

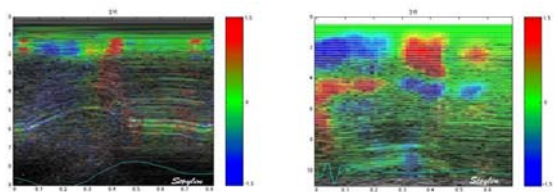
Echocardiographic evaluation of Myocardial Strain

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Faculty of Medicine
Norwegian University of Science and Technology

<http://folk.ntnu.no/stoylen/lectures>
<http://folk.ntnu.no/stoylen/strainrate>

The beginning:

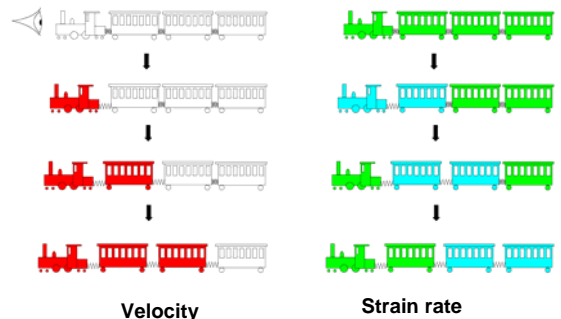


Heimdal, Stoylen et al 1998

Overview

- Basic concepts
 - Motion vs. Deformation imaging
- Technology
 - Tissue Doppler
 - Speckle tracking
 - Pitfalls
- Clinical use
 - Indications
 - Pitfalls
 - Approach to strain rate analysis
- Future directions
 - Automated analysis
 - 3D strain

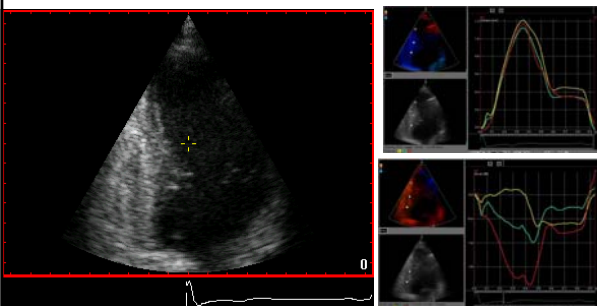
Motion vs. deformation:



Velocity

Strain rate

Motion vs. deformation:



Strain vs strain rate:

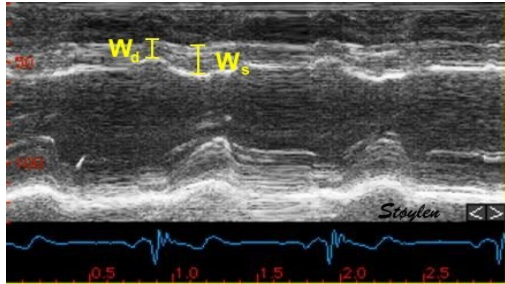
$$\epsilon = \frac{L - L_0}{L_0} \quad SR = \frac{d\epsilon}{dt}$$



Stoylen

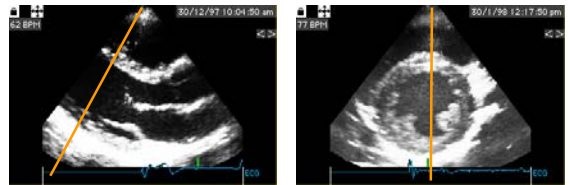
Strain 25%
Strain rate 1s⁻¹ vs 2s⁻¹

Wall thickening = Transmural strain:

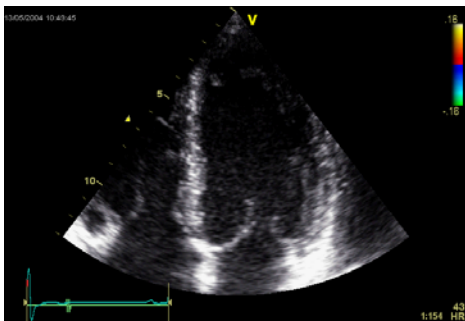


$$WT = \frac{W_D - W_S}{W_D} = \epsilon_T$$

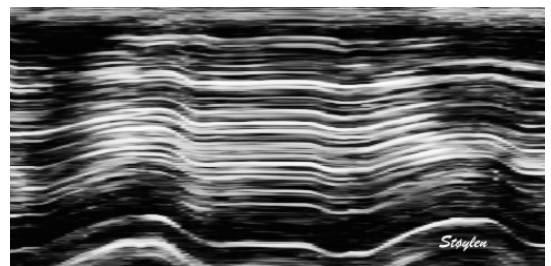
Limited feasibility



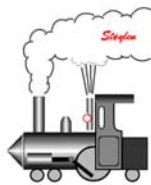
Longitudinal function:



Longitudinal strain:



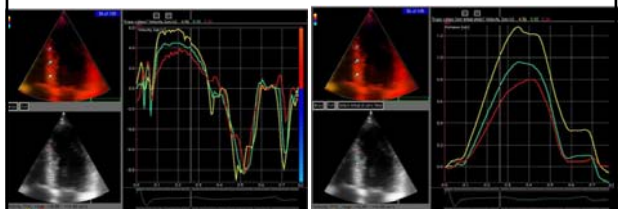
Tissue Doppler:



The Doppler effect: $f_D = f_0 \frac{v}{c}$

For reflected ultrasound: $f_D \approx 2f_0 \frac{v}{c} \cos(\alpha)$

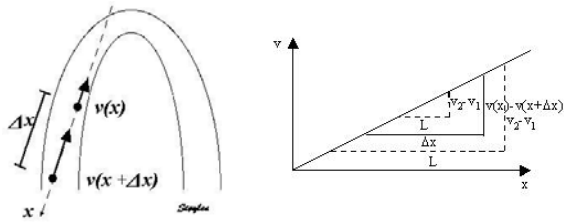
Decreasing from base to apex



Velocity

Motion

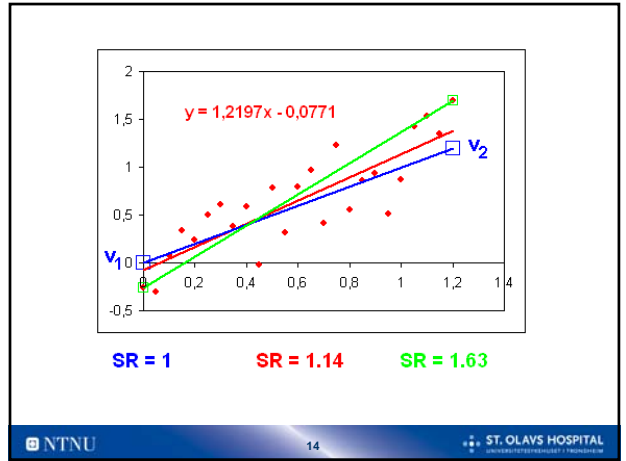
Strain rate:



Heimdal, stoylen et al 1998

Fleming et al 1994

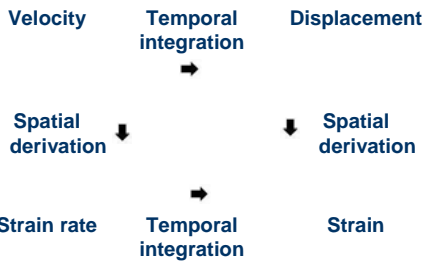
$$SR = \frac{v(x) - v(x + \Delta x)}{\Delta x} = \frac{\Delta v}{\Delta x} = \frac{v1 - v2}{r} = VG$$



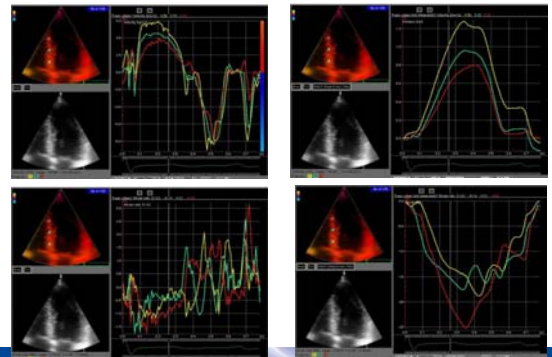
SR = 1

SR = 1.14

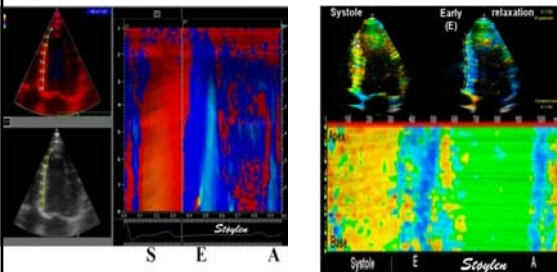
SR = 1.63



One dataset, four modalities:



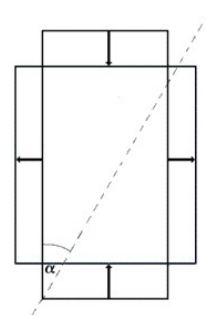
Curvilinear anatomical M-mode



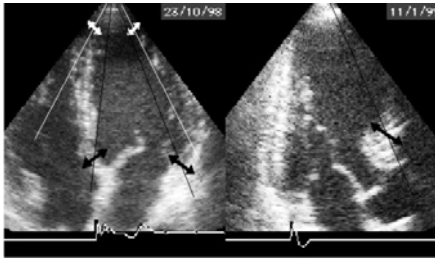
Velocity

Strain rate

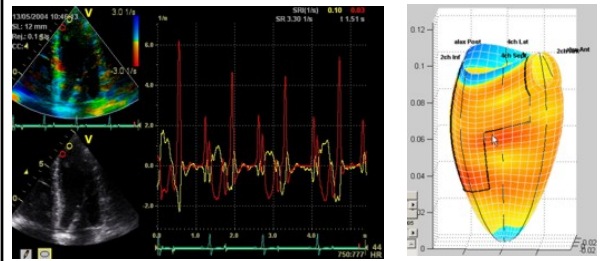
The angle problem:



The angle problem:



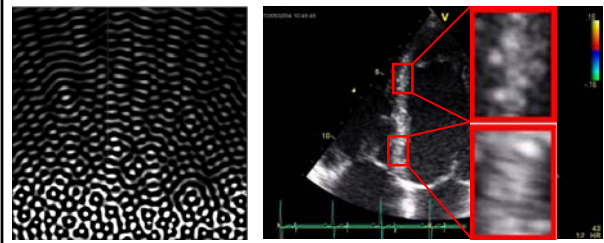
The angle problem:



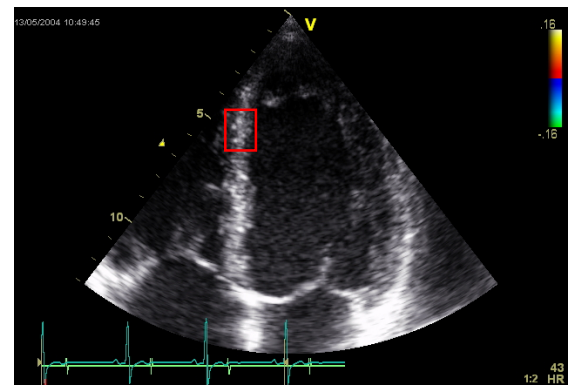
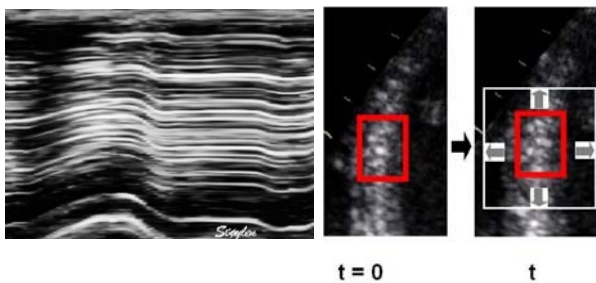
Apical zone

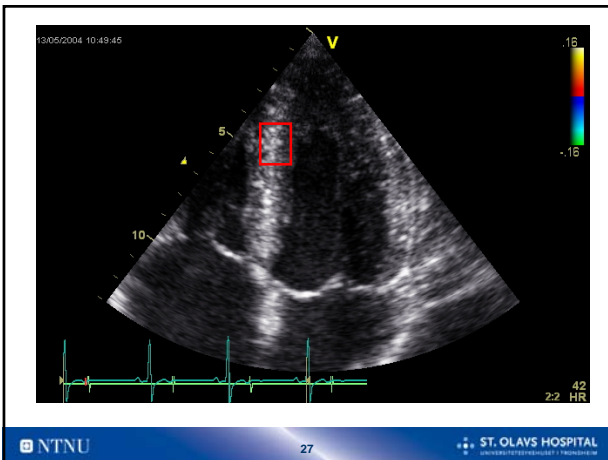
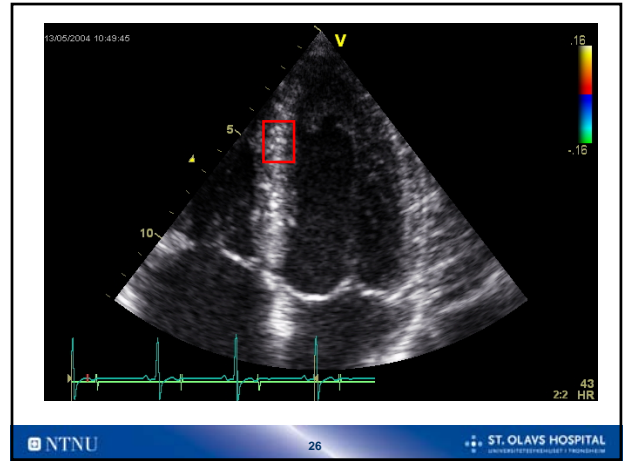
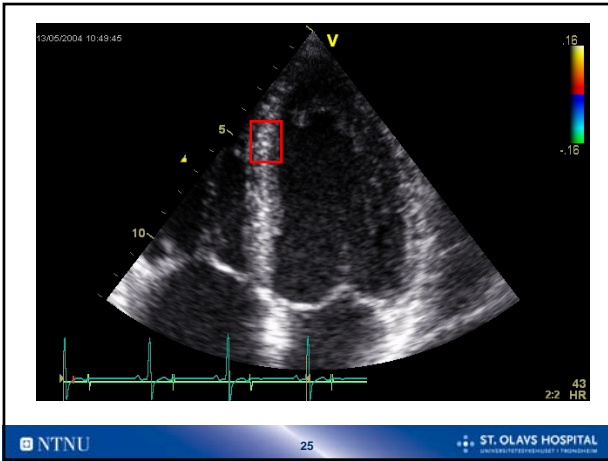


Speckle tracking:



The speckle pattern follows the myocardial motion





Tracking:

- Motion:
 - Displacement
 - Velocity
- Deformation:
 - Strain
 - Strain rate

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ST. OLAVS HOSPITAL

Resulting in:

V

5

10

16

-16

87 HR

82 HR

Angle independent tracking

NTNU

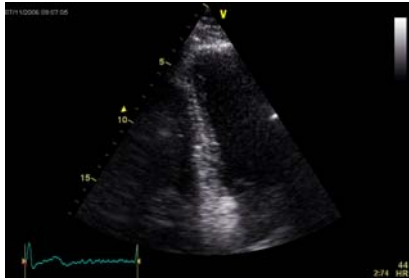
ST. OLAVS HOSPITAL

One dataset, four modalities:

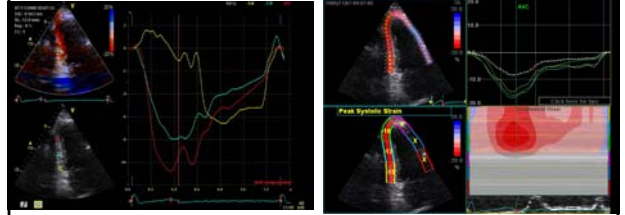
NTNU

ST. OLAVS HOSPITAL

Smoothing:



Smoothing:



Speckle tracking vs. Tissue Doppler:

- Basic principles are the same
- Majority of clinical evidence is in tissue Doppler
- Normal values may differ
- Different frame rates
- Angle sensitivity
- Smoothing

Integrated analysis:



- Longitudinal: Tissue Doppler
- Transverse: Speckle tracking
- Allows for faster tracking
- Longitudinal data with high frame rate
- Angle independent
- Can be applied without tissue Doppler

Integrated analysis:



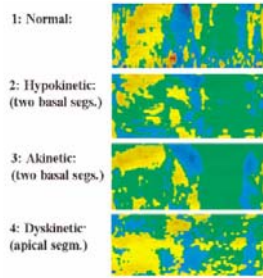
- Longitudinal: Tissue Doppler
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- Allows for faster tracking
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Clinical use:

- Strain rate imaging is basically:
 - About systolic function
 - Regional function
- Average (global) systolic strain /strain rate
 - little documentation of advantages compared to annular velocity / displacement
- Diastolic strain rate so far not shown to be useful

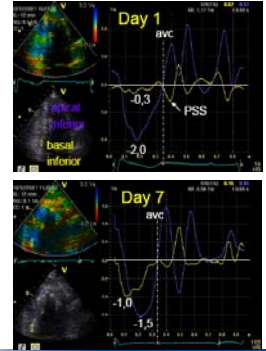
Myocardial infarction:

- **Diagnosis:**
 - Stoylen et al 2000: WMS by SRI similar accuracy and reproducibility as 2D



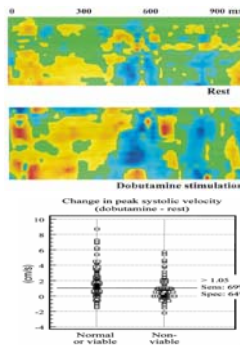
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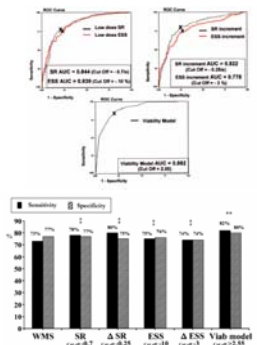
Myocardial infarction:

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- **Viability:**
 - Hoffmann et al 2002 (LDDE vs PET)

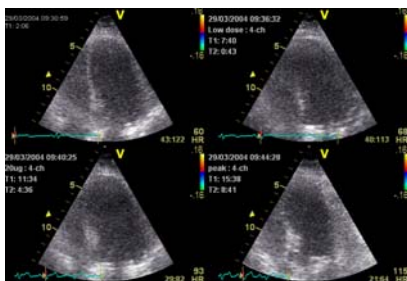


Myocardial infarction:

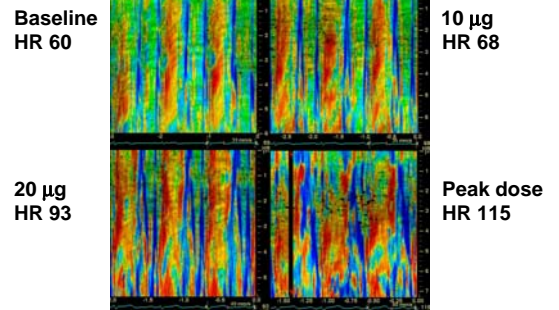
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 - Ingul et al 2005: recovery of function in MI
- **Viability:**
 - Hoffmann et al 2002 (LDDE vs PET)
 - Haneekom et al 2005 (LDDE vs recovery of function after revascularisation)



