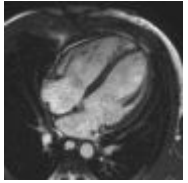


Semmelweis Egyetem

KARDIOLÓGIAI
KÖZPONT

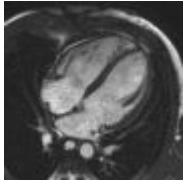
atoth@atoth.sote.hu

Modern képalkotó technikák: MR



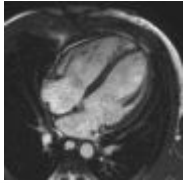
Előadás vázlatosan

- Történelem
- Tulajdonságok, eloszlás, energiaszintek
- T1 és T2 relaxáció, precesszió
- MR hardver: mágnes, tekercsek
- Gerjesztés, alapszekvenciák: fid, echo
- Lokalizáció, szeletkiválasztás
- Frekvencia és fázis kódolás, fast imaging
- Biztonság, a mi MR-ünk, példák



Történelem I.

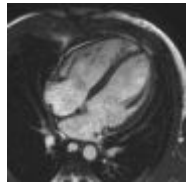
- 1934-39: Rabi
 - Proton mágneses momentum
 - RF spektrum, mágneses grádiensek
- 1946: mágneses rezonancia jelensége
 - 1952: Bloch & Purcell – Nobel
- 195x – 6x: nem képalkotó eszköz (NMR)
- 1972: CT
 - Hounsfield



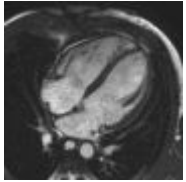
Történelem II.

- 1973: backprojection MRI – Lauterbur
- 1975: Fourier imaging – Ernst ('91: Nobel)
- 1977: echo planar imaging (EPI) – Mansfield
- 1980: Fourier transzform. MRI – Edelstein
- 1986: grádiens echo, multi slice (5 min)
- 1987: MRA – Dumoulin
- 2003: Lauterbur & Mansfield – Nobel díj

Elemek mágneses tulajdonságai

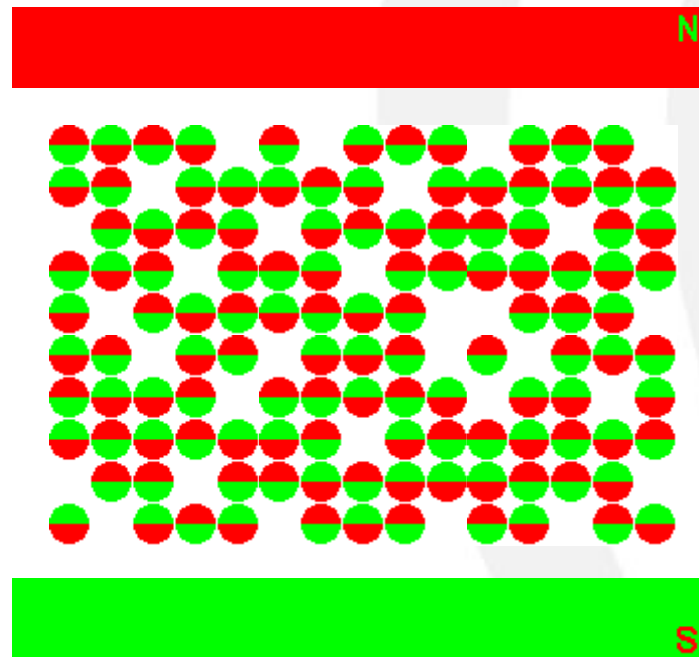


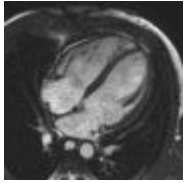
Elem	Izotóp	Párosítatlan proton	Párosítatlan neutron	Spin	γ (MHz/T)	Természetes	Biológiai
H	^1H	1	0	1/2	42.575	99.985	0.63
C	^{13}C	0	1	1/2	10.71	1.11	0.094
Na	^{23}Na	1	2	3/2	11.27	100	0.00041
P	^{31}P	1	0	1/2	17.25	100	0.0024



Boltzmann eloszlás

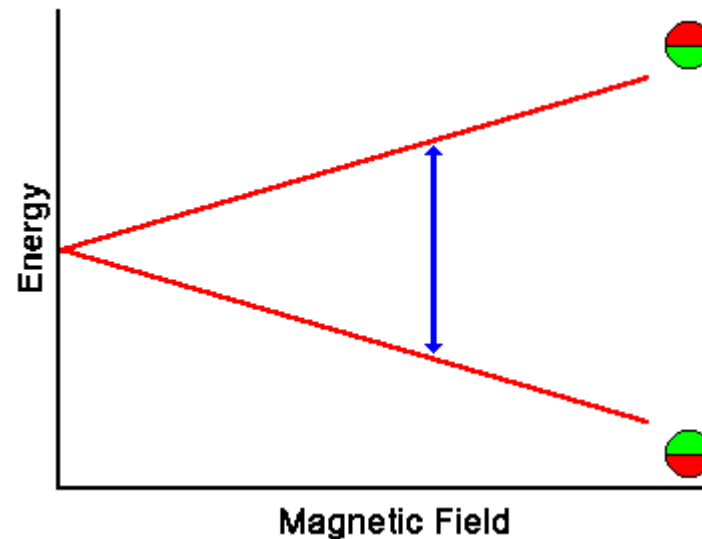
- $N^-/N^+ = e^{-E/kT}$, ahol
 - k: Boltzmann konstans ($1.3805 \cdot 10^{-23}$ J/K)

