

Om du ønsker, kan du sette inn navn, tittel på foredraget, o.l. her.

Måling av regional myokardfunksjon med ultralyd.

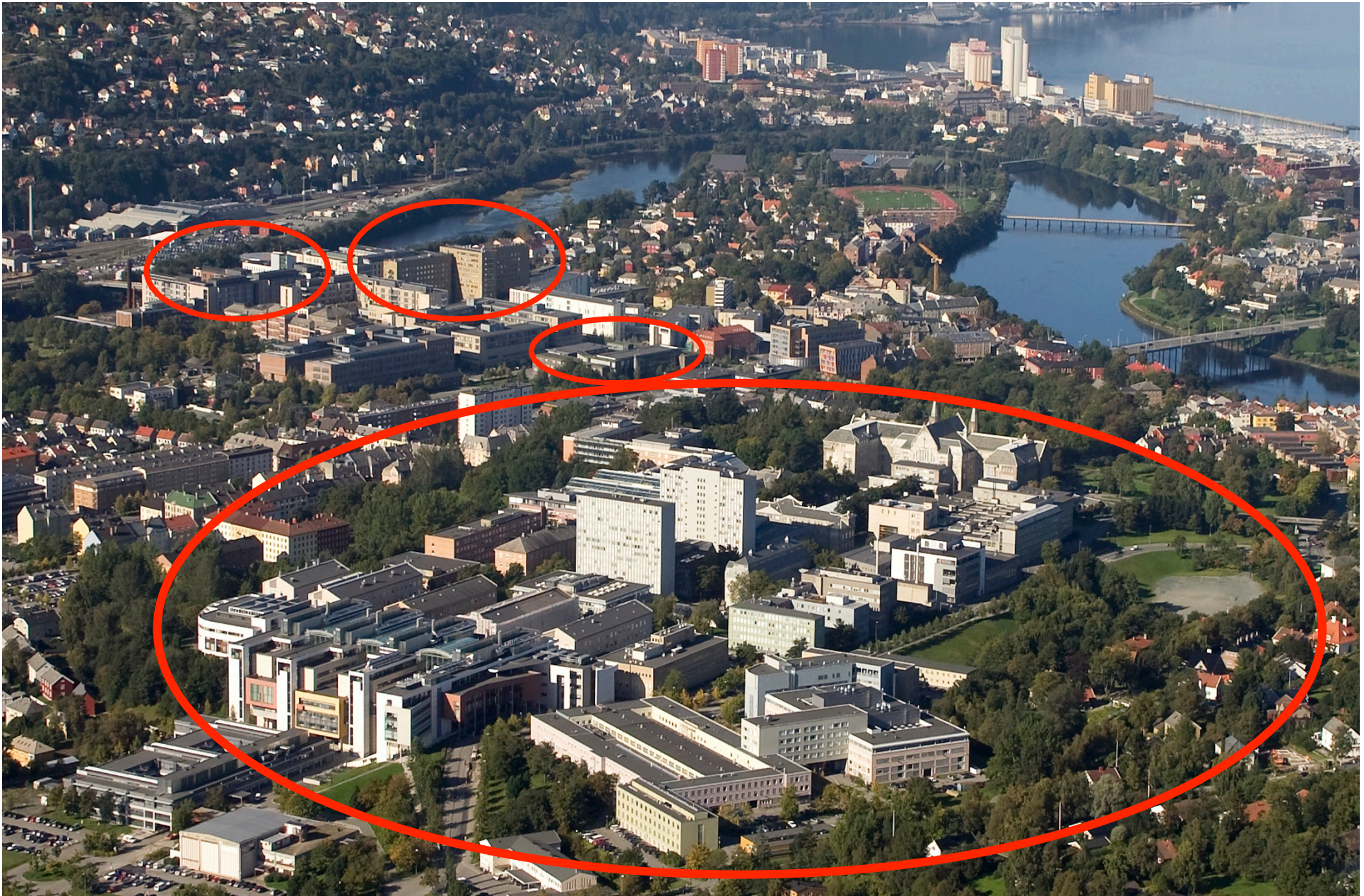
Ole Storsteins prisforedrag 2012

Asbjørn Støylen,
Professor, Dr. Med.

ISB

DMF

NTNU





3 Liv Hatle og Bjørn Angelsen



ST. OLAVS HOSPITAL
UNIVERSITETSSYKEHUSET I TRONDHEIM



NTNU

Det skapende universitet

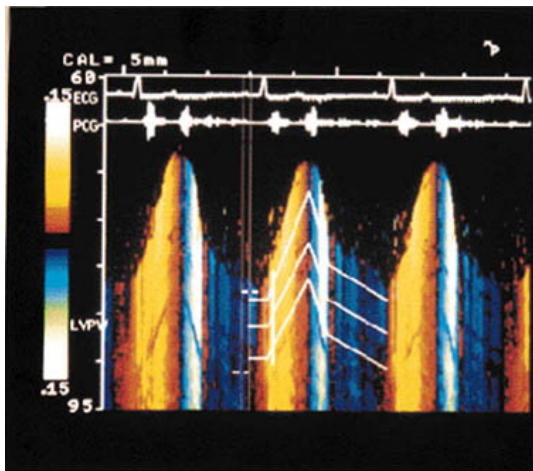


Terje Skjærpe

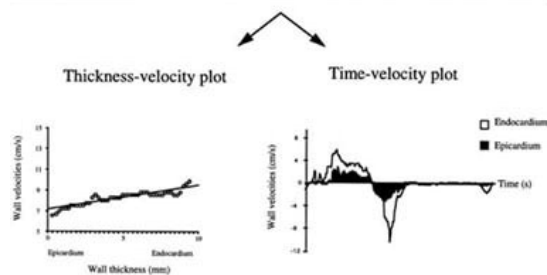


Hans Torp

Farge vevsdoppler hastighetsgradient transmuralt



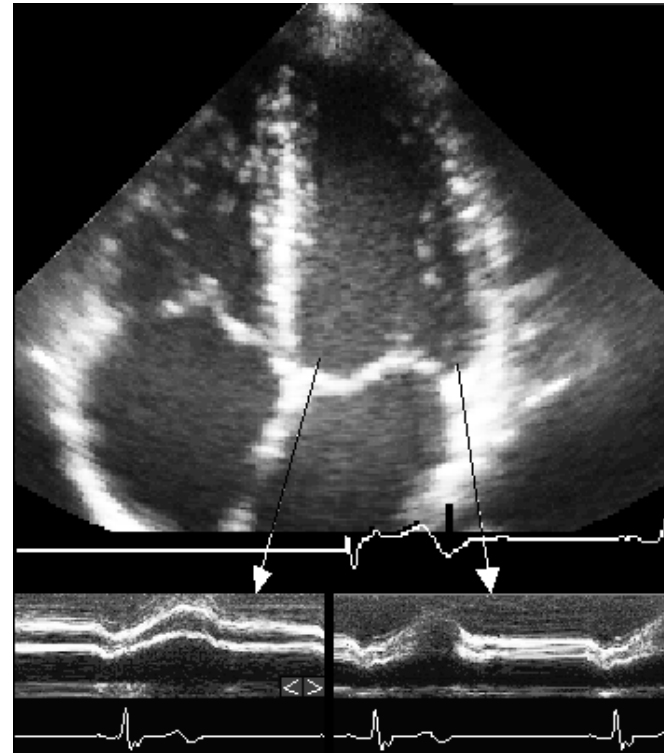
- Fleming et al 1994
- Uematsu et al 1995



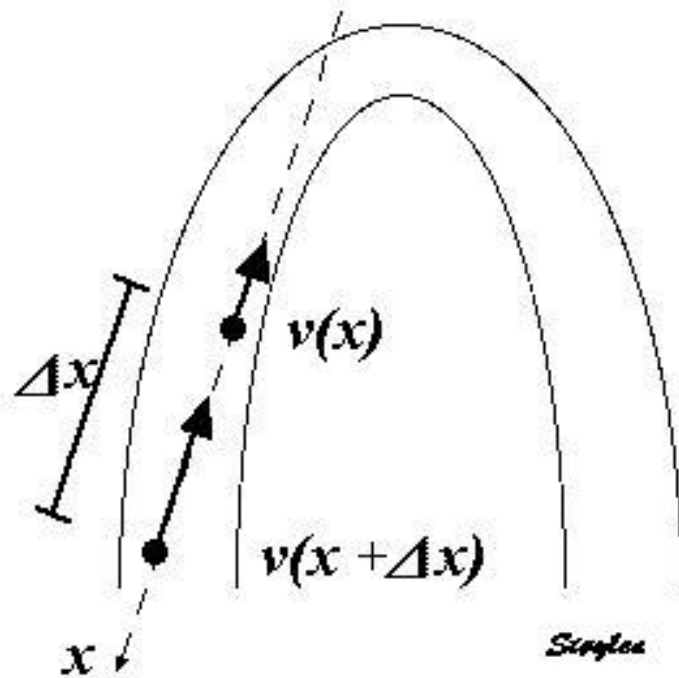
Deformasjon (strain) med vevsdoppler:



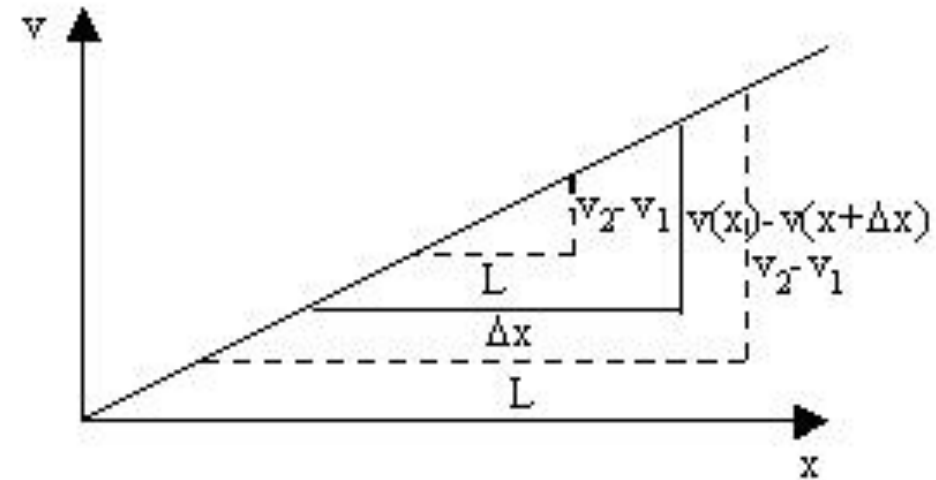
Andreas Heimdal



Strain rate:



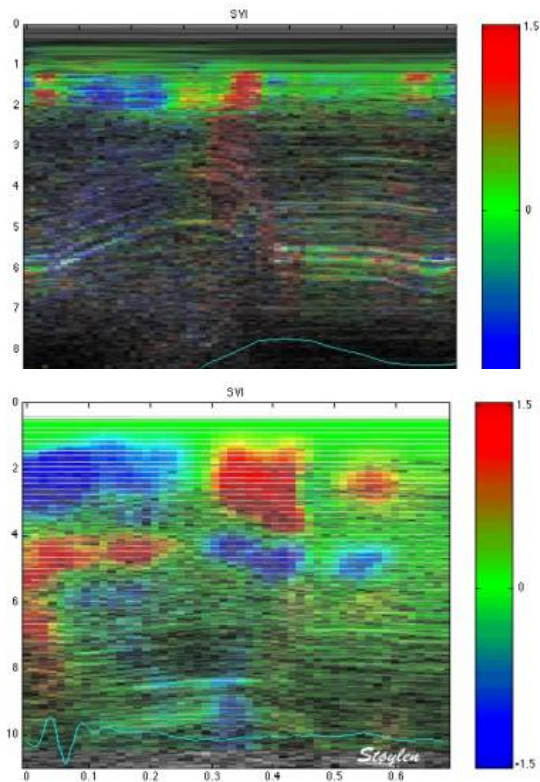
Heimdal et al 1998



Fleming et al 1994

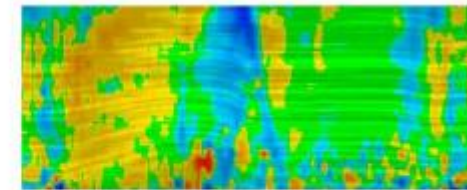
$$SR = \frac{v(x) - v(x + \Delta x)}{\Delta x} = \frac{\Delta v}{\Delta x} = \frac{v_1 - v_2}{r} = VG$$

Strain rate imaging:

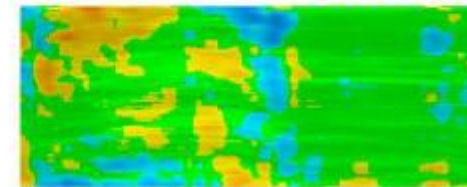


Heimdal et al 1998

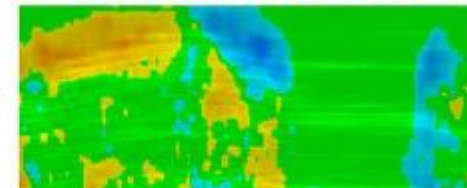
1: Normal:



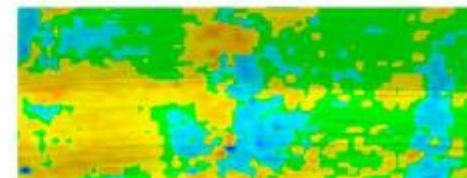
2: Hypokinetic:
(two basal segs.)



3: Akinetic:
(two basal segs.)



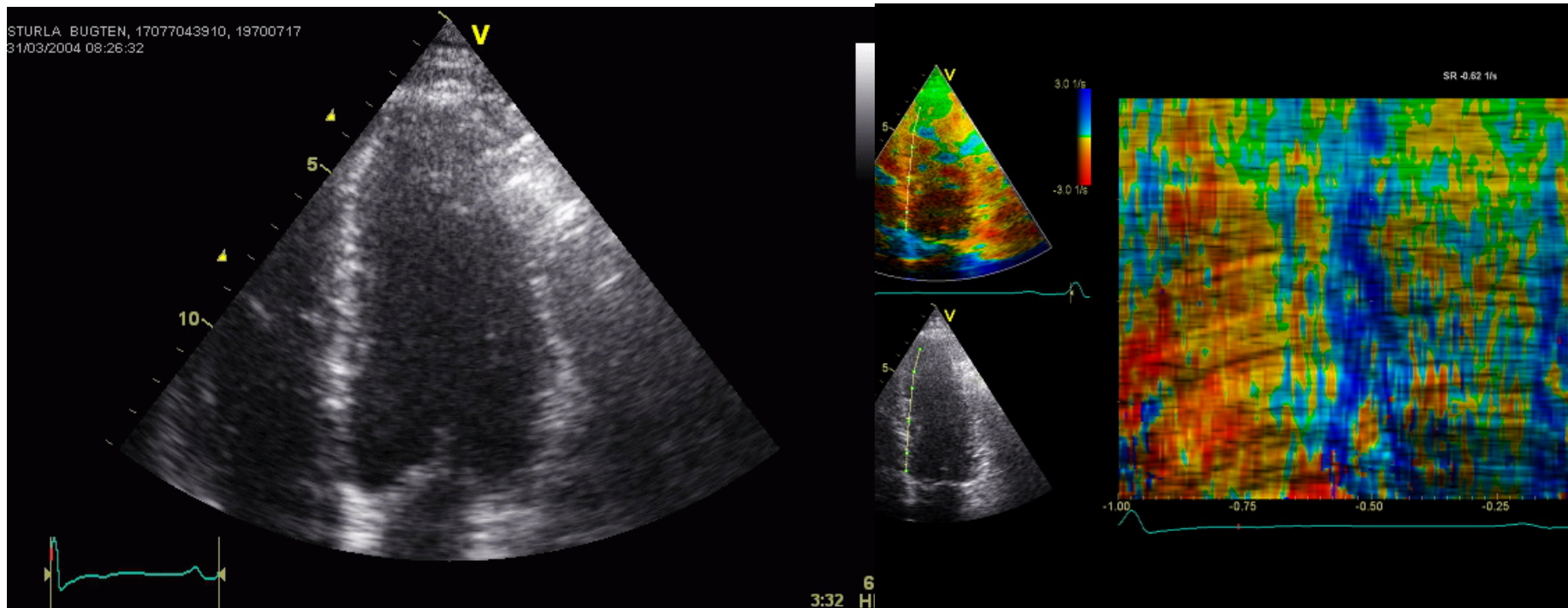
4: Dyskinetic:
(apical segm.)



Støylen et al 1999

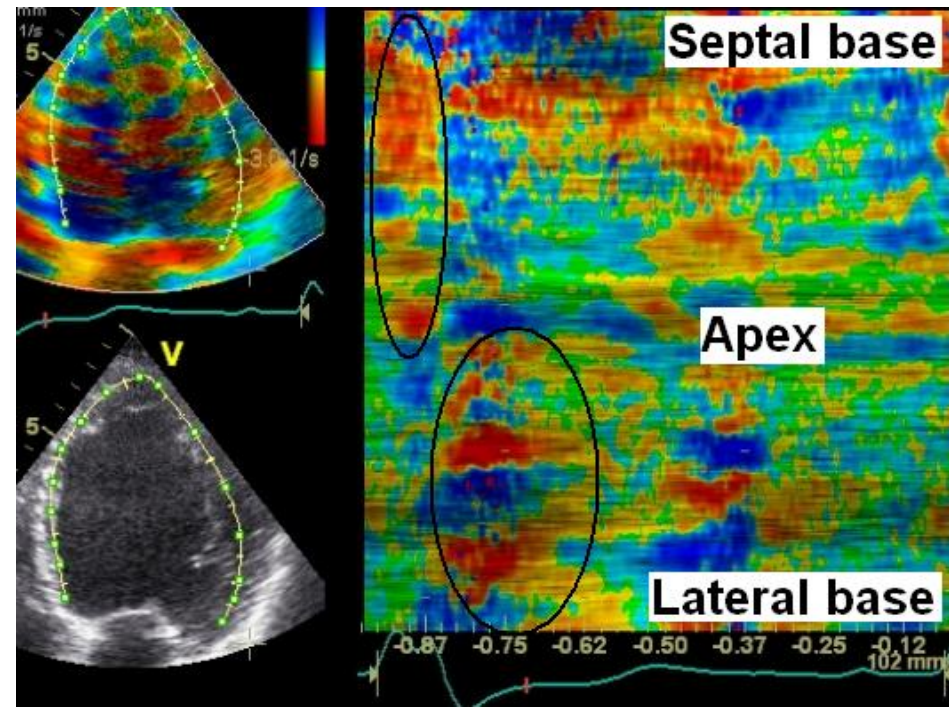
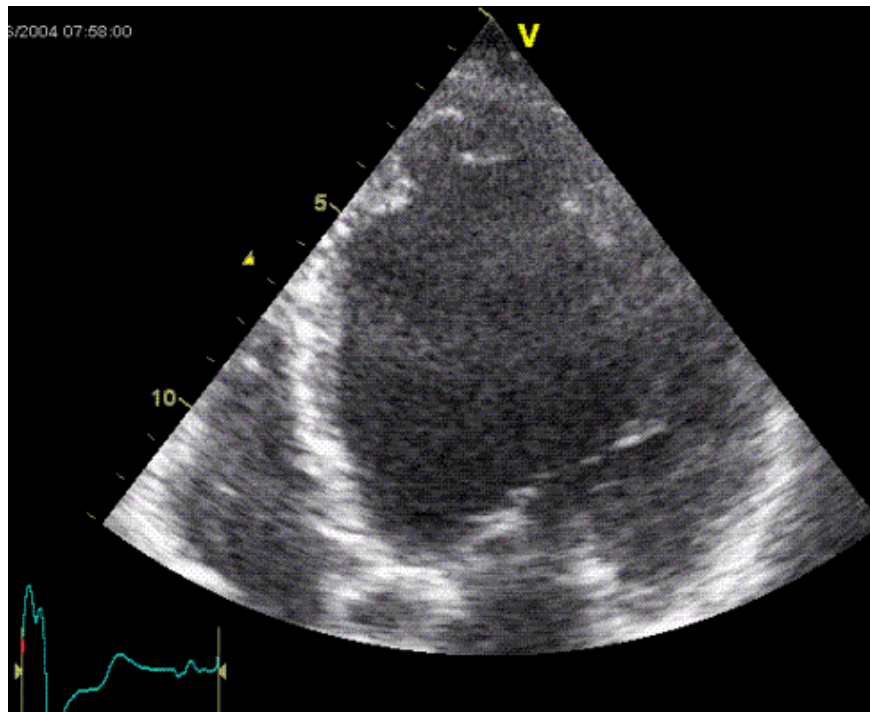
Støylen et al 2000

