FYS-KJM 4740

MR-teori og medisinsk diagnostikk

Kap 4
MR signal og kontrast

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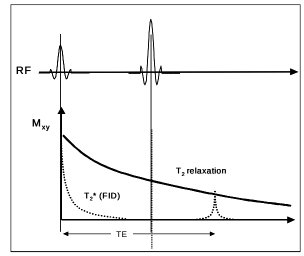
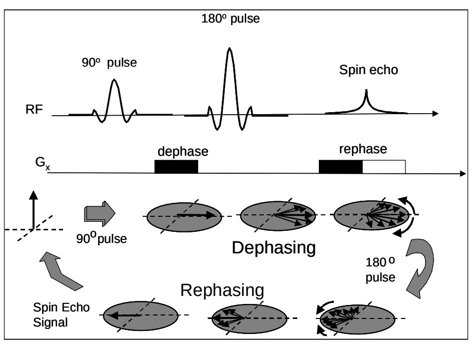
SE signal





Effekt av multiple RF-pulser

$$\frac{d\mathbf{M}}{dt} = \begin{pmatrix} -1/T_2 & \gamma\mathbf{G}\cdot\mathbf{r} & 0 \\ -\gamma\mathbf{G}\cdot\mathbf{r} & -1/T_2 & \gamma B_{1x} \\ 0 & -\gamma B_{1x} & -1/T_1 \end{pmatrix} \begin{pmatrix} M_{x'} \\ M_{y'} \\ M_{z'} \end{pmatrix} + \begin{pmatrix} 0 \\ 0 \\ M_0/T_1 \end{pmatrix}$$

'Steady state' betingelse:

$$\mathbf{M}(t^{+}{}_{n+1}) = \mathbf{R}_{\alpha}\mathbf{M}(t^{-}{}_{n+1}) = \mathbf{M}(t^{+}{}_{n})$$

$B_{1x}=0$ ⇒ $M_{z'}(t^{-}{}_{n+1}) = E_1 M_{z'}(t^{+}{}_{n}) + (1-E_1)M_0$; E_1=exp(-t/T1).

$M_z(t^+{}_n)$=z-magn rett før RF puls # n

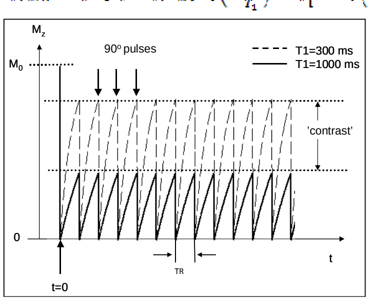
$M_z(t^-{}_n)$=z-magn rett etter RF puls # n

SE - sekvens

Med flip = 90 grader inntreffer 'Steady state' umiddelbart og $M_z(t^+)=0$

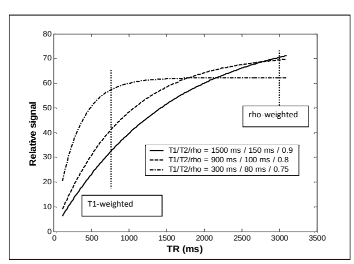
NB: endret fra kompendiet (eq. 4-1)!

$$M_z(t_{n+1}) = M_0 - [M_0 - M_z(t^{+}{}_{n})]\exp\left(-\frac{t_{n+1}}{T_1}\right) = M_0\left[1 - exp\left(-\frac{t_{n+1}}{T_1}\right)\right]$$



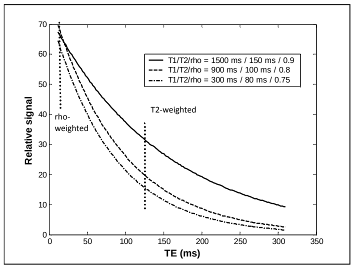
SE: T1-vekting og proton-density vekting

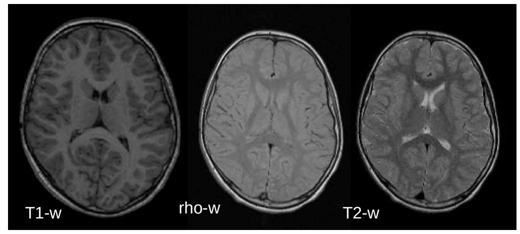
$M_z(TR) = M_0[1 - \exp(-TR/T_1)]$



$SI(TR,TE) \propto M_z(TR)\sin(\alpha)\exp(-TE/T2) = M_0[1-\exp(-TR/T1)]\exp(-TE/T2)$