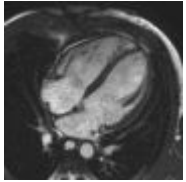




Zeeman splitting ($\frac{1}{2}$ spin)

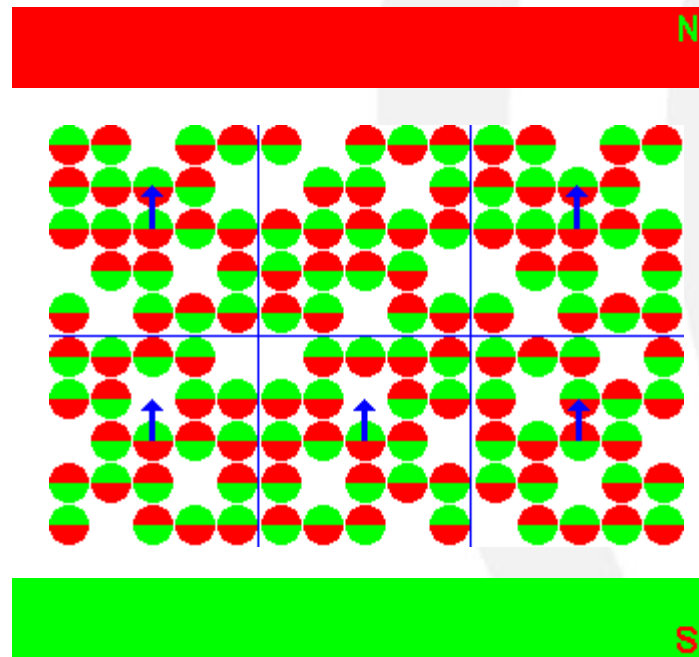
- $E = h \gamma B$, ahol
 - h : Plank állandó ($6.626 \cdot 10^{-34}$ J s)



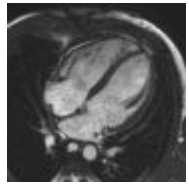


Spin csoportok

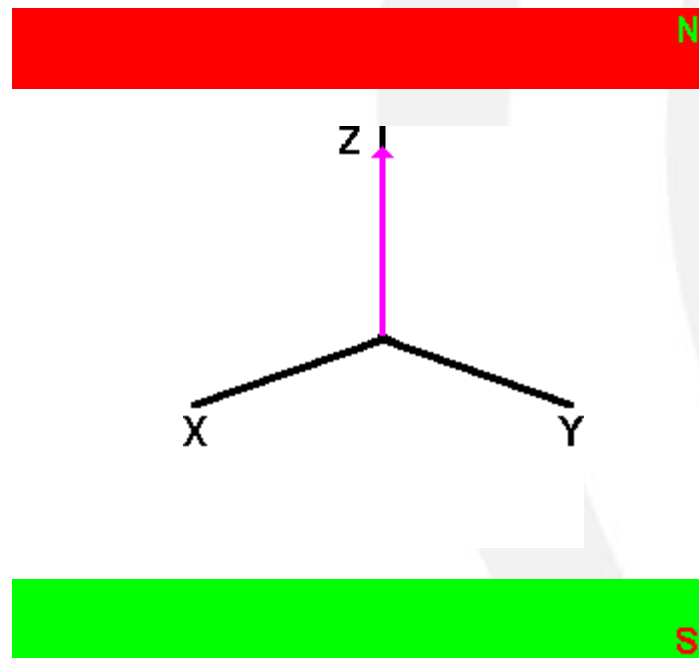
- $N^-/N^+ = e^{-E/kT}$, ahol
 - k: Boltzmann konstans ($1.3805 \cdot 10^{-23}$ J/K)

