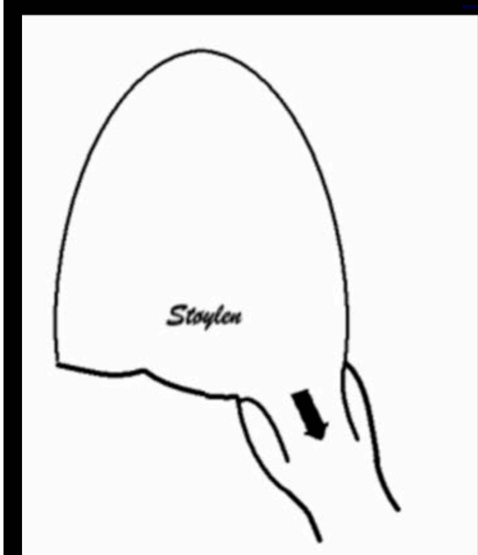
Apical rotation, LV twist and LV torsion



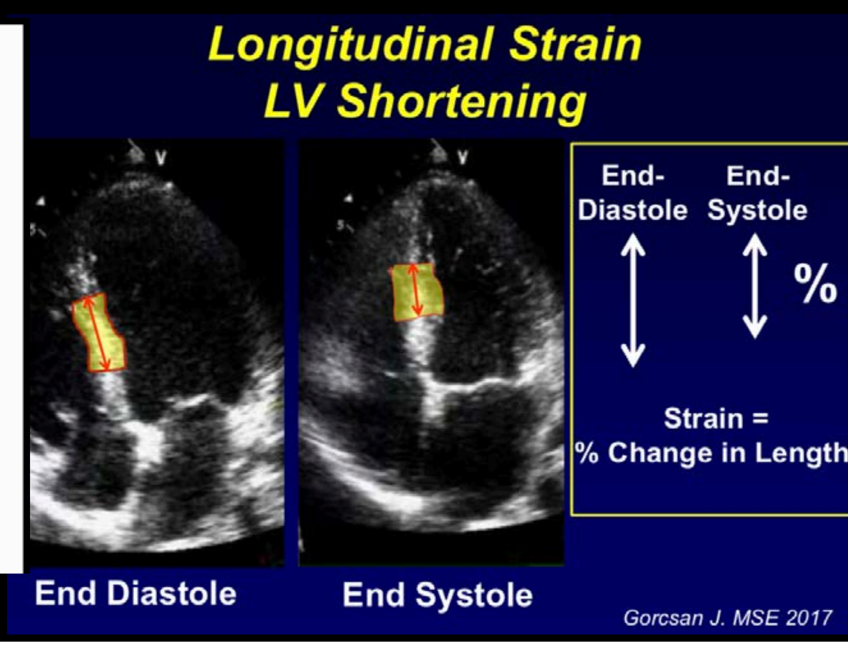
Otto CM, ed. *The Practice of Clinical Echocardiography, 5th edition.* Elsevier Saunders, Philadelphia, Pennsylvania 2016