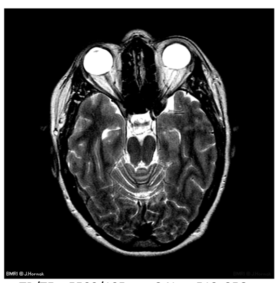
SE: T2-vekting og proton-density vekting





SE

TR/TE= 450/14 ms, 1 Nex, 256x192 matrix



TR/TE = 5500/105 ms, 2 Nex, 512x256 matrix

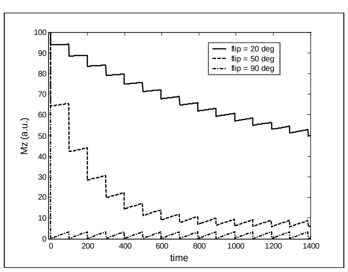
GRE sekvenser

- A flip angle α <90º is commonly used (to maximize the signal at short TR) and the MR signal therefore becomes a function of α.
- The condition TR>> T2 can generally not be assumed which significantly complicates the magnetization behaviour.
- The MR signal depends on T1, T2 and T2* relaxation.

Non-steady state (GRE)

Z-magnetisering $M_z(t^+)=M_z(t^-)*\cos(\alpha)$

$$M_z(t_{n+1}) = M_0 - [M_0 - M_z(t^-_{n+1})\cos(\alpha)]\ \exp(-t_{n+1}/T_1)$$



$$\mathbf{M}(t^+_{n+1}) = \mathbf{R}_\alpha \mathbf{M}(t^-_{n+1}) = \mathbf{M}(t^+_n)$$

XY-magnetisering $M_{xy}(t^+)=M_z(t^-)*\sin(\alpha)$

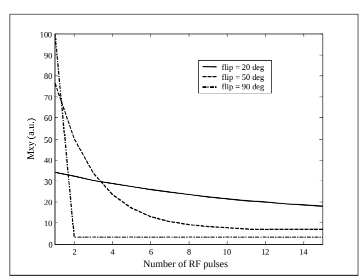


Figure -. The transverse magnetization (Mxy) following multiple RF-excitation pulses when TR << T1 (T1 = 600 ms, TR = 20 ms). Note that the lowest flip angle (20 deg) gives the highest steady state signal for this combination of TR/T1.

‘Spoiled Gradient Echo’

Stedy-state: $M_z(t^-_n)=M_z(t^-_{n+1})$

Fravær av ‘transverse coherence’: $M_{xy}(t^-_n)=M_{xy}(t^-_{n+1})=0$

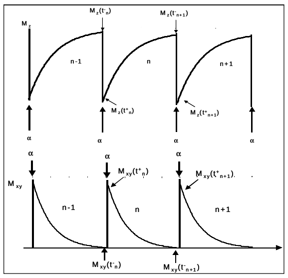


Figure -. The evolution of M_z (top) and M_{xy} (bottom) under steady state condition and for TR >> T2 so that $M_{xy}(t^-_{n-1}) = M_{xy}(t^-_{n+1})=0$.

‘Spoiled Gradient Echo’

$$M_{x',y'}(t^-{}_{n+1}) = M_{x',y'}(t^-{}_n) = 0 \qquad M_{z'}(t^-{}_{n+1}) = E_1 M_{z'}(t^+{}_n) + (1-E_1)M_0$$

$$\begin{bmatrix} M_{y'}(t+_{n+1}) \\ M_{z'}(t+_{n+1}) \end{bmatrix} = \begin{bmatrix} \cos(\alpha) & \sin(\alpha) \\ -\sin(\alpha) & \cos(\alpha) \end{bmatrix} \begin{bmatrix} M_{y'}(t-_{n+1}) \\ M_{z'}(t-_{n+1}) \end{bmatrix}$$

$M_y(t^-_{n+1})=0$

$$\begin{bmatrix} M_{y'}(t+_{n+1}) \\ M_{z'}(t+_{n+1}) \end{bmatrix} = \begin{bmatrix} \sin(\alpha) \\ \cos(\alpha) \end{bmatrix} M_{z'}(t-_{n+1})$$

(vis!)

$$M_{y'} = M_0 \frac{\sin(\alpha)(1-E_1)}{1-E_1\cos(\alpha)}$$

E_1=exp(-t/T1).