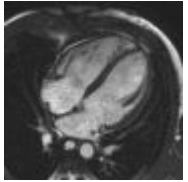


Összes magnetizáció



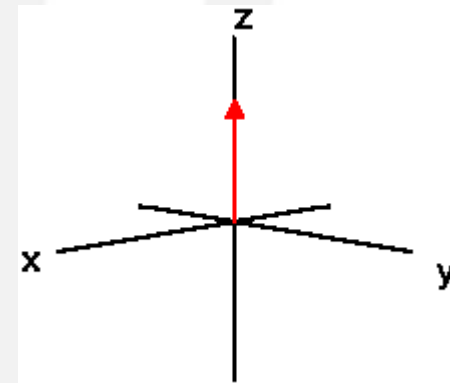
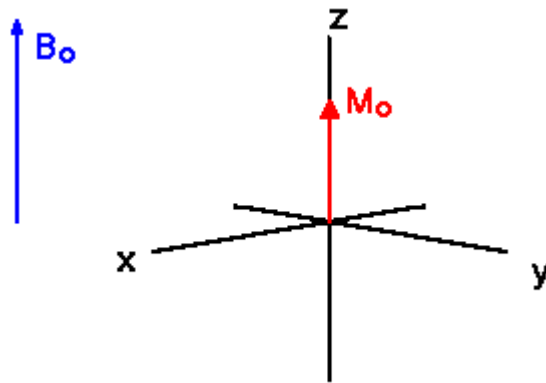
- Föld mágneses térereje: $2-5 \cdot 10^{-5}$ Tesla
 - 1 Tesla = 10^4 Gauss

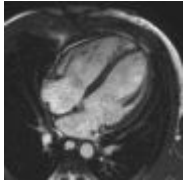




T1 relaxáció: „spin-rács”

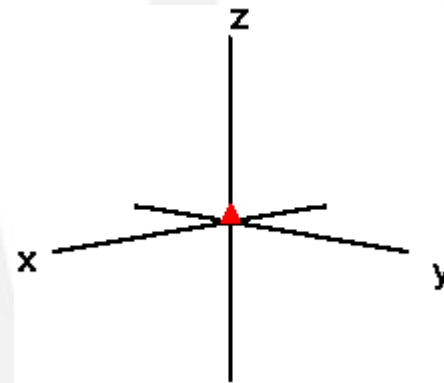
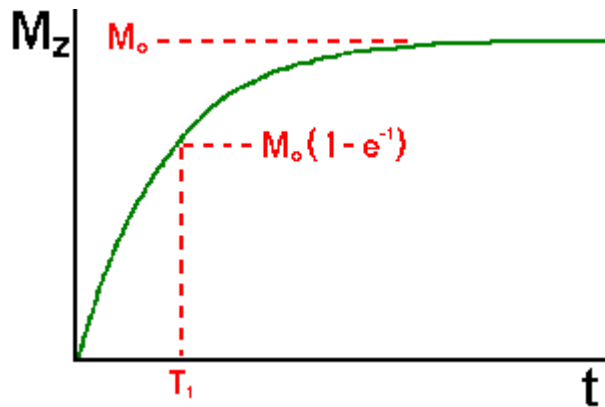
- Kitérítjük egyensúlyi helyzetéből a rendszert

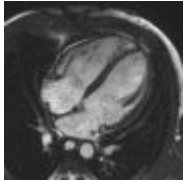




T1 relaxáció: szaturáció

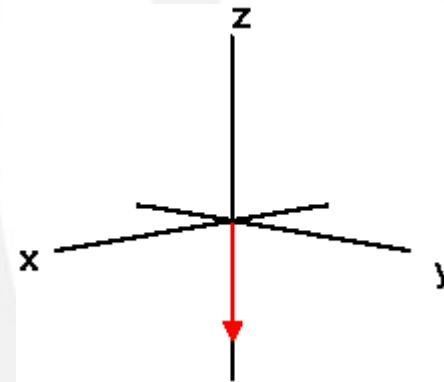
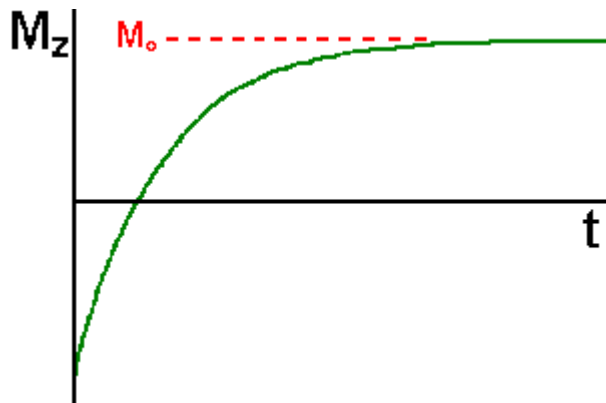
- $M_z = M_0 (1 - e^{-t/kT_1})$