11

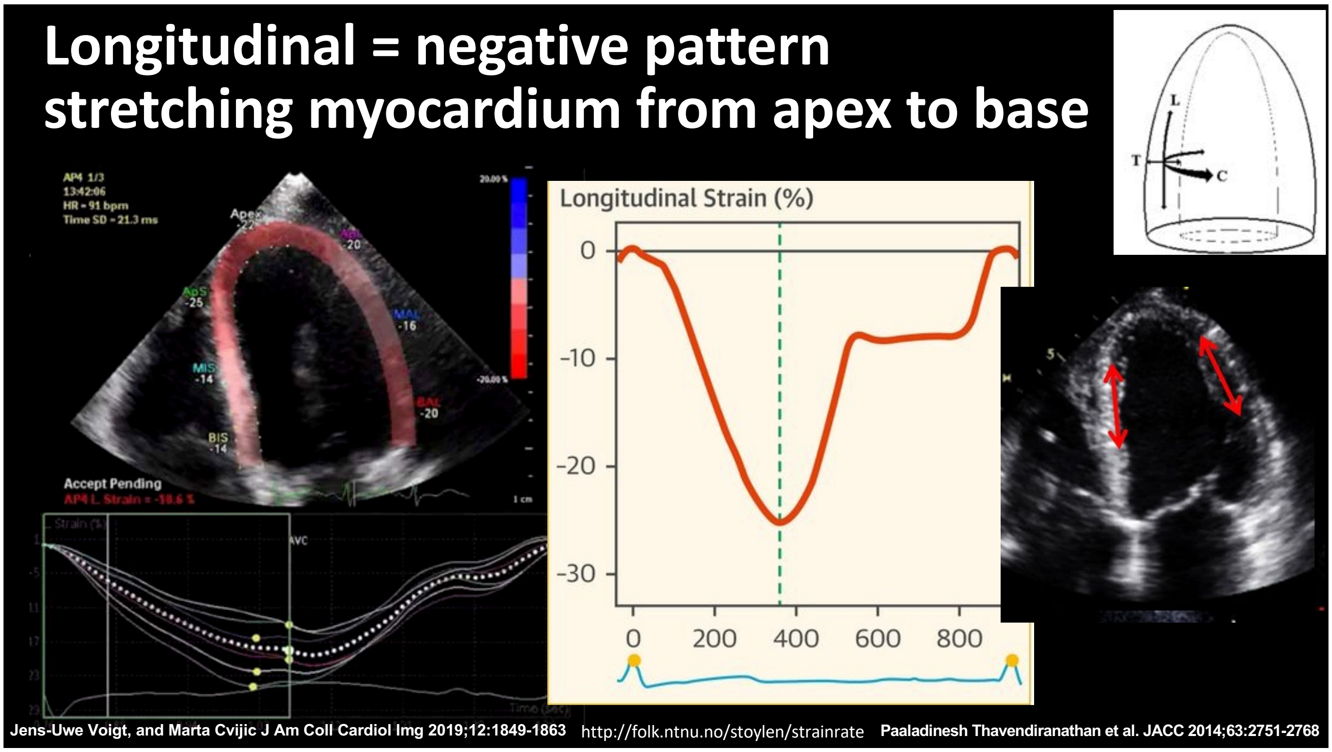
Longitudinal = length, base to apex



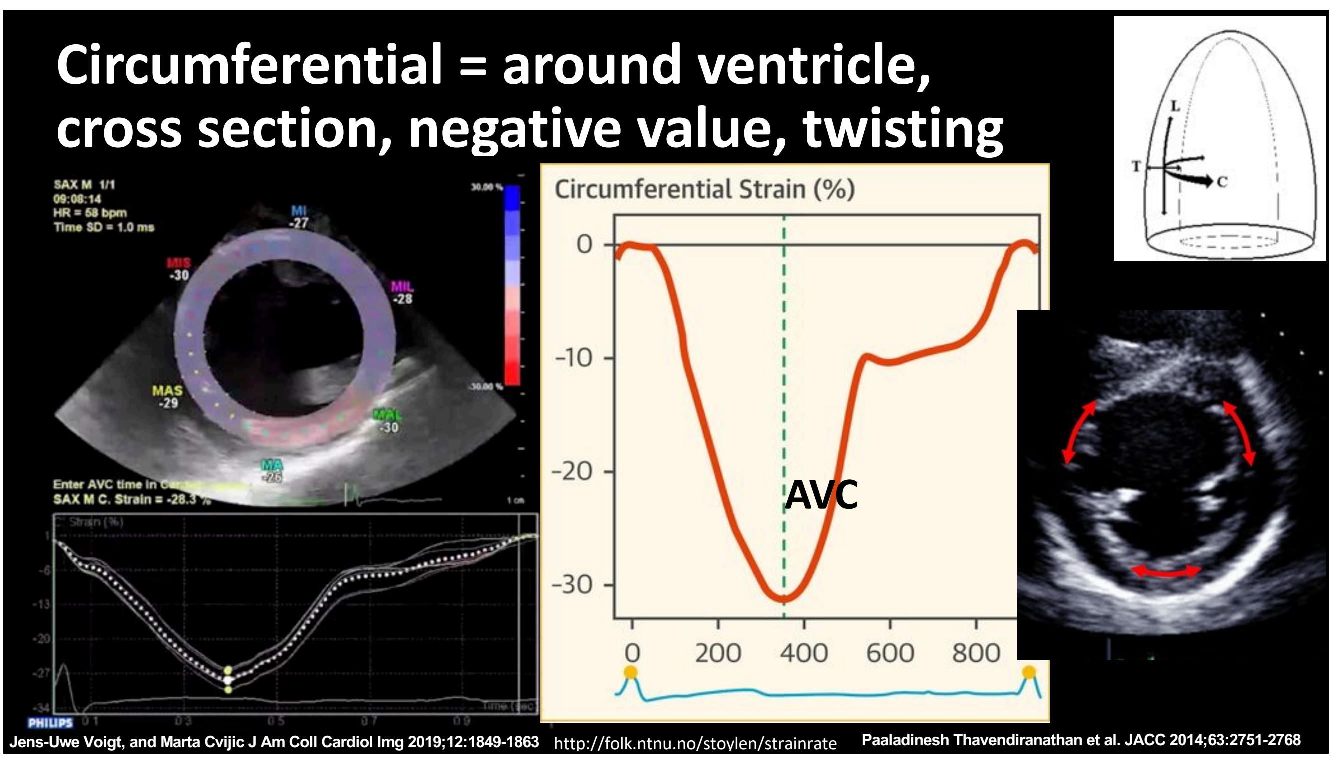
http://folk.ntnu.no/stoylen/strainrate



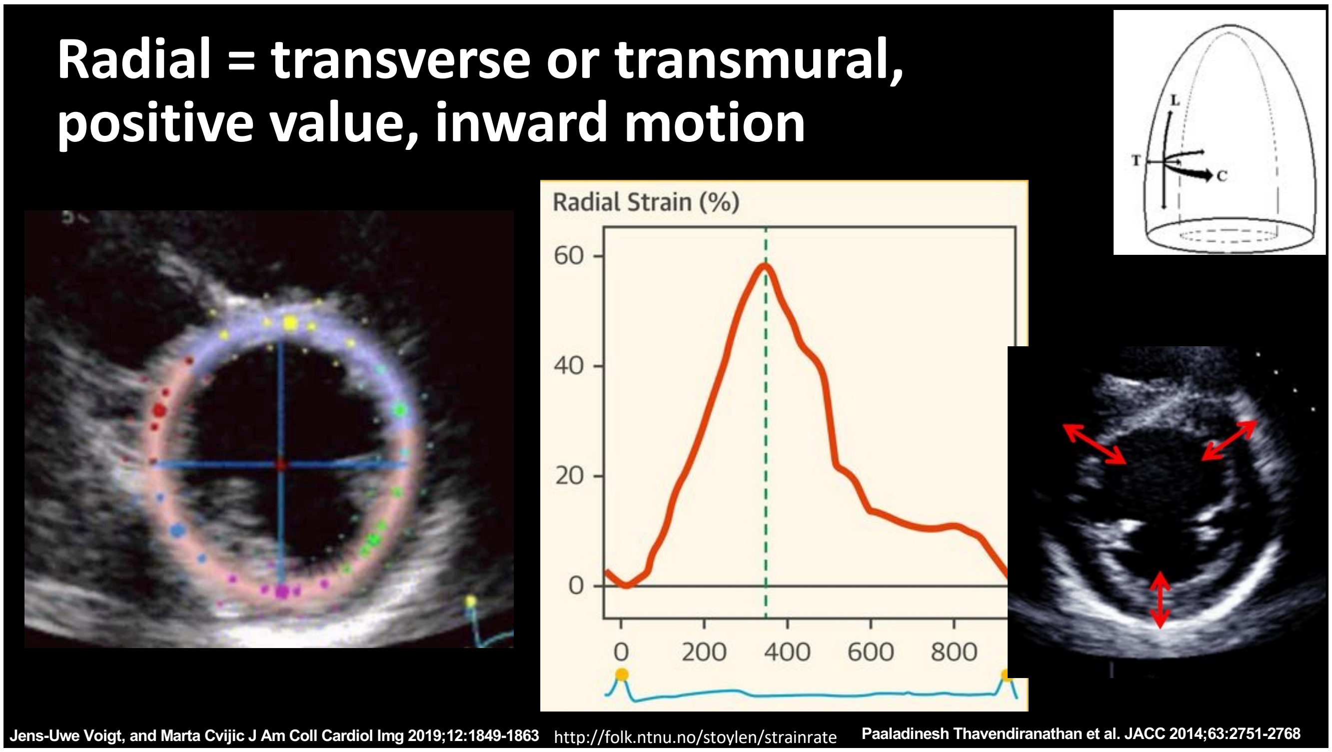
12


Longitudinal = negative pattern stretching myocardium from apex to base
Longitudinal Strain (%)
0
-10
-20
-30
0 200 400 600 800
Accept Pending
AVC
Jens-Uwe Voigt, and Marta Cvijic J Am Coll Cardiol Img 2019;12:1849-1863
http://folk.ntnu.no/stoylen/strainrate
Paaladinesh Thavendiranathan et al. JACC 2014;63:2751-2768

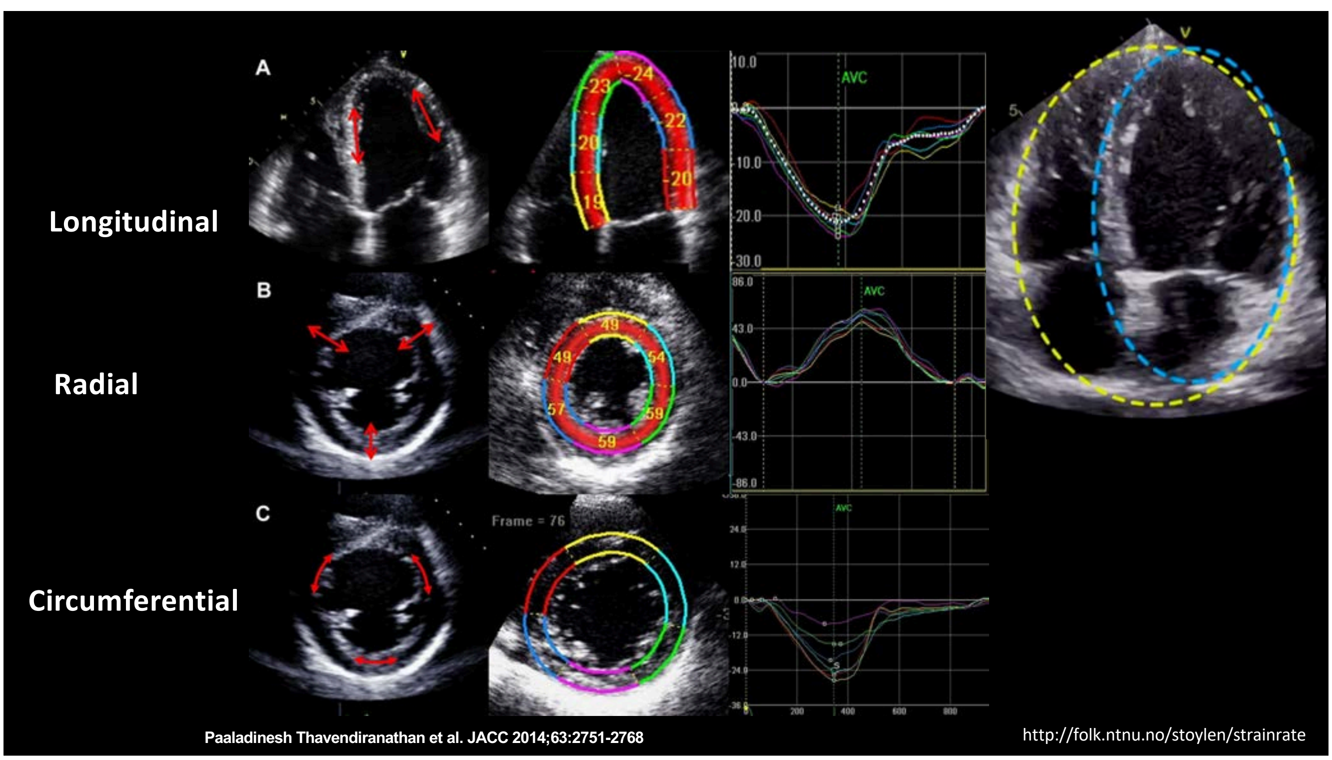
13


Circumferential = around ventricle, cross section, negative value, twisting
Circumferential Strain (%)
0
-10
-20
-30
0 200 400 600 800
AVC
PHILIPS
Jens-Uwe Voigt, and Marta Cvijic J Am Coll Cardiol Img 2019;12:1849-1863
http://folk.ntnu.no/stoylen/strainrate
Paaladinesh Thavendiranathan et al. JACC 2014;63:2751-2768

14

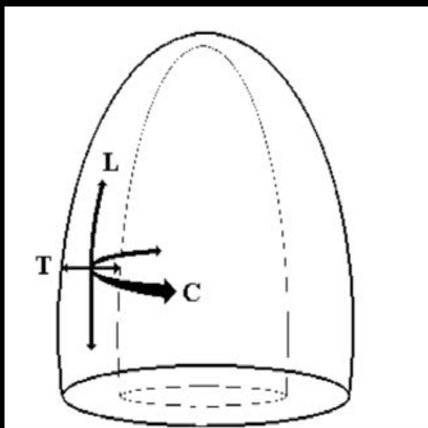

Radial = transverse or transmural, positive value, inward motion
L
T
C
Radial Strain (%)
60
40
20
0
0
200
400
600
800
Jens-Uwe Voigt, and Marta Cvijic J Am Coll Cardiol Img 2019;12:1849-1863
http://folk.ntnu.no/stoylen/strainrate
Paaladinesh Thavendiranathan et al. JACC 2014;63:2751-2768

15


A
B
C
Longitudinal
Radial
Circumferential
AVC
Frame = 76
Paaladinesh Thavendiranathan et al. JACC 2014;63:2751-2768
http://folk.ntnu.no/stoylen/strainrate

16

Different directions will have different values



Orientation of cardiac strain along Longitudinal (L), Circumferential, and Radial (transverse, T) axes

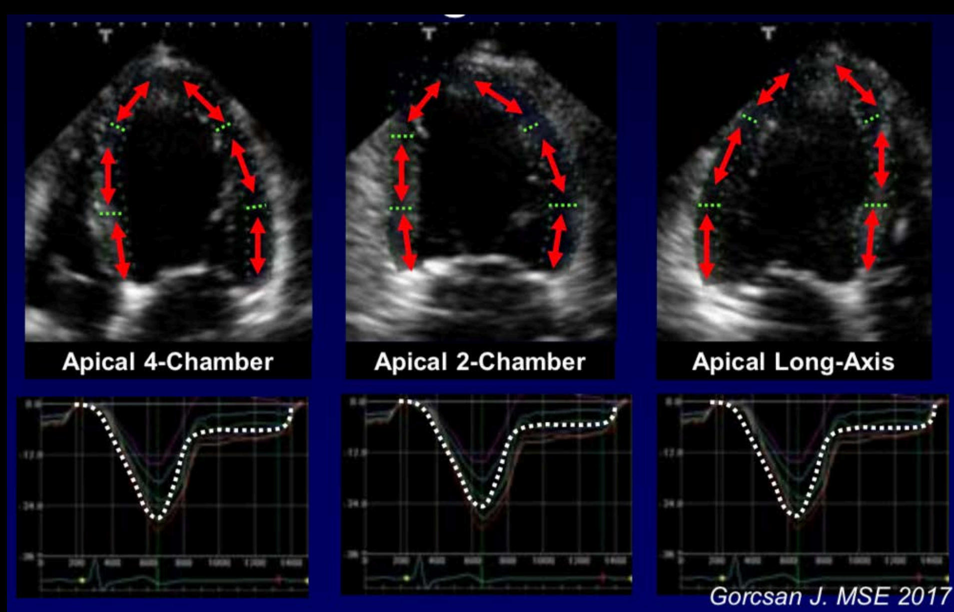
from: http://folk.ntnu.no/stoylen/strainrate

LV Strain normal range (TTE)	
Longitudinal	17-23%
Circumferential	23-27%
Radial	41-59%

http://folk.ntnu.no/stoylen/strainrate

17

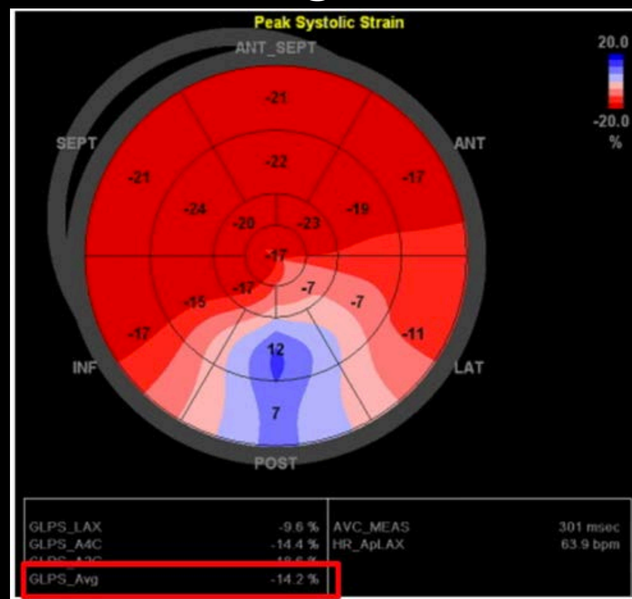
Global Longitudinal Strain is averaged



18

How to report these changes?

