

FYS-KJM 4740

MR-teori og medisinsk diagnostikk

Kap. 10  
Spinn i bevegelse

Beskrive bulk flow som en serie-ekspansjon:

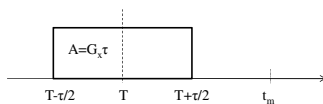
$$\mathbf{r}(t) = \mathbf{r} + \mathbf{v}t + \frac{1}{2}\mathbf{a}t^2$$

v=hastighet; a=akselerasjon

Ved konstant flow (a=0) in en gradient G(t) får vi i en fase-effekt lik:

$$\phi(t) = \gamma \int_0^t (\mathbf{r} + \mathbf{v}\tau) \mathbf{G}(\tau) d\tau = \mathbf{r} \gamma \int_0^t \mathbf{G}(\tau) d\tau + \mathbf{v} \gamma \int_0^t \mathbf{G}(\tau) \tau d\tau$$

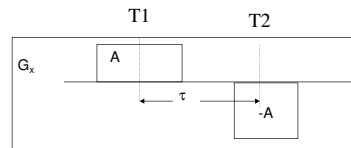
Effekt av konstant gradient i utlesnings(x) -retningen



$$\phi(t_m) = \gamma \int_{T-t/2}^{T+t/2} x(t) G_x dt = \gamma \int_{T-t/2-t_m}^{T+t/2-t_m} (x_m + vt') G_x dt' = \gamma v_m A + \gamma A (T - t_m)$$

Fase-effekt er proporsjonal med flow-hastighet.  
Proporsjonalitetskonstant = første-momentet av arealet under Gradient x tids-kurven

Effekt av bipolare gradienter

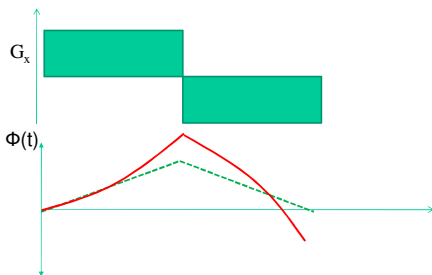


$$\phi(\tau) = v \gamma A T_1 - v \gamma A T_2 = -\gamma A v (T_2 - T_1) = -\gamma A v \tau$$

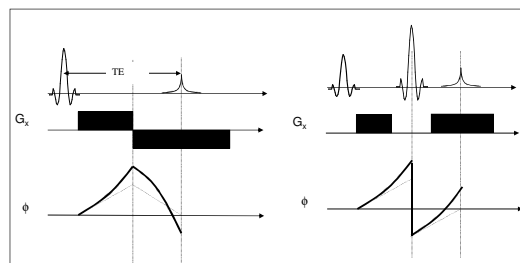
0. ordens moment:  $\int G(t) dt$

1. ordens moment:  $\int G(t) t dt$

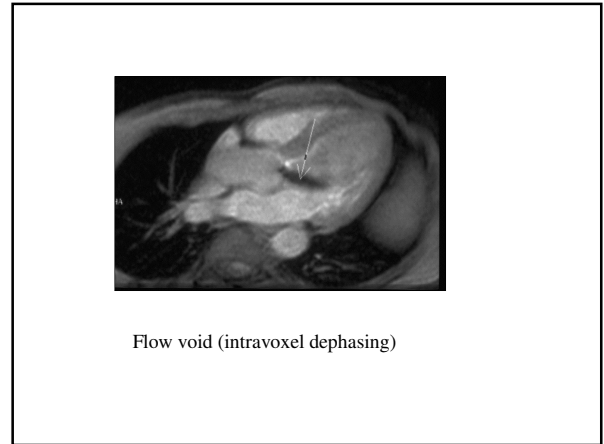
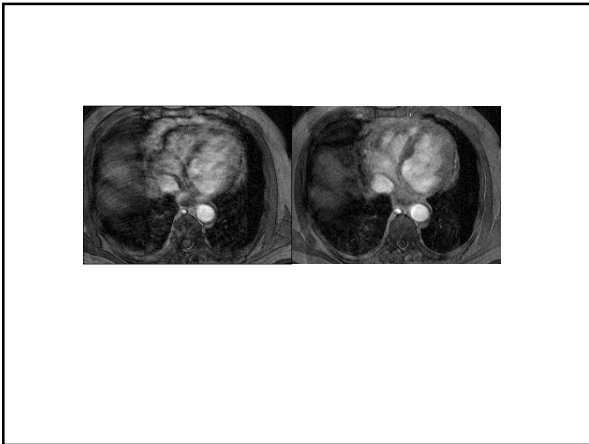
Effekt av bipolare gradienter