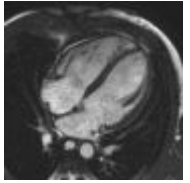




T1 relaxáció: inverzió

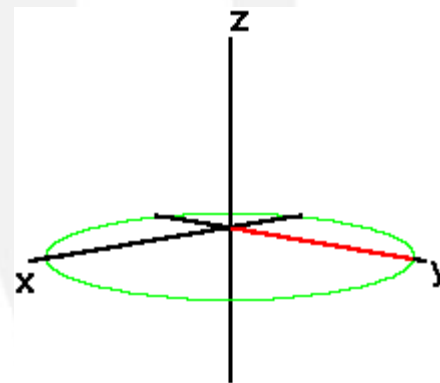
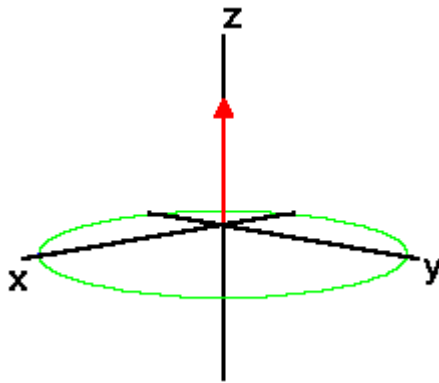
- $M_z = M_0 (1 - 2e^{-t/kT_1})$

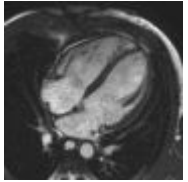




Precesszió: Larmor egyenlet

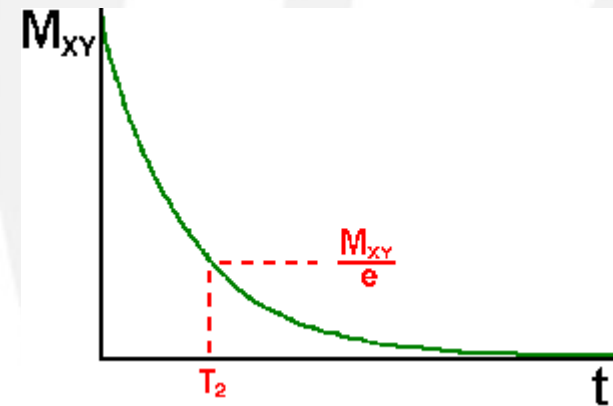
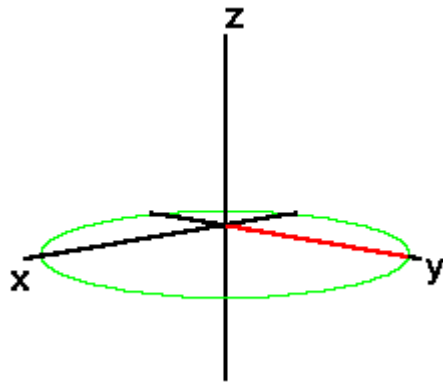
- $\omega_0 = \gamma B_0$, ahol
 - ω_0 : Larmor frekvencia
 - γ : gyormágneses együttható (H: 42.6 MHz/T)



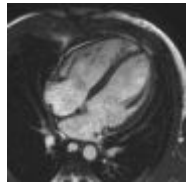


T2 relaxáció: „spin-spin”

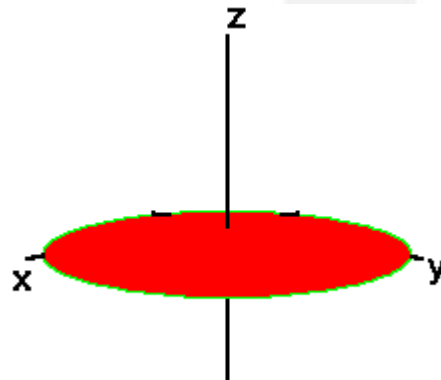
- $M_{xy} = M_{xy0} e^{-t/T_2}$
 - A fáziskoherencia gyorsan elvész