Stress echocardiography

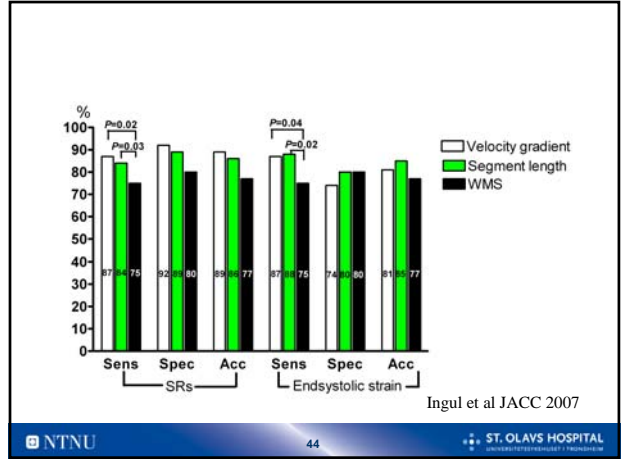


Stress echocardiography



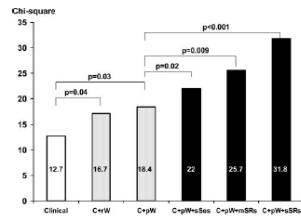
Stress echocardiography:

- Voigt 2003, 2004
 - 44 pats: Feasibility 85% (traces) to 95% (CAMM)
 - PSI best parameter (AUC 0.9)
 - SRI (CAMM) better than WMS (sens/spec 89/86 vs 82/81%)
- Ingul 2007; accuracy vs angiography:
 - 197 patients; automated analysis.
 - Feasibility WMS 98%, SR 84%, ϵ 79% of segments at peak stress
 - Peak SR $> -1.2s^{-1}$ best parameter (AUC 0.9)
 - Sensitivity/specificity vs. angio 85/90%, significantly better than WMS (73/80%)



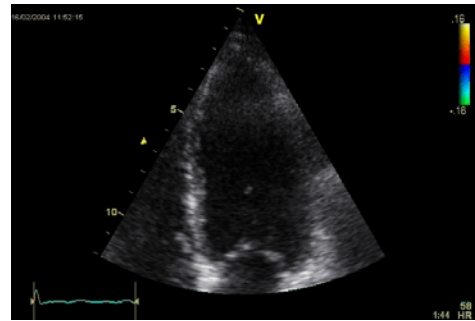
Stress echocardiography:

- Ingul 2007; additional prognostic value:
 - 646 patients, mean 5.2 years
 - WMS predictor of ischemia
 - Segmental ischemia at peak stress by SRI independent predictor of mortality

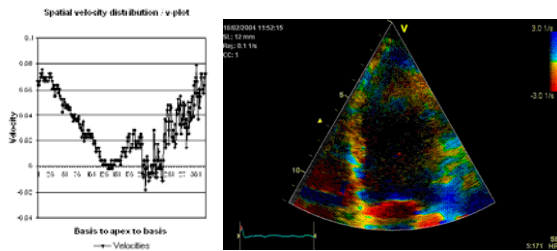


Ingul et al Circulation 2007

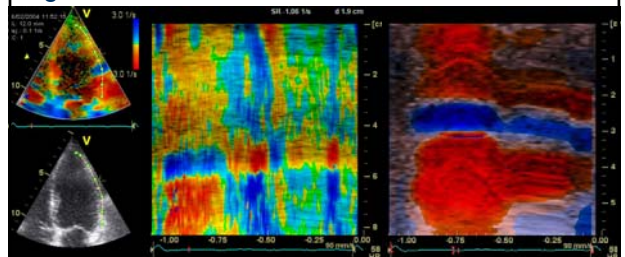
Reverberations:



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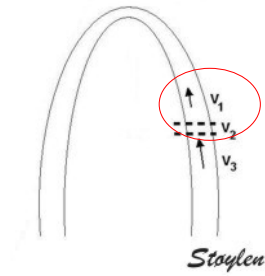
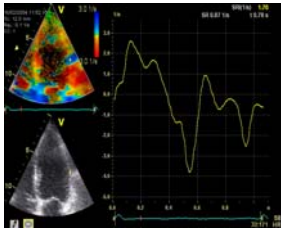


More than 80% of patients show artefacts that affects strain rate imaging in one or more segments!



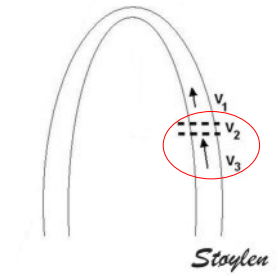
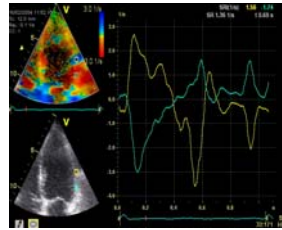
Støylen 2003, Sagberg 2004, Malm 2005

Reverberation artefact:



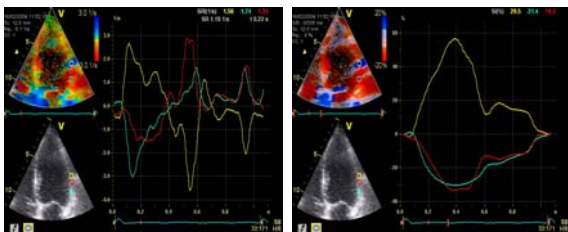
Apparent dyskinesia

Reverberation artefact:



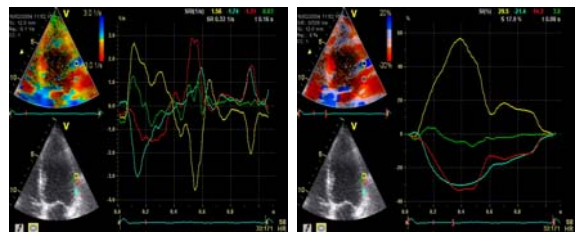
Apparent hyperkinesia

Reverberation artefact:



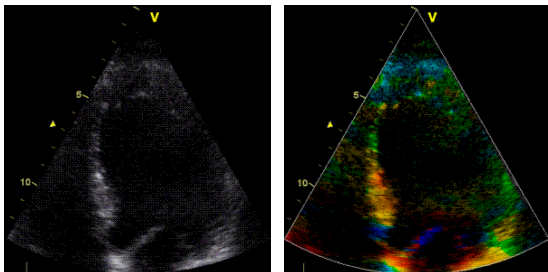
Apparent normal strain rate

Reverberation artefact:

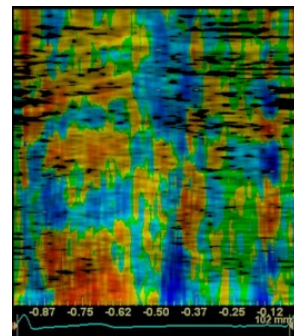


Apparent initial dyskinesia

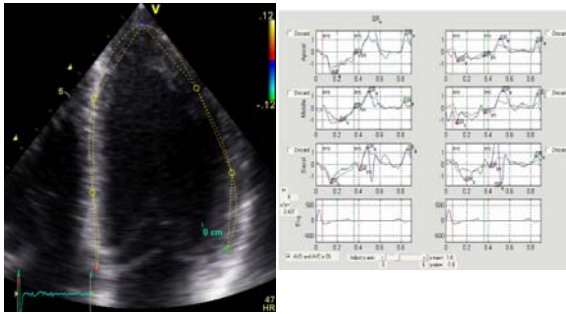
Shadowy reverberations



Shadowy reverberations



Automated analysis:

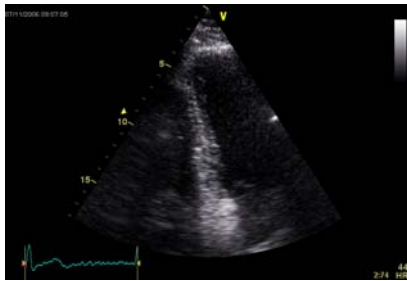


Ingul et al. JASE 2005

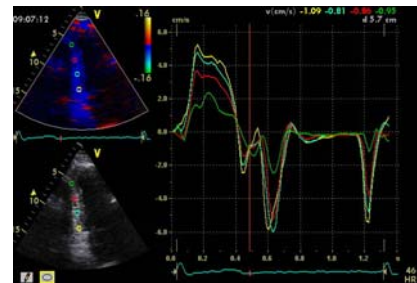
Results:

- 80% feasibility (segments) with automated
- 92% feasibility with manual analysis
- Sensitivity and specificity (infarcted segments) similar
- Segments with low quality data should be rigorously excluded from analysis also with manual software
- Studies reporting too high feasibility may
 - either be selected for image quality – not representative
 - or subject to biased post processing

Example: inferior infarct:

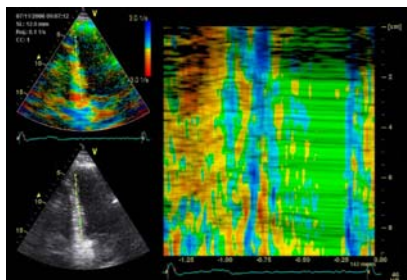


1: Assess velocity curves



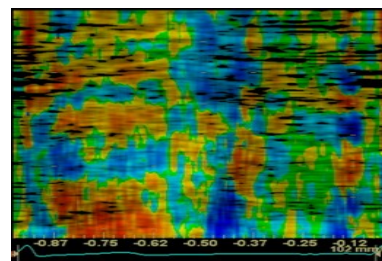
Normal distribution?