Kurvet M-mode

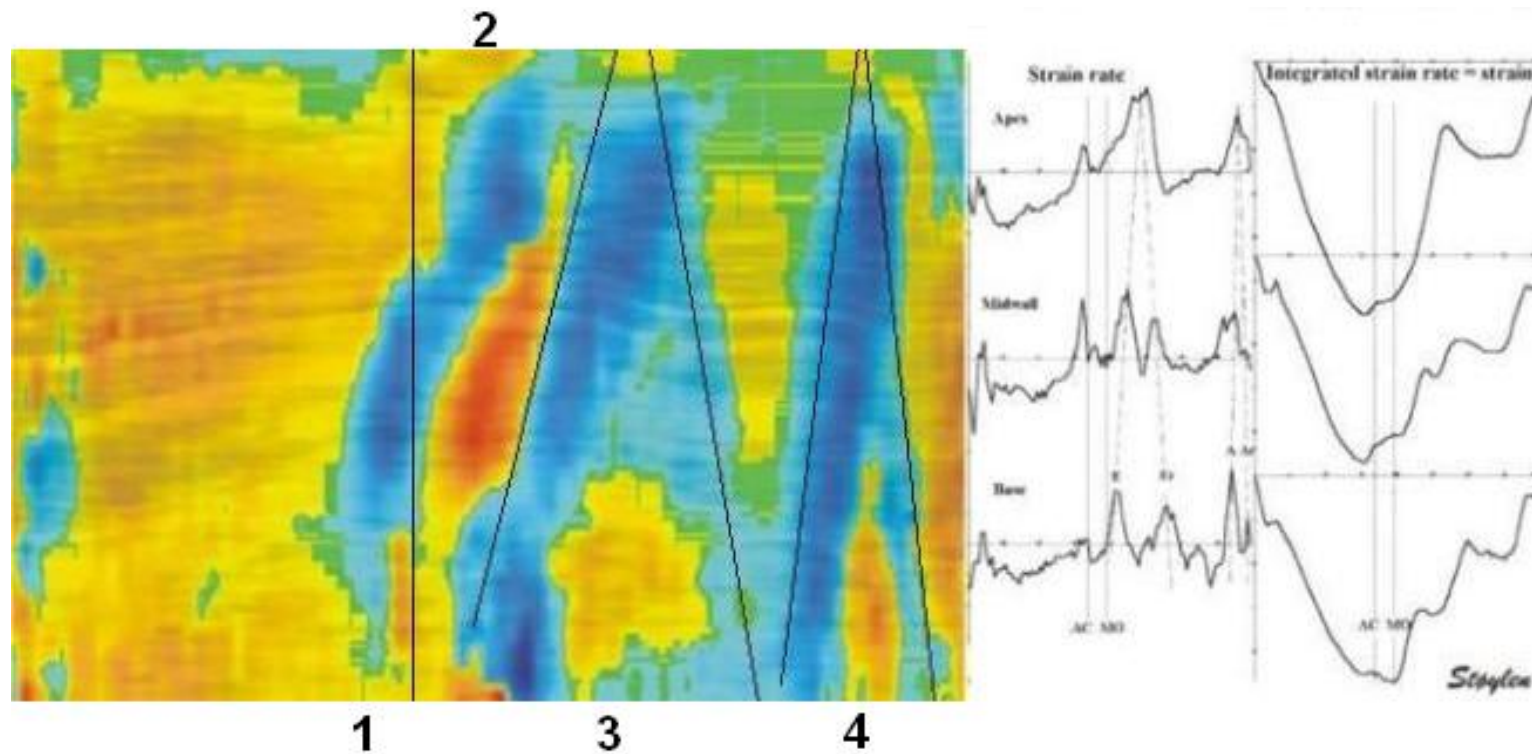


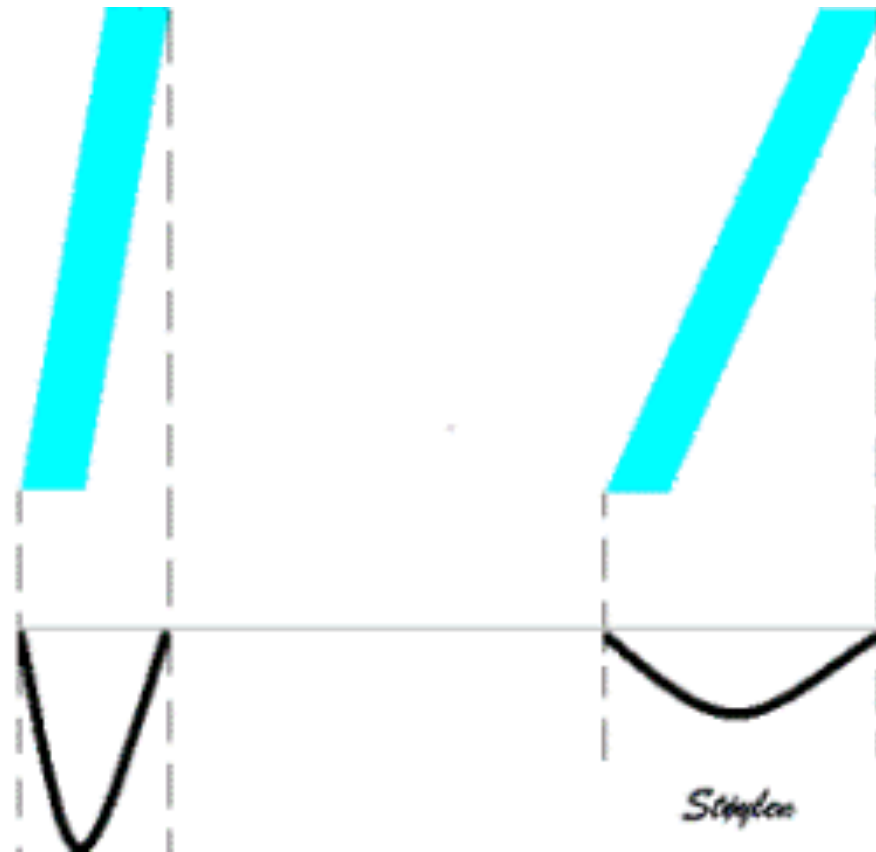
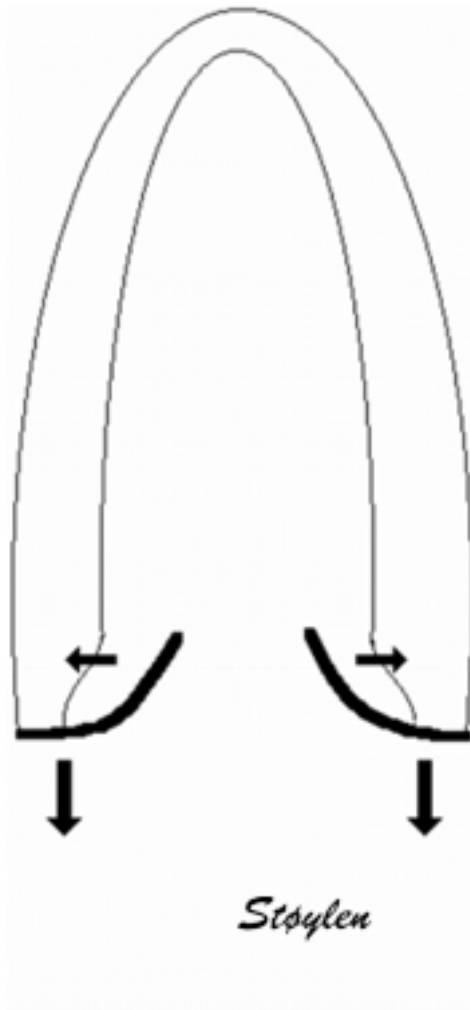
**Kvalitativ deformasjonsinformasjon,
kvantitativ timing informasjon**

Timing



Ny fysiologisk informasjon:

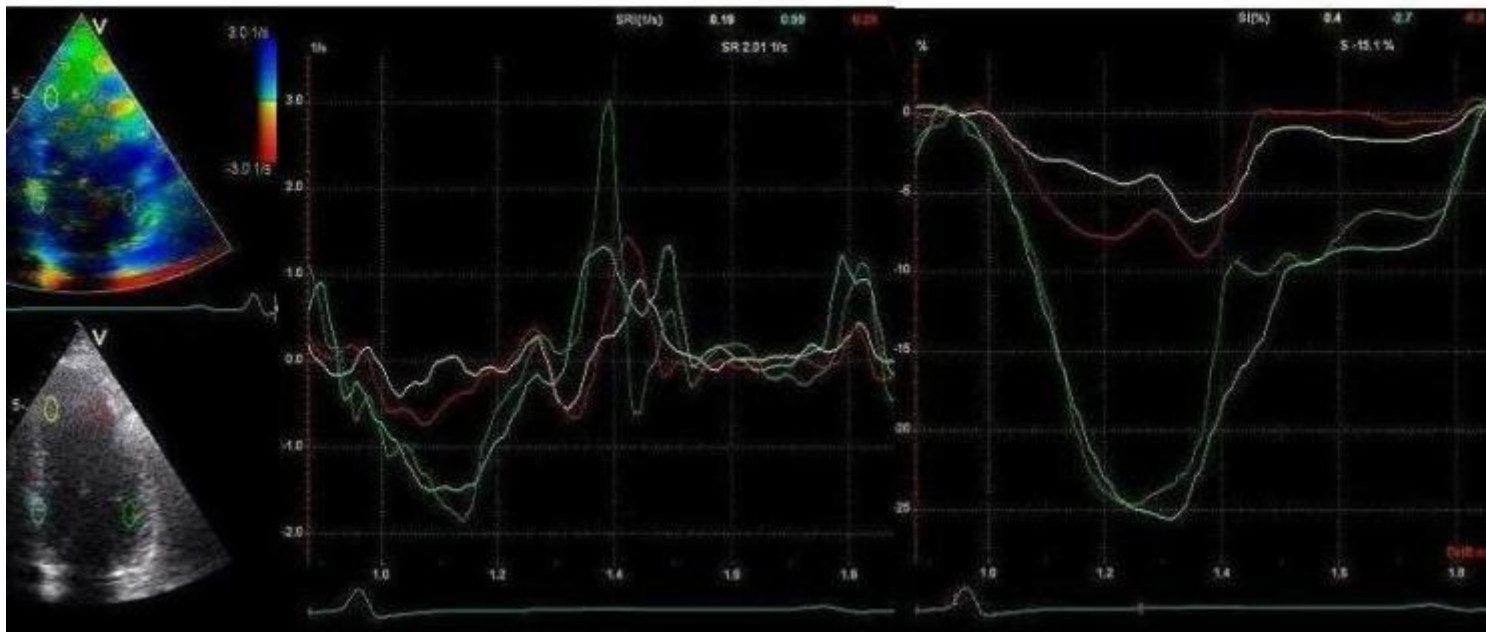




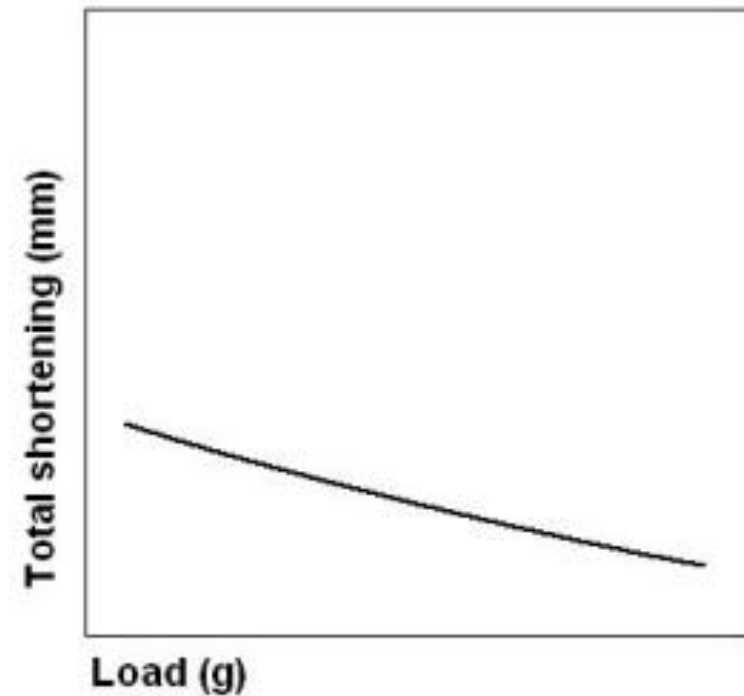
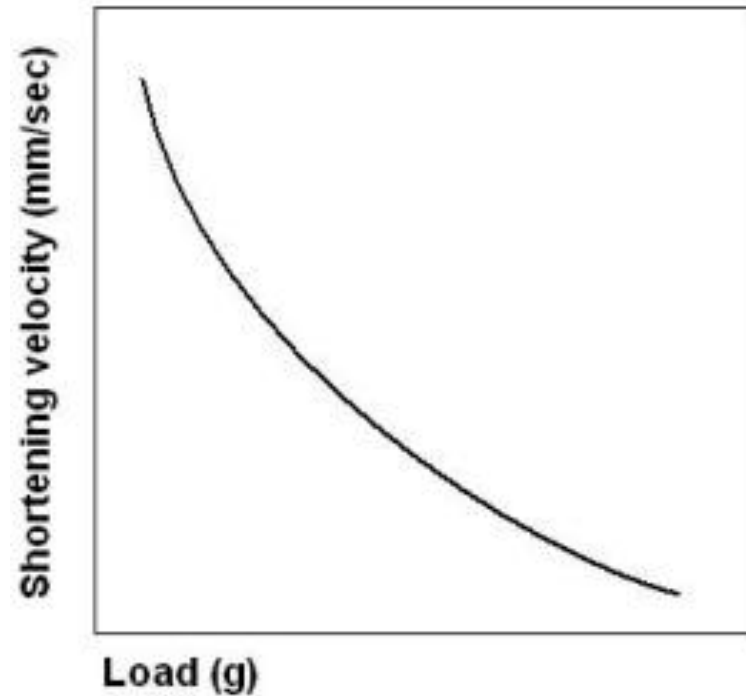
Kvantitative målinger

Strain rate

Strain



Er strain rate load uavhengig?

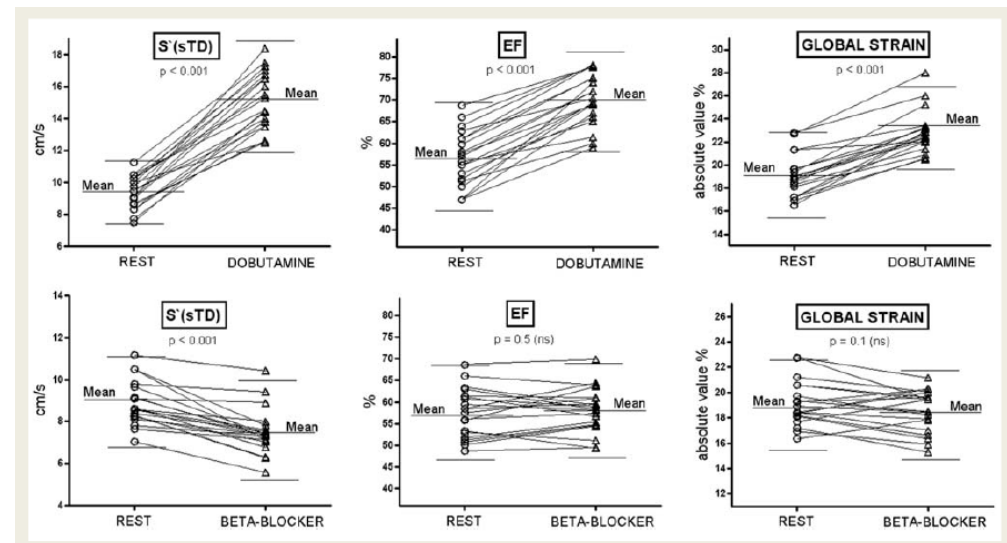


Sonnenblick 1962

Selvsagt ikke

Globale deformasjonsmål er ikke direkte kontraktilitetsmål:

- Tidlig systoliske mål (Hastigheter og strain rate) mer sensitive for kontraktilitesendring
 - Nærmere knyttet til kontraktilitet
- enn endesystoliske (EF, Annulus displacement, Strain)



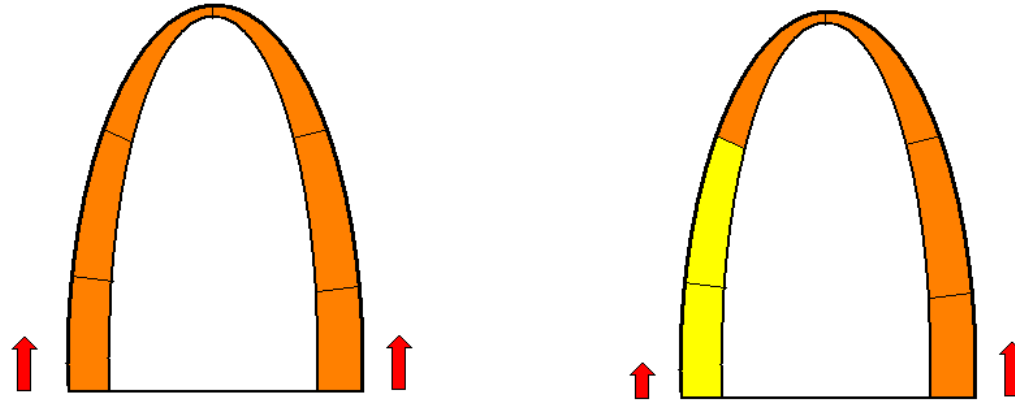
Globale funksjonsmål vs. infarktstørrelse:

- **Global strain bedre enn EF (Gjesdal 2007)**
- **Global strain likeverdig med WMSI (Eek 2010)**
- **Global strain likeverdig med annulus displacement (Thorstensen 2012)**

Regionale funksjonsmål vs. Infarktlokalisasjon:

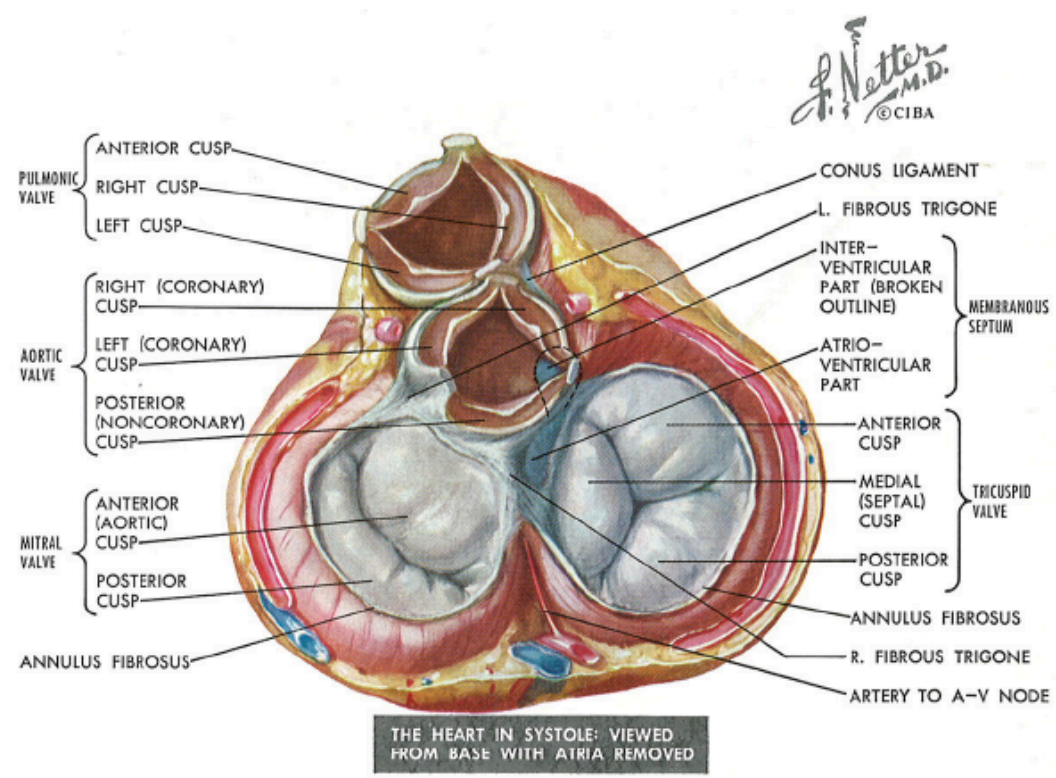
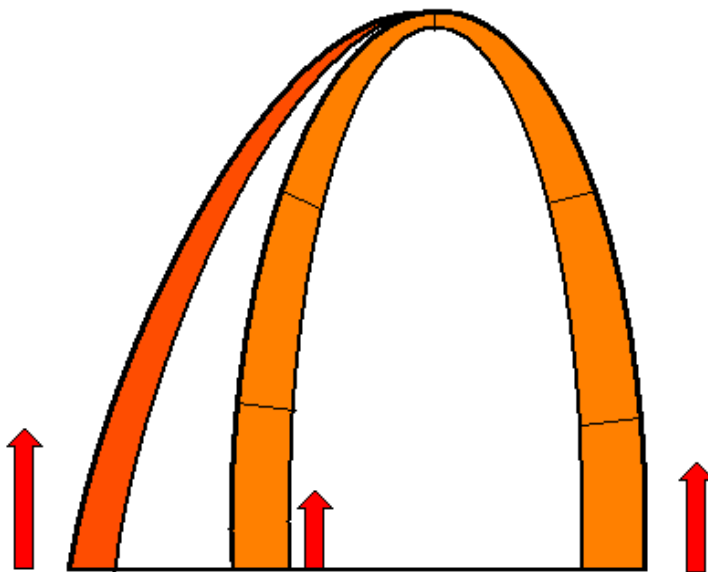
- **Strain likeverdig med WMS (Støylen 2000, Grenne 2010)**

Får vi regional informasjon fra annulusmål?



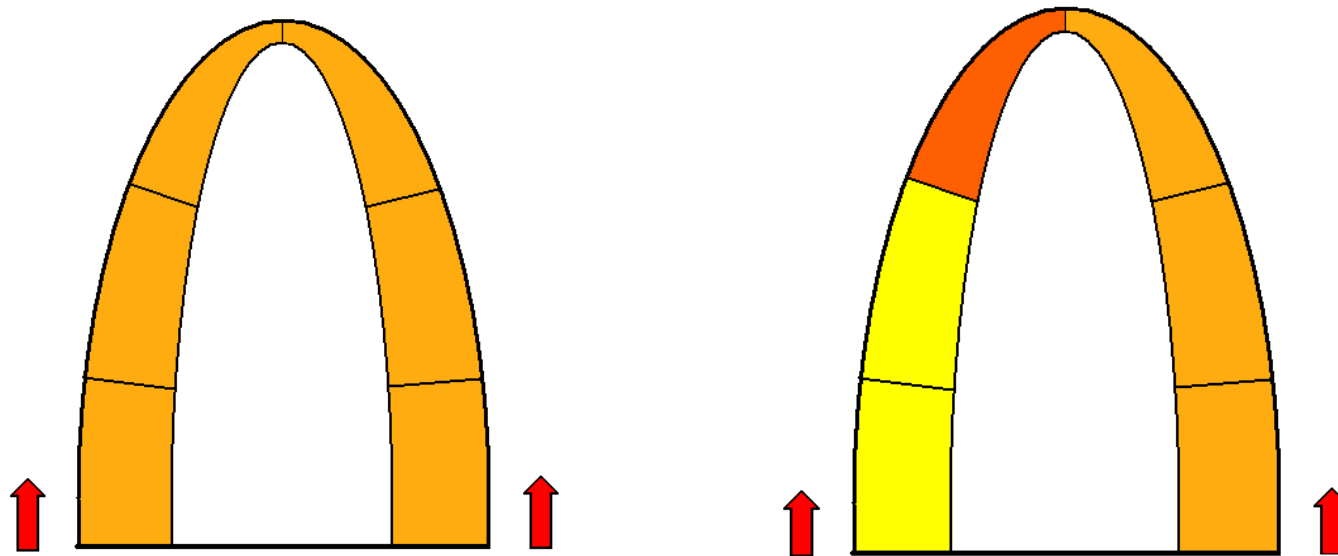
Hypotese: annulusmål er regionale.