- Compare segments
- Timing of peak values
- GLS averages
- More negative-red (more stretching) better
- Blue is bad



Ho, J Cardiac Kinetics: Taking the stress out of strain

19

The Strain of Mitral Regurgitation and LV Remodeling

I. **Introduction**

II. **Myocardial Structure and Rotation**

III. **Strain Concepts**
   - A. Basic Concepts
   - B. Principles of Speckle Tracking
   - C. Strain and Strain Rate by Speckle Tracking

IV. **Loading Conditions**

V. **Cellular Response**

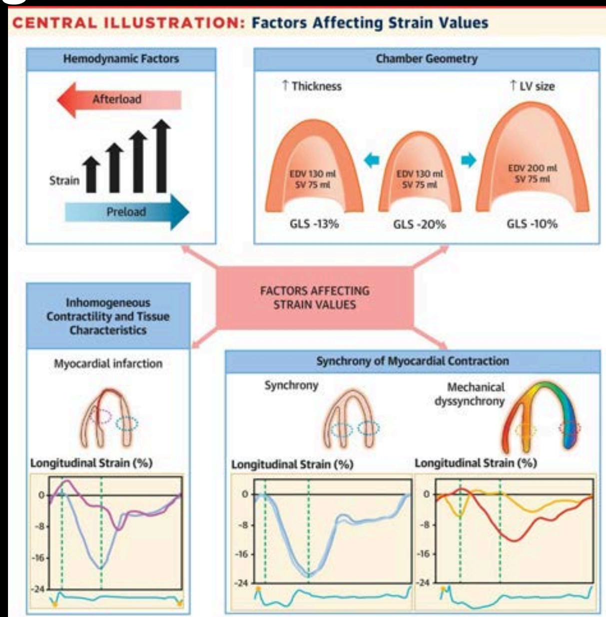
VI. **Mitral Valve Regurgitation**

VII. **Mitral Valve Repair**

VIII. **Summary**

20

Loading conditions affect deformation



Jens-Uwe Voigt, and Marta Cvijic J Am Coll Cardiol Img 2019;12:1849-1863

21

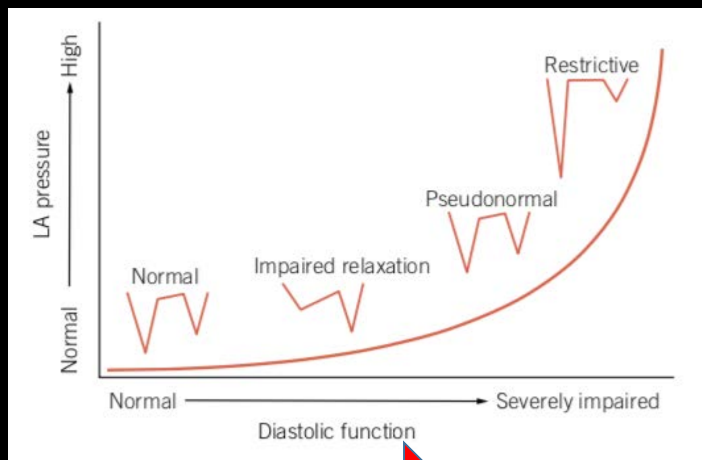
Stress + Pressure = Diastolic dysfunction

↑ stress (strain) = ↑ increased pressure

↑ pressure = ↑ adaptive measures (remodeling)

22

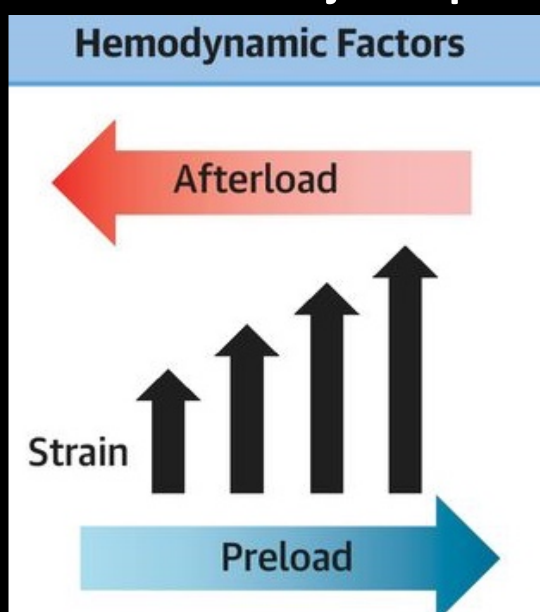
More pressure leads to more dysfunction



Sidebotham DA, ed. *Practical Perioperative Transesophageal Echocardiography, 3rd edition*. Oxford University Press, Oxford, England 2018

23

Preload and afterload have a major impact on deformation



Jens-Uwe Voigt, and Marta Cvijic J Am Coll Cardiol Img 2019;12:1849-1863

24

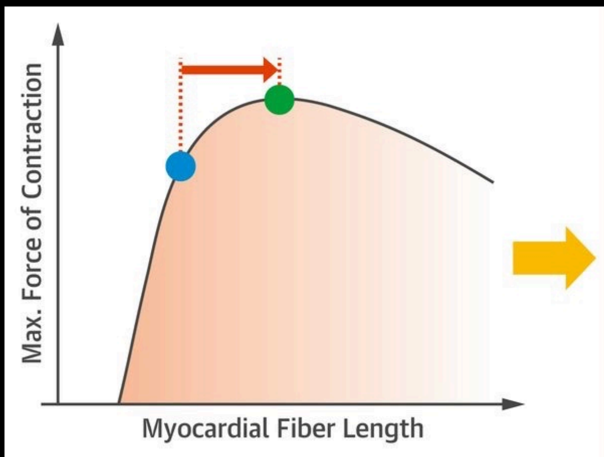
Simply put, what effects inside the chambers, either by volume, pressure or stiffness (causing stress), will effect chamber remodeling (or deformation) in response to adapt

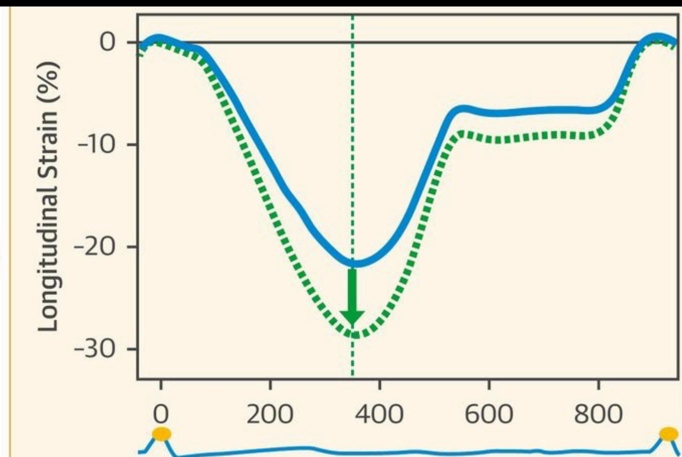
25

… and strain will help us detect this sooner

26

Less time to stretch = less power = decreased values



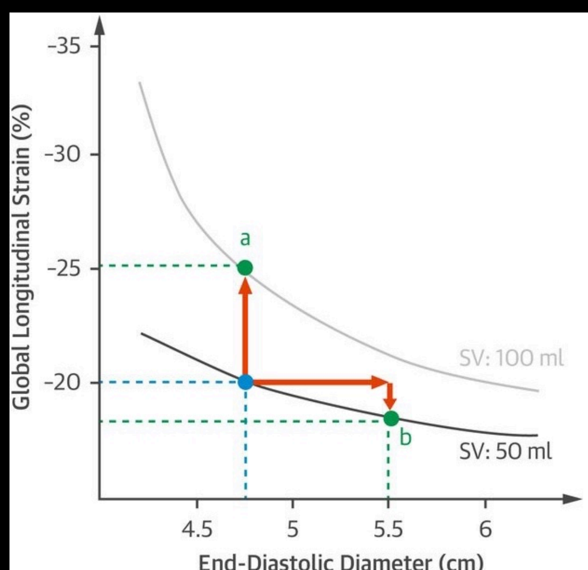


Jens-Uwe Voigt, and Marta Cvijic J Am Coll Cardiol Img 2019;12:1849-1863

27

Goal: Maintain stroke volume

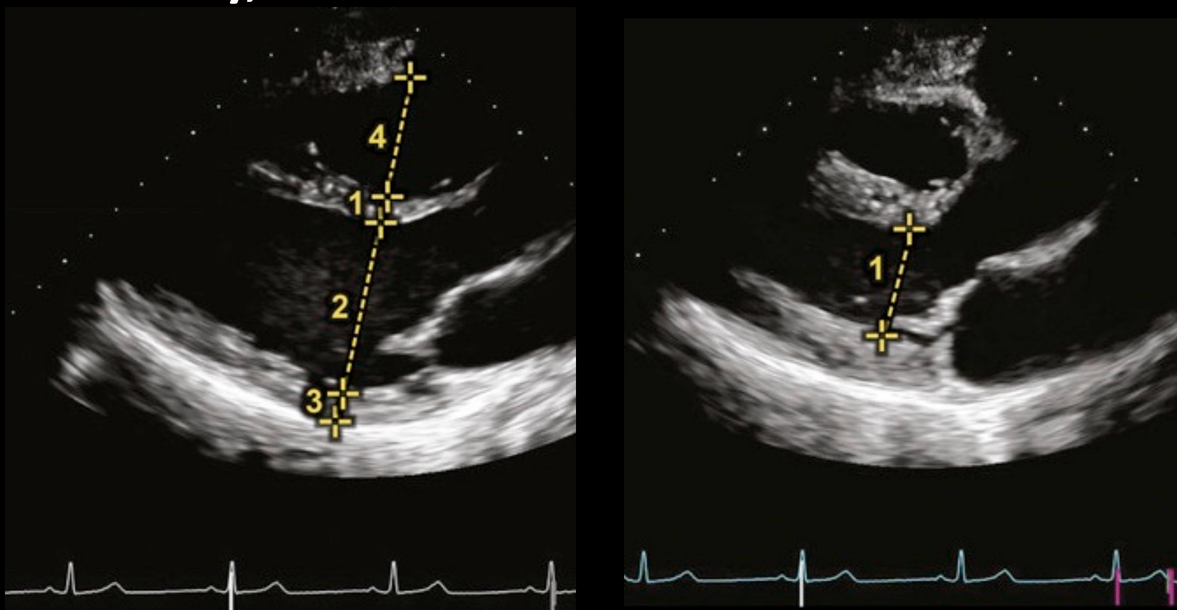
- Acute volume over-load initially leads to higher strain
- Deformation increases from increased load
- Not reflective of increased strain, but of volume overload itself