‘Spoiled Gradient Echo’ (SPGR)

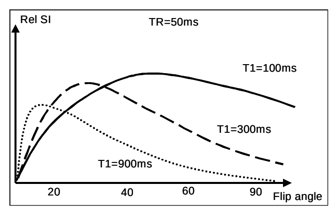
$$M_T(TE,TR,\alpha) = M_0 \frac{\sin(\alpha)(1-\exp(-TR/T1))}{1-\exp(-TR/T1)\cos(\alpha)} \exp(-TE/T2^*)$$

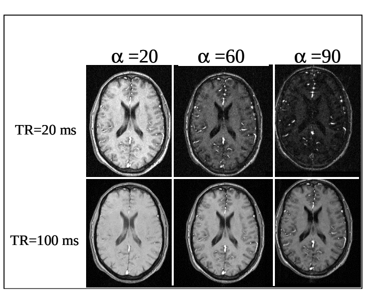
Maksimum M_T=maksimum signal:

$$\frac{\delta M_T}{\delta \alpha} = 0 \Rightarrow \cos(\alpha_e) = \exp(-TR/T1)$$

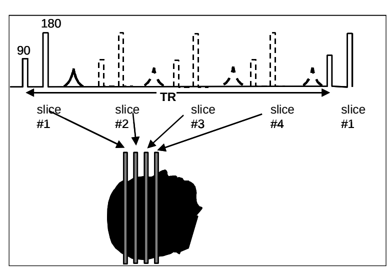
‘Spoiled Gradient Echo’ (SPGR)

- Short TR (TR/T1 << 1) combined with large flip angle gives T1-weighting
- Long TR (TR/T1 ≈1) combined with low flip angle gives T2*-weighting

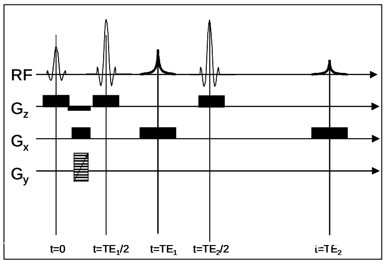


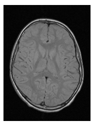


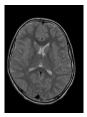
Multi-slice sekvenser



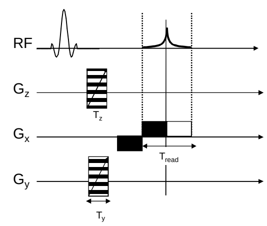
Dobbel-ekko sekvenser







3D-opptak: erstatte snitt-seleksjons grad med fasekoding i z-retn:



'3D' (volum) opptak:

$$\rho(x,y,z) = \frac{1}{2\pi}\int_{k_x}\int_{k_y}\int_{k_z} M_T(k_x,k_y)\exp\left(j\left(k_x x + k_y y + k_z z\right)\right)dk_x dk_y dk_z$$

Snitt-tykkelse gitt ved:

$$\delta z = \frac{2\pi}{\gamma G_{z\_max} T_z}$$

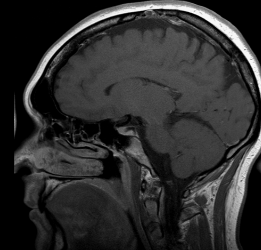
Muliggjør tynnere snitt enn ved 2D!

Total opptakstid:

$$T_{acq} = TR \cdot N_y N_z \cdot NEX$$

NEX = 'Number of excitations'

SE vs GRE



TR/TE/ST :516ms/12ms/3mm
20 snitt (2D)

TR/TE/flip/ST :20ms/1.8ms/30° /1.3 mm
128 snitt (3D)

2D vs 3D