- Nedsatt funksjon i en vegg avspeiles i redusert
- Hastighet eller bevegelse i tilstøtende annulus



THE HEART IN SYSTOLE: VIEWED FROM BASE WITH ATRIA REMOVED

Men VV er ikke isolert



- **AV-planet er (relativt) stivt**
- **Strain/Strain rate er load avhengig**
- **Longitudinell interaksjon er en del av load**
- **Redusert kontraktilitet i noen segmenter vil**
- **Føre til økt deformasjon i øvrige i samme vegg**

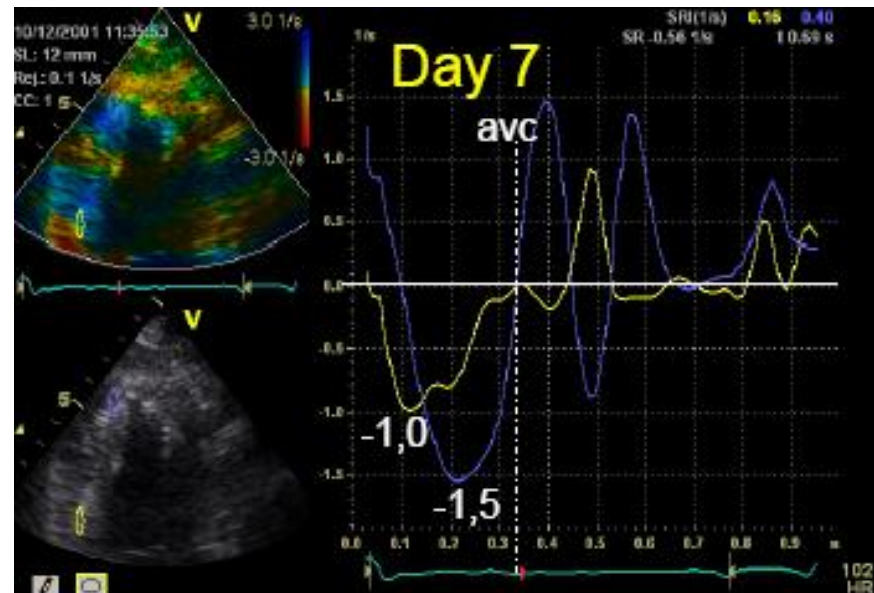
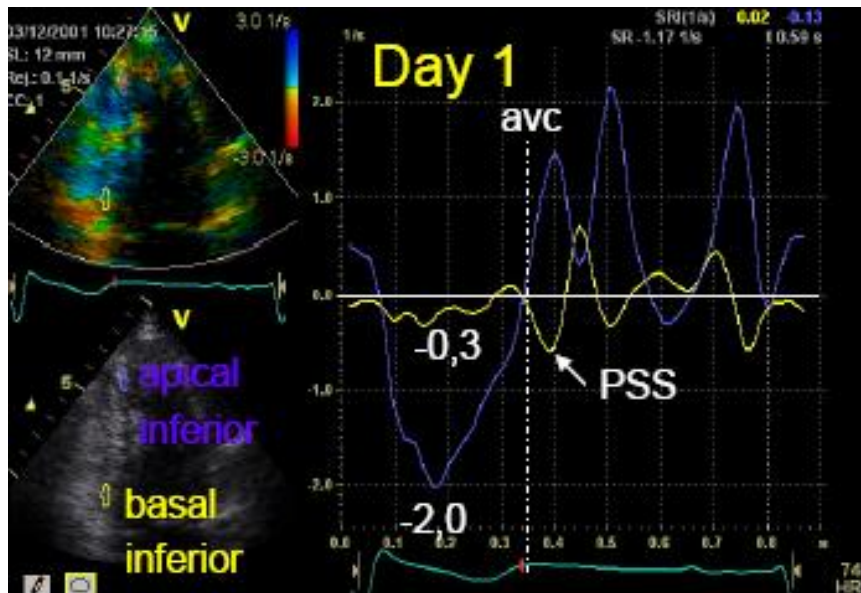
AMI vs kontroller

	Mean			
	MAE (cm)	S' (pw) (cm/s)	S'(cTVI) (cm/s)	SR _s (S ⁻¹)
Pasienter	1.2	7.7	4.8	1.0
Kontroller	1.6*	9.9*	7.6*	1.4*
Mean intra subject varians (max – min)				
Pasienter	0,41	2,8	2,5	1,6
Kontroller	0,41	3,4	2,8	1,0*

Regionale funn: infarsert vs fjern vegg

	MAE (cm)	S' (pw) (cm/s)	S'(cTVI) (cm/s)	SR _s (S ⁻¹) Segm.	SR _s (S ⁻¹) Vegg.
Close	1,2	7,7	4,9	0,8	1.0
Remote	1,2	7,2	5,1	1,1*	1.1

Longitudinell infarktstudie:

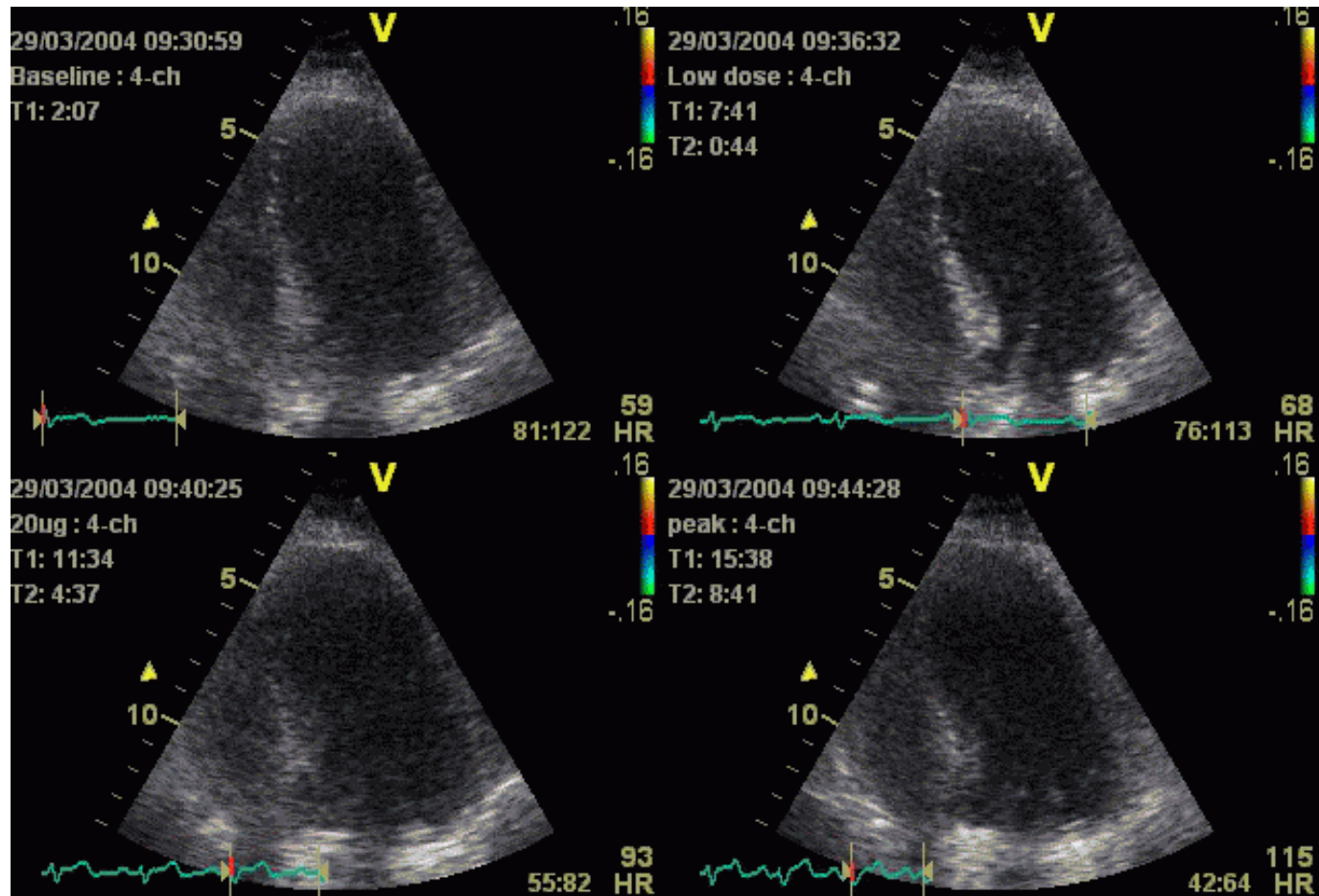


- Kvantitativ deformasjonsmåling kan beskrive
- funksjonsgjenvinning i infarktsegmenter
- Regress av hyperkinesi i non-infarktsegmenter fulgte recovery i infarktsegmenter

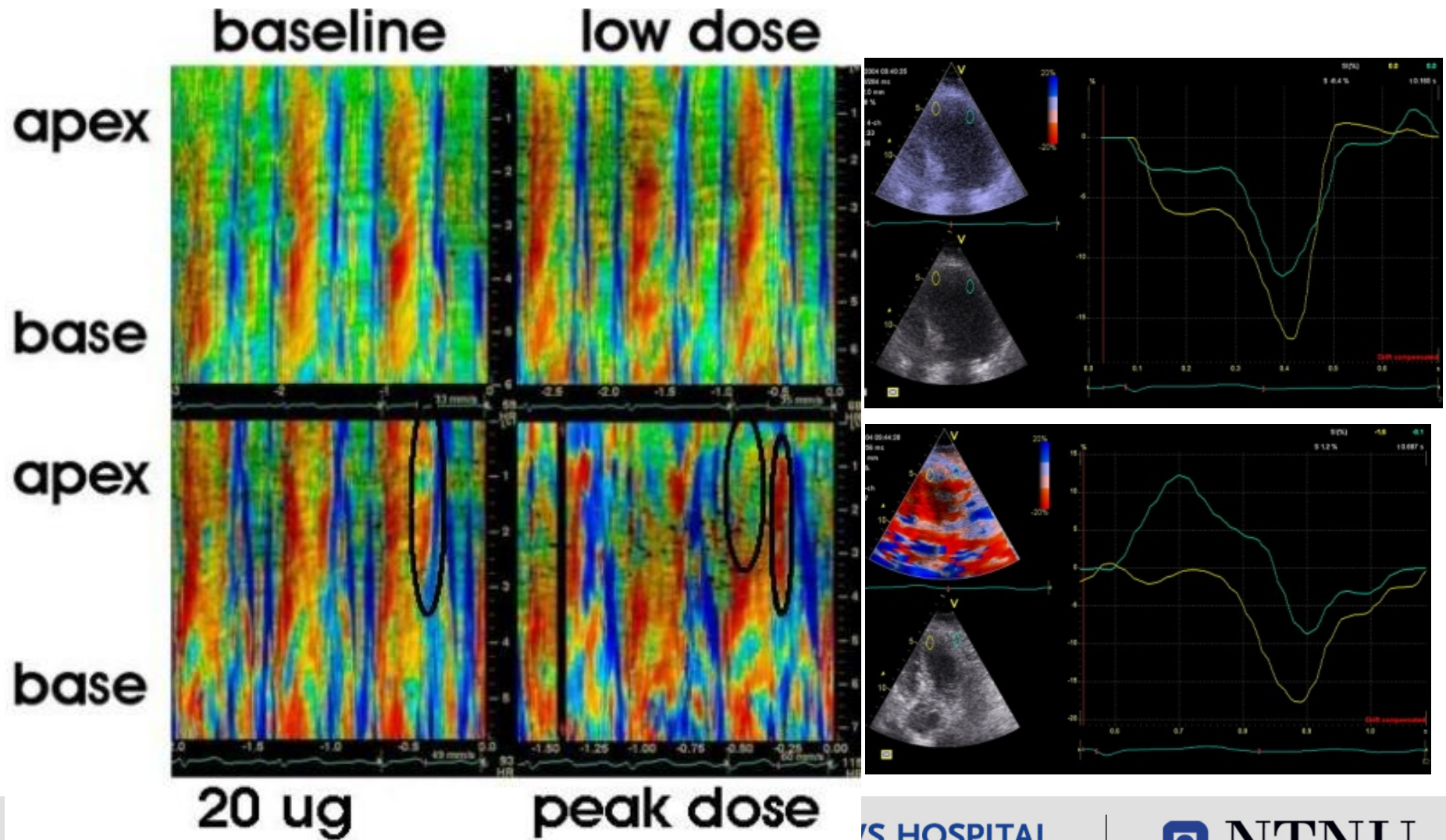
Altså:

- Annulusmål gir ikke regional informasjon
- Deformasjonsmål (inkl WMS) nødvendig
- Annulusmål måler ikke kontraktilitet
- Deformasjonsmål viser ujevn kontraktilitet selv om deformasjon i seg selv ikke er kontraktilitetsmål

Stress echo:

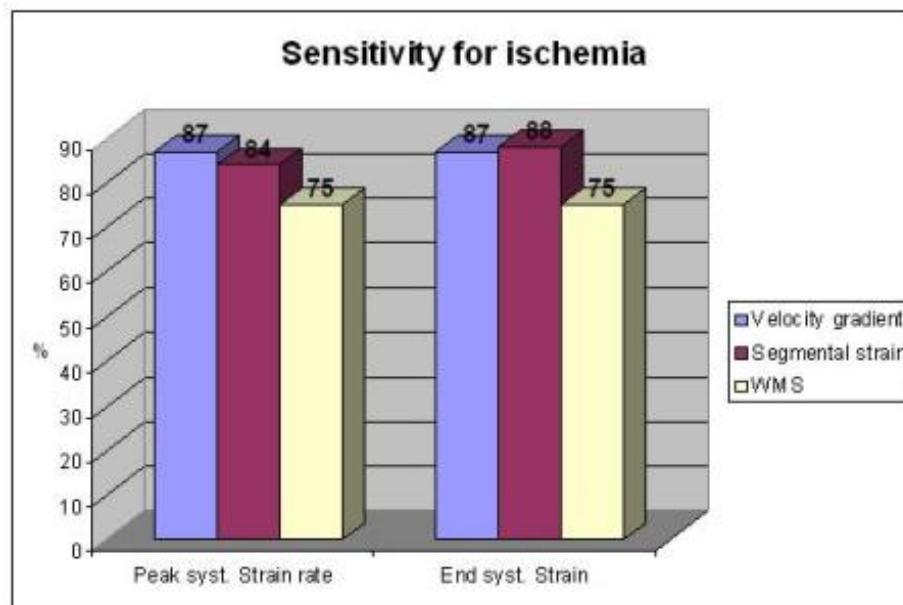


Strain rate imaging

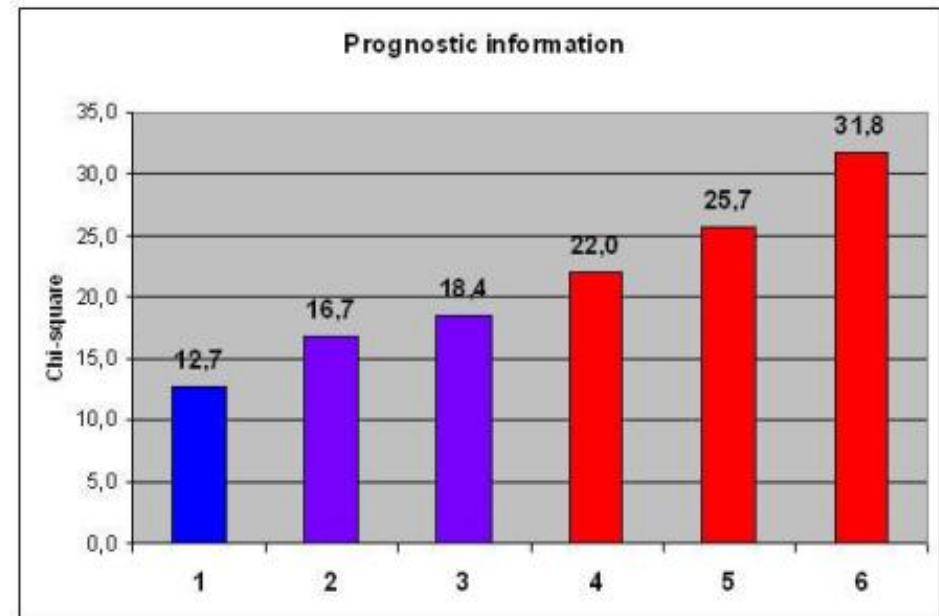


Deformation imaging gave added information:

Diagnostic



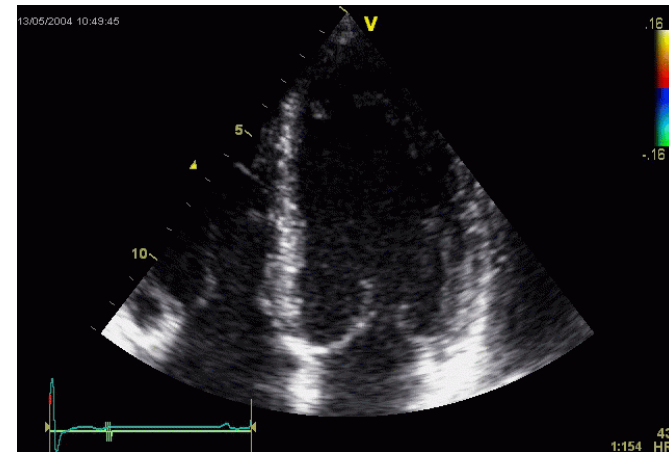
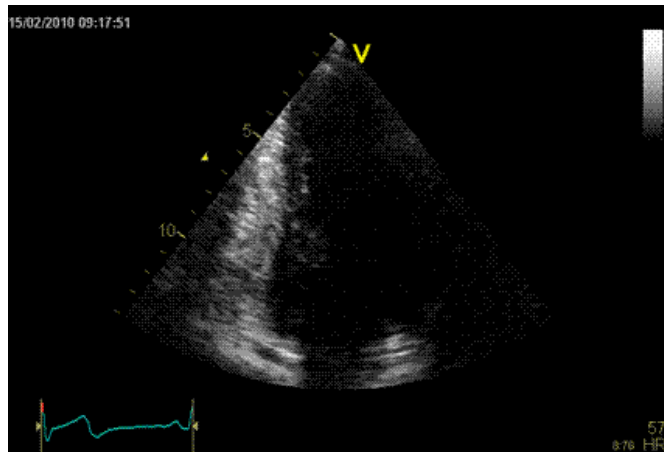
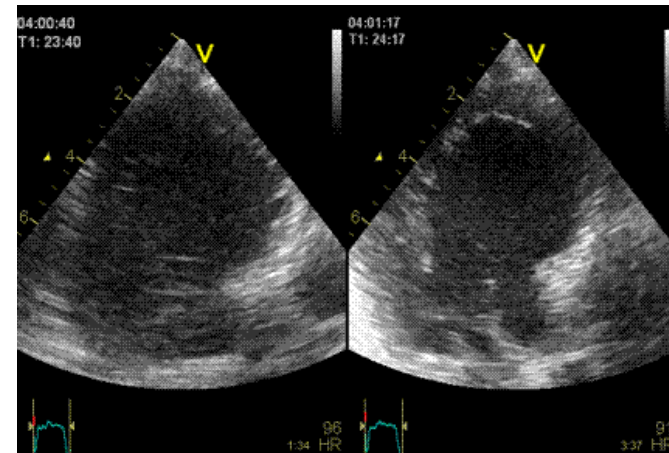
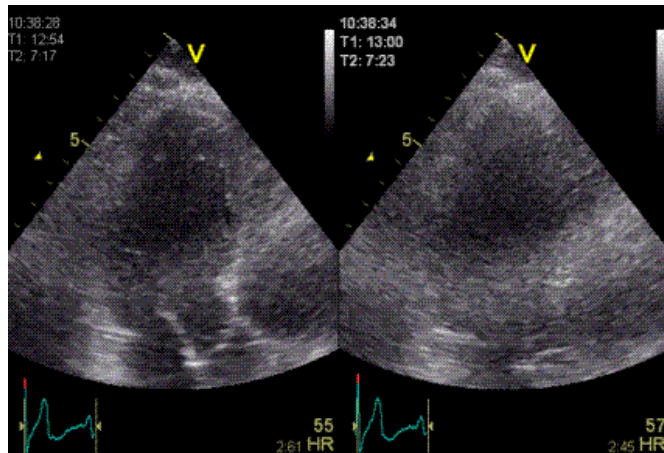
Prognostic

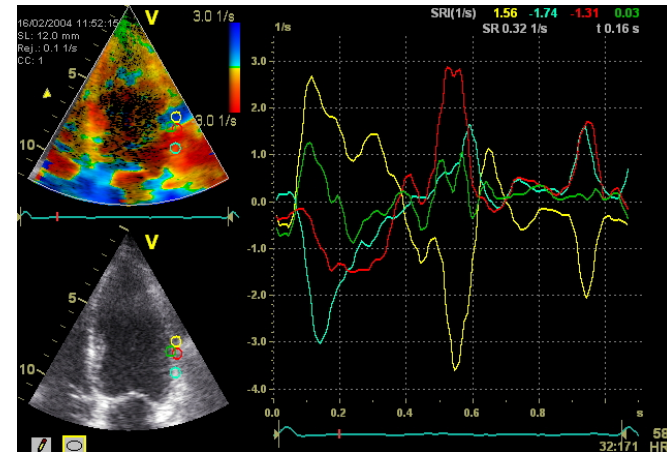
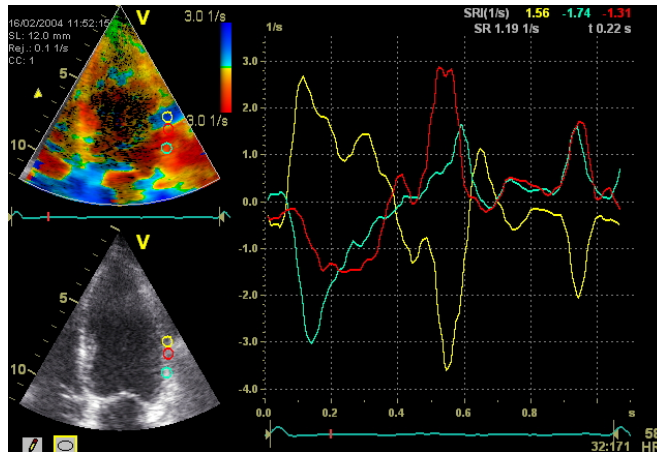
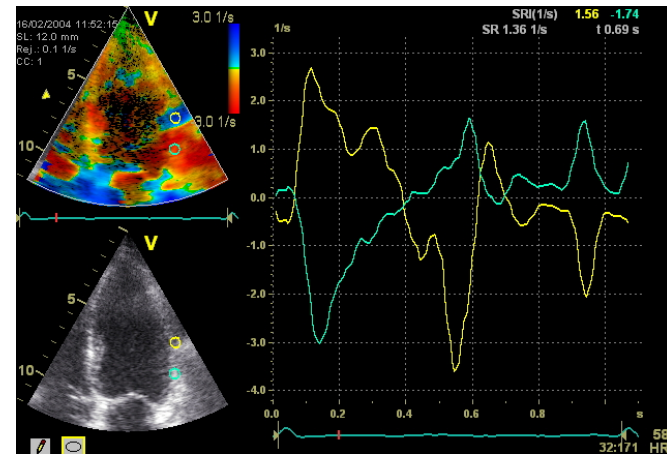
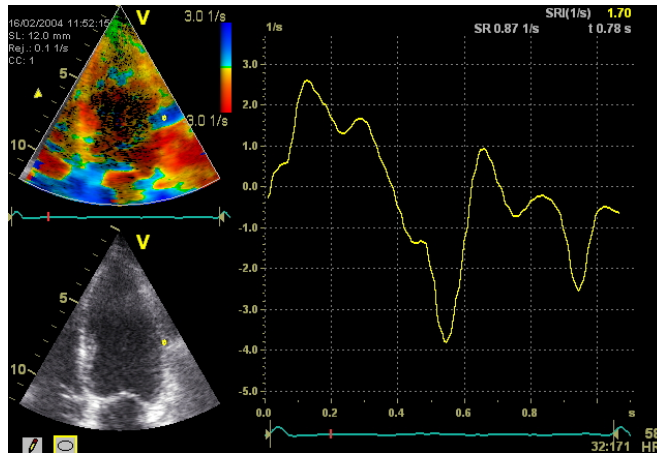