Jens-Uwe Voigt, and Marta Cvijic J Am Coll Cardiol Img 2019;12:1849-1863

28

Eventually, differences in chamber size become less

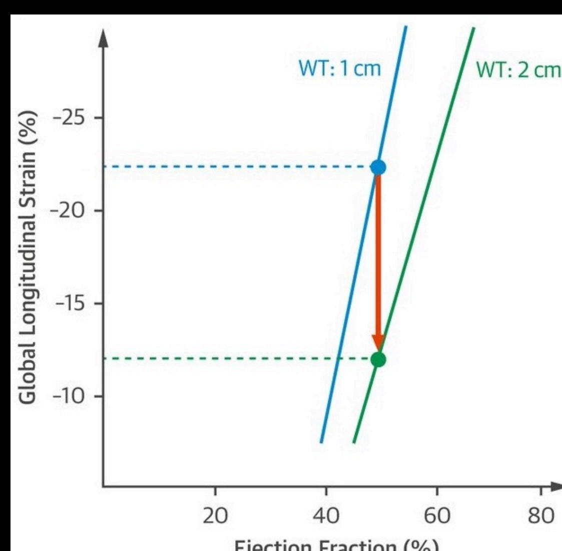


Carol Mitchel et al. Journal of the American Society of Echocardiography 2019 32, 1-64DOI: (10.1016/j.echo.2018.06.004)

29

Chronic pressure overload (AS or HTN)

- **Increasing wall thickness and decreasing chamber size offset excess wall stress**
- **EF remains normal while GLS is significantly reduced**



Jens-Uwe Voigt, and Marta Cvijic J Am Coll Cardiol Img 2019;12:1849-1863

30

Pathophysiology of MR

Cioffi G et al. *European Journal of Heart Failure* 2005 Dec;7(7)112-7

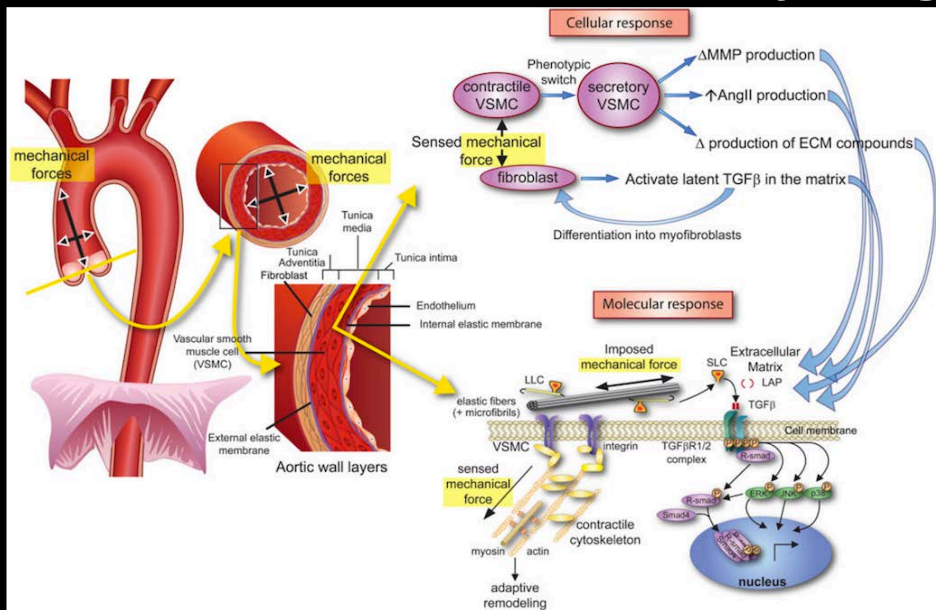
31

The Strain of Mitral Regurgitation and LV Remodeling

- **I. Introduction**
- **II. Myocardial Structure and Rotation**
- **III. Strain Concepts**
  - A. Basic Concepts
  - B. Principles of Speckle Tracking
  - C. Strain and Strain Rate by Speckle Tracking
- **IV. Loading Conditions**
- **V. Cellular Response**
- **VI. Mitral Valve Regurgitation**
- **VII. Mitral Valve Repair**
- **VIII. Summary**

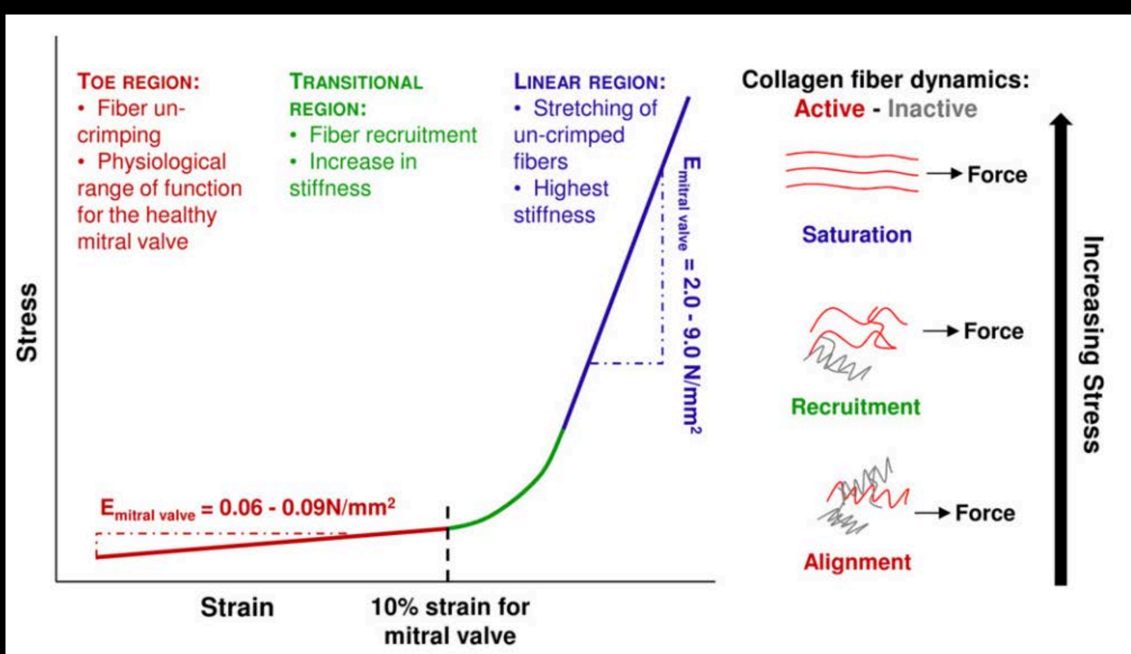
32

The cellular level affects everything!



De Backer J European Heart Journal (2015) 36,2131-2133

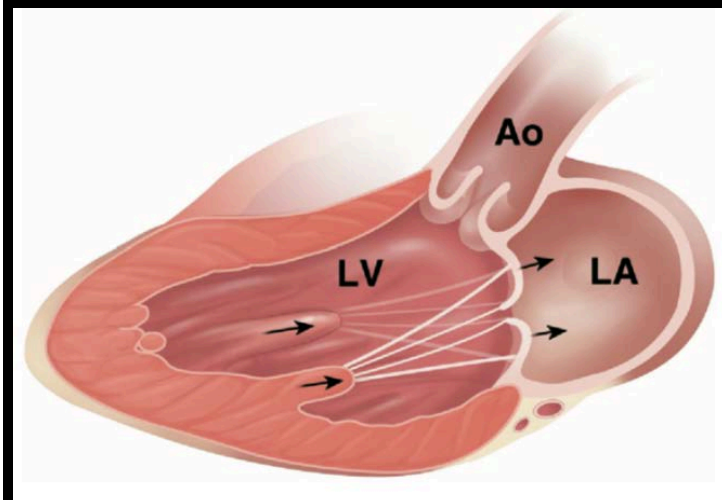
33

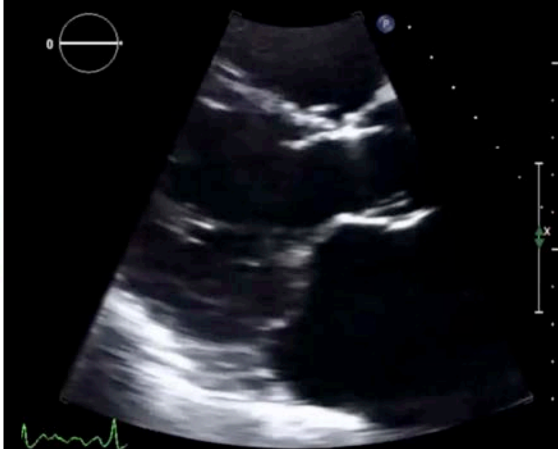


Richards JM et al J of Vet Cardiology (2012)14, 47-58

34

Excessive stretching leads to fibrosis



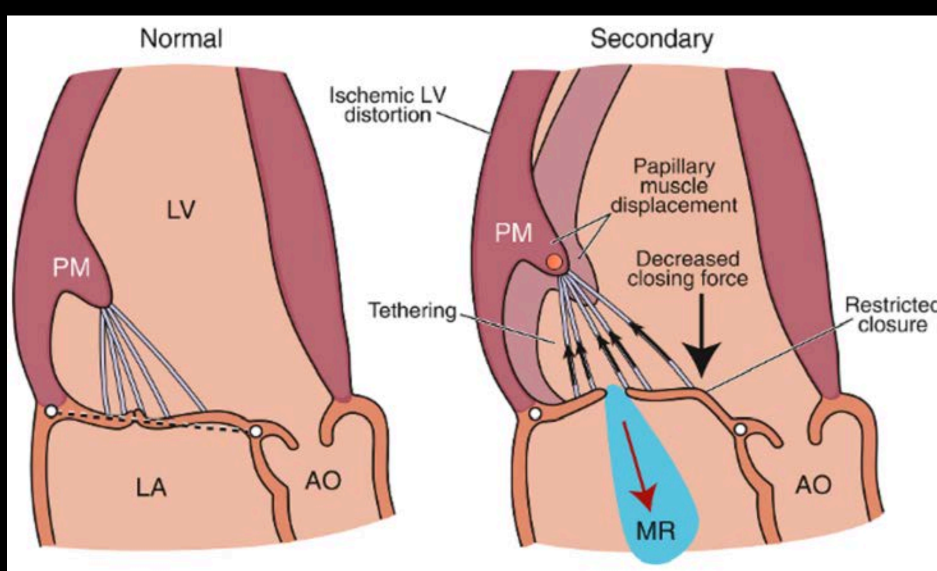


Levine R and Durst R, ed comment JACC:CVI,1,3,2008:304-6

Otto CM, ed. *The Practice of Clinical Echocardiography, 5th edition.* Elsevier Saunders, Philadelphia, Pennsylvania 2016

