

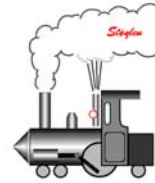
Tissue Doppler and speckle tracking. Different methods for strain and strain rate imaging. Different limitations and advantages

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

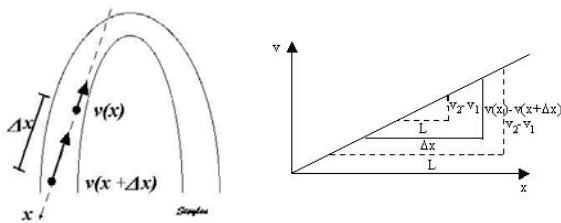
Tissue Doppler:



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

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

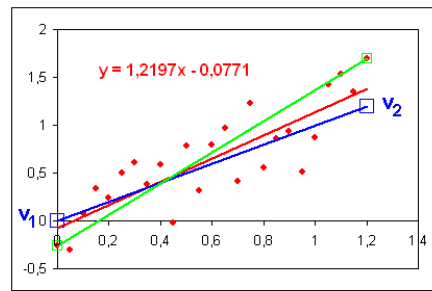
Strain rate:



Heimdal, stoylen et al 1998

Fleming et al 1994

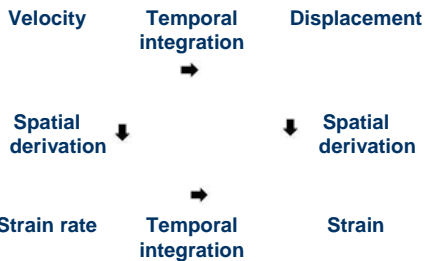
$$SR = \frac{v(x) - v(x + \Delta x)}{\Delta x} = \frac{\Delta v}{\Delta x} = \frac{v1 - v2}{r} = VG$$



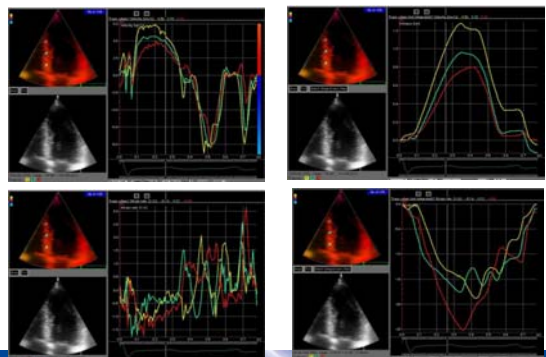
SR = 1

SR = 1.14

SR = 1.63

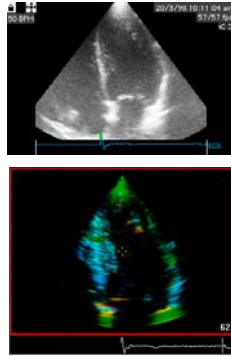
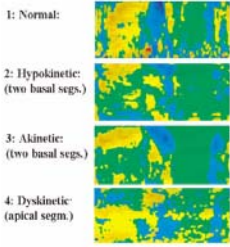


One dataset, four modalities:



Validation

- Stoylen et al 1999 – Wall motion by 2D echo



Validation

- Stoylen et al 1999 – Wall motion by 2D echo
- Stoylen et al 2000 – Coronary angiography

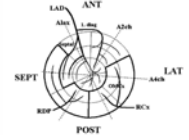
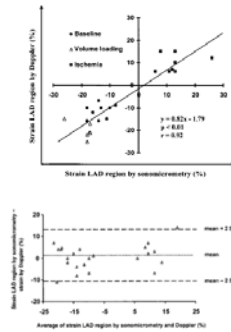


Table 4 Sensitivity and specificity of the 2 methods for angiography-positive segments

Method	Sensitivity	Specificity	Positive-predictive value	Negative-predictive value	Accuracy
SSE positive	70%	90%	80%	84%	83%
Echo-positive	72%	91%	83%	84%	84%
Both echo and SSE	63%	95%	88%	82%	84%
Either echo, SSE, or both	78%	85%	86%	87%	83%

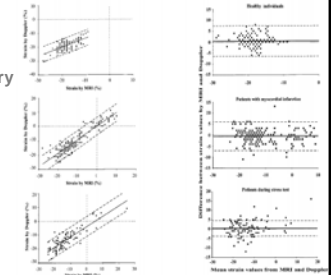
Validation

- Stoylen et al 1999 – Wall motion by 2D echo
- Stoylen et al 2000 – Coronary angiography
- Urheim et al 2000 – Ultrasonomicrometry

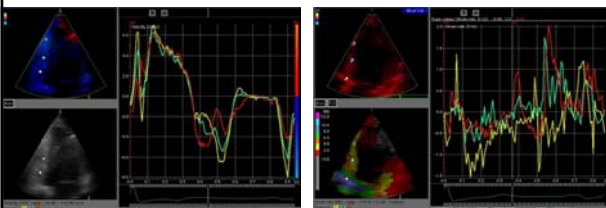


Validation

- Stoylen et al 1999 – Wall motion by 2D echo
- Stoylen et al 2000 – Coronary angiography
- Urheim et al 2000 – Ultrasonomicrometry
- Edvardsen et al 2002 – MR tagging



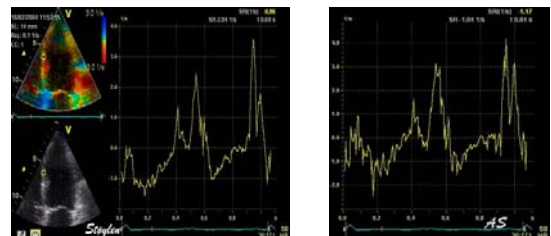
Random noise:



Velocity

Strain rate

Strain length- improved signal / noise ratio

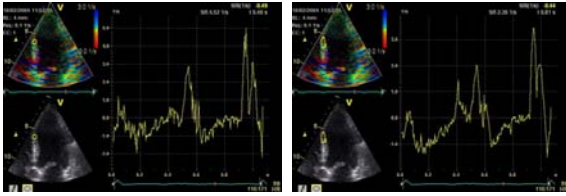


Offset 14 mm

4 mm

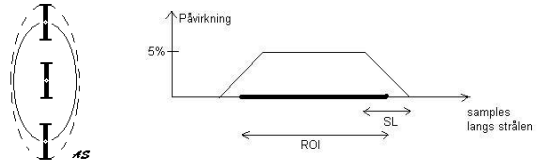
Increased offset – reduced axial resolution

Spatial averaging



Offset 4 mm, no temporal smoothing
ROI 6x6 mm ROI 12x6 mm

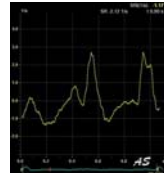
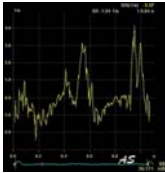
Spatial smoothing



Romlig midling reduces axial and lateral resolution
Axial resolution = Strain length + ROI length

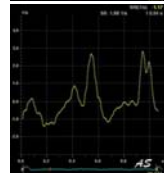
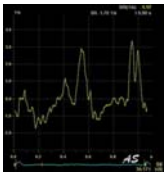
Temporal smoothing (Frame rate 185, offset 4 mm)

No smoothing



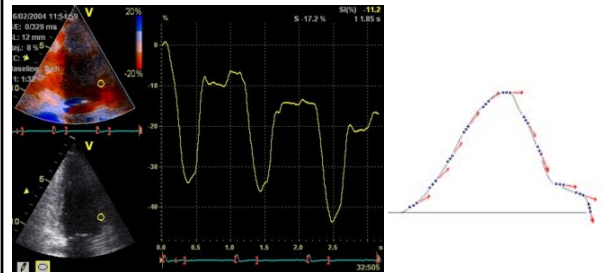
Flat smoothing
7 samples
= 35 ms

Gaussian smoothing
40 ms

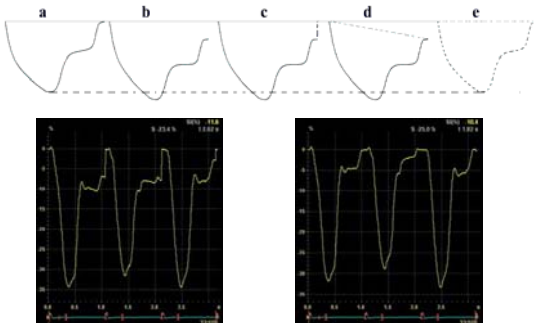


Gaussian smoothing
80 ms

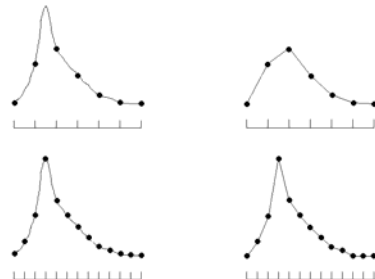
Drift (Strain)