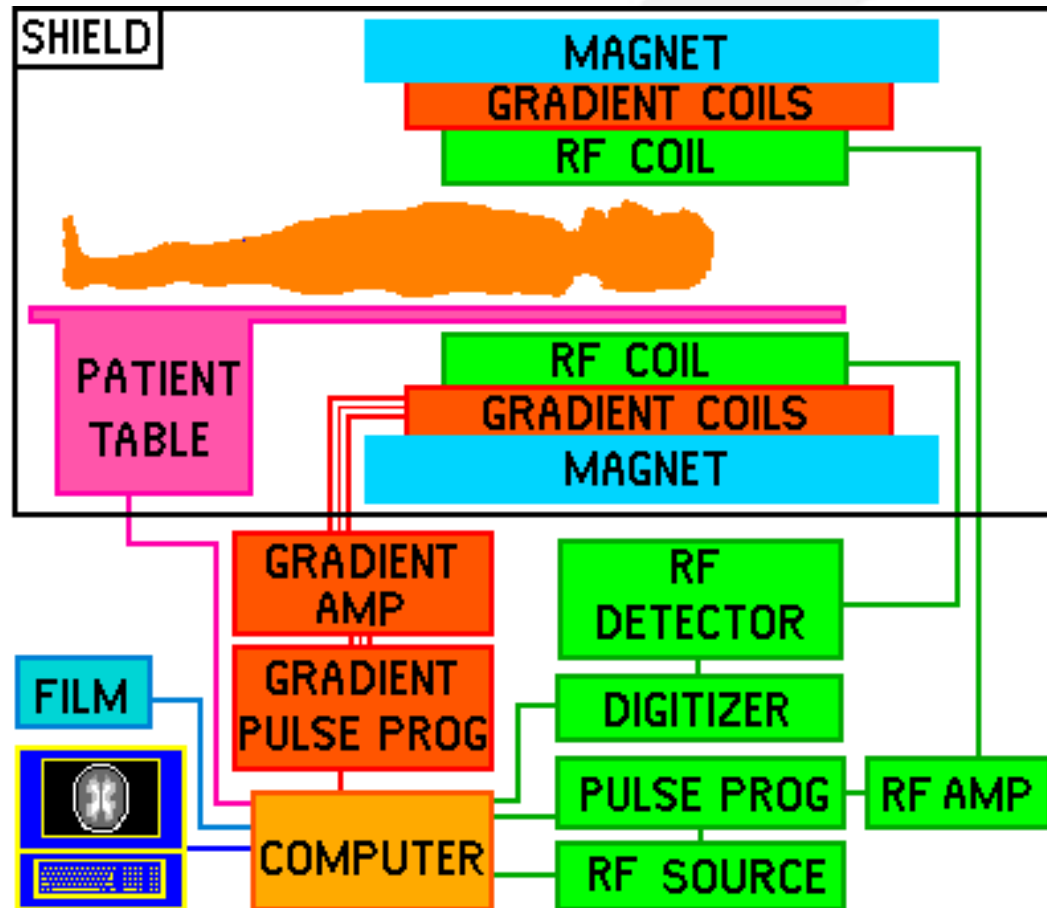
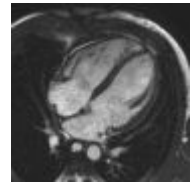
A T1, a T2 és a T2*



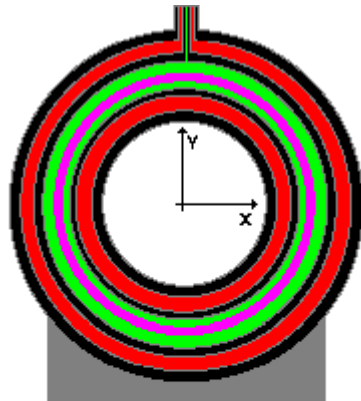
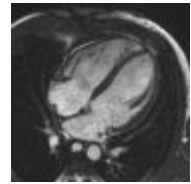
- A T2 mindig rövidebb, mint a T1
 - A T2* még rövidebb: a rendszer tökéletlenségét is magában foglalja
 - $1/T2^* = 1/T2 + 1/T2_{\text{tök}}$



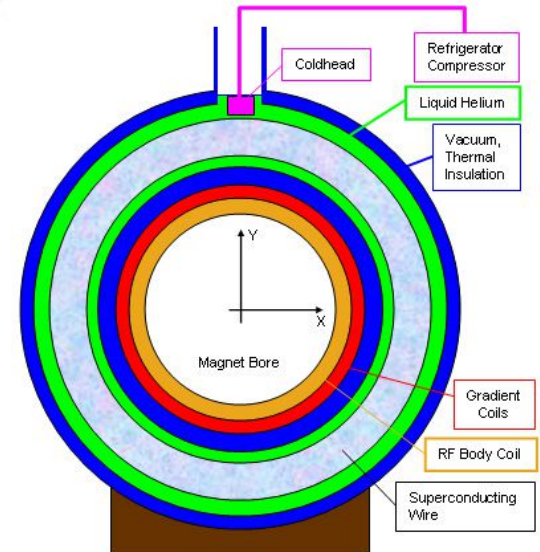
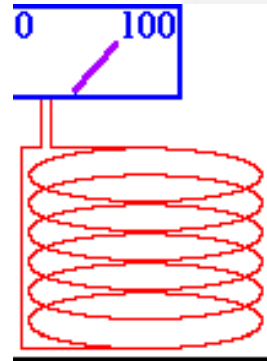
MR hardver