Ingul 2007

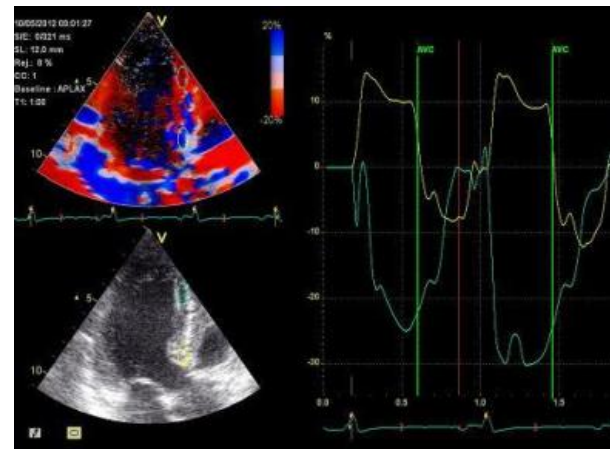
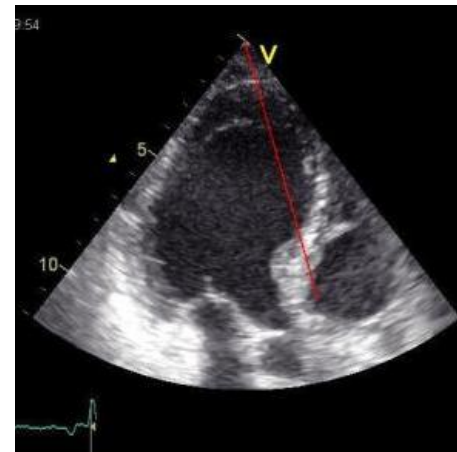
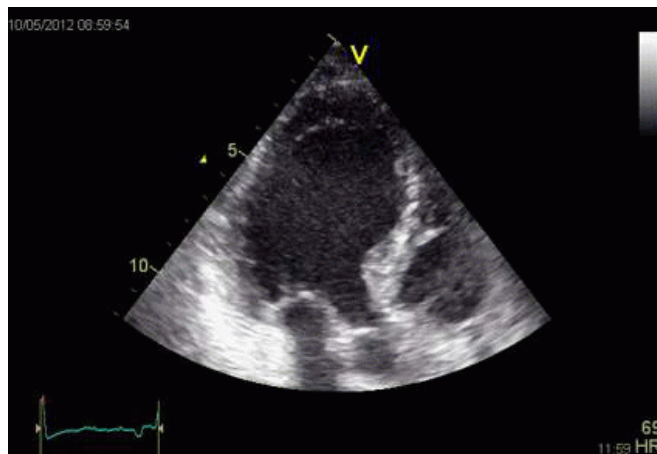
Björk 2007

Billedkvalitet





Vinkelfeil

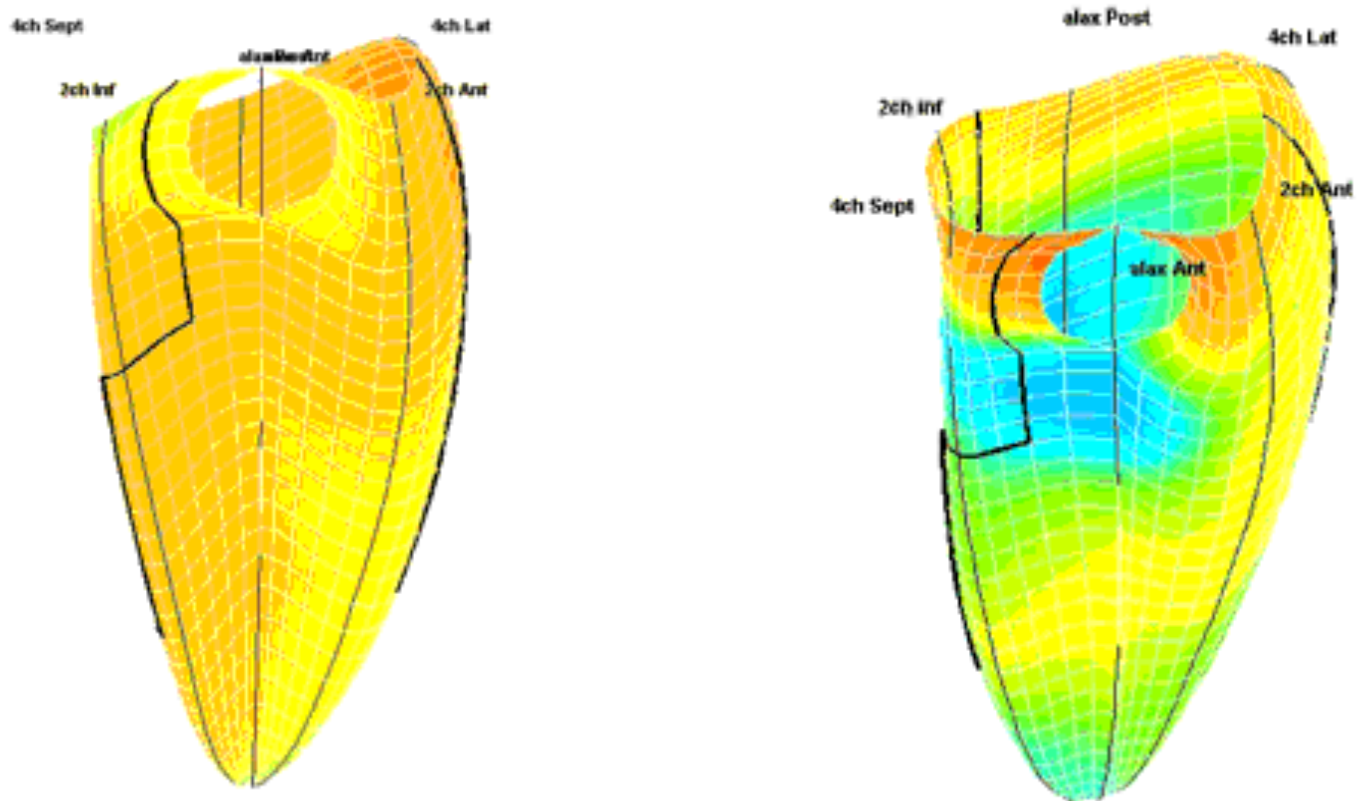


Segmenter med artefakter må forkastes

- **> 80% av pasientene har et eller flere segmenter med artefakter**
- **20-40% av segmenter avhengig av metode må forkastes**

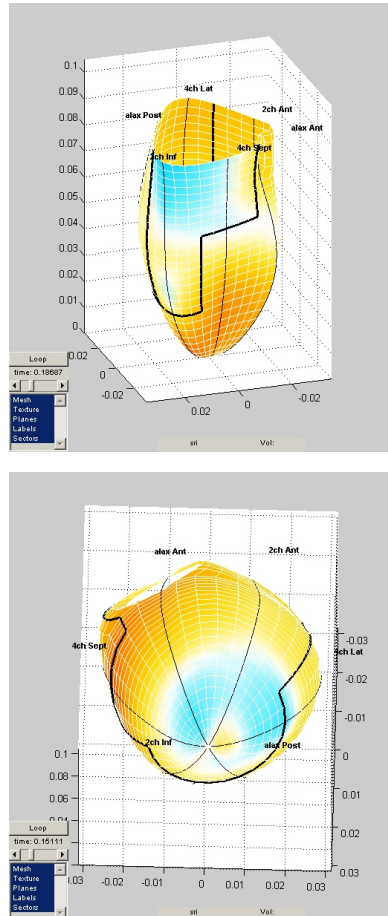
Sagberg 2004,
Ingul 2005
Dalen 2009

Strain on a 3D surface:



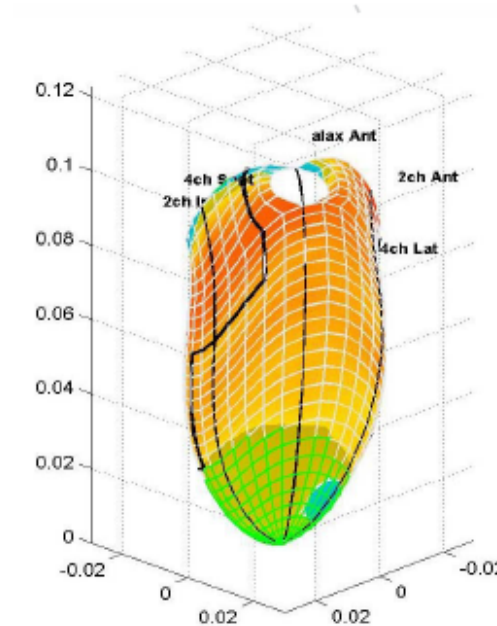
E. Sagberg

Display



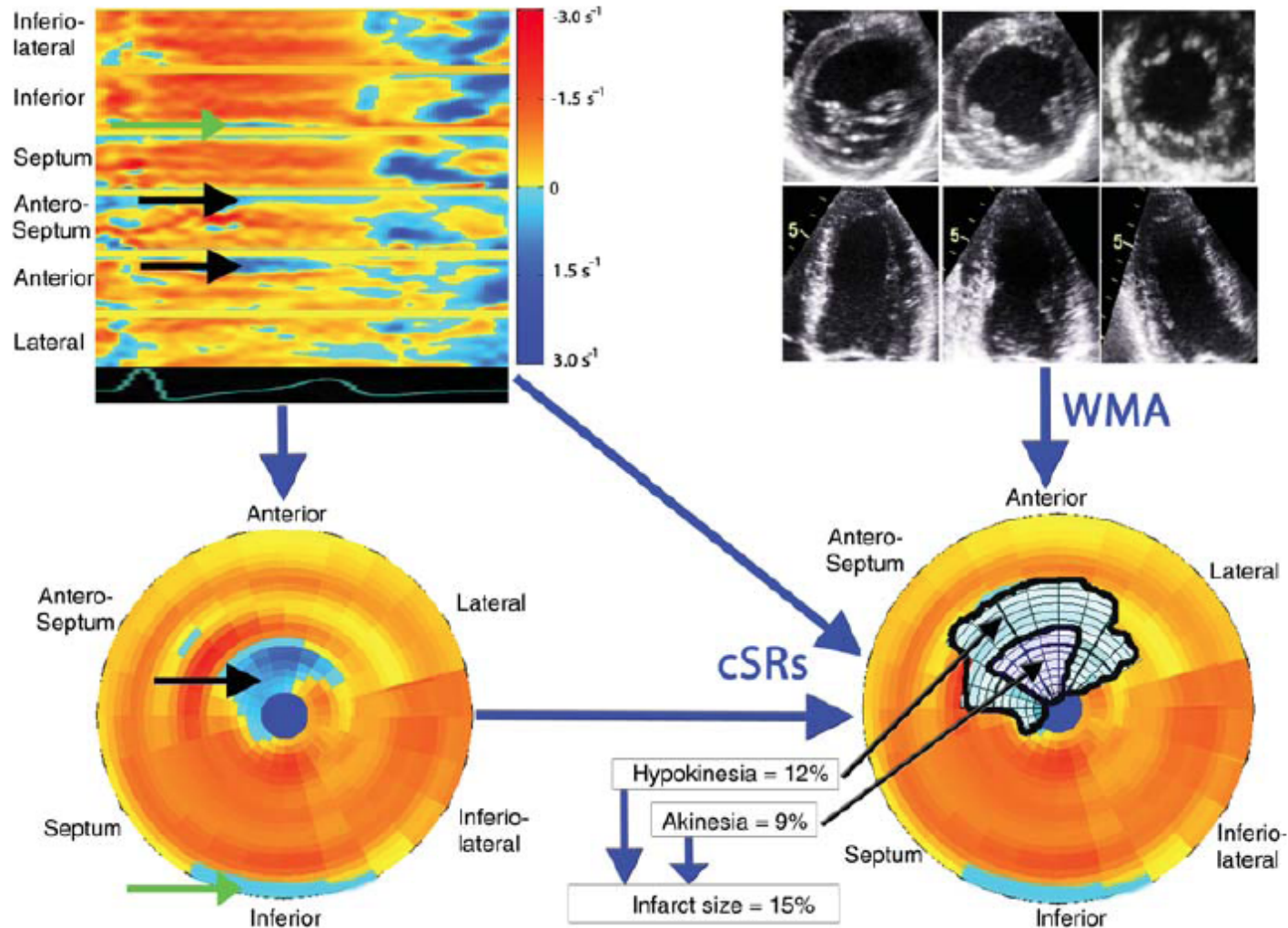
Støylene 2003

Infarktareal



Korrelasjon med WMSI

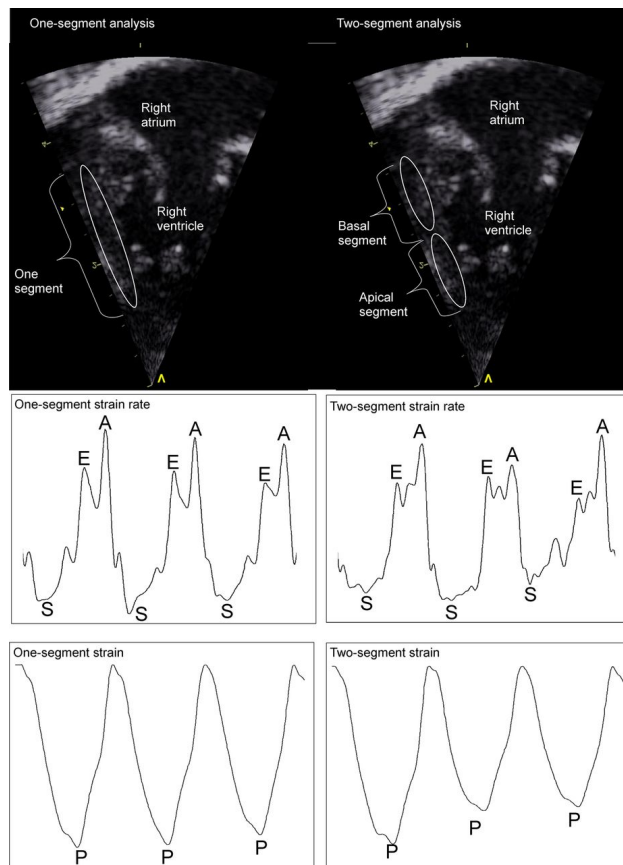
Malm 2006



Korrelasjon med MR G-LE

Krever hardhendt editering av artefakter, basert på B-mode

Barn.



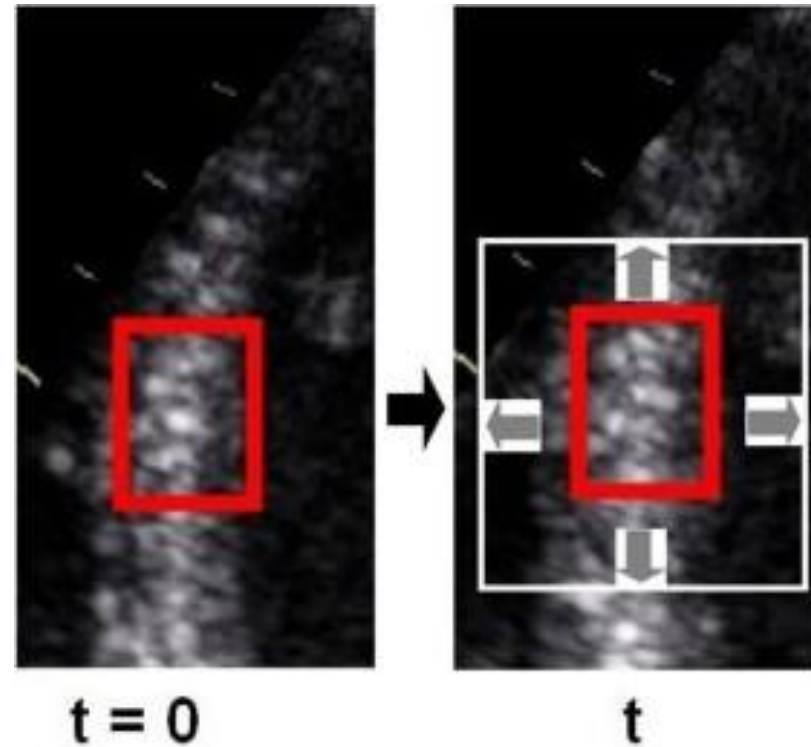
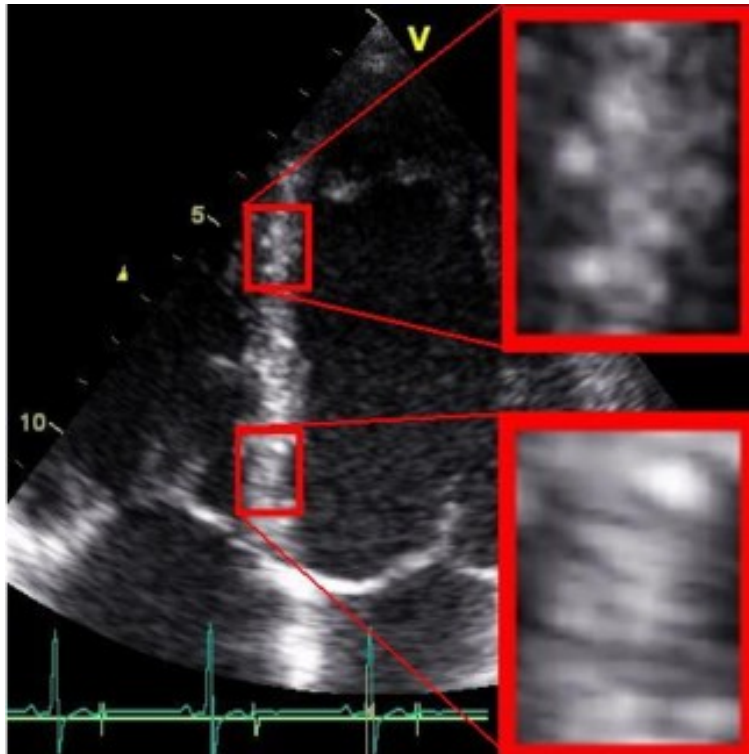
- AV-plan displacement og hastighet funksjon av hjertestørrelse
- Strain og strain rate normaliserer for størrelse
- Vevsdoppler bedre ved høy HR
- Ikke behov for segmental diagnostikk, hele veggen et segment, gir globale verdier og god reproduserbarhet
- Strain / strain rate mer sensitiv for neonatal iskemi enn FS

Nestaas E et al. BMJ Open 2012;2:e001636

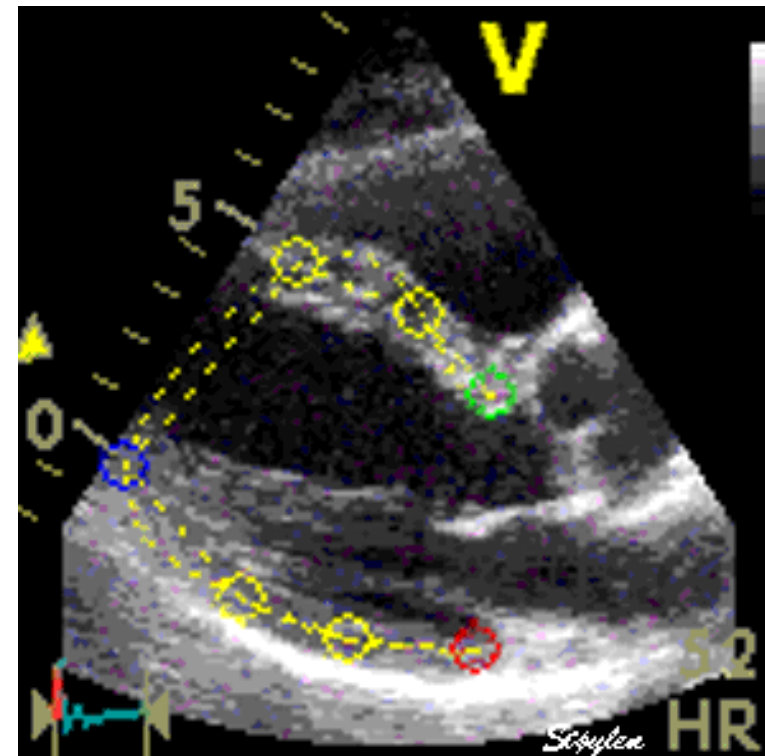
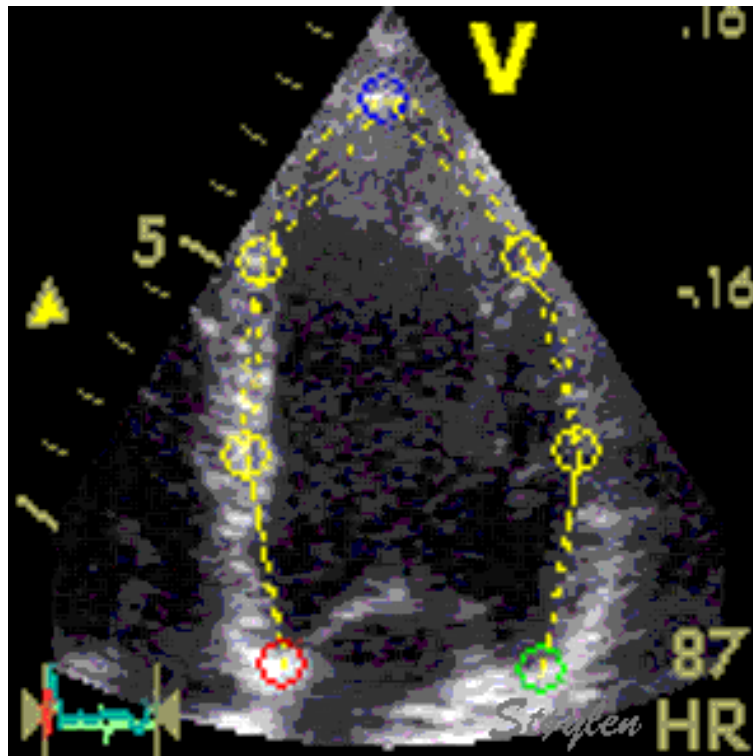
Speckle tracking