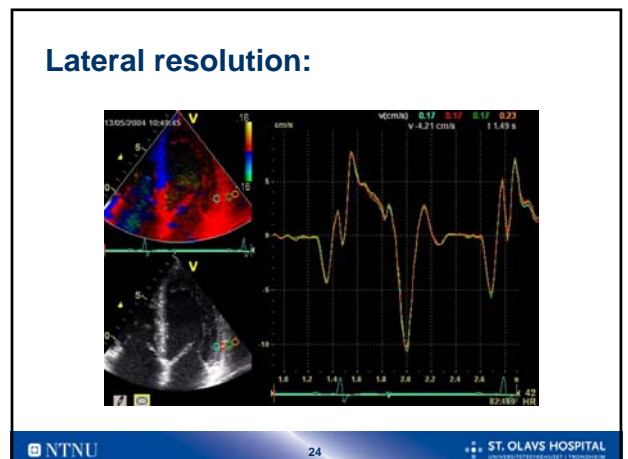
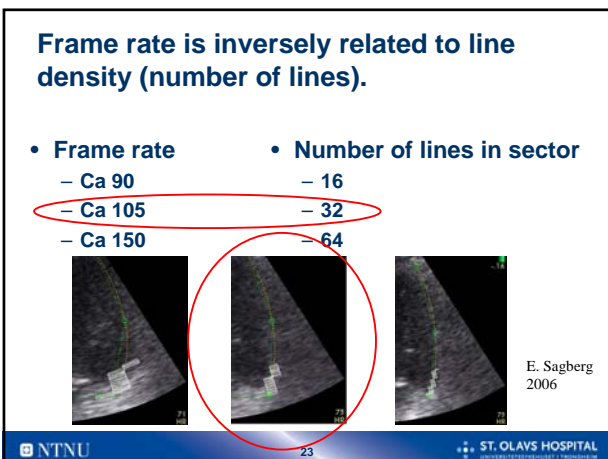
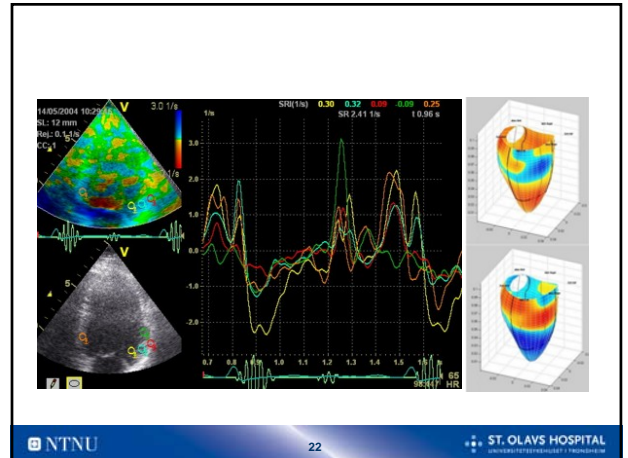
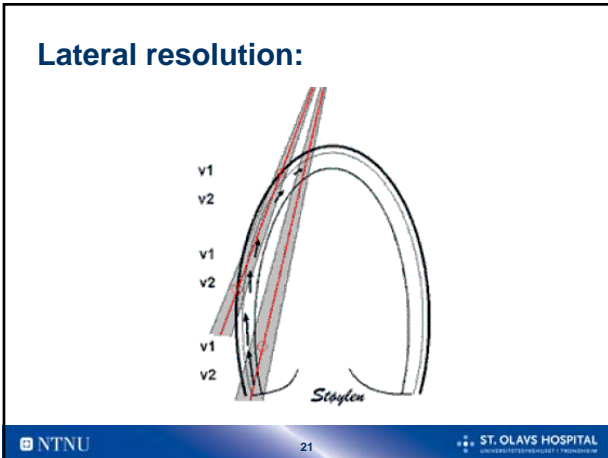
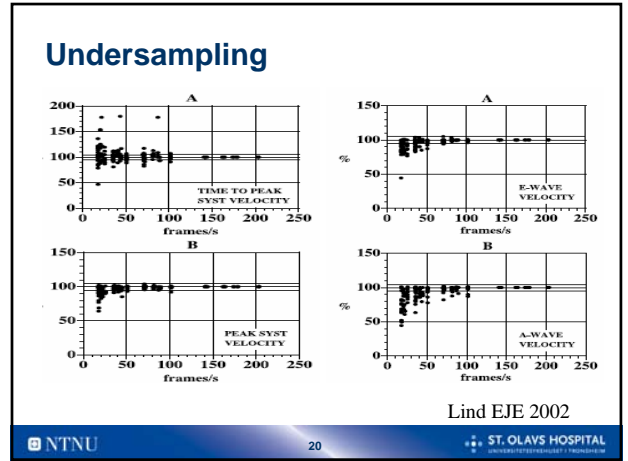
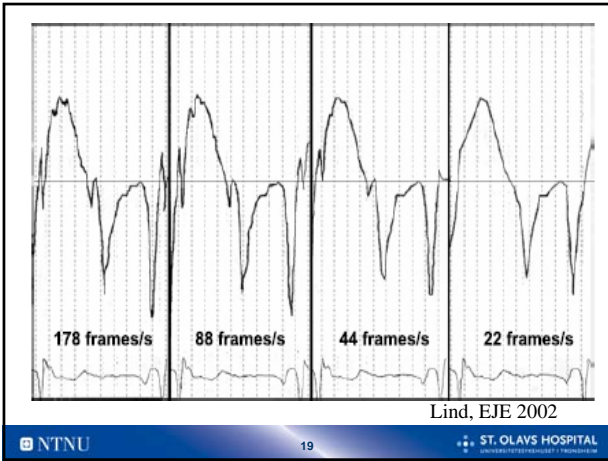
Drift



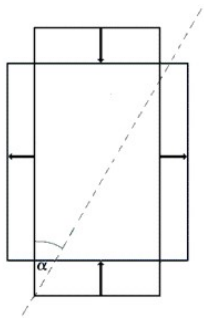
Importance of frame rate:



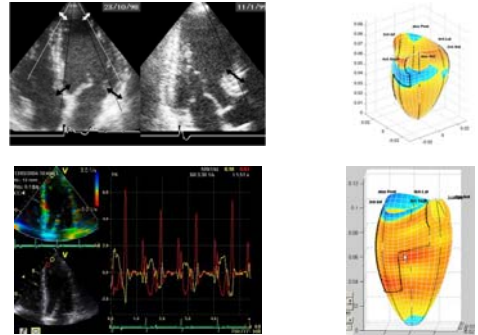
For lav frame rate gir undersampling



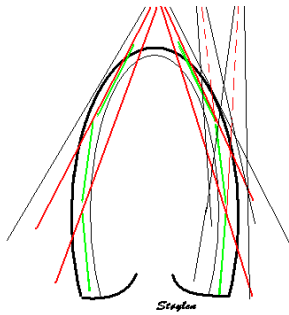
The angle problem:



The angle problem:



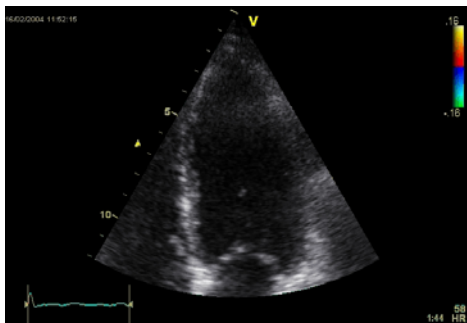
Alignment with the wall:



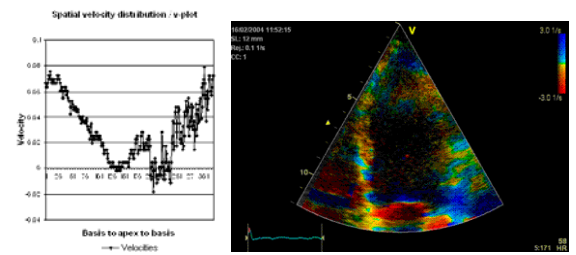
Apical sone



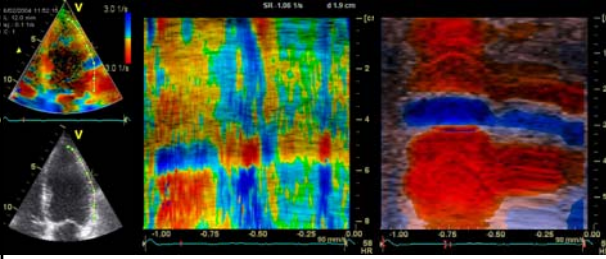
Reverberations:



Reverberations:

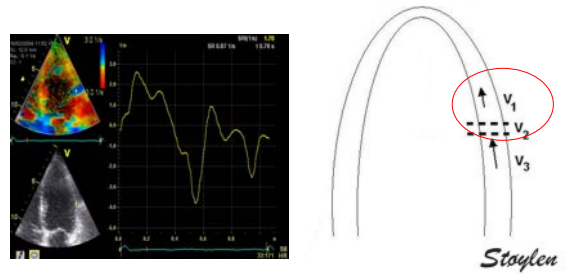


More than 80% of patients show artefacts that affects strain rate imaging in one or more segments!



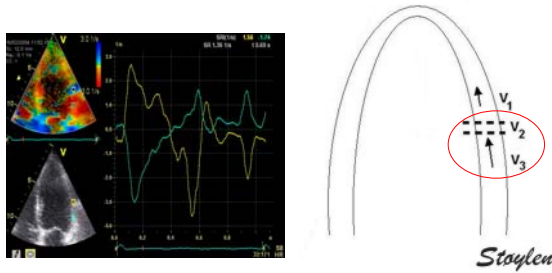
Støylen 2003, Sagberg 2004, Malm 2005

Reverberation artefact:



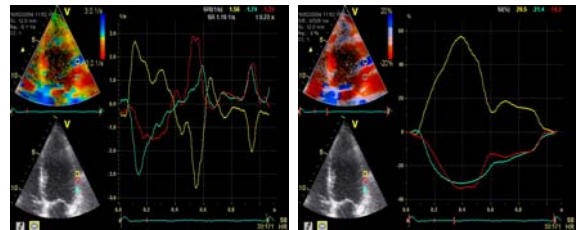
Apparent dyskinesia

Reverberation artefact:



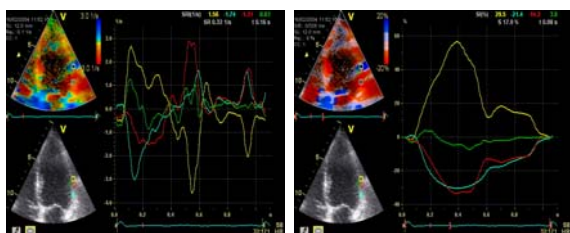
Apparent hyperkinesia

Reverberation artefact:



Apparent normal strain rate

Reverberation artefact:

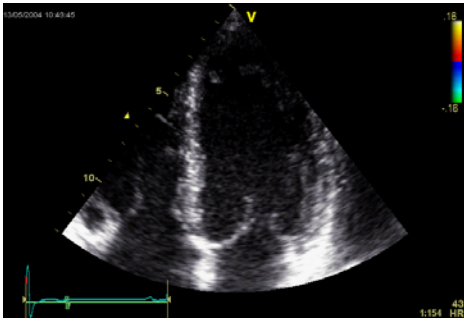


Apparent initial dyskinesia

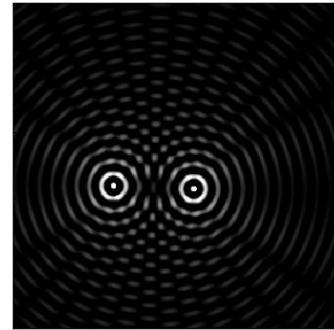
Strain by tissue Doppler:

- Very well documented
- Lacks somewhat in user friendliness
- High frame rate
- Poor lateral resolution
- Angle dependent
- Moderately smoothing dependent
- Pitfalls

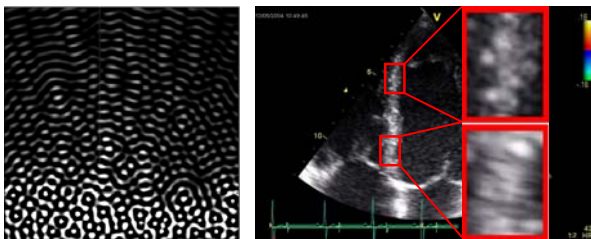
What is speckle tracking?



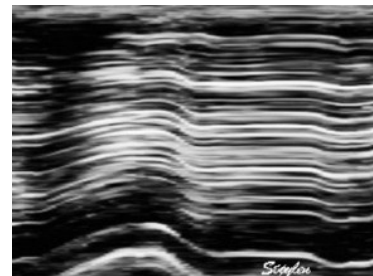
Interference



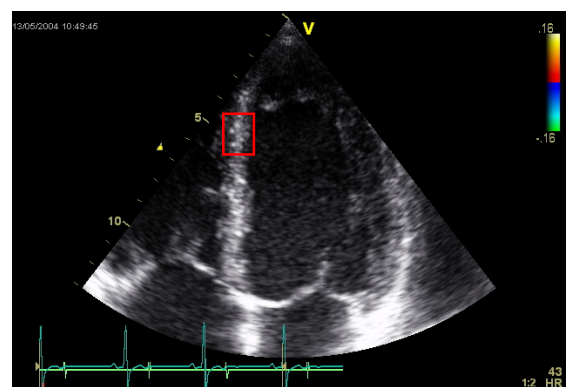
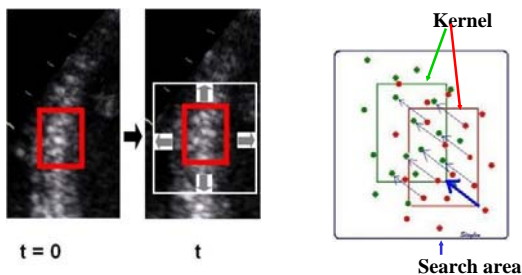
1: Speckle pattern is random; each kernel has a unique "fingerprint"