2: Assess Curved M-mode



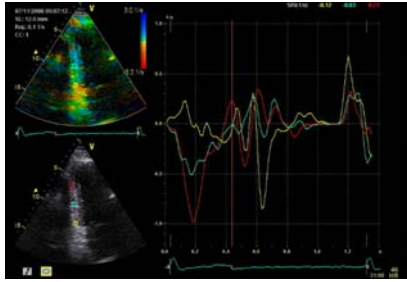
Extent of pathology

2: Assess Curved M-mode

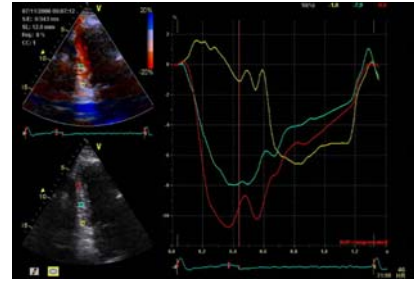


Extent of pathology
Presence of artifacts

3: Assess both strain rate



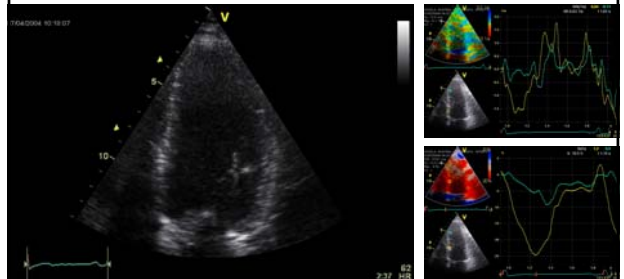
3: And strain



Strain rate imaging

- Is about regional systolic function
- Is basically an add-on to ordinary echo
 - In case of doubt
 - Stunning/recovery/viability
- Spatial information
 - Location
 - Extent

A case of doubt:

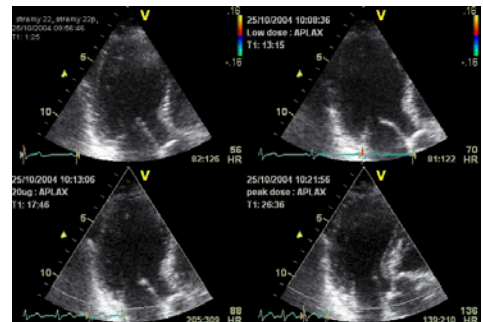


Coronary angiography:

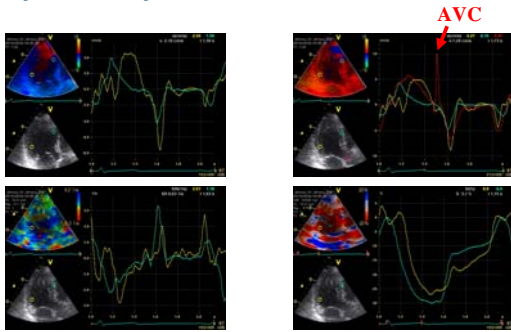


Before After
PCI with stent delivery

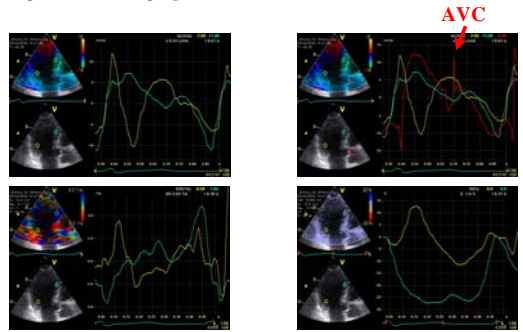
In stress echo:



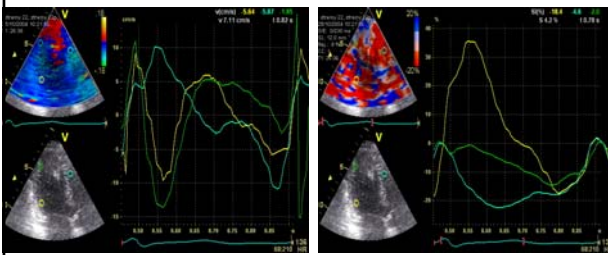
Asynchrony baseline:



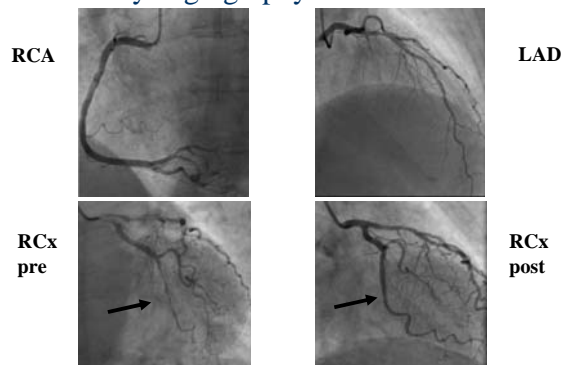
Asynchrony peak:



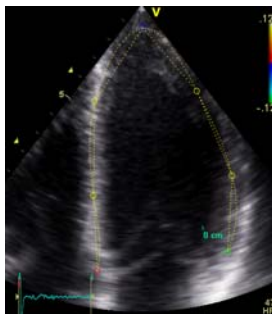
Velocity vs Strain:



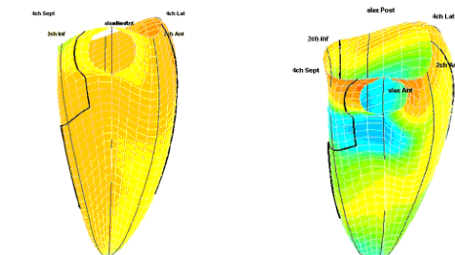
Coronary angiography:



3D reconstruction:

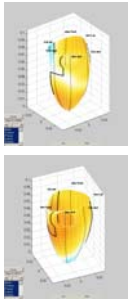


Strain on a 3D surface:

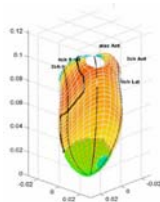


E. Sagberg

Display

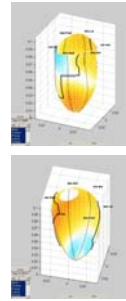


Area measurement

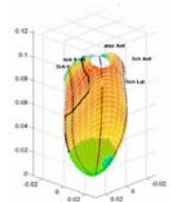


S. Malm

Display

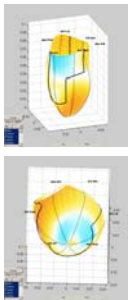


Area measurement

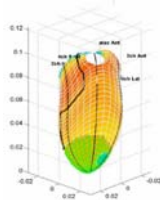


S. Malm

Display

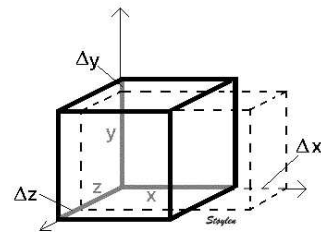


Area measurement

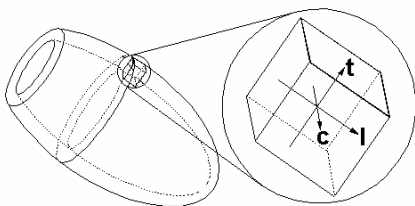


S. Malm

Strain in three dimensions:



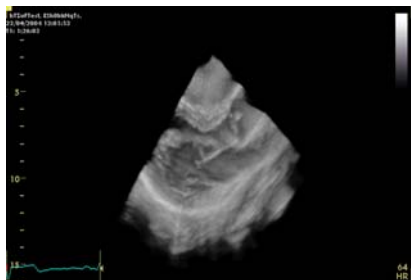
In the left ventricle:



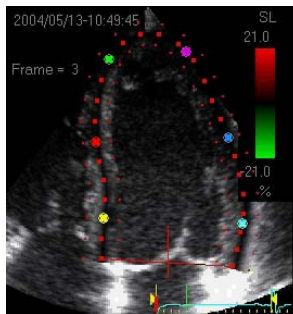
How to measure strain in three dimensions?

- 3D acquisition – speckle tracking
 - Limited frame rate
 - Limited line density
- Geometrical models
 - Based on geometrical assumptions

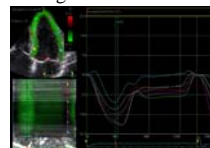
3D acquisition:



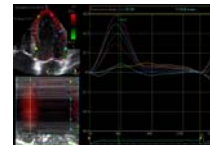
Experience from 2D strain:



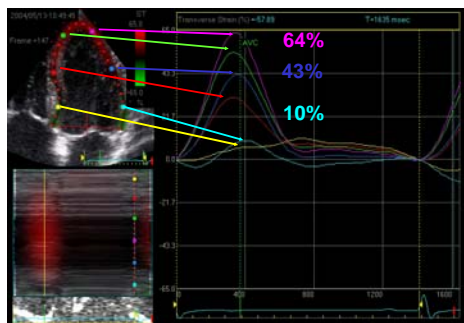
Longitudinal



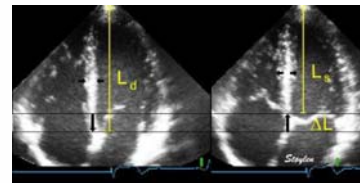
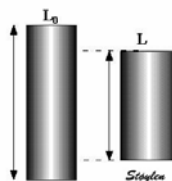
Transmural



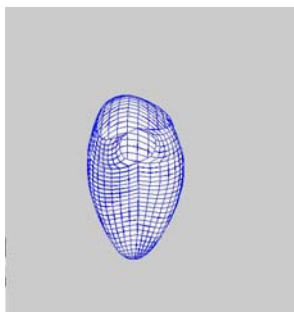
Lateral resolution – transmural strain:



Incompressibility:

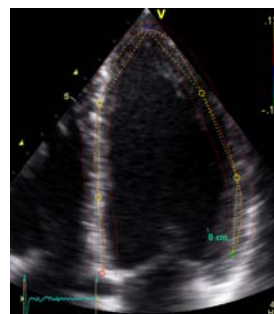


Deformation in 3D



$$(\epsilon_x + 1) (\epsilon_y + 1) (\epsilon_z + 1)$$

Wall thickening:



- **Strain in 3D recordings is probably dependent on a breakthrough in technology, allowing for higher line density.**
- **Strain in 3D is possible by using geometrical modelling and incompressibility assumptions**
- **A combination may be feasible in the near future**

Is it useful?

Added value of 3D strain (accuracy and robustness of diagnosis) needs to be established in clinical studies