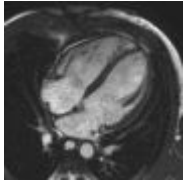
Mágnes



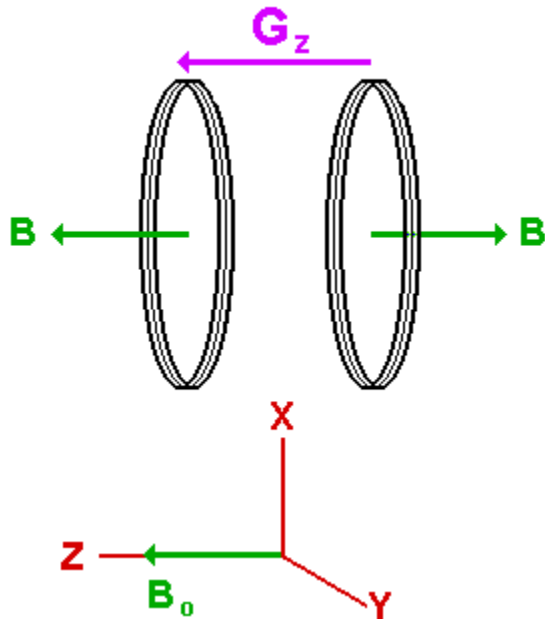
- Black** Vacuum
- Green** Liquid Helium
- Red** Liquid Nitrogen
- Grey** Container & Support
- Magenta** Superconducting Coil