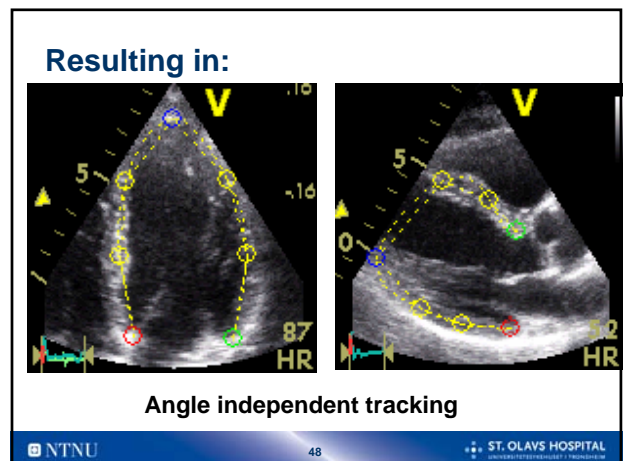
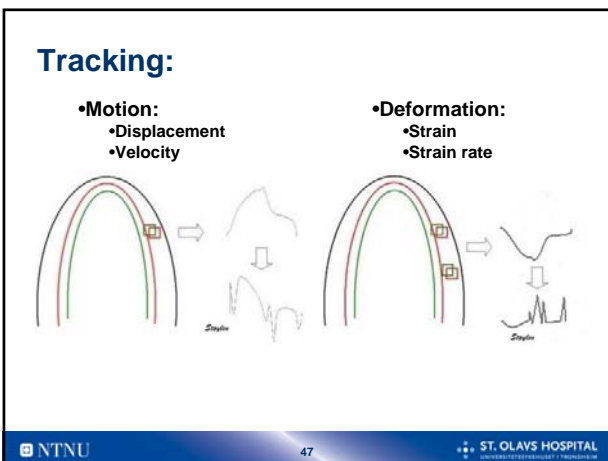
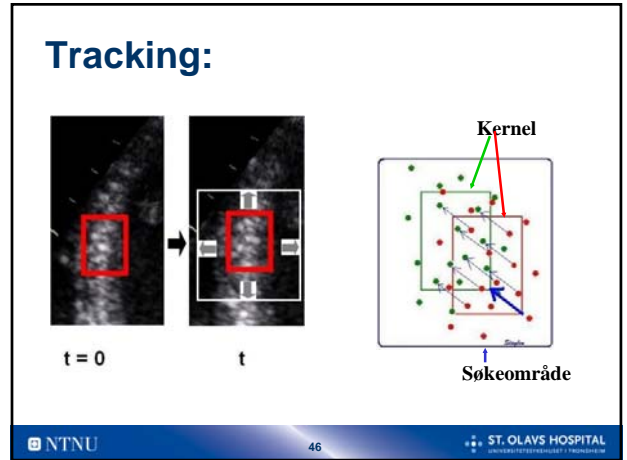
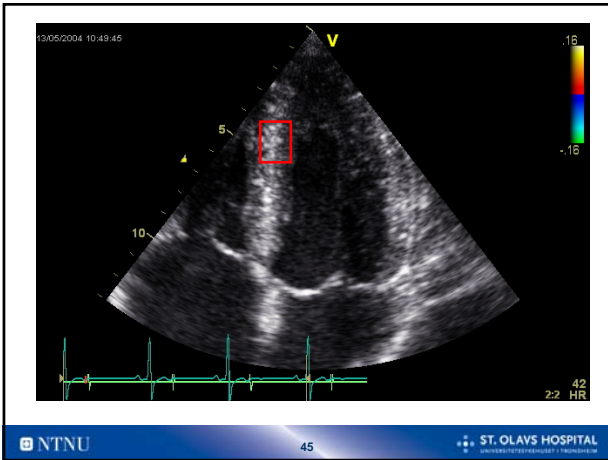
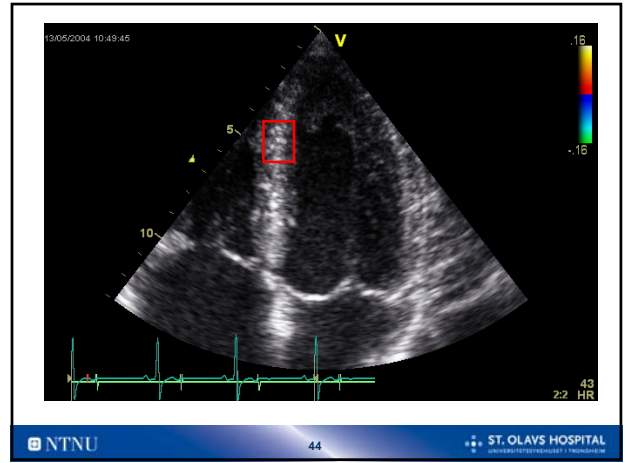
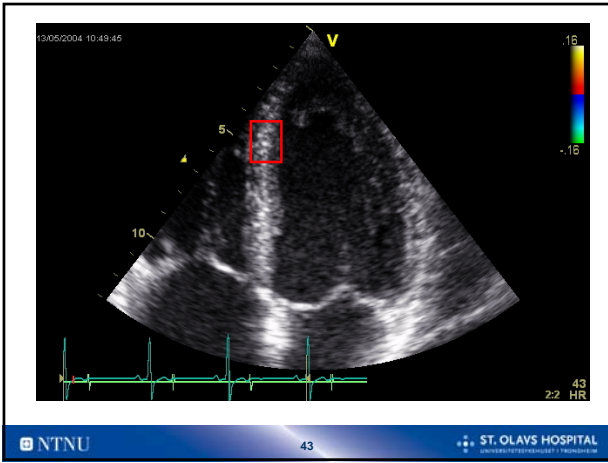


2: Speckle pattern is fairly constant and follows the myocardial motion.