Fase-effekt i GRE og SE



For å unngå fase-effekter for stasjonære spinn:  
0.ordens gradientmomentet = 0 ved ekkosenter

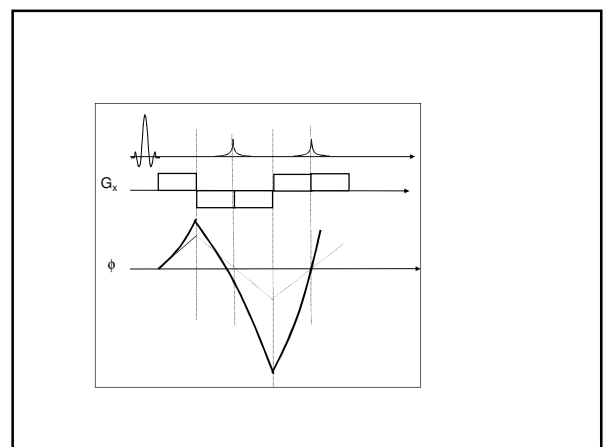
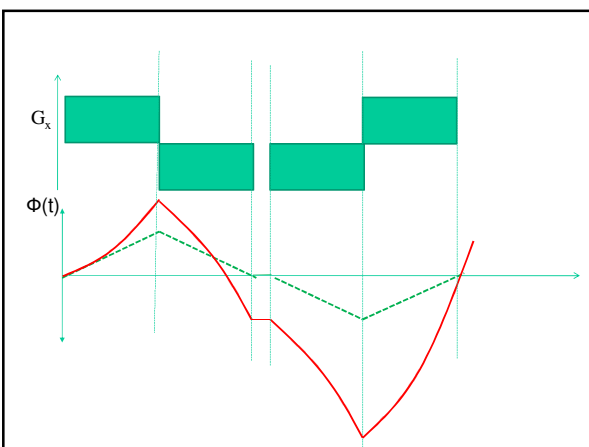
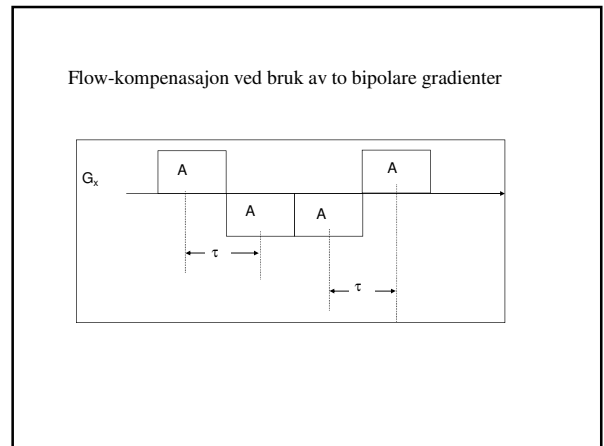


Siden fase-effekt er proporsjonal med flow-hastighet kan vi kvantifisere flow dersom vi kan måle fasen nøyaktig. Dette krever imidlertid at  $\Phi \ll \pi$  slik at:

$$|v_{\max}| = \pm \pi / \gamma A \tau$$

Magnitude image

Phase (flow) image



Feilregistrering grunnet flow

Spinn v. posisjon  $y$  ved tid  $t_1$

$$\varphi = \gamma \Delta A y(t_1)$$

$\Delta A$  = endring i grad. areale mellom sussecutive fasesteps

Hvor er samme spinn ved ekko-avlesning ( $t_2$ )?

$$\Delta y = v \sin(\alpha) \tau$$

$$\Delta r = \Delta y \cos(\alpha) = v \sin(\alpha) \cos(\alpha) \tau$$

Feilregistrering grunnet flow

Inntreffer kun i faseretningen  
Bare for kar med vinkel  $\neq 0^\circ$  i forhold til både fase og frekvensretning