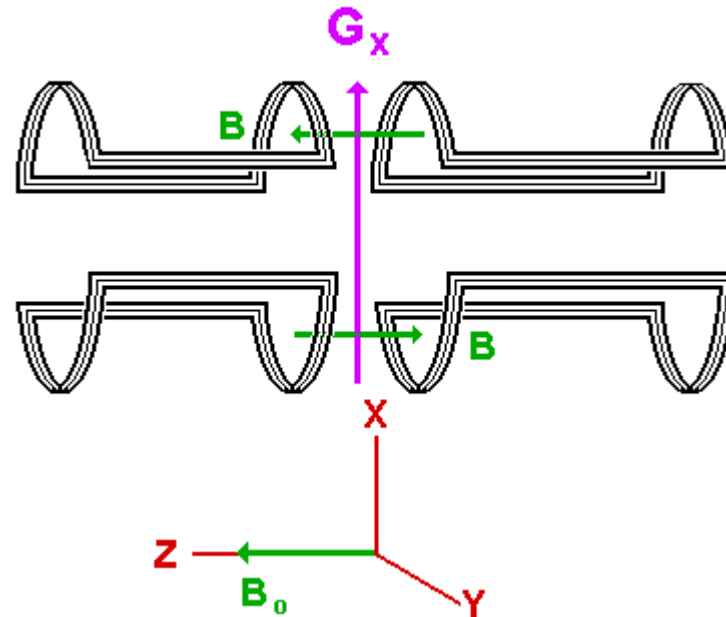
Grádiensek



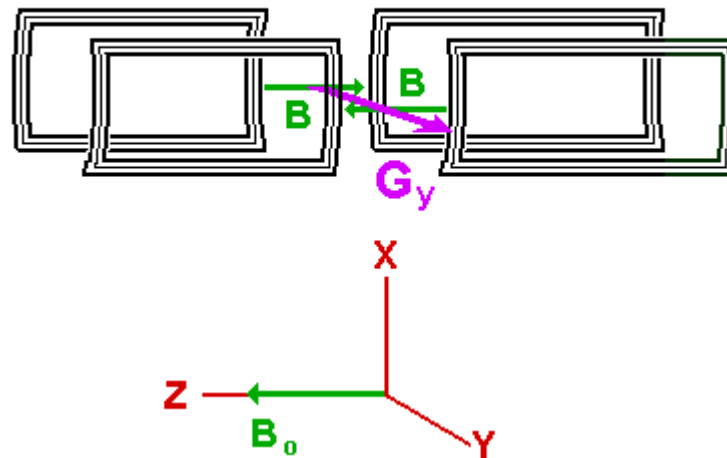
Z Gradient Coil



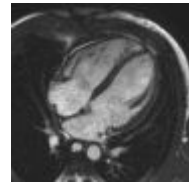
X Gradient Coil



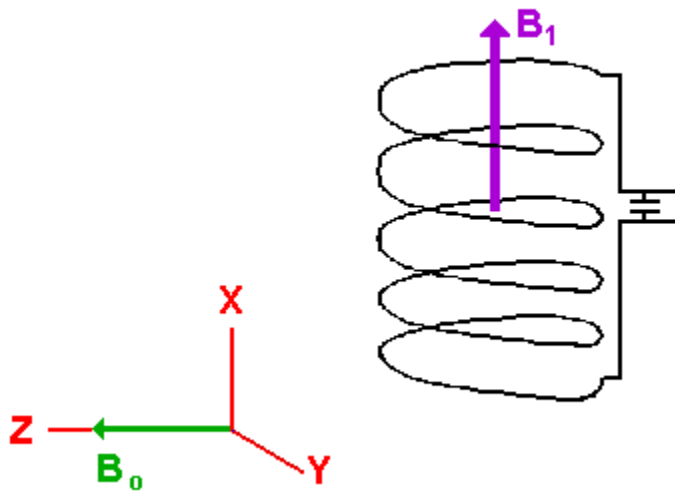
Y Gradient Coil



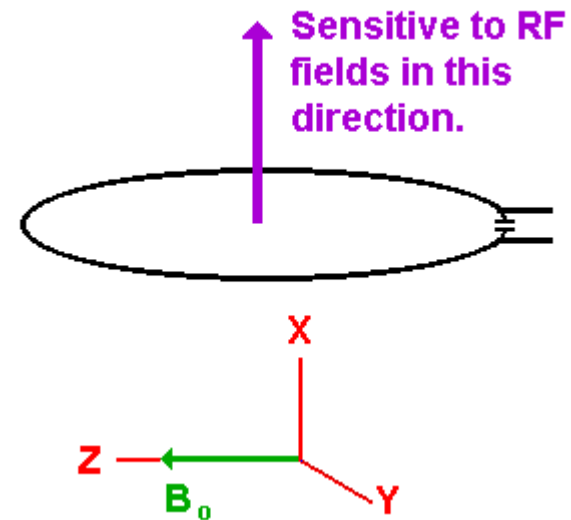
Tekercsek 1/3



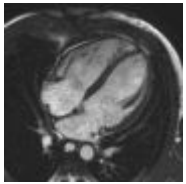
Multi-Turn Solenoid



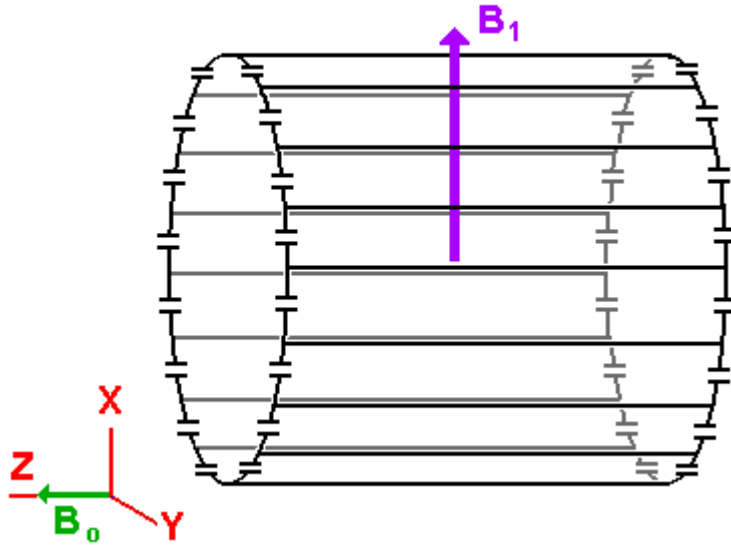
Surface Coil



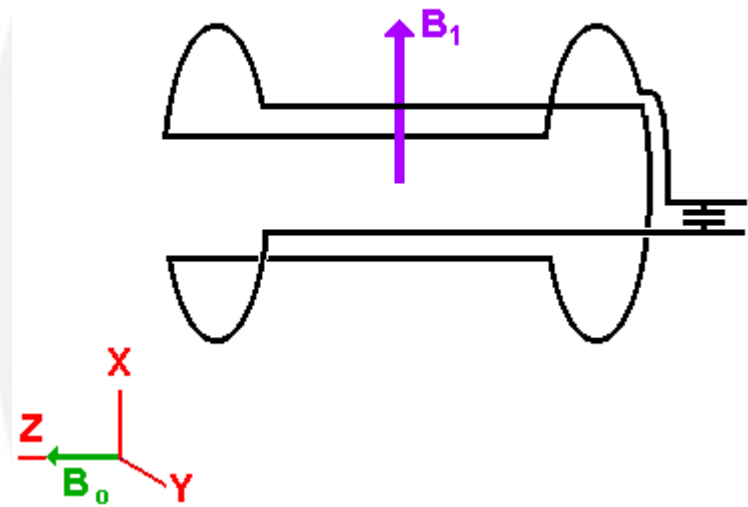
Tekercsek 2/3



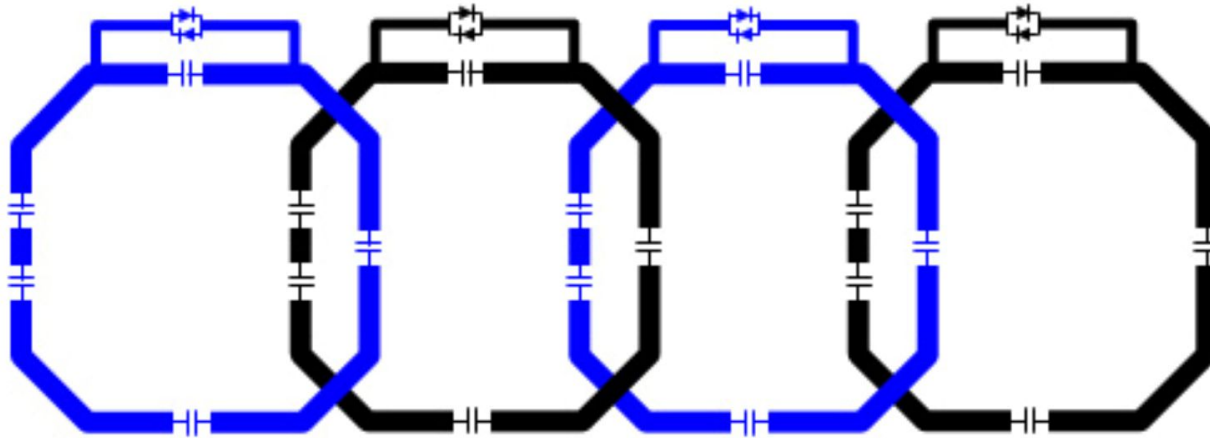
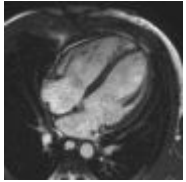
Bird Cage Coil