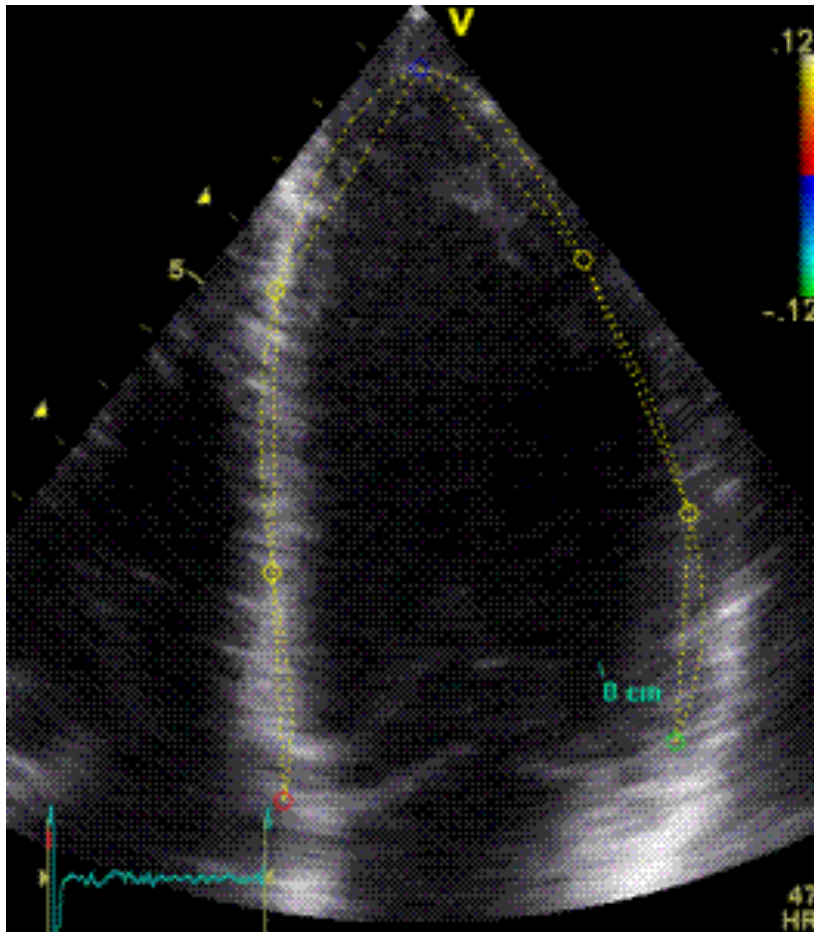
Speckle tracking



Kan i prinsippet tracke i alle retninger

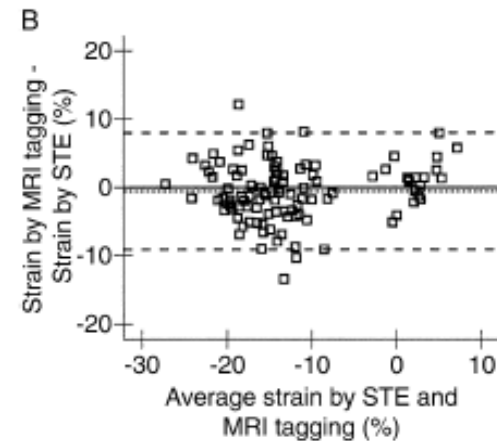
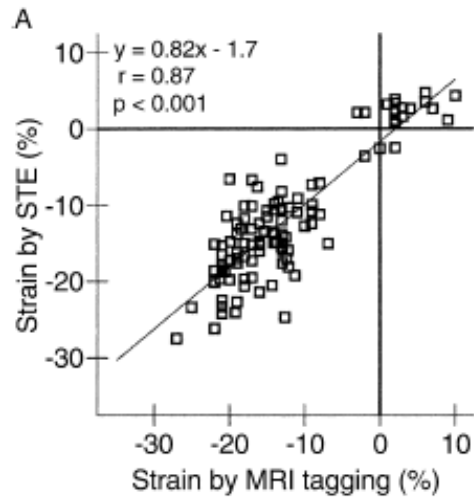
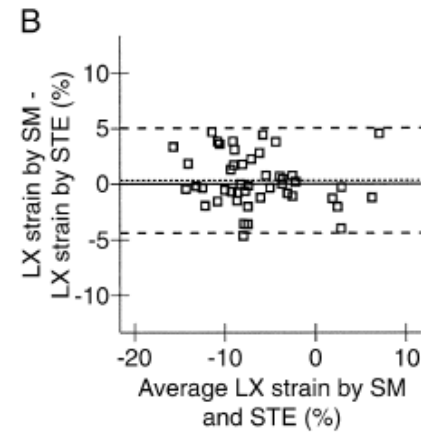
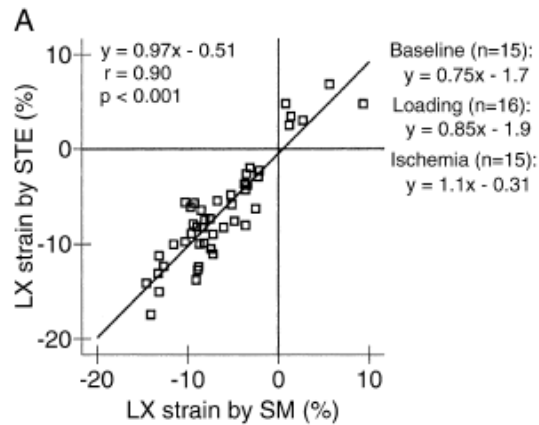


Segmental strain

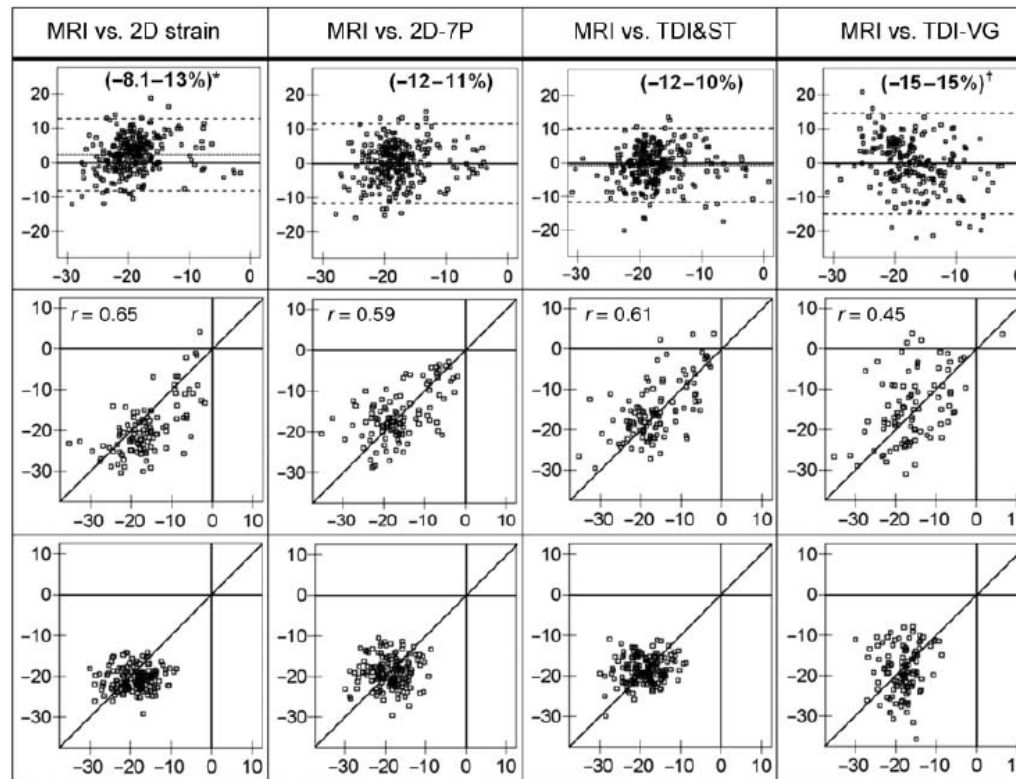


- Kan tracke med bare vevdoppler (longit.)
- Bare speckle tracking
- Kombinert

Validering ultrasonomikrometri og MR:



Sammenligning mellom metoder



Amundsen 2008

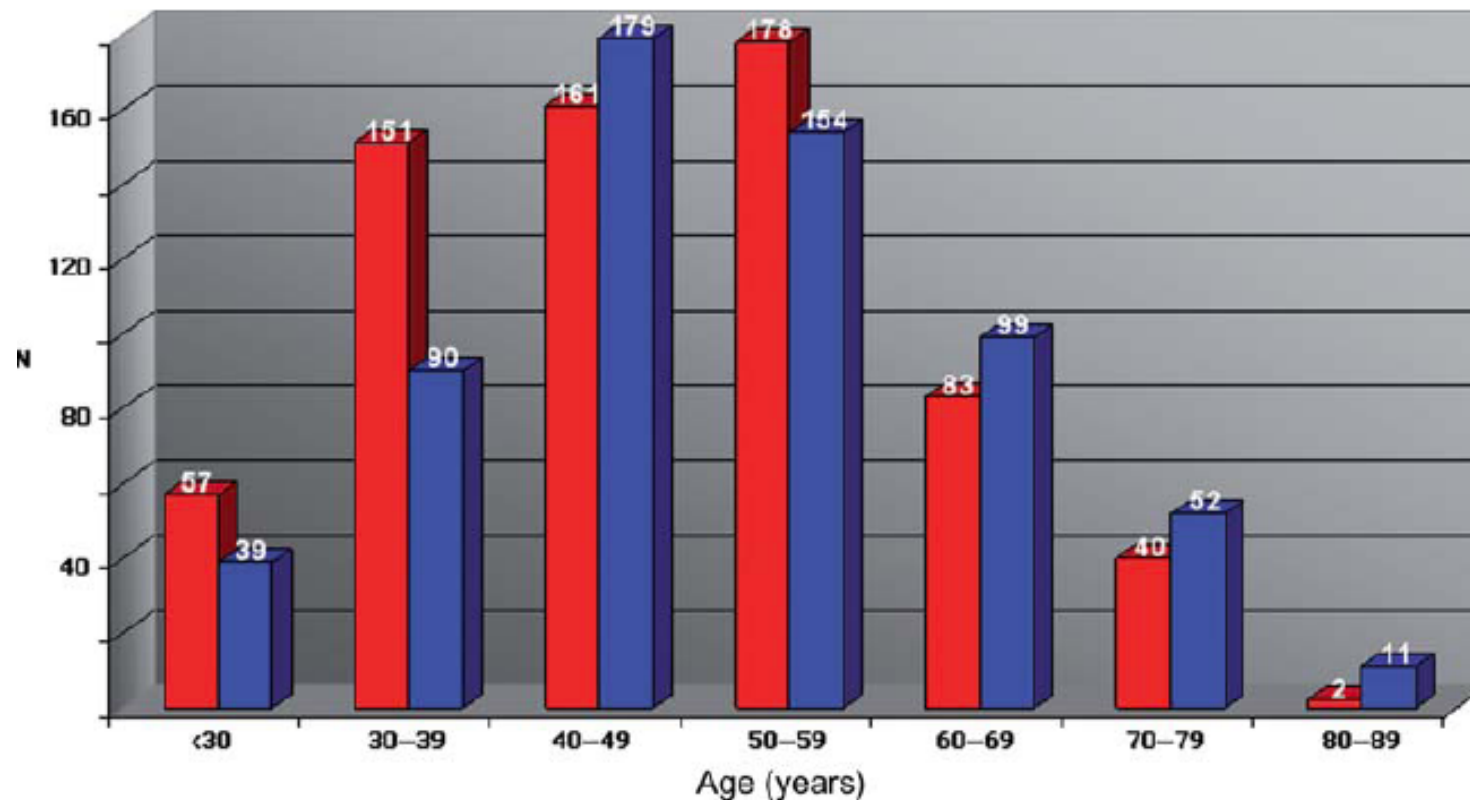
Reproduserbarhet:

Table 5 Reproducibility of systolic deformation indices obtained by two different applications

Method	Mean, inter-observer		COR, inter-observer		Mean Error, inter-observer	
	2D-St	D + St	2D-St	D + St	2D-St	D + St
Global S_{ES}	-0.21	-0.19	0.02	0.02	6%	4%
Global SR_S	-1.1 s^{-1}	-1.2 s^{-1}	0.2 s^{-1}	0.2 s^{-1}	10%	8%
Segmental S_{ES}	-0.21	-0.19	0.07	0.08	14%	18%
Segmental SR_S	-1.1 s^{-1}	-1.2 s^{-1}	0.5 s^{-1}	0.5 s^{-1}	17%	16%

HUNT EKKO substudien.

1266 *normale*



Definert normalpopulasjon uten å bruke cut off fra historiske data

Konvensjonelle Dopplermålinger

Table 2. Conventional Doppler Measurements by Age and Sex

	Mitral E, cm/s	Mitral A, cm/s	E/A Ratio	DT, ms	IVRT, ms	Pulm S, cm/s	Pulm D, cm/s	Pulm S/D Ratio	LVOT Vmax, m/s	LVOT VTI, cm
Female sex										
Feasibility, no. (%)	657 (99)	657 (99)	657 (99)	657 (99)	653 (98)	646 (98)	637 (96)	635 (96)	654 (99)	654 (99)
<40 y (n=208)	80±16	48±15	1.85±0.76	212±55	85±16	58±12	55±11	1.09±0.31	1.01±0.17	20.8±3.5
40–60 y (n=336)	74±15	59±15	1.32±0.40	220±66	95±20	59±12	48±12	1.29±0.35	1.02±0.16	21.6±3.4
>60 y (n=119)	69±16	75±18	0.96±0.32	244±79	105±23	62±12	43±11	1.51±0.39	1.01±0.17	21.7±3.7
All (n=663)	75±16	58±18	1.42±0.62	218±66	93±21	59±12	49±12	1.26±0.37	1.01±0.16	21.4±3.5
Male sex										
Feasibility, no. (%)	599 (99)	599 (99)	599 (99)	599 (99)	597 (99)	583 (97)	583 (97)	578 (96)	591 (98)	591 (98)
<40 y (n=126)	75±15	44±14	1.86±0.64	217±65	91±17	52±11	55±12	0.99±0.29	0.99±0.17	20.0±3.3
40–60 y (n=327)	64±15	52±14	1.30±0.42	232±81	100±21	55±11	47±11	1.22±0.31	0.99±0.18	20.4±3.6
>60 y (n=150)	61±14	65±18	0.99±0.34	269±97	118±29	62±13	43±11	1.50±0.40	0.96±0.18	20.3±3.7
All (n=603)	66±15	54±17	1.34±0.54	238±85	103±24	56±12	48±12	1.23±0.37	0.98±0.18	20.3±3.6

Kvinner mean HR 66, menn 63

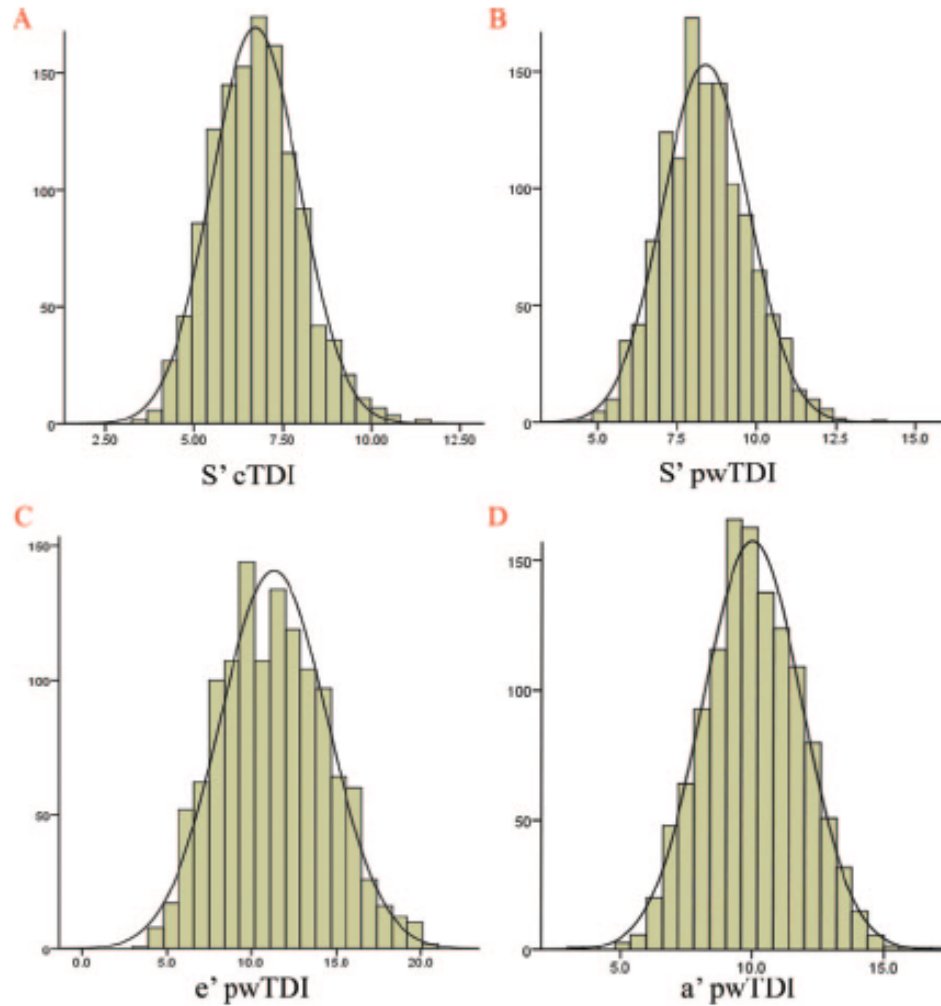
Annulus hastigheter

Table 3. Age- and Sex-Specific Mean Annular Velocities by pwTDI and cTDI

	LV (Mean of 4 Walls)				RV (Free Wall)		
	S' (pwTDI)	S' (cTDI)	e' (pwTDI)	a' (pwTDI)	S' (pwTDI)	e' (pwTDI)	a' (pwTDI)
Female sex							
Feasibility, no. (%)	652 (98%)	657 (99%)	652 (98%)	652 (98%)	648 (98%)	648 (98%)	648 (98%)
<40 y, cm/s	8.9±1.1	7.2±1.0	14.6±2.3	8.8±1.9	13.0±1.8	14.7±2.9	12.4±3.5
40–60 y, cm/s	8.1±1.2	6.5±1.0	11.3±2.4	10.0±1.9	12.4±1.9	13.1±2.9	15.0±3.5
>60 y, cm/s	7.2±1.2	5.7±1.1	8.2±3.2	10.6±1.9	11.8±2.0	11.0±2.3	16.1±3.1
All, cm/s	8.2±1.3	6.6±1.1	11.8±3.2	9.7±2.0	12.5±1.9	13.3±3.0	14.4±3.7
Male sex							
Feasibility, no. (%)	590 (98%)	601 (99%)	590 (98%)	590 (98%)	586 (97%)	586 (97%)	586 (97%)
<40 y, cm/s	9.4±1.4	7.6±1.2	14.1±2.7	9.1±1.7	13.2±2.0	14.5±2.9	12.3±3.5
40–60 y, cm/s	8.6±1.3	6.9±1.3	10.7±2.3	10.4±1.6	12.8±2.2	12.5±3.2	14.3±3.7
> y, cm/s	8.0±1.3	6.4±1.2	8.2±1.9	11.1±1.6	12.5±2.3	11.0±3.0	15.8±4.2
All, cm/s	8.6±1.4	6.9±1.3	10.8±3.0	10.3±1.7	12.8±2.2	12.5±3.3	14.2±3.9

**Hastighetene avtar med alder,
Menn > Kvinner**

Annulus hastigheter:



E/e' er aldersavhengig

Table 5. E/e' Ratio by Age, Wall, and Method

	pwTDI*				pwTDI†	cTDI†
	<40 y	40–59 y	≥60 y	All		
No.	327	651	263	1241	100	100
Mean	5.6±1.3	6.5±1.7	8.2±2.6	6.6±2.1	6.9±2.3	9.1±3.4
Mean septum-lateral	5.6±1.3	6.5±1.8	8.2±2.7	6.6±2.1	6.9±2.2	9.2±3.4
Inferoseptum	6.5±1.7	7.4±2.0	9.0±3.1	7.5±2.4	7.9±2.4	10.1±3.4
Anterolateral	5.1±1.3	6.0±1.8	7.6±3.0	6.1±2.2	6.3±2.4	8.6±3.9
Inferior	5.7±1.6	6.7±2.0	8.4±2.9	6.8±2.3	7.1±2.8	9.6±3.8
Anterior	5.4±1.6	6.5±2.0	8.5±3.0	6.6±2.4	7.2±2.8	9.0±3.7

**Som forklarer nesten hele "gråsonen" fra 8 – 15
Øvre normalgrense (mean + 2 SD) > 60: 13,4**

Strain og strain rate per vegg og nivå

Table 2 Segmental longitudinal systolic strain (S_{es}) and strain rate (SR_s)

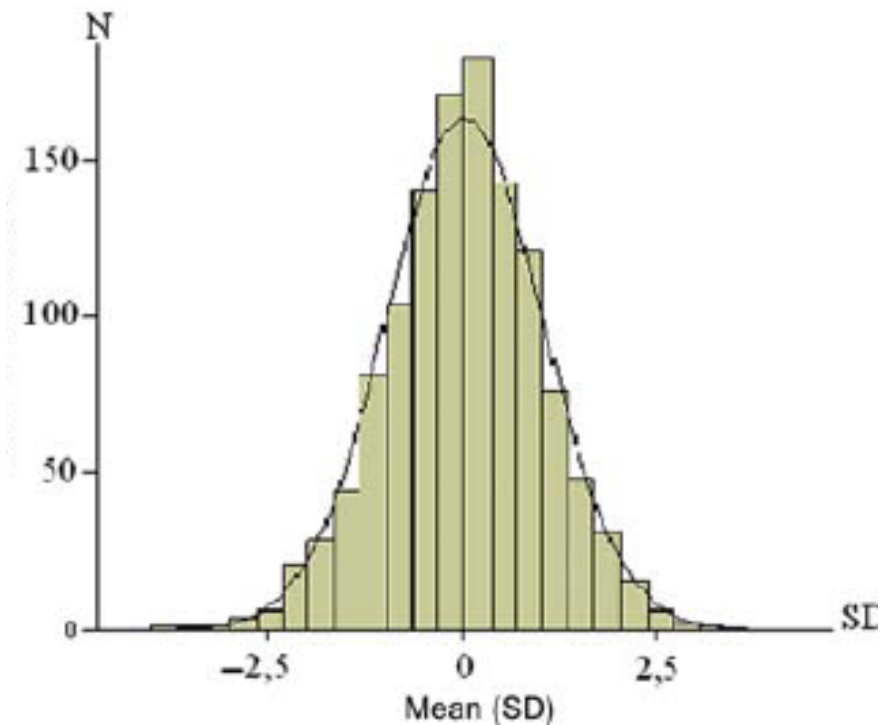
	Inferoseptum	Anterolateral	Inferior	Anterior	Inferolateral	Anteroseptum	Mean
Apical							
S_{es} (%), mean (SD)	-17.8 (3.9)	-14.6 (4.0)	-17.6 (4.3)	-14.3 (4.7)	-15.5 (4.3)	-16.1 (3.9)	-16.4 (4.3) ^{2,3}
SR_s (s^{-1}), mean (SD)	-1.08 (0.24)	-1.03 (0.29)	-1.08 (0.23)	-0.98 (0.30)	-1.06 (0.28)	-0.95 (0.26)	-1.04 (0.26) ³
Mid-ventricular							
S_{es} (%), mean (SD)	-17.9 (3.5)	-16.4 (3.5)	-17.3 (3.7)	-17.4 (3.6)	-17.0 (3.8)	-17.1 (3.5)	-17.3 (3.6) ^{1,3}
SR_s (s^{-1}), mean (SD)	-1.10 (0.20)	-0.94 (0.22)	-1.08 (0.27)	-1.01 (0.31)	-1.05 (0.29)	-1.05 (0.28)	-1.05 (0.26) ³
Basal							
S_{es} (%), mean (SD)	-14.6 (3.9)	-19.2 (3.7)	-15.9 (3.9)	-17.7 (4.1)	-17.0 (4.0)	-13.9 (4.5)	-16.2 (4.3) ^{1,2}
SR_s (s^{-1}), mean (SD)	-0.85 (0.21)	-1.22 (0.27)	-0.91 (0.24)	-1.07 (0.24)	-1.10 (0.25)	-0.95 (0.23)	-0.99 (0.27) ^{1,2}
Mean							
S_{es} (%), mean (SD)	-16.8 (4.0) ^{8,9}	-16.6 (4.1) ^{6,9}	-17.0 (4.0) ^{5,8,9}	-16.8 (4.3) ⁹	-16.5 (4.1) ^{4,6,9}	-16.0 (4.1) ⁴⁻⁸	-16.7 (4.1)
SR_s (s^{-1}), mean (SD)	-1.01 (0.25) ^{5,8,9}	-1.05 (0.28) ^{4,9}	-1.03 (0.26) ^{8,9}	-1.02 (0.28) ^{8,9}	-1.07 (0.27) ^{4,6,7,9}	-0.99 (0.27) ⁴⁻⁸	-1.03 (0.27)