35

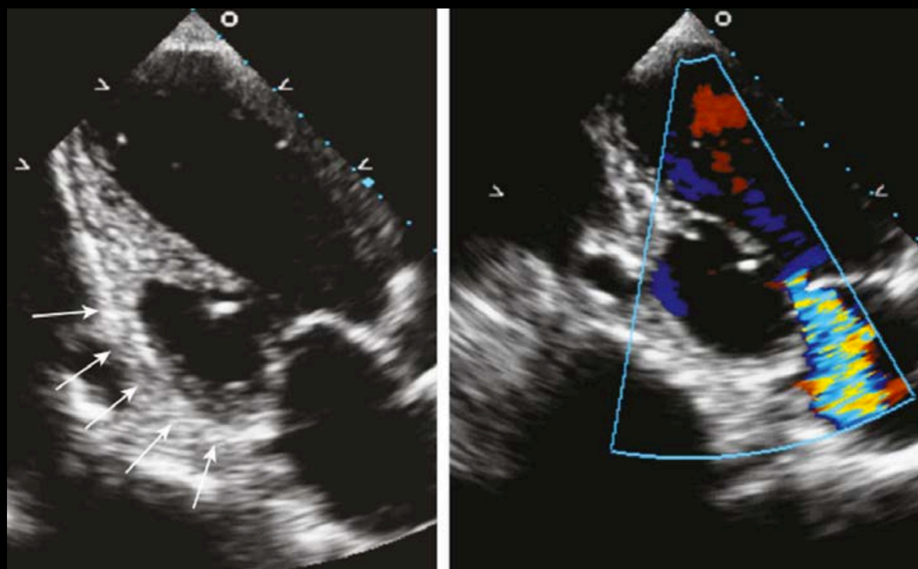
Excessive stretching leads to fibrosis



Otto CM, ed. *The Practice of Clinical Echocardiography, 5th edition.* Elsevier Saunders, Philadelphia, Pennsylvania 2016

36

Excessive stretching leads to fibrosis



Otto CM, ed. *The Practice of Clinical Echocardiography, 5th edition.* Elsevier Saunders, Philadelphia, Pennsylvania 2016

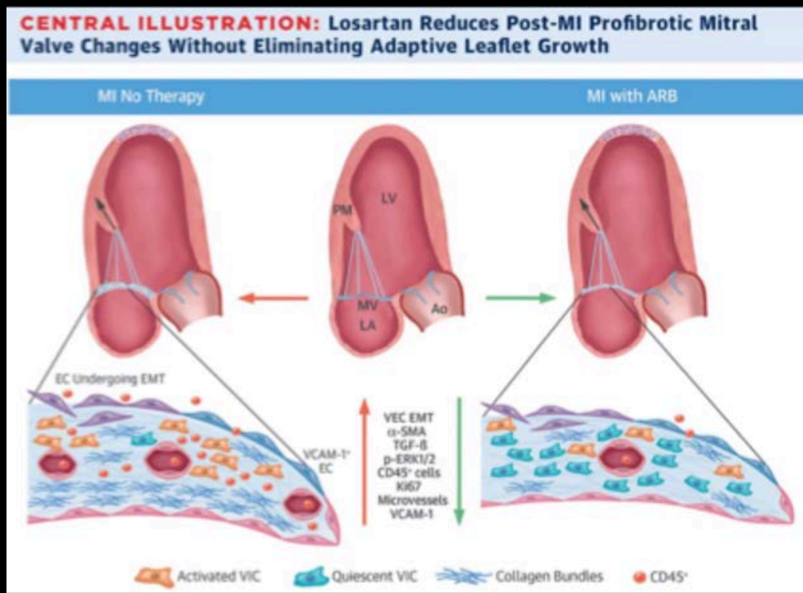
37

Fibrosis = Scar

- Deformation creates myocardial scar at interstitial level
- Scars become thick and influence things like mitral regurgitation
- Fibrosed scar does not stretch

38

Bottom Line: MMPs Rule
Everything begins, and maybe one day can end, at the cellular level!



Philipp E. Bartko et al. JACC 2017;70 1232-1244

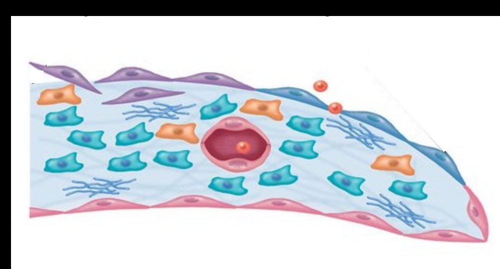
39

ARB

Degenerative

Delling FN, Vasan RS. *Circulation*. 2014;129:2158-70

Ischemic



Bartko PE *et al.* JACC 2017;70:1232–44

ARBs reasonable following most repairs to limit disease progression and prevent recurrent MR

40

The Strain of Mitral Regurgitation and LV Remodeling

I. **Introduction**

II. **Myocardial Structure and Rotation**

III. **Strain Concepts**
  - A. Basic Concepts
  - B. Principles of Speckle Tracking
  - C. Strain and Strain Rate by Speckle Tracking