**Effekt av pulsatil flow**

Ved periodisk variasjon i fase-effekt i blod blir MR-signalet modulert av en fasekomponent:

$$S(y) = \int_{k_y} M \cdot \exp(jy k_r) \exp(j\theta(k_y)) dk_y$$

Hvor  $\theta(k)$  kan uttrykkes som en Fourier serie (siden periodisk):

$$\theta(k_y) = \exp \left[ jA \sum_n c_n \exp(jn \omega_c k_y) \right]$$

A= maks amplitude og  $c_n$  er konstanter

**Pulstatil flow gir ghosting i faseretningen!**

Avstand mellom hvert *ghost* objekt er gitt ved:

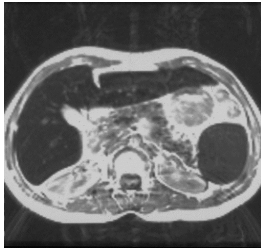
$$\Delta y_g = N_y TR / T_c$$

$T_c$  = periode på pulsilitet

TR = repetition time (steady state sekvenser) eller ekko spacing (FSE, EPI)

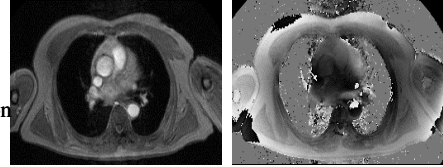
$N_y$  = antall fasekodinger

Pulsasjons-artefakter (i faseretning) forårsakes også av respirasjon

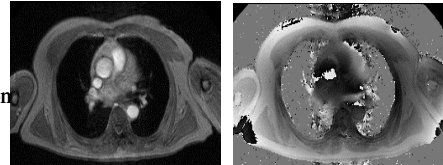


### Kvantifisering av flow

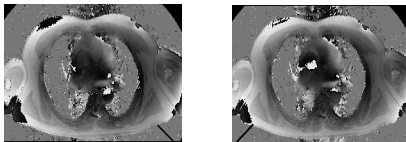
Uten flow Compensation



Med flow Compensation

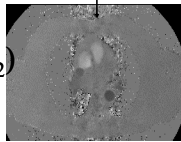


### Flow kvantifisering ved subtraksjon



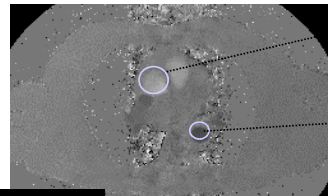
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$$v = c (\phi_1 - \phi_2)$$