- Forskjeller på nivå / vegg mindre enn variasjonen

Global strain og strain rate

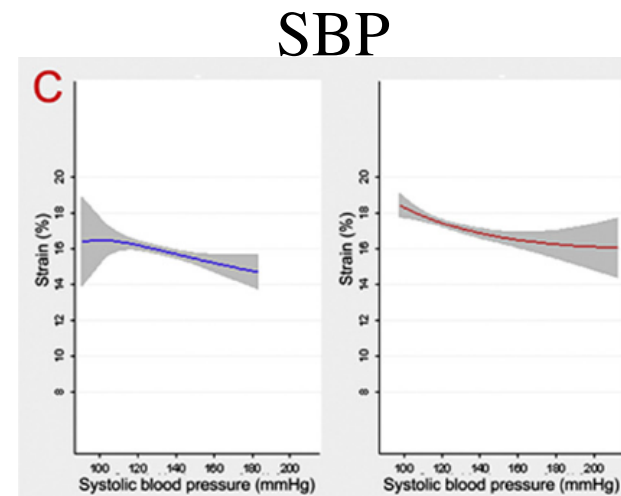
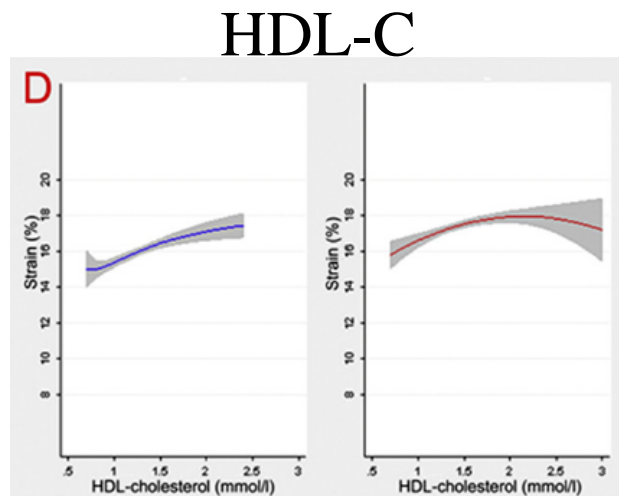
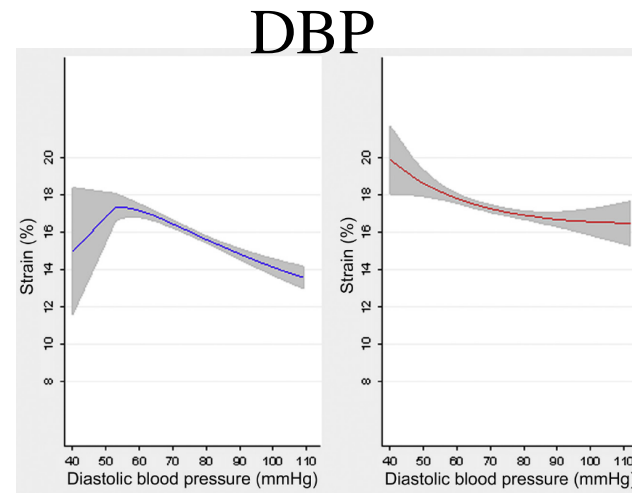
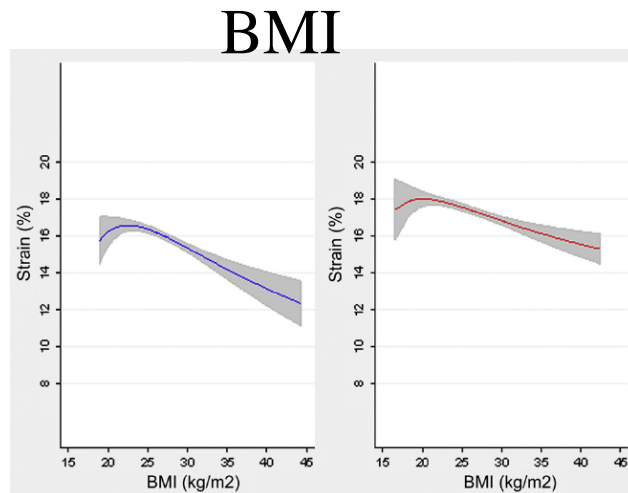
Table 3 Global longitudinal systolic strain and strain rate

	Female ³	Male ³
<40 years⁴ (208 women/126 men)		
S_{es}^1 (%), mean (SD)	-17.9 (2.1)	-16.8 (2.0)
SR_s^2 (s ⁻¹), mean (SD)	-1.09 (0.12)	-1.06 (0.13)
40–60 years⁴ (336 women/327 men)		
S_{es}^1 (%), mean (SD)	-17.6 (2.1)	-15.8 (2.2)
SR_s^2 (s ⁻¹), mean (SD)	-1.06 (0.13)	-1.01 (0.12)
>60 years (119 women/150 men)		
S_{es}^1 (%), mean (SD)	-15.9 (2.4)	-15.4 (2.4)
SR_s^2 (s ⁻¹), mean (SD)	-0.97 (0.14)	-0.97 (0.14)
Mean⁵		
S_{es}^1 (%), mean (SD)	-17.4 (2.3)	-15.9 (2.3)
SR_s^2 (s ⁻¹), mean (SD)	-1.05 (0.13)	-1.01 (0.13)



Avtar med alder, Kvinner > menn, begge normalfordelt

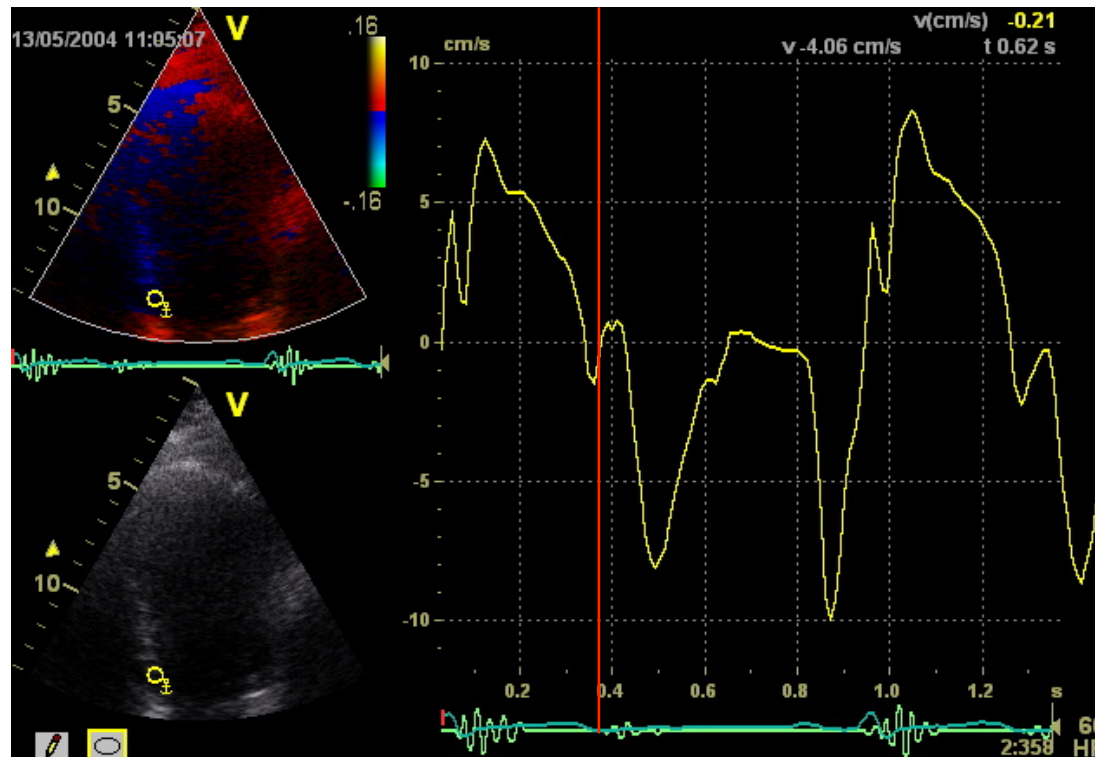
Sammenheng med risikofaktorer



Risikofaktorer:

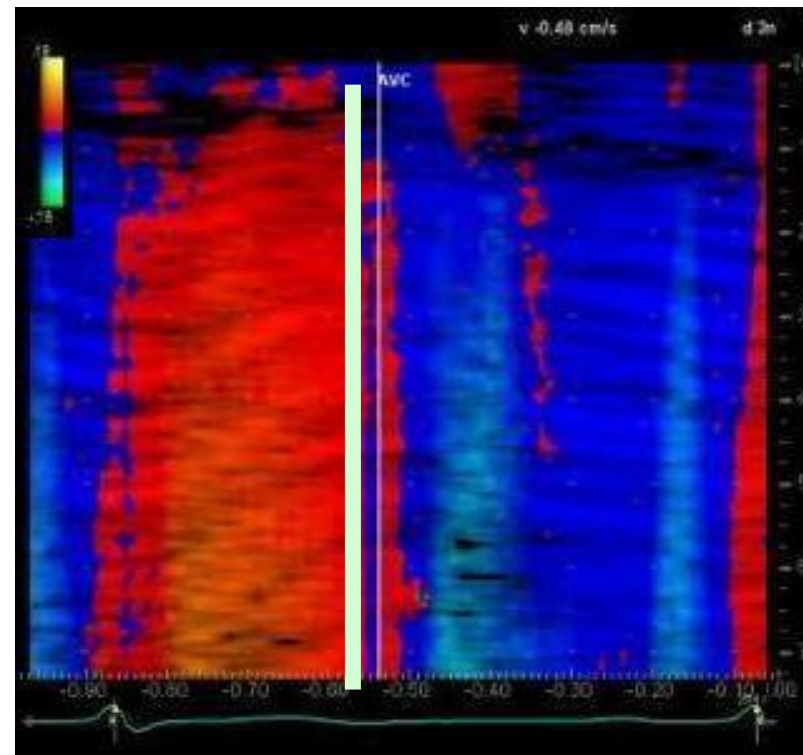
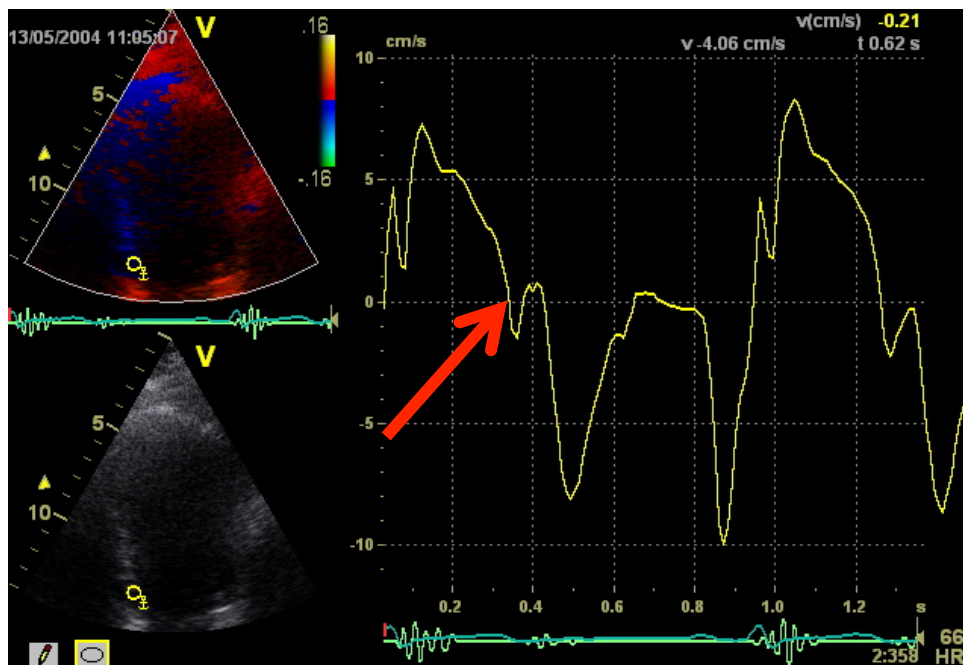
- Slo også ut for S' og e'
- Røyking slo ikke ut for VV funksjon.
- Derimot for høyre ventrikkel S' og e'

Automatisk deteksjon av AVC

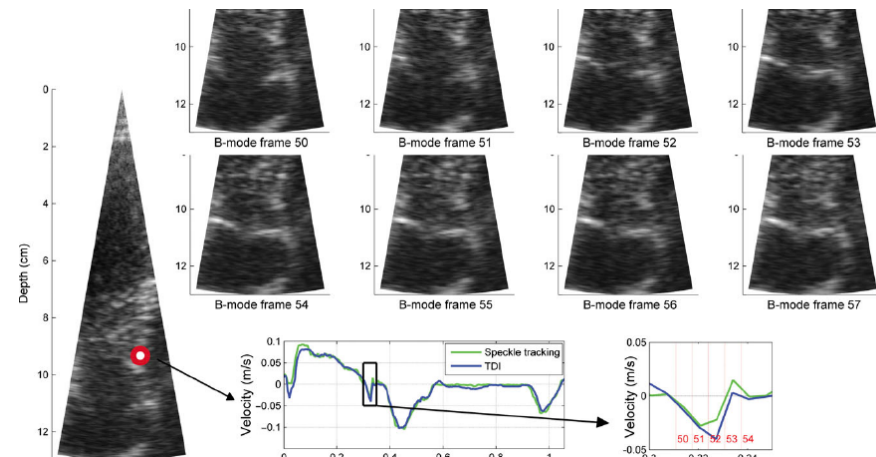
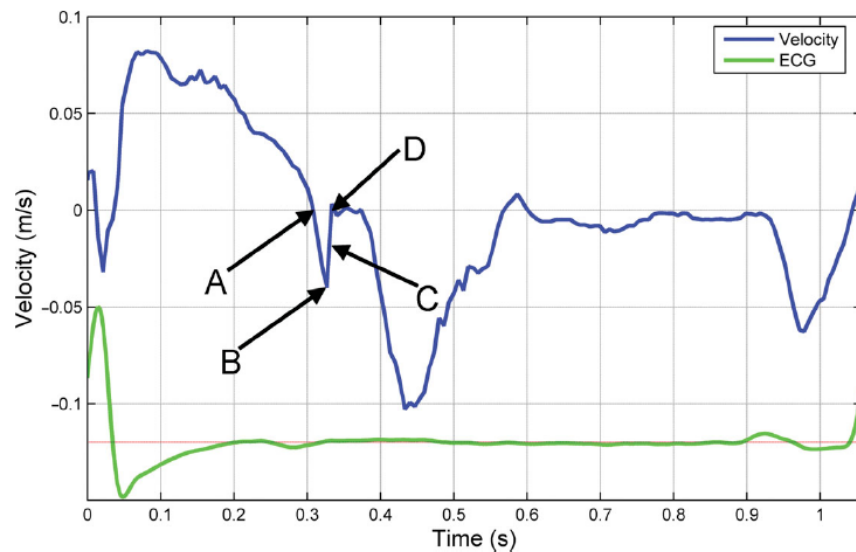


**Basert på deteksjon av akselerasjon.
Fono for identifisering av korrekt tidspunkt**

AVC?

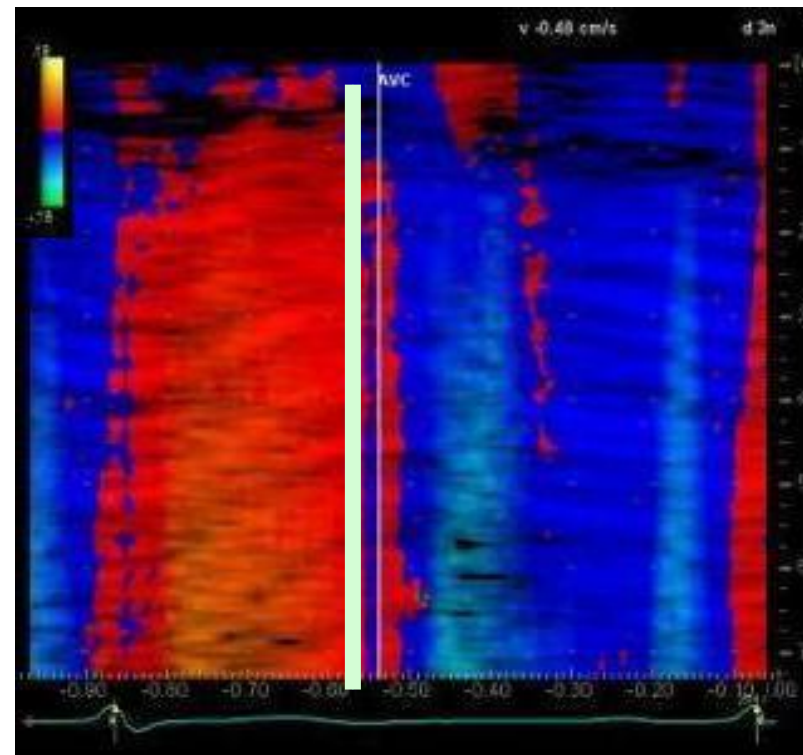
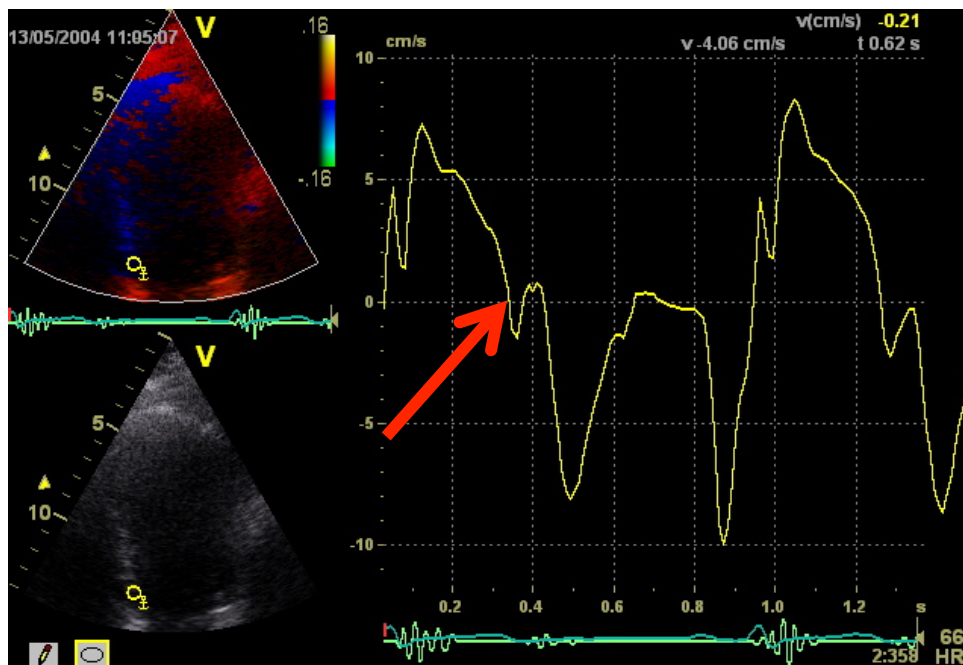


Validering av av AVC tidspunkt

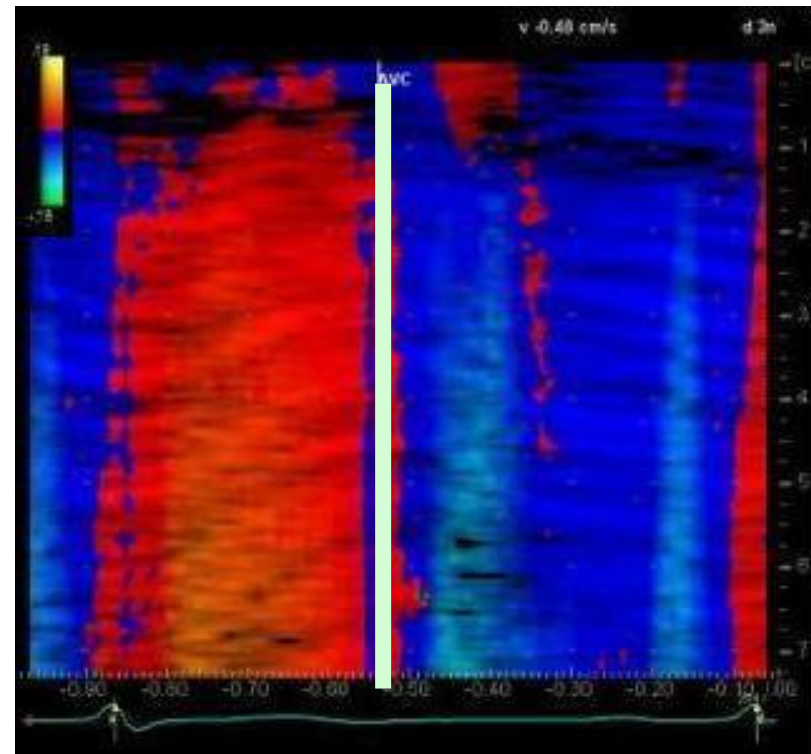
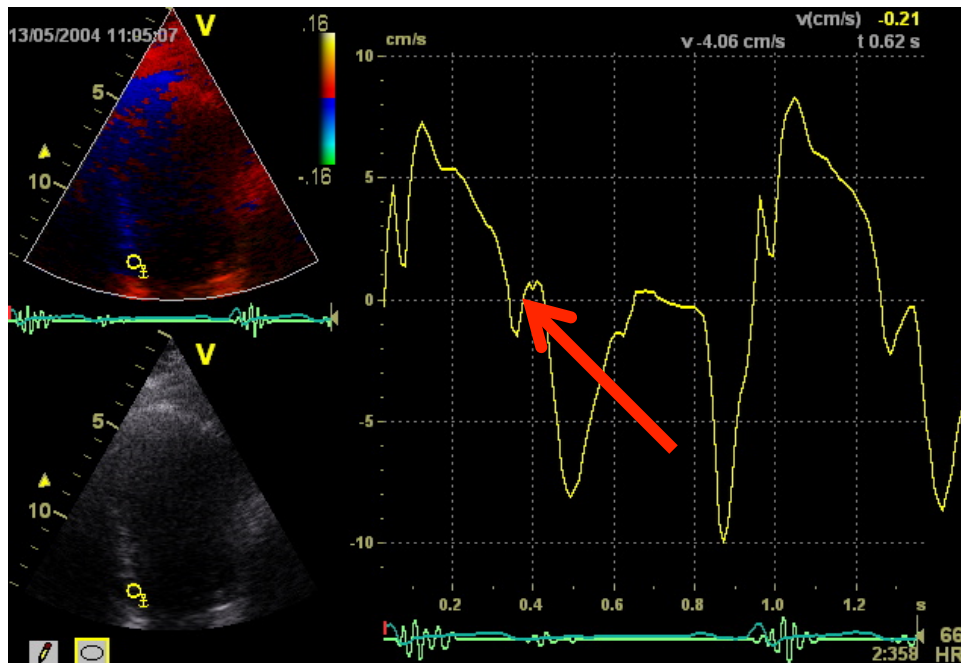