IV. **Loading Conditions**

V. **Cellular Response**

VI. **Mitral Valve Regurgitation**

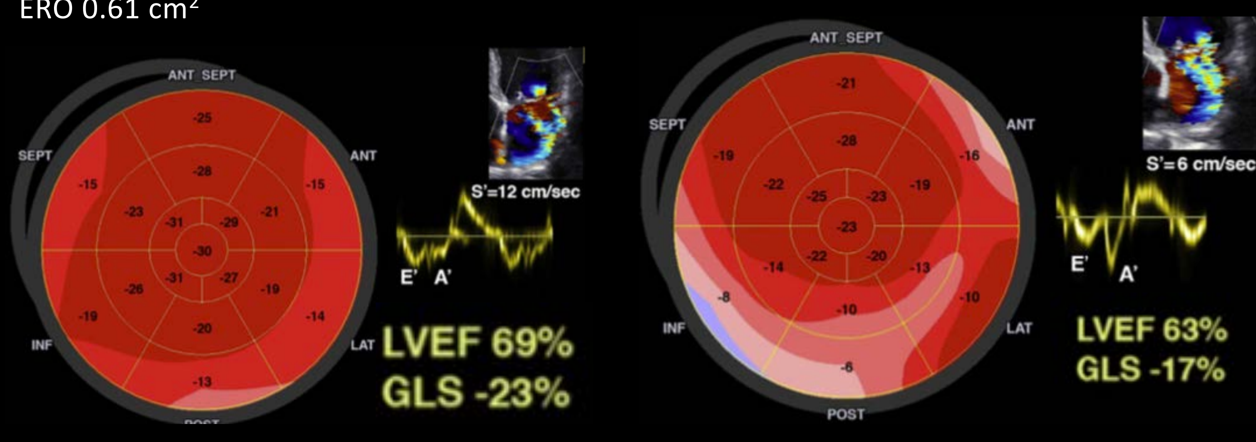
VII. **Mitral Valve Repair**

VIII. **Summary**

41

Severe primary MR GLS with normal EF

Normal EF, 60 yo female BSA 1.48 m^2
ERO 0.61 cm^2

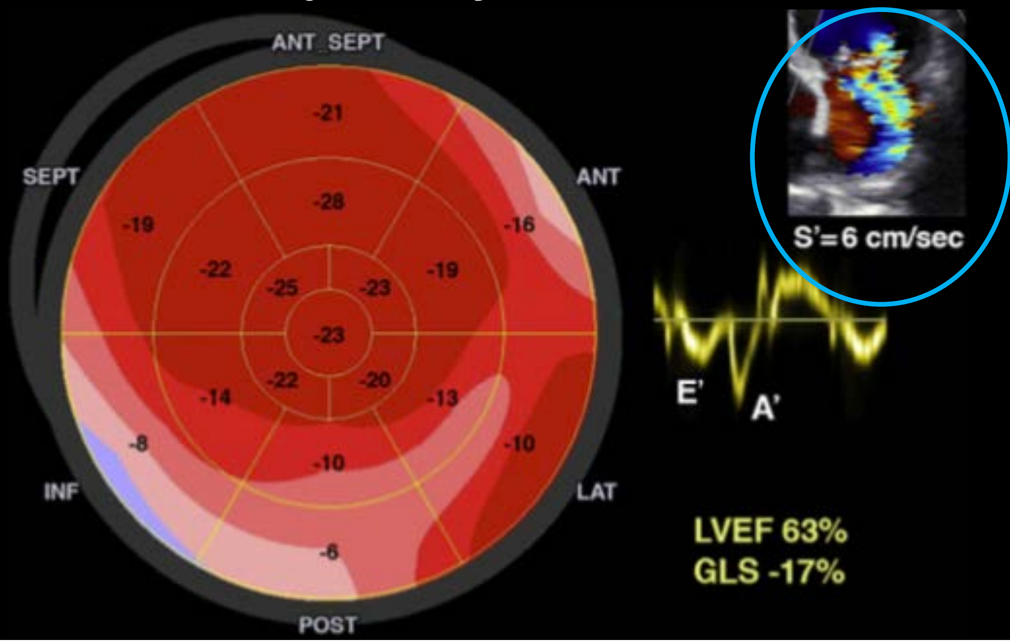


Reduced GLS 75yo male BSA 1.7 m^2
ERO 0.50 cm^2

Galli et al JACC: CVI vol7 no 11 2014 1151-66

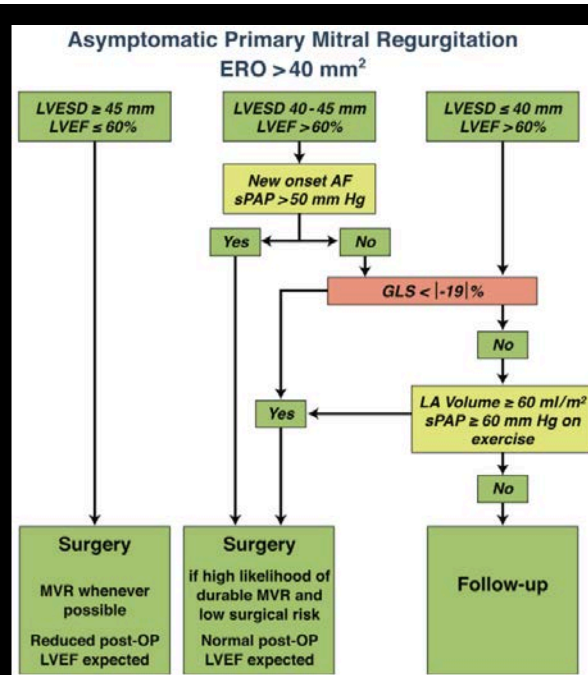
42

Severe primary MR GLS with normal EF



43

Bottom line:
GLS may prompt earlier intervention and preserve post op LV function!



Galli et al JACC: CVI vol7 no 11 2014 1151-66

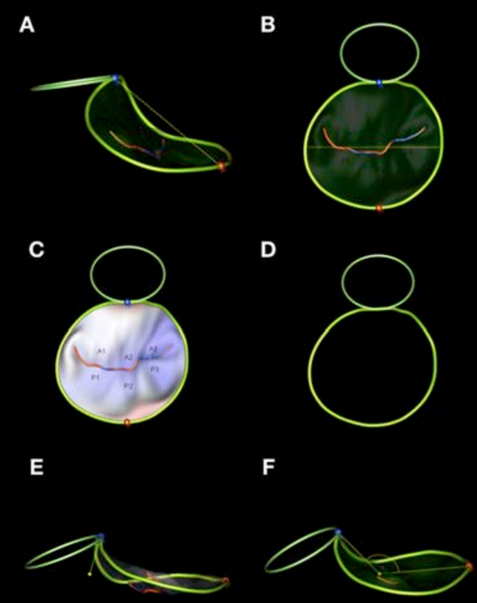
44

GLS is our warning signal!

45

Secondary MR
and
ventricular remodeling

46

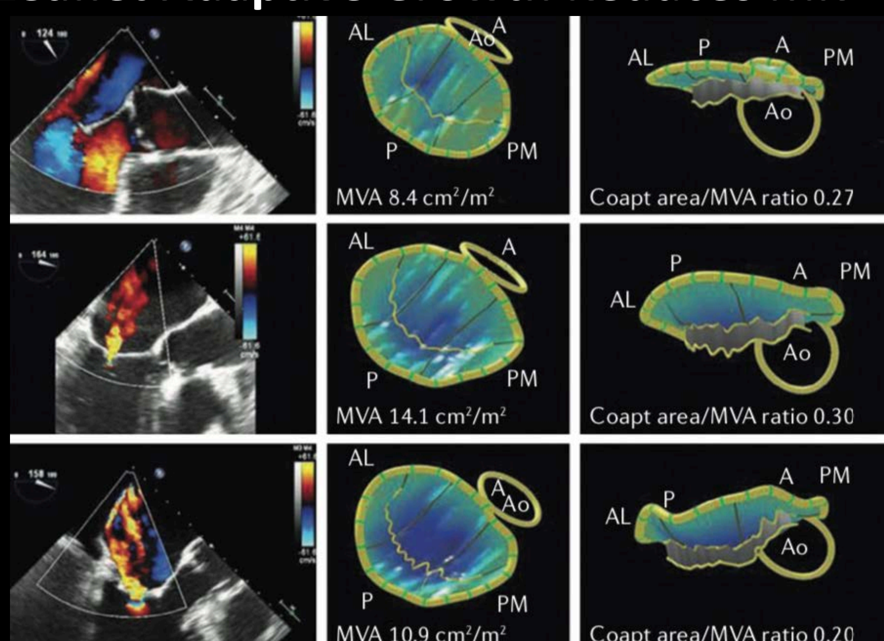


Video provided by Feroze Mahmood MD

Zhe Tang, MD Journal of the American Society of Echocardiography 2019 32, 503-513DOI: (10.1016/j.echo.2018.11.009)

47

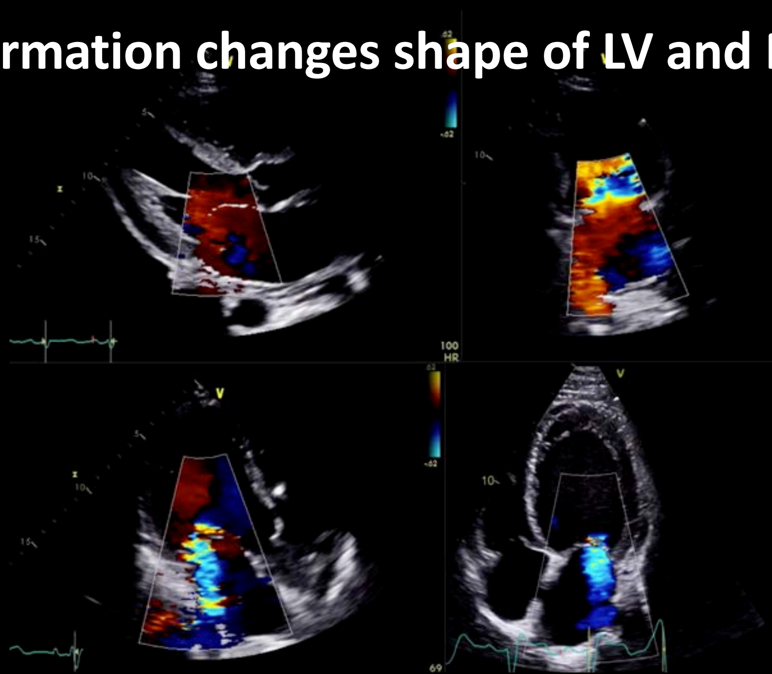
Leaflet Adaptive Growth Reduces MR



Debonnaire, P et al. Eur Heart J: Cardiovasc.Imaging 16,290-299 (2015)

48

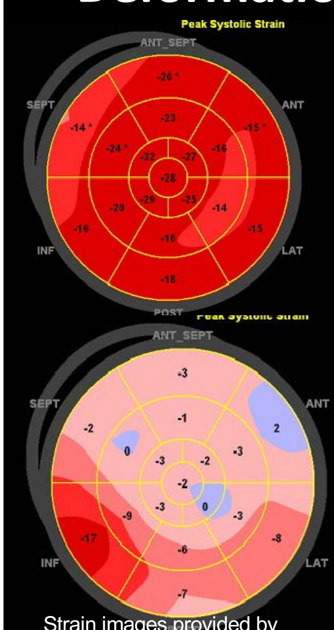
Deformation changes shape of LV and MR

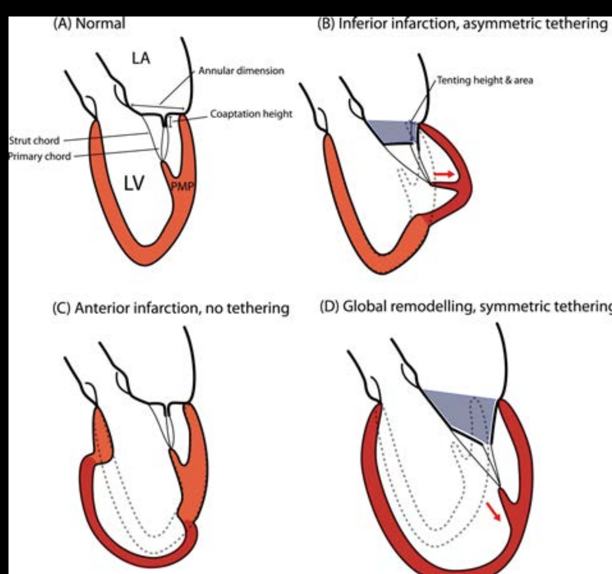


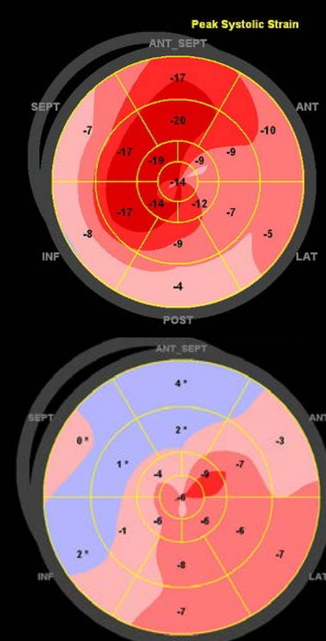
Video clips provided by *THE* Bonita Anderson