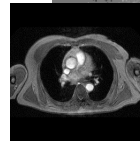


### Phase Contrast Flow Quantification

Vmean 46 cm/s  
Vmax 103 cm/s

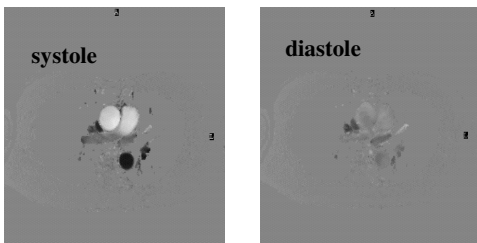


Vmean -54 cm/s  
Vmax -70 cm/s



TD 154 ms

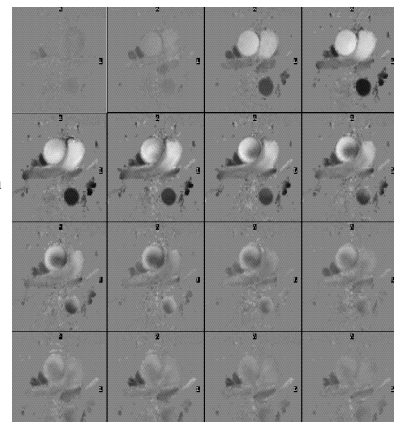
### MR Velocity Maps

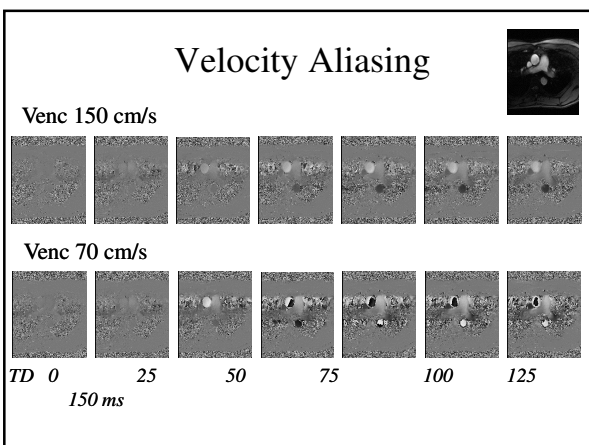
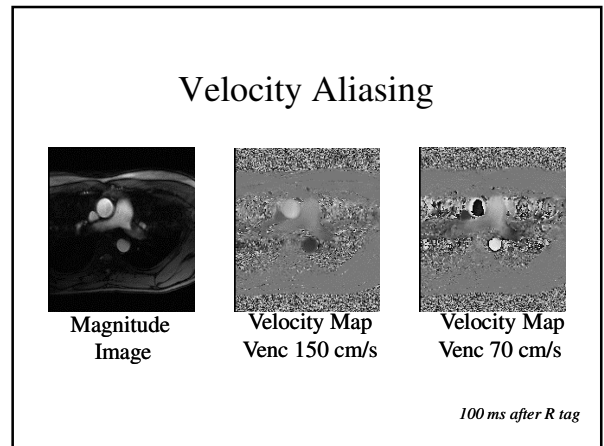
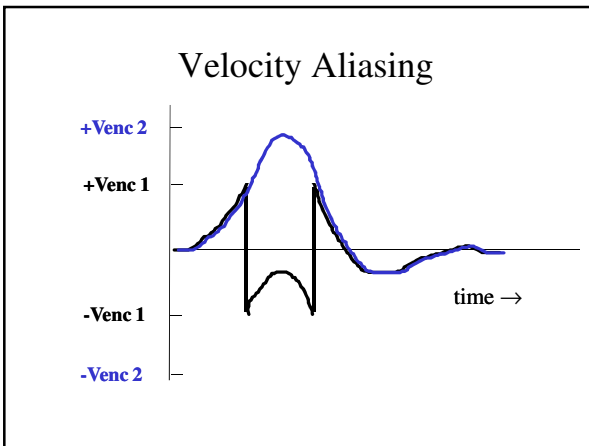
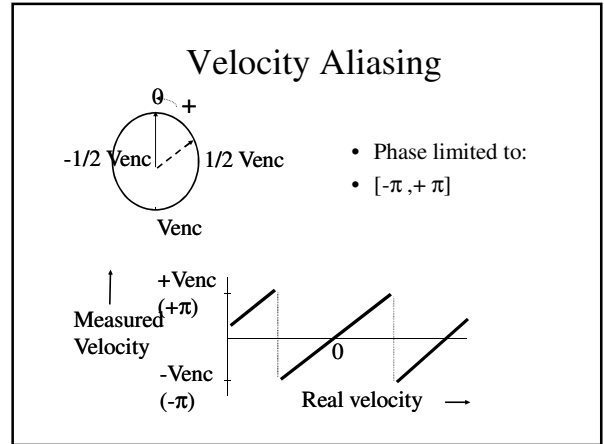
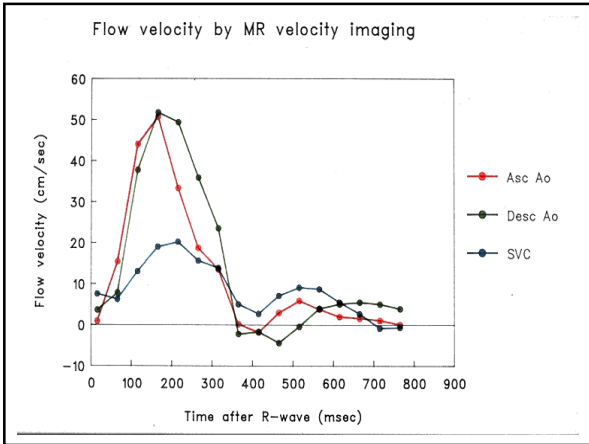


### Velocity map

temporal resolution  
40 ms

16 phases of 22





- ### Limitations with MR flow measurements
- Complex flow  $\rightarrow$  flow void (*use short TE*)
  - aliasing (*use correct  $V_{enc}$* )
  - Angulation (*correct positioning*)
  - Flow missregistration (*use short TE*)