- B-mode og TVI 1:1
- Smal sektor
- Frame rate ca 150
– (Tidsoppl. 7 ms)

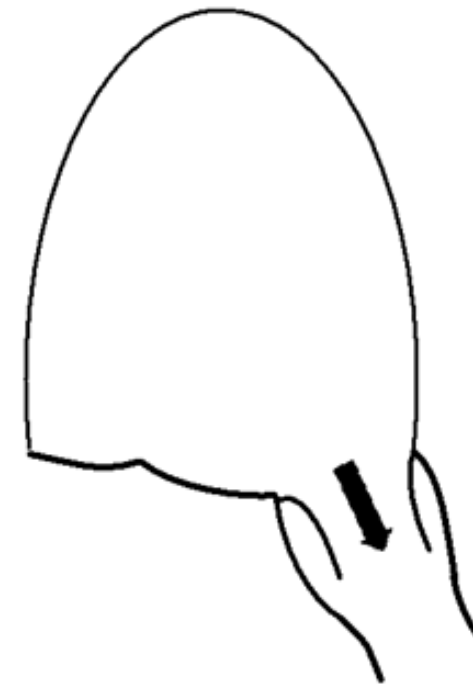
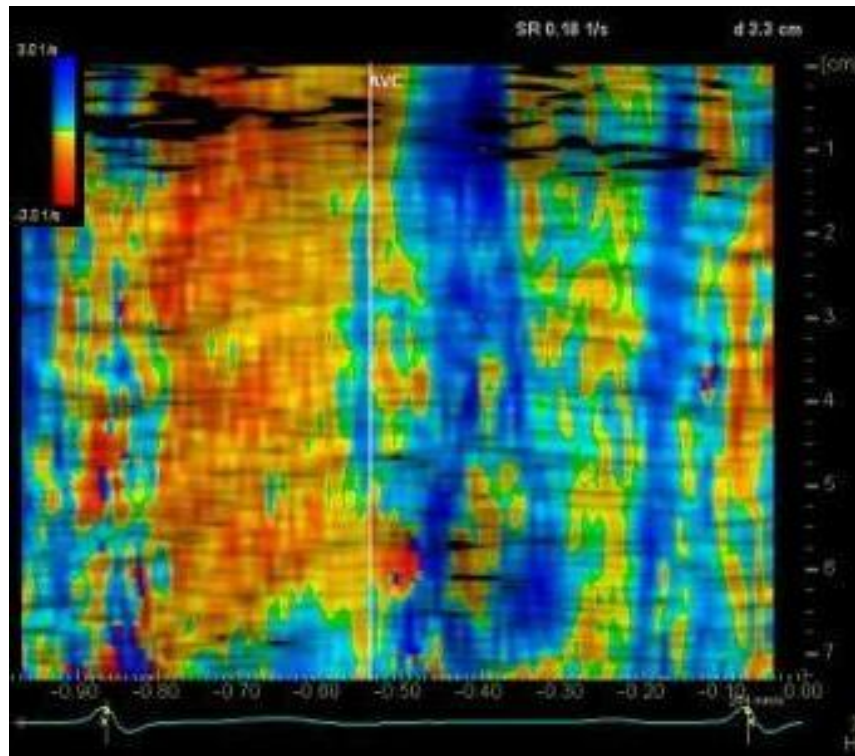
AVC?



AVC!



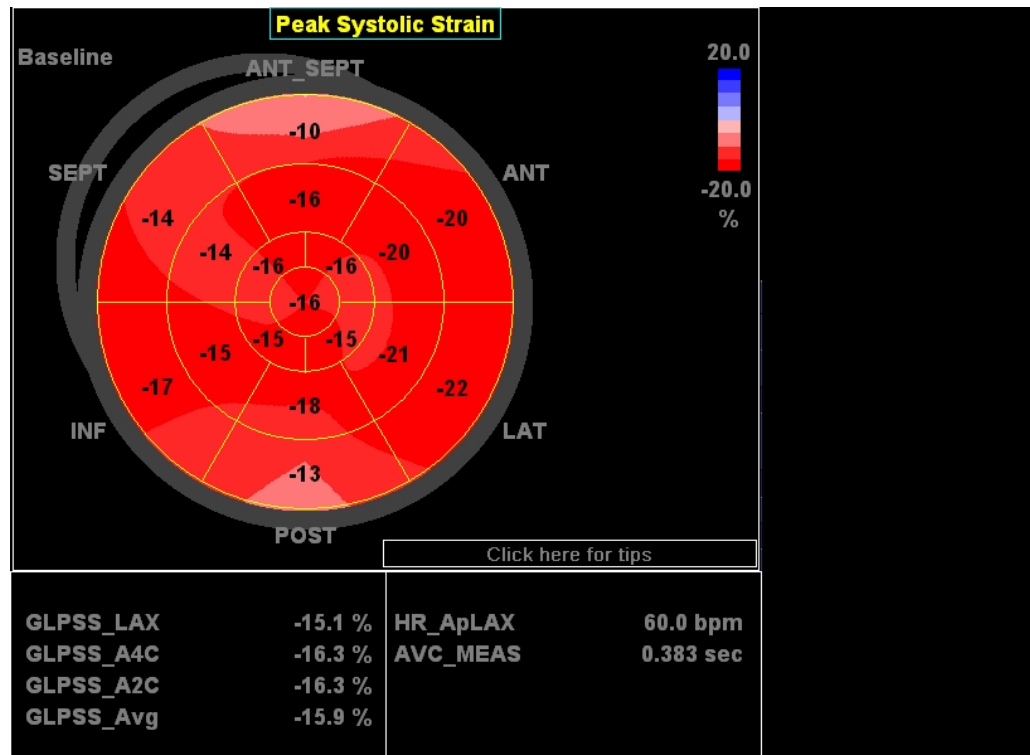
Aorta lukning



Trening - Vevsdoppler nyttig for å se treningseffekter

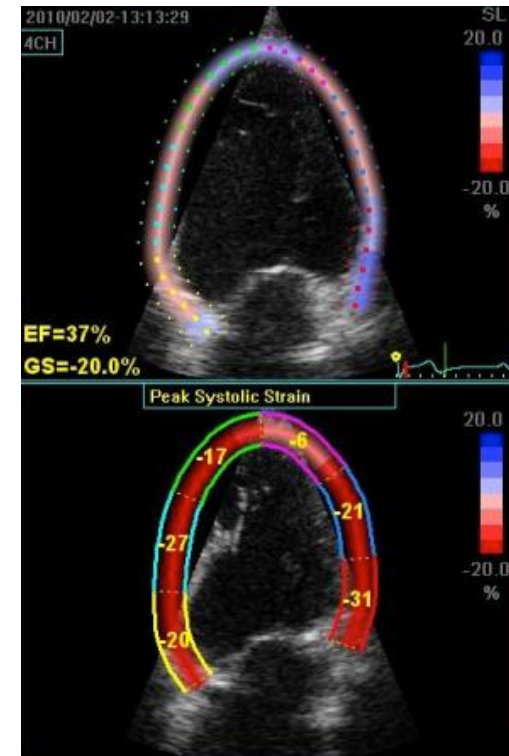
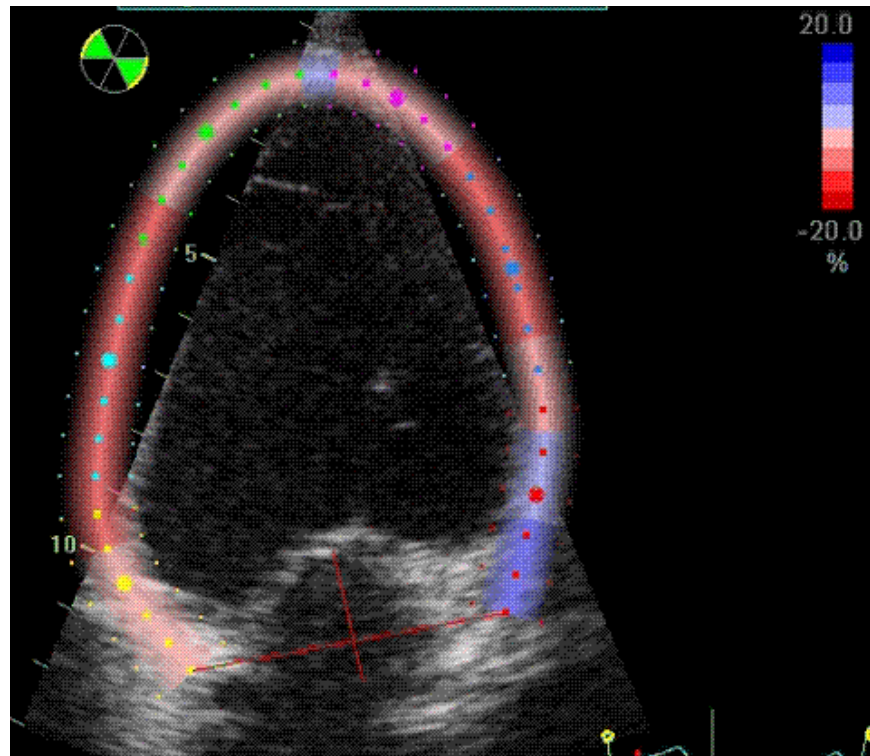
- **I hjertesvikt**
 - (Wisløff 2007)
- **Hypertensjon**
 - (Mølmen-Hansen 2012)
- **Aldring**
 - (Mølmen-Hansen 2012)
 - Systolisk funksjon
 - Diastolisk funksjon
- **Diastolisk stress test**
 - (Rustad 2008)

AFI



- (Forførende) brukervennlig
- (Tilsynelatende) Robust

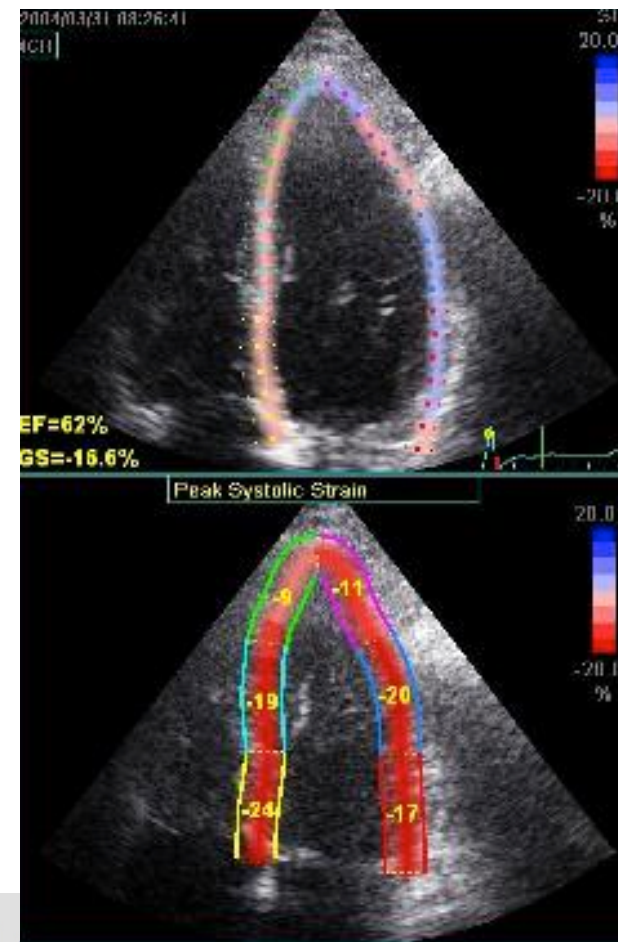
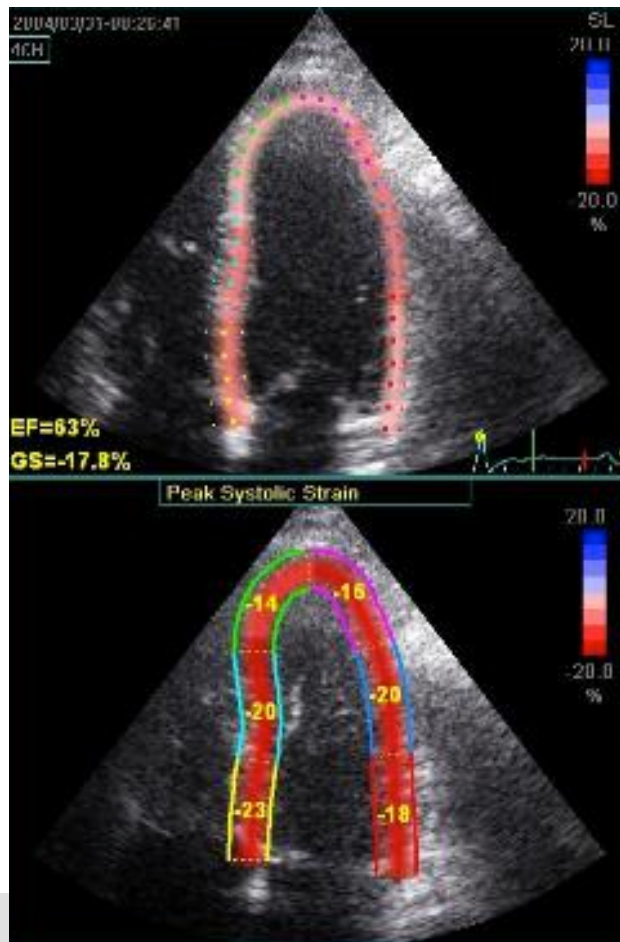
Speckle tracking (AFI):



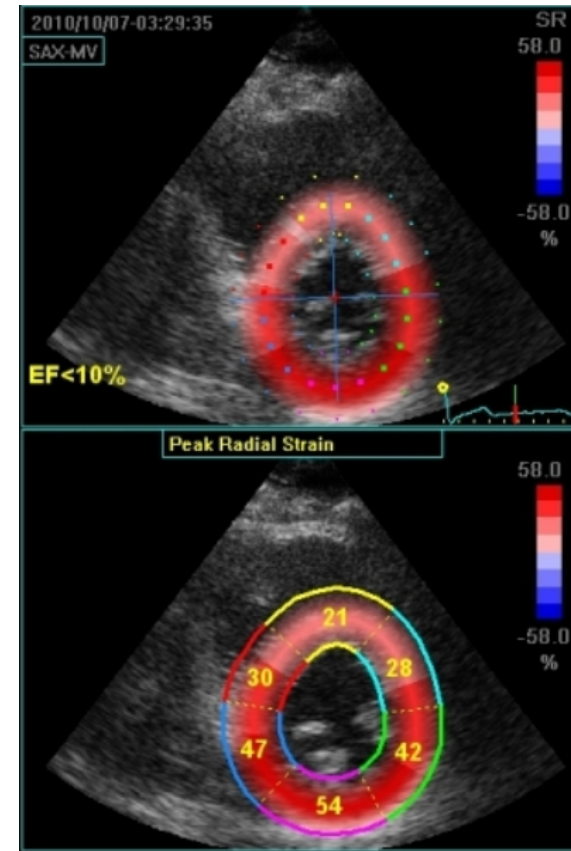
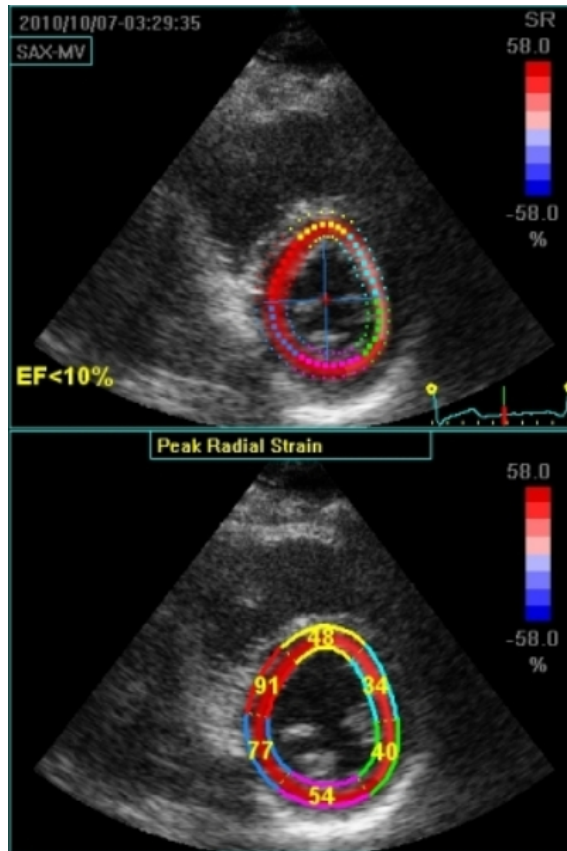
Glating av AV-plan bevegelse langs ROI

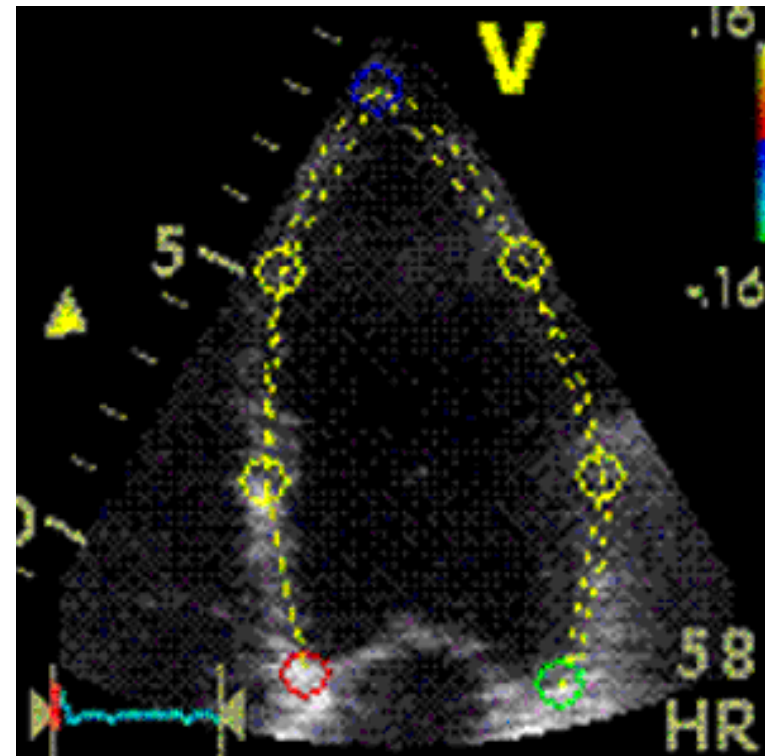
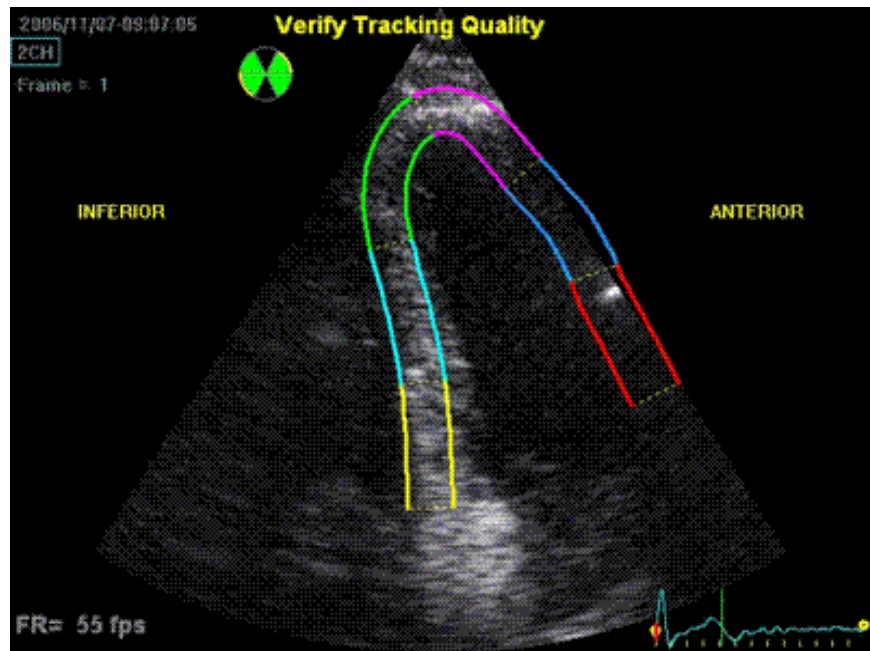
Speckle tracking