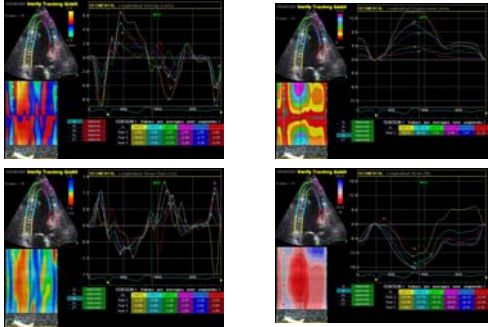


Thus the kernel can be tracked from one frame to the next:

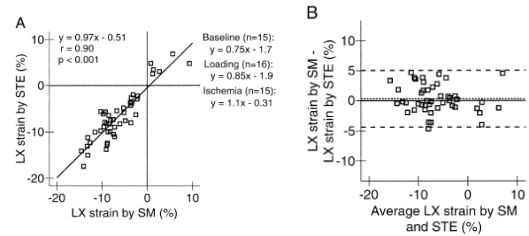




One dataset, four modalities:

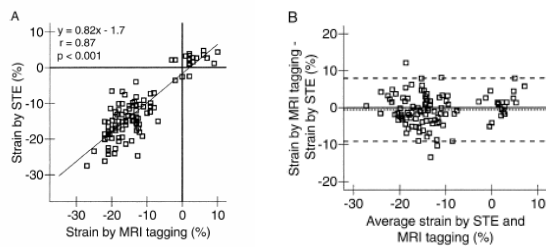


Validation – ultrasonomicrometry:



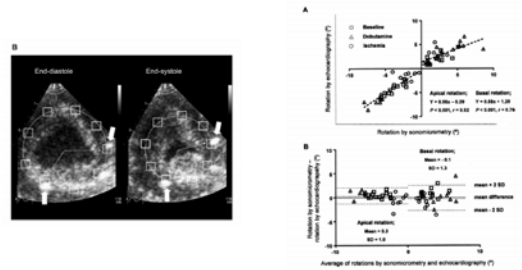
Amundsen et al 2006

Validation – MR tagging



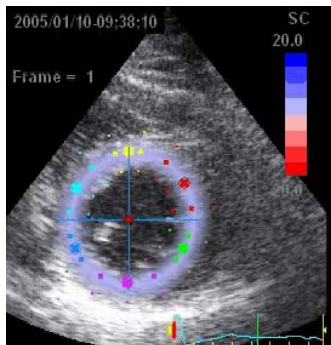
Amundsen et al 2006

Speckle tracking – rotation:



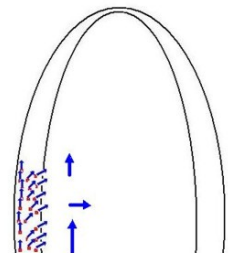
Helle-Valle et al 2005

Rotation and circumferential strain

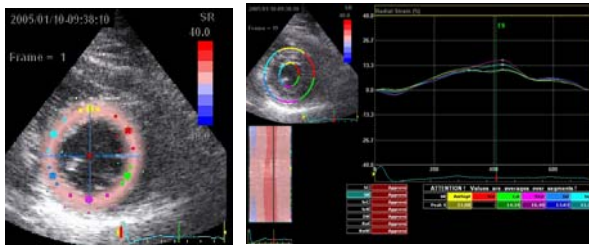


2D strain:

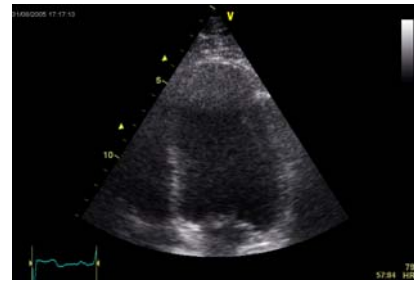
- Deformation in two dimensions simultaneously
- Tracking of more kernels
- Stable speckles (akoustic tagging)



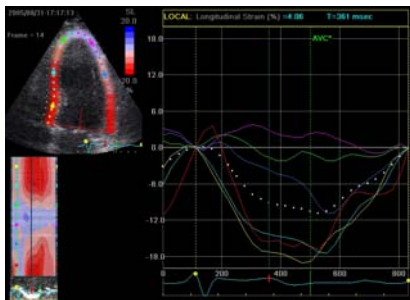
2D strain transmural strain



Longitudinell deformasjon: Eksempel (FVI):

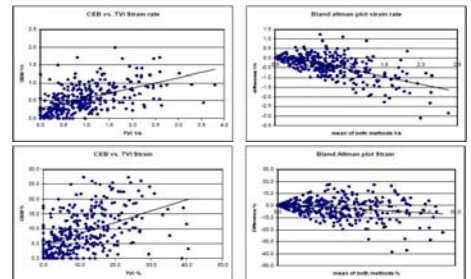


Longitudinell deformasjon: Eksempel (FVI):



Validation – DTI:

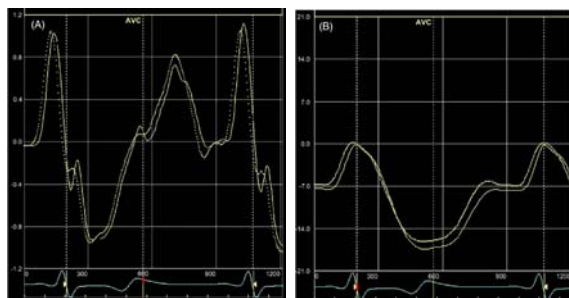
R = 0.53



R = 0.47

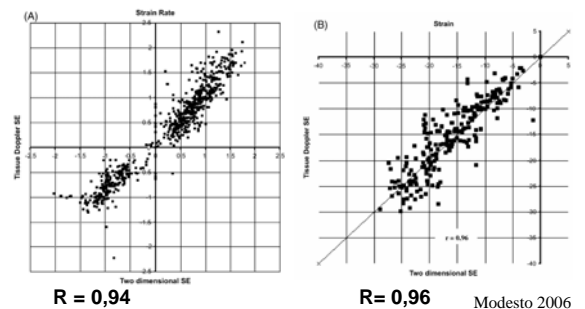
Støylen 2004: www.folk.ntnu.no/stoylen/strainrate

Validation – DTI:



Modesto 2006

Validation – DTI:



R = 0,94

R = 0,96

Modesto 2006

Validation – MR tagging:

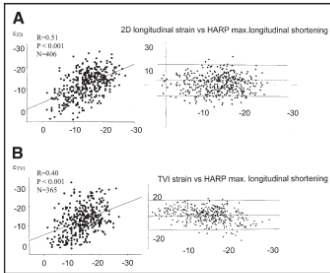


Figure 1. Correlation and Bland-Altman limits of agreement for longitudinal strain. (A) ϵ_{2D} versus HARP MRI and (B) ϵ_{TVI} versus HARP MRI.

Cho et al 2006

Validation – MR tagging:

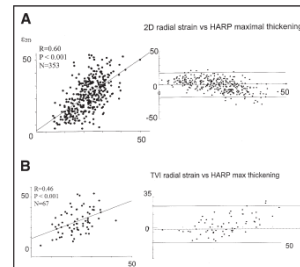


Figure 2. Correlation and Bland-Altman limits of agreement for radial strain. (A) ϵ_{2D} versus HARP MRI and (B) ϵ_{TVI} versus HARP MRI.

Cho et al 2006

Diagnostics (transmural strain):

Table 3. Sensitivity and specificity of myocardial deformation parameters for distinction between non-transmural infarction defined as hyperenhancement 1-50% and transmural myocardial infarction defined as $>50\%$ hyperenhancement by CMR.

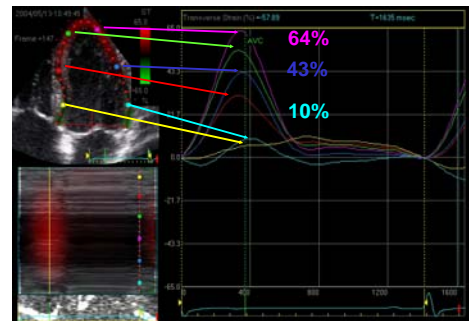
	Data-based estimate	Bootstrap-based estimate	95% Bootstrap CI	
			Lower limit	Upper limit
Circumferential strain				
Sensitivity (%)	70.4	69.3	64.4	74.5
Specificity (%)	71.2	69.7	65.3	74.7
Cut-off value (%)	≤ -11.10	≤ -10.70	-11.30	-10.40
Circumferential SR				
Sensitivity (%)	70.6	70.2	65.2	75.1
Specificity (%)	60.1	58.9	54.8	63.0
Cut-off value (s^{-1})	≤ -1.00	≤ -1.00	-1.03	-0.95
Radial strain				
Sensitivity (%)	70.0	66.8	61.7	72.0
Specificity (%)	71.2	68.4	63.8	72.9
Cut-off value (%)	> -16.30	15.08	13.30	17.00
Radial SR				
Sensitivity (%)	70.1	69.2	64.3	74.1
Specificity (%)	70.6	69.7	65.0	74.0
Cut-off value (s^{-1})	> -1.06	> -1.05	1.01	1.10

Table 4. Sensitivity and specificity of myocardial deformation parameters for distinction between non-infarction defined as hyperenhancement 0% and non-transmural myocardial infarction defined as 1-50% hyperenhancement by CMR.

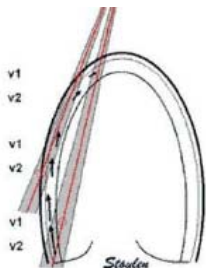
	Data-based estimate	Bootstrap-based estimate	95% Bootstrap CI	
			Lower limit	Upper limit
Circumferential strain				
Sensitivity (%)	71.4	70.4	62.2	78.3
Specificity (%)	64.3	63.9	60.1	67.7
Cut-off value (%)	> -16.30	> -16.68	-17.60	-15.70
Circumferential SR				
Sensitivity (%)	72.0	71.5	63.6	78.9
Specificity (%)	51.2	51.1	48.1	54.3
Cut-off value (s^{-1})	> -1.40	> -1.40	-1.44	-1.33
Radial strain				
Sensitivity (%)	70.1	69.5	60.7	78.7
Specificity (%)	57.2	56.9	53.4	60.4
Cut-off value (%)	≥ 27.10	≥ 27.40	25.50	29.40
Radial SR				
Sensitivity (%)	71.6	71.2	62.9	78.8
Specificity (%)	55.5	55.4	52.2	58.8
Cut-off value (s^{-1})	≥ 1.35	≥ 1.36	1.29	1.44

Becker et. Al EJE nov 2006

Lateral resolution – transmural strain:



Feasibility and reproducibility:



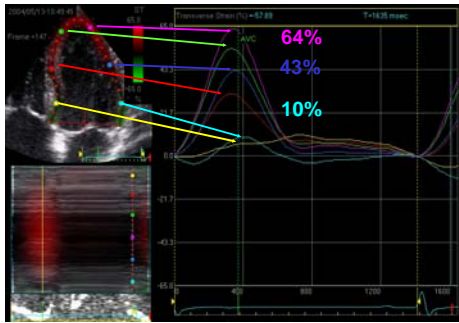
- 2DS had:
 - Better feasibility: 76 vs 66% of segs
 - Better reproducibility CoR 5,0 vs 7,9%
 - Good over all correlasjon 2DS vs DTI 74%,
 - Poor in basal segs (37%)

Amundsen 2005

Speckle tracking

- Low frame rate:
 - Too big change from frame to frame (same effect with higher heart rate)
- High frame rate:
 - Poorer lateral resolution:
 - Poor lateral tracking
 - Less angle independence

Lateral resolution – transmural strain:



Heart rate sensitivity:

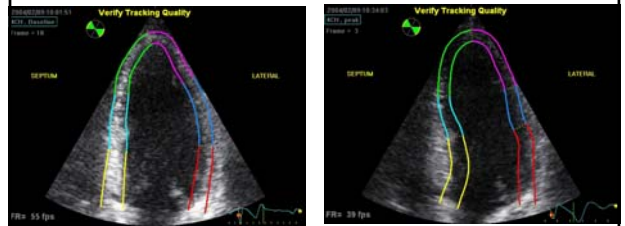


Image quality:



Smoothing:

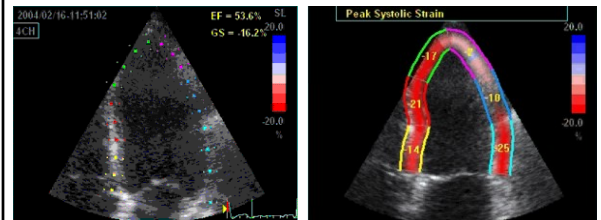
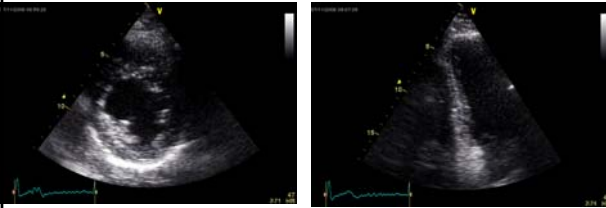


Table 2 Myocardial deformation parameters related to relative degree of myocardial hyperenhancement by cMRI

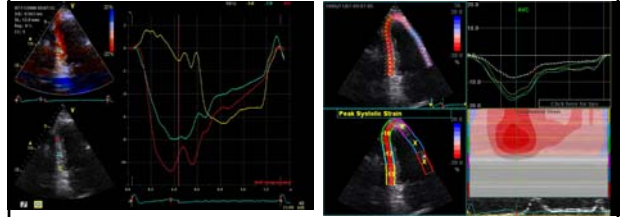
Segmental hyperenhancement	Circumferential strain (%)	Radial strain (%)	Circumferential SR (s ⁻¹)	Radial SR (s ⁻¹)
0%, non-infarcted (n = 42)	-18.6 ± 5.6	27.7 ± 8.0	-1.42 ± 0.34	1.43 ± 0.55
1-50%, non-transmural infarction (n = 106)	-12.8 ± 6.7	20.5 ± 6.2	-1.07 ± 0.48	1.12 ± 0.37
51-100%, transmural infarction (n = 131)	-8.1 ± 5.3	11.6 ± 8.5	-0.81 ± 0.44	0.79 ± 0.45
rMANOVA (all groups of hyperenhancement)	<0.0001	<0.0001	<0.0001	<0.0001
Post hoc test (normal (group 1) vs. non-transmural late enhancement (groups 2 and 3))	<0.0002	<0.0002	<0.0002	<0.0002
Post hoc test (non-transmural (groups 2 and 3) vs. transmural late enhancement (groups 4 and 5))	0.0016	0.0458	<0.0002	0.0020

Strain values were not zero in completely non-viable segments. This may be due to measurement artefacts related to tethering from adjacent segments. These artefacts are likely to have affected in particular segments with low myocardial deformation. However, in spite of these artefacts, a distinction of hyper-enhancement categories was still possible.

Example: Inferior infarct



Example: Inferior infarct



If smoothing reduces sensitivity needs to be established

2D strain:

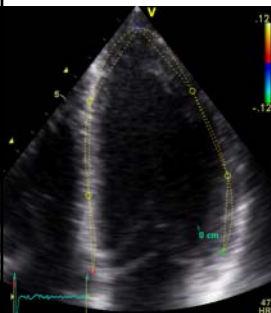
- Fairly well validated
- Little clinical documentation
- User friendly
- Low frame rate; may be HR dependent
- Angle independent
- Sensitive to reverberations and drop outs
- Highly smoothing dependent
- Strain measurable in all directions
 - Little validation so far
 - No documentation of added clinical value

Integrated analysis:

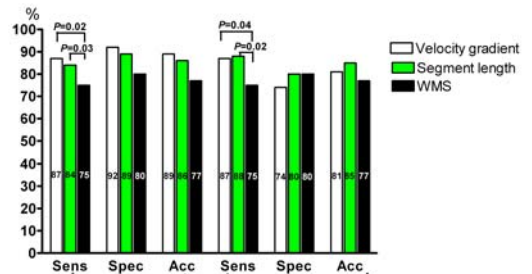


- Longitudinal: Tissue Doppler
- Transverse: Speckle tracking
- Allows for faster tracking
- Longitudinal data with high frame rate

Integrated analysis:



- Longitudinal: Tissue Doppler
- Transverse: Speckle tracking
- Allows for faster tracking
- Longitudinal data with high frame rate
- Angle independent even with tissue Doppler (segment length)
- Can be applied without tissue Doppler
- Can use segment tracking as base for longitudinal velocity gradient (mid segment ROI)



Ingul et al JACC 2007