49

Deformation causes stress, changing strain patterns





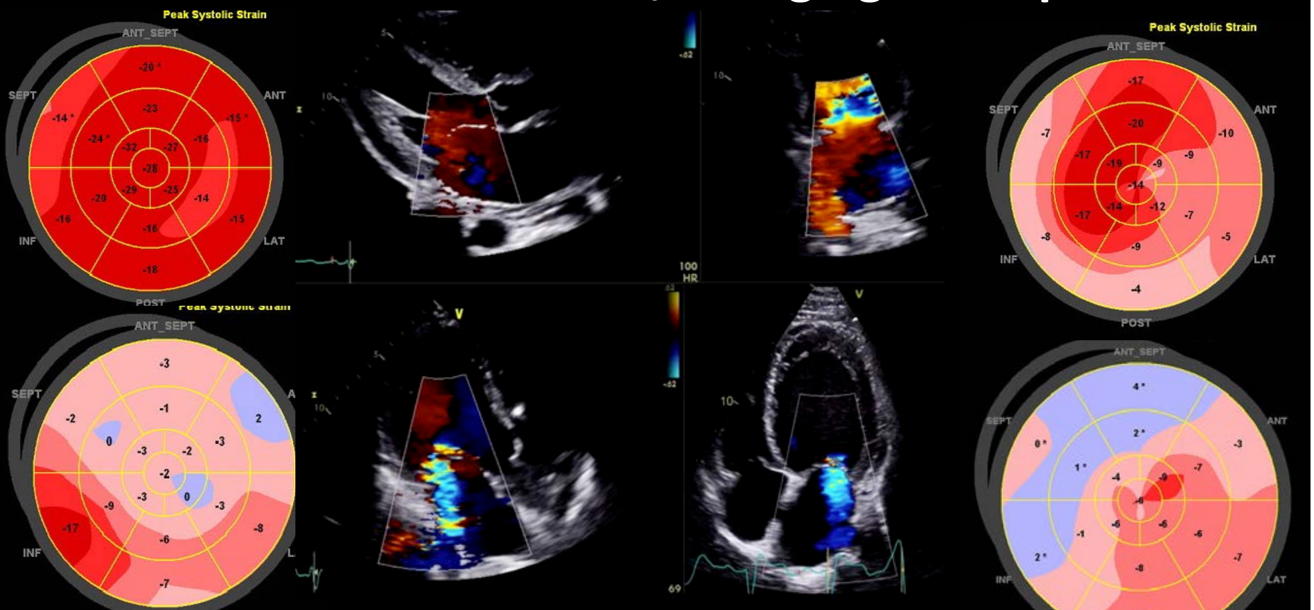


Strain images provided by Bonita Anderson

Sidebotham DA et al. Journal of the American Society of Echocardiography 2014 27, 345-366DOI: (10.1016/j.echo.2014.01.005)

50

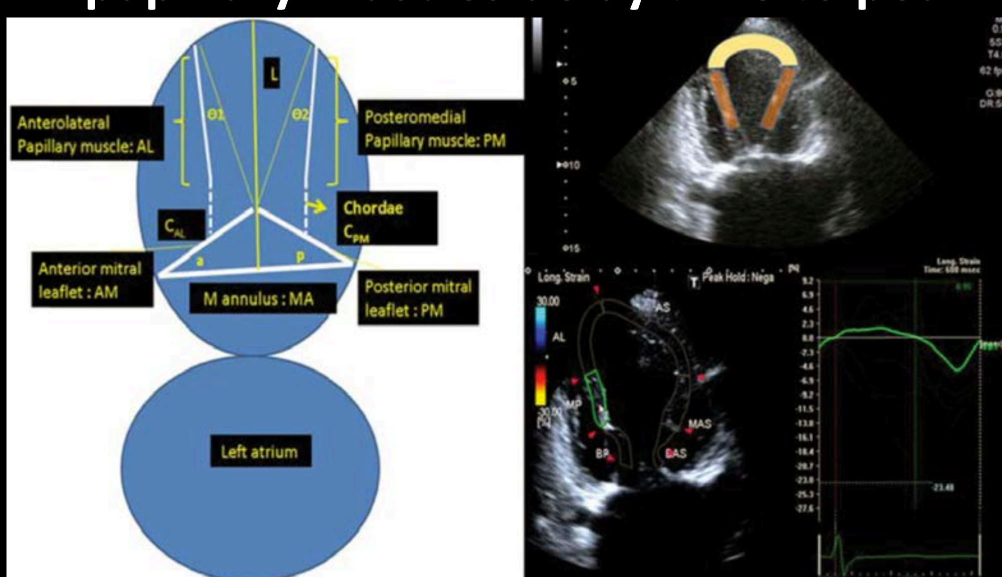
Deformation causes stress, changing strain patterns



Strain images and video clips provided by Bonita Anderson

51

IMR remodeling distorts myocardium, papillary muscles delay time to peak



Graspa J et al. EHJ Cvi2015.16.53-61

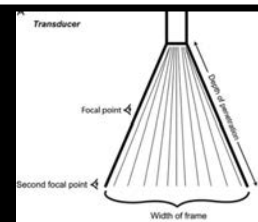
52

The Strain of Mitral Regurgitation and LV Remodeling

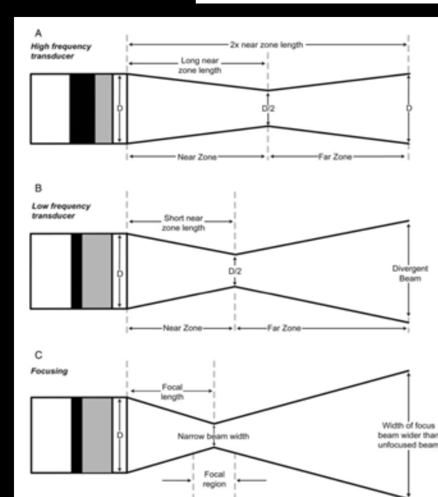
I. **Introduction**
II. **Myocardial Structure and Rotation**
III. **Strain Concepts**
   A. Basic Concepts
   B. Principles of Speckle Tracking
   C. Strain and Strain Rate by Speckle Tracking
IV. **Loading Conditions**
V. **Cellular Response**
VI. **Mitral Valve Regurgitation**
VII. **Mitral Valve Repair**
VIII. **Summary**

53

Speckle Tracking in the OR



- Largely overcomes angle dependence limitations of TDI
- Depends on spatial resolution, varies along lateral axis
- Lateral resolution affected by beam width and depth of imaging.
- Wider beams typically diverge further in far field and at greater depth, decreasing lateral resolution

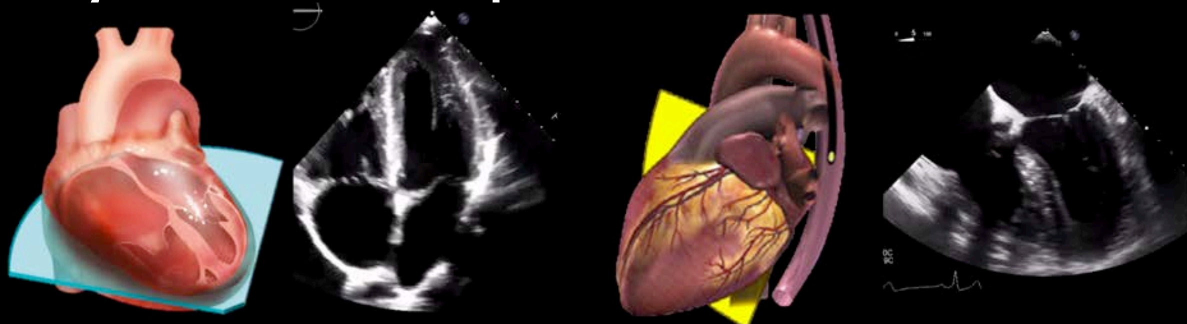


Ng and Swanevelder, Continuing Ed in Anesthesia, Critical Care & Pain;Vol11.No5,2011

54

Speckle Tracking in the OR

- Lateral resolution varies affecting comparison from TTE and TEE
- Anesthetized state and positive-pressure ventilation may confound intraop strain



Otto CM, ed. *The Textbook of Clinical Echocardiography, 6th edition.* Elsevier Saunders, Philadelphia, Pennsylvania 2018

55

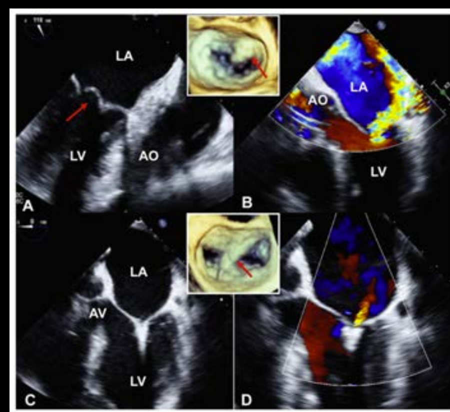
Mitral valve repair

- Durable mitral repair is potentially curative and associated with lower mortality and complications than replacement
- Management of secondary MR remains controversial:
  - Inconsistent image guidance
  - Recurrent MR following inappropriate use of simple ring annuloplasty
  - Postop diastolic dysfunction

56

Edge-to-Edge repair

- Surgical – Alfieri stitch
- Percutaneous – MitraClip
- Changes flow pattern to double orifice
- Peak flow is reduced by half
- Valvular stress is doubled



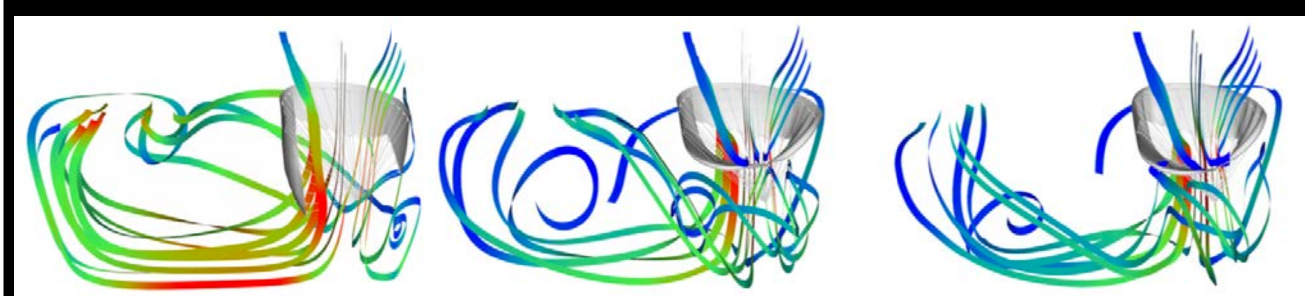
Percutaneous E-E

Alkhouli et al JACC:CVI;10-5.2017
Lau KD et al. *Journal of Biomechanics* 44(2011)2409-2417
Drake *et al* in CM Otto *Practice of Clinical Echocardiography, 6th ed.* Elsevier 2020 *in press*

57

Edge-to-Edge repair

Downstream flow



Normal	Edge-to-edge <u>without</u> annuloplasty	Edge-to-edge <u>with</u> annuloplasty