Curvature dependency



Målt strain avhengig av bredden på ROI

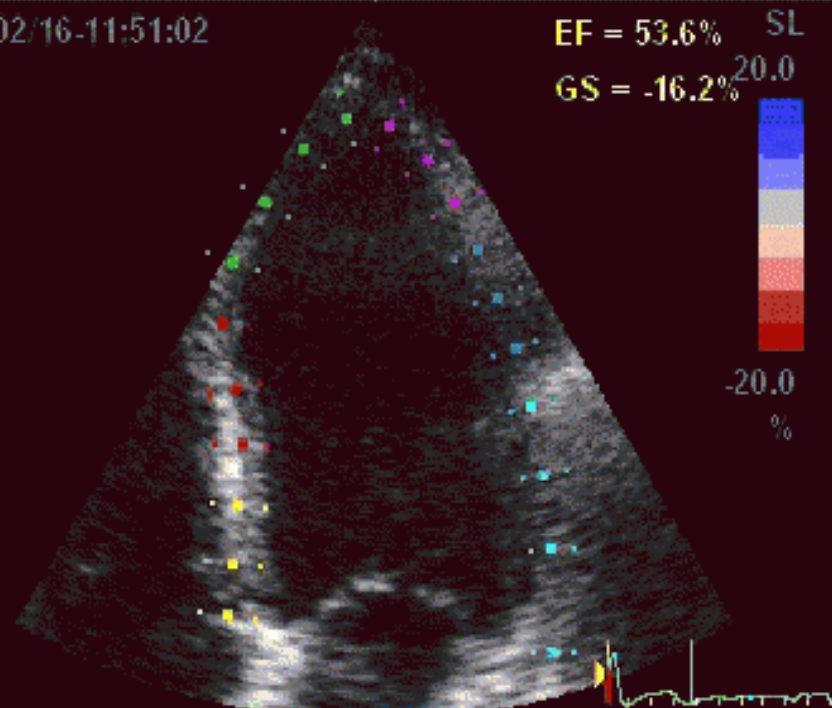




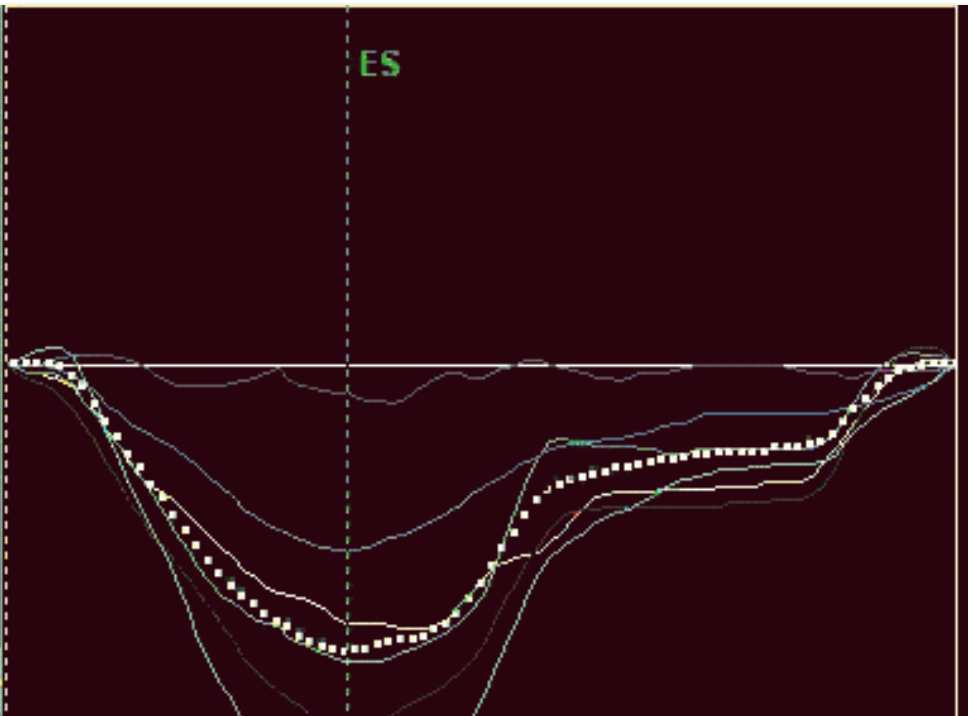
2004/02/16-11:51:02

4CH

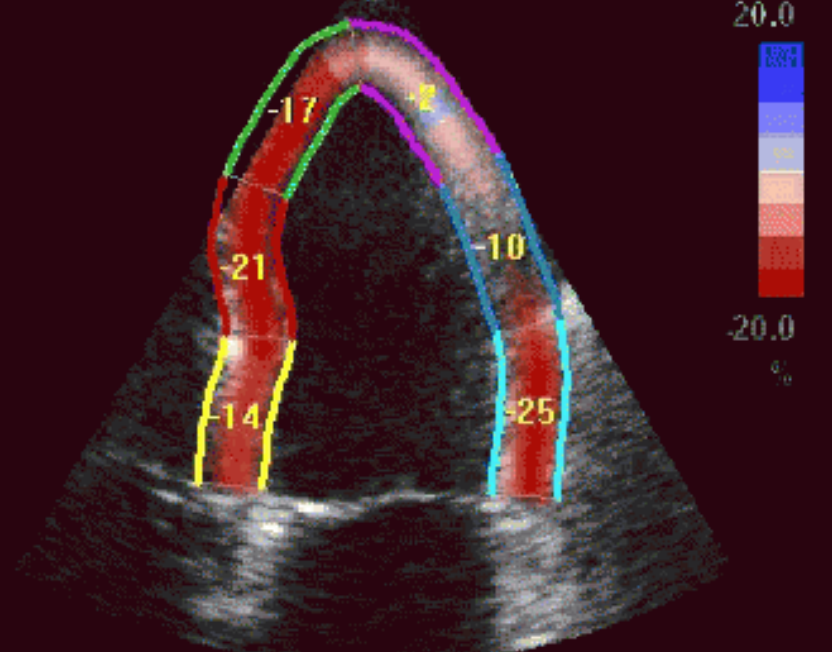
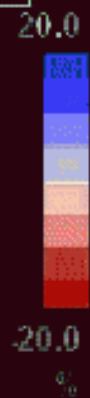
EF = 53.6% SL
GS = -16.2%



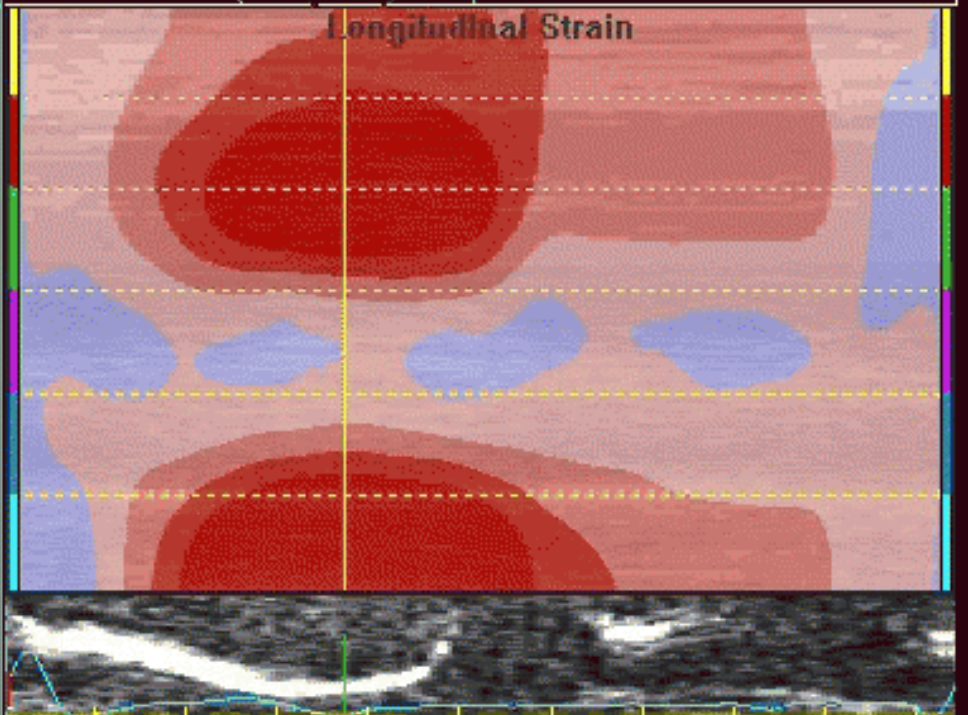
ES



Peak Systolic Strain



Longitudinal Strain



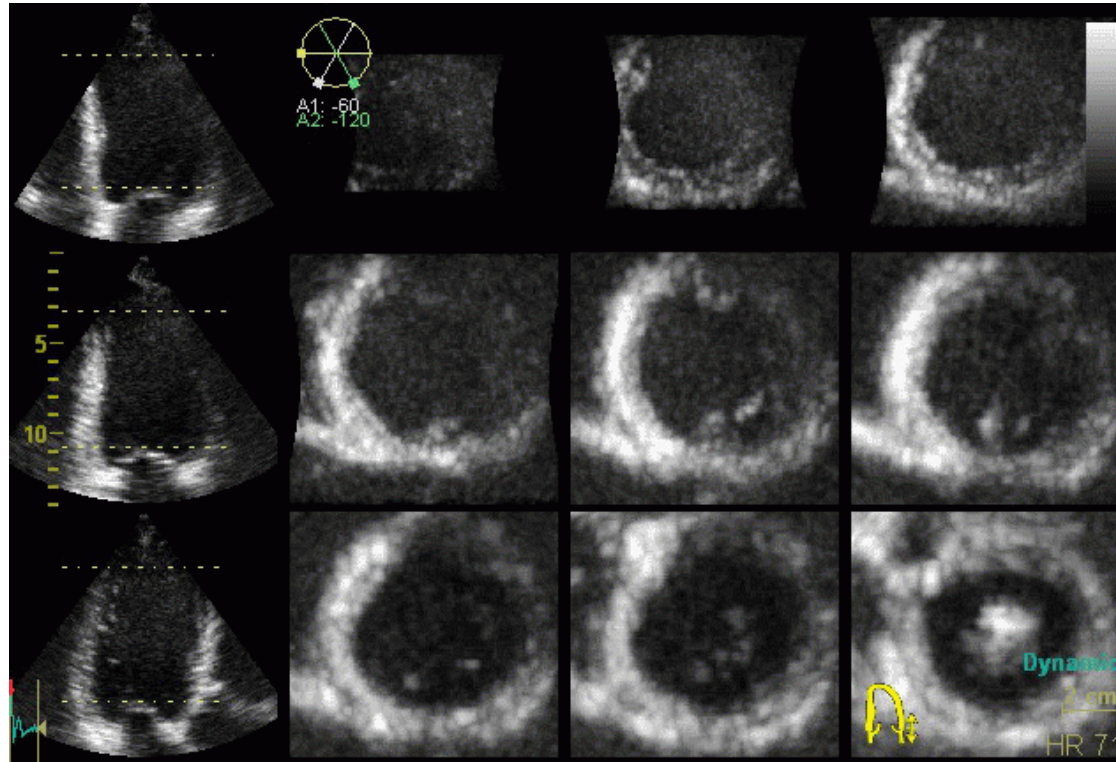
Sammenligning mellom metoder (N=100):

Table 4 Mean (SD) segmental longitudinal end-systolic strain (S_{es}) and peak systolic strain rate (SR_s)

	Method 1 ST and TDI	Method 2 TDI fixed ROIs	Method 3 TDI tracked ROIs	Method 4 ST (AFI)
Apical				
S_{es} (%), mean (SD)	-18.0 (3.6) ¹	-14.6 (9.0) ⁸	-17.2 (9.1) ⁷	-18.7 (6.6) ⁶
SR_s (s ⁻¹), mean (SD)	-1.12 (0.27) ⁶	-1.46 (0.85) ⁸	-1.31 (0.73) ⁸	-1.12 (0.37) ⁶
Mid-ventricular				
S_{es} (%), mean (SD)	-17.2 (3.2)	-18.2 (7.4) ²	-16.9 (7.1) ⁷	-18.3 (4.7) ²
SR_s (s ⁻¹), mean (SD)	-1.08 (0.22) ⁶	-1.29 (0.56) ⁸	-1.40 (0.58) ⁸	-0.99 (0.23) ⁶
Basal				
S_{es} (%), mean (SD)	-17.2 (3.5) ¹	-19.6 (9.3) ⁸	-17.1 (8.6) ¹	-18.0 (6.2) ¹
SR_s (s ⁻¹), mean (SD)	-1.03 (0.24) ⁶	-1.71 (0.94) ⁵	-1.59 (0.74) ⁵	-1.12 (0.36) ⁶
Mean				
S_{es} (%), mean (SD)	-17.4 (3.4) ³	-17.7 (8.5) ²	-16.7 (8.1) ⁷	-18.4 (5.9) ⁴
SR_s (s ⁻¹), mean (SD)	-1.08 (0.25) ⁶	-1.45 (0.79) ⁵	-1.43 (0.67) ⁵	-1.07 (0.33) ⁶

- Kombinert metode gir minst spredning
- hastighetsgrad (TVI) mest.
- Hastighetsgrad uten tracking underestimerer i apex.
- AFI gir litt mer strain / strain rate

3D/4D echo:



- 3D strain dårligere enn 2D strain og 2D WMS (V3 probe)
- 3D WMS (dynamic short axis) kan være bedre enn 2D WMS
 - Hvis parasternalt vindu er dårlig
 - I utvalgte pasienter

Er deformasjonsavbildning nyttig?

- Den har definitivt gitt ny fysiologisk kunnskap og forståelse
- Klinisk er den kun et tillegg.
 - Ved tvil / Usikkerhet
 - Gir bedre timing og i noen tilfelle kvantitering
- Den er avhengig av at en forkaster dårlige data
- En må vurdere alle ting, ikke bare en enkelt måleparameter:
 - Farge
 - Timing
 - Peak verdier
 - Kurveform

Et tankekors:

- **M-mode ekkokardiografi – frame rate opp mot 1000**
- **Pulset vevsdoppler – effektiv frame rate ca 300**
 - Gir hastighetsinformasjon med høy tidsoppløsning
- **Farge vevsdoppler – frame rate ca 100 - 150**
 - gir simultan hastighet over hele sektor – regional funksjon
- **Speckle tracking (B-mode) – frame rate 50**
- **3D ekko – frame rate 25 (Uten stitching).**

2D TVI frame rate 1200

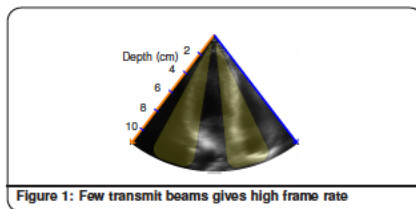


Figure 1: Few transmit beams gives high frame rate

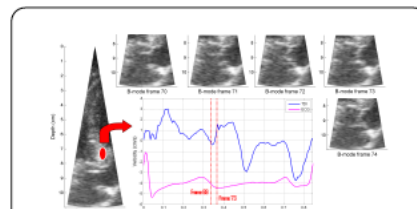


Figure 3: Aortic Valve Closure occurs at or near peak positive acceleration [1]

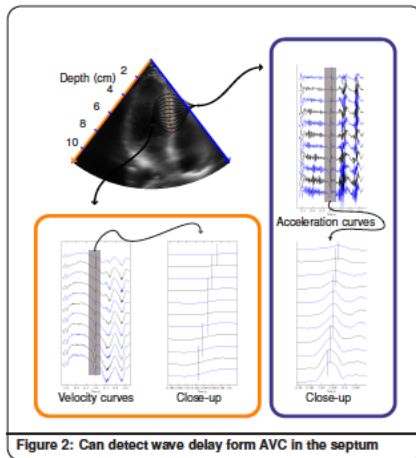


Figure 2: Can detect wave delay from AVC in the septum

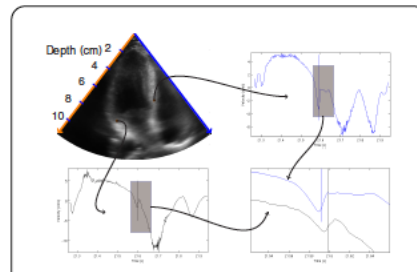
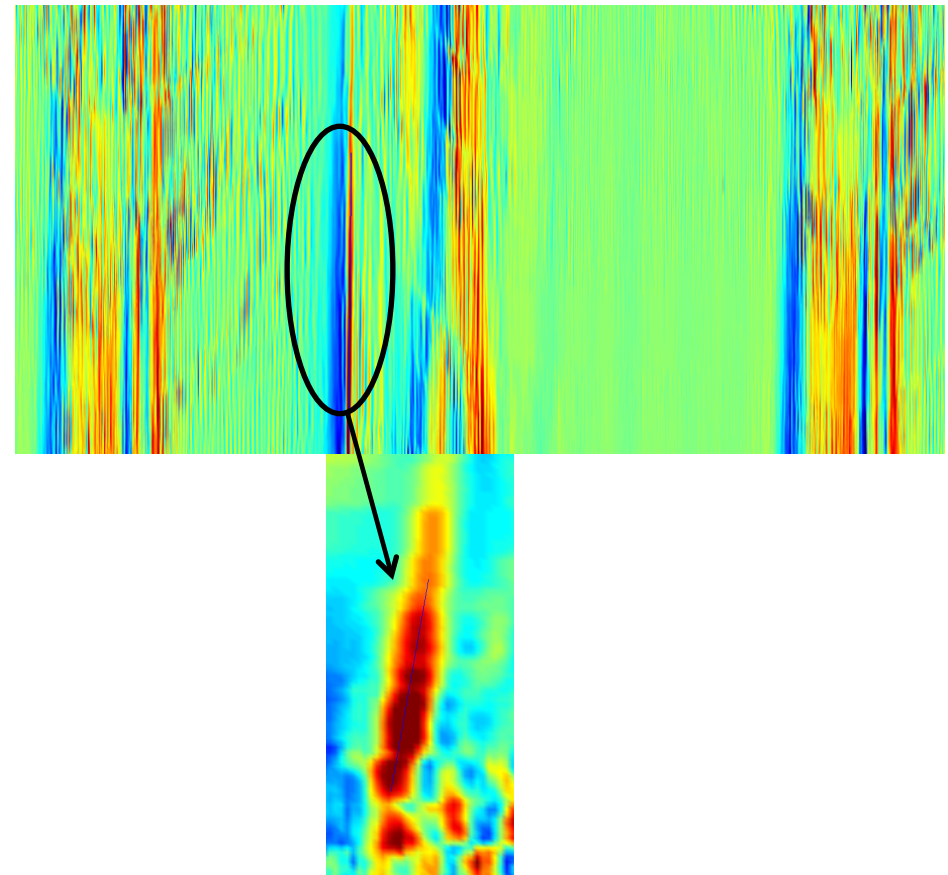


Figure 4: Delay from septal base to basal lateral wall

Conclusions

- New TDI approach for very high frame rate concurrent imaging of both LV walls
- New method is useable for detecting the propagation time of the shear wave starting with AVC

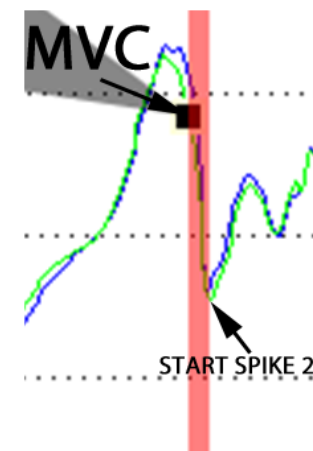
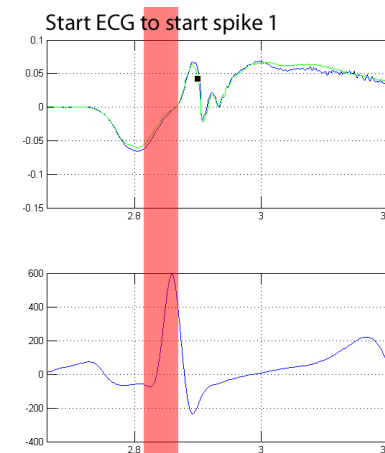
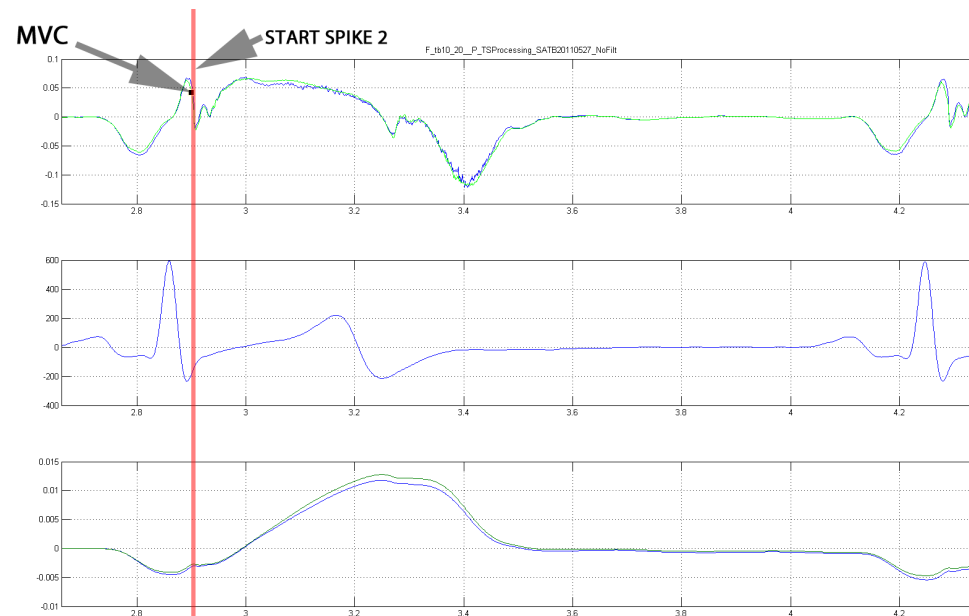


Propagasjon av AVC lukkeklippet som skjærbølge

Aase et al; euroecho 2011

Schistad Lund; Leuven 2012

Pre ejeksjonsperioden



- **Elektromekanisk delay**
- **Bifasisk spike i septum**
- **Første spike før MVC**

3D TVI med 500 FPS

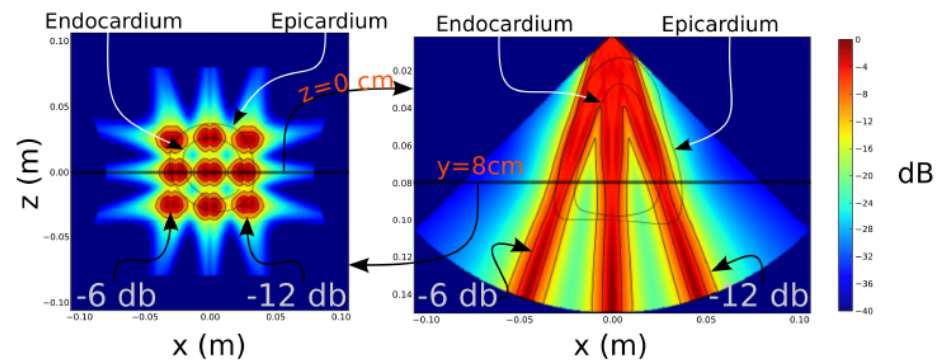
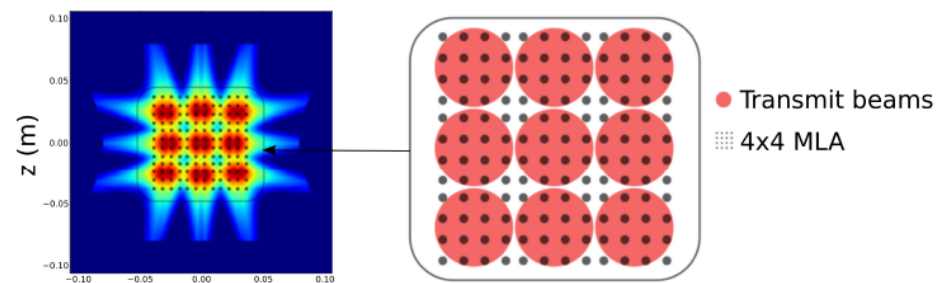


Fig. 2. Sensitivity plots of 3D TVI acquisition simulated with Field II. The contours, made from 3D B-mode, marks the endocardium and epicardium of the left ventricle.



Hva mangler vi?

- **For høyere Frame rate:**
 - Høyere MLA faktor
- **For å få bedre billedkvalitet:**
 - **Faeabberasjonskorreksjon**
 - Når ultralysstrålen passerer forskjellige vev har den forskjellig hastighet – deler av pulsen kommer ut av fase
 - **Reverberasjonssuppresjon**
 - 2: Harmonisk ikke nok

www.folk.ntnu.no/stoylen/strainrate