Lau KD et al. *Journal of Biomechanics* 44(2011)2409-2417

58

Elevated gradient following edge-to-edge repair

Trans-valvular gradient of > 4.4 mmHg by echo or > 5.0 mmHg invasively predict significantly worse outcomes…

equal to those with > 2+ MR

Percutaneous E-E

Neuss M et al. *JACC:CVI* 2017,10(9):931-9

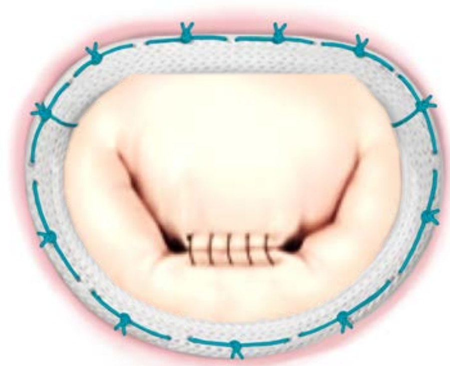
Drake *et al* in CM Otto *Practice of Clinical Echocardiography, 6th ed.* Elsevier 2020 *in press*

59

Edge-to-Edge repair

High gradients, reduced flow, turbulence, and limited durability have prompted most surgeons to abandon

Considered "bail out" procedure



Surgical E-E

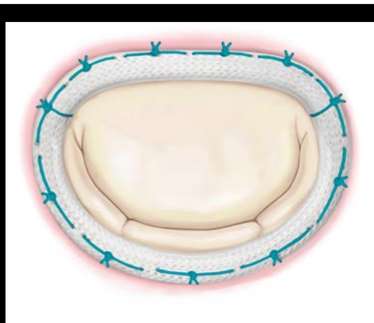
Bhudia SK et al. Ann Thorac Surg. 2004 May;77(5):1598-606

Drake *et al* in CM Otto *Practice of Clinical Echocardiography, 6th ed.* Elsevier 2020 *in press*

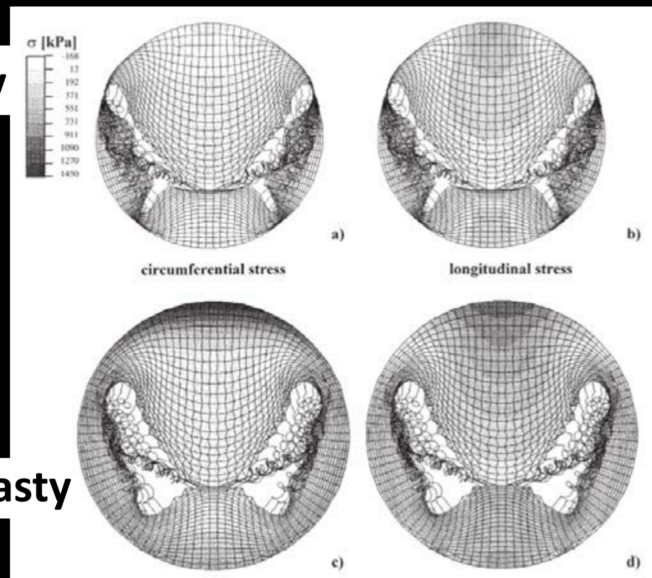
60

Edge-to-Edge repair

Edge-to-edge with annuloplasty



Edge-to-edge without annuloplasty

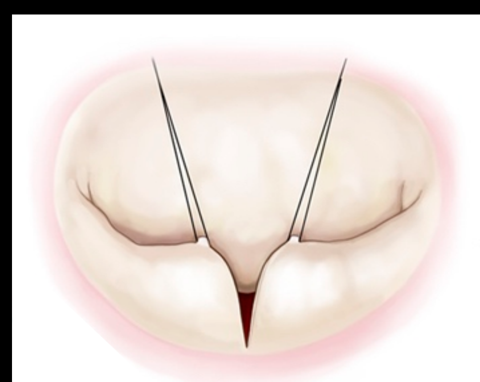


E. Votta et al. J Heart Valve Dis 2002;11:810-822
Lau KD et al. *Journal of Biomechanics* 44(2011)2409-2417

61

Leaflet resection

- **Reduces leaflet area**
- **Restores normal hemodynamic patterns**
- **Introduces scar at the coaptation surface**
- **Increases leaflet stiffness (unquantified)**



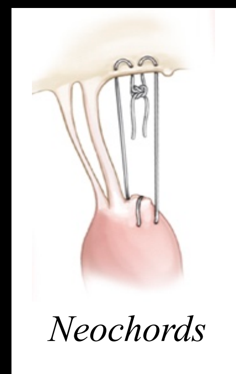
Richards JM et al J of Vet Cardiology (2012)14, 47-58

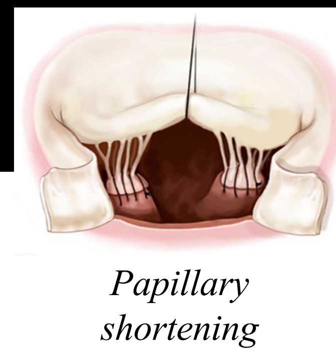
Drake *et al* in CM Otto *Practice of Clinical Echocardiography, 5th ed.* Elsevier 2016

62

Artificial chords / papillary shortening

- **Optimally restore native tension**
- **Change direction of applied force depending on attachment points**
- **Increase stress on native chordae**
- **3% increase in leaflet area**
- **2.8 x increase in leaflet thickness**





Richards JM et al J of Vet Cardiology (2012)14, 47-58

Drake *et al* in CM Otto *Practice of Clinical Echocardiography, 5th ed.* Elsevier 2016

63

Mitral valve repair (for secondary disease)

Annular dilatation

- **Critical influence on stress distribution**
- **Accelerates degeneration**
- **May cause repair failure**

E. Votta et al. J Heart Valve Dis 2002;11:810-822

64

Mitral valve repair (for secondary disease)

Reductive ring annuloplasty is effective for secondary MR if:

- **Tenting area < 1 cm^2**
- **Tenting height < 1 cm**

Long axis view in late systole

Tenting area - cm^2	**< 1**
Tenting height - cm	< 1
A2 closing angle - degrees	< 25
P2 closing angle - degrees	< 45
A2 inversion angle - degrees	< 20

E. Votta et al. J Heart Valve Dis 2002;11:810-822

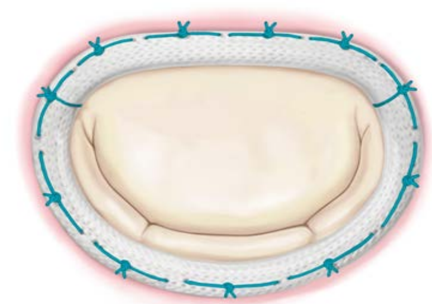
Drake *et al* in CM Otto *Practice of Clinical Echocardiography, 6th ed.* Elsevier 2020 *in press*

65

Reductive ring annuloplasty

- **Reduces AP and intercommissural diameters of mitral annulus**
- **Alters distribution of stress across leaflets**
- **Reduces peak stress**
- **Increases bending stress**
- **Lowers papillary muscle/ chordae tension**
- **Flat ring configuration reduces peak strain on posterior leaflet by 78%**

Richards JM et al J of Vet Cardiology (2012)14, 47-58



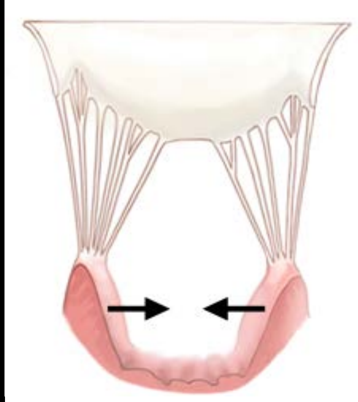
Simple ring

Drake *et al* in CM Otto *Practice of Clinical Echocardiography, 5th ed.* Elsevier 2016

66

Papillary muscle approximation

- Relieves tension on marginal chords
- Increases coaptation
- Reverse LV remodeling
- Difficult to assess adequate approximation intraoperatively
- Increases diastolic dysfunction



Papillary approximation

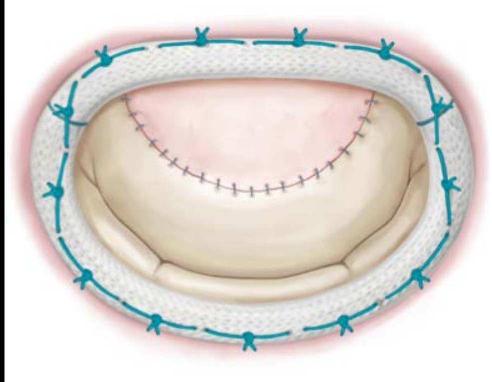
Harmel EK et al. Heart 2018;104:1783-1790

Drake *et al* in CM Otto *Practice of Clinical Echocardiography, 5th ed.* Elsevier 2016

67

Leaflet augmentation

- Mimics adaptive growth
- Has the effect of lengthening marginal chords
- Does not increase diastolic dysfunction
- Technically demanding



Leaflet augmentation

Richards JM et al J of Vet Cardiology (2012)14, 47-58

Drake *et al* in CM Otto *Practice of Clinical Echocardiography, 5th ed.* Elsevier 2016

68

Mechanical Valve

- Dramatically changes mechanical conditions of atrioventricular canal
- Restricts annular deformation
- Increases turbulent flow
- Increases thrombogenicity
- Incomplete re-endothelization
- Systemic anticoagulation and prosthetic failure


Mechanical prosthesis


Tissue prosthesis

Drake *et al* in CM Otto *Practice of Clinical Echocardiography, 6th ed.* Elsevier 2020 *in press*

69

The Strain of Mitral Regurgitation and LV Remodeling

I. **Introduction**
II. **Myocardial Structure and Rotation**
III. **Strain Concepts**
   A. Basic Concepts
   B. Principles of Speckle Tracking
   C. Strain and Strain Rate by Speckle Tracking
IV. **Loading Conditions**
V. **Cellular Response**
VI. **Mitral Valve Regurgitation**
VII. **Mitral Valve Repair**
VIII. **Summary**

70

Summary

- MR severity related to ventricular geometry
- Altered strain reflects early ventricular dysfunction, despite preserved EF
- Reduced GLS predicts post op LV dysfunction
- Earlier detection of dysfunction allows for earlier correction and may help to restore LV function and life expectancy
- Echo provides valuable insight that allows cardiologist to tailor interventional strategy

71

Thank you!

72

Everyone PLEASE get up and do the Hula with our Hawaiian Hula Hosts!

73

The Strain of Mitral Regurgitation and LV Remodeling

Karen G. Zimmerman, BS, ACS, RDCS, RVT, FASE

ASE

HAWAII
2020

74