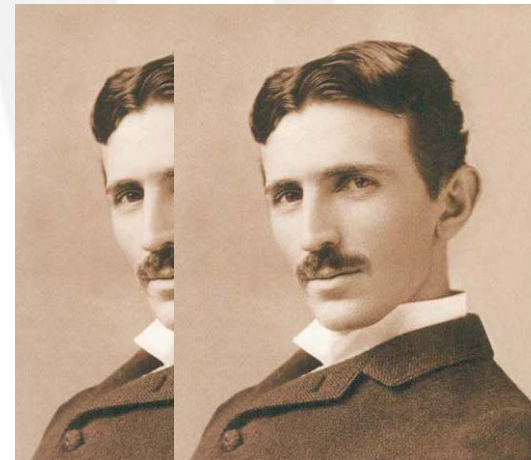
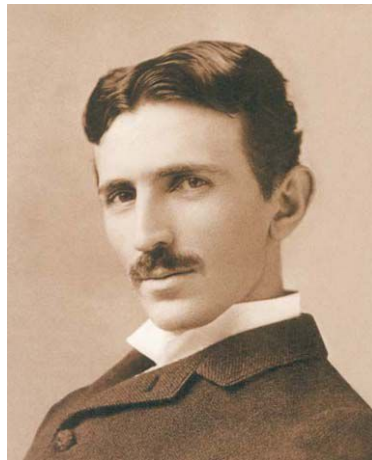
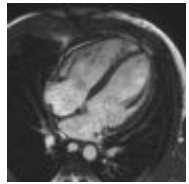
Saddle Coil

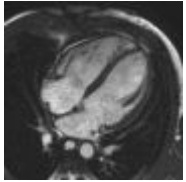


Tekercsek 3/3

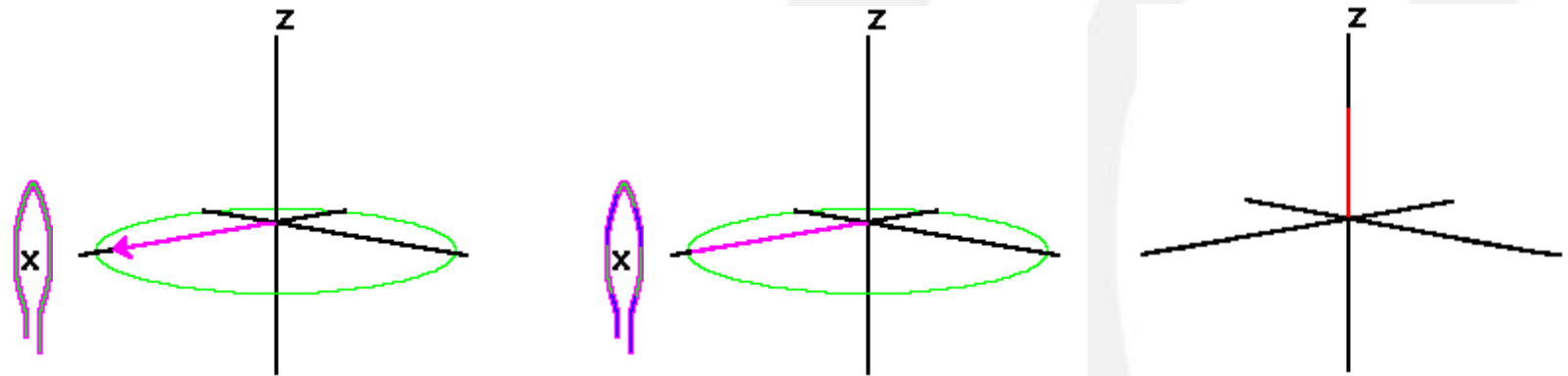


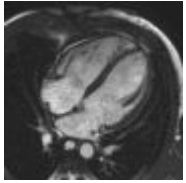
Philips Achieva 1.5T Dual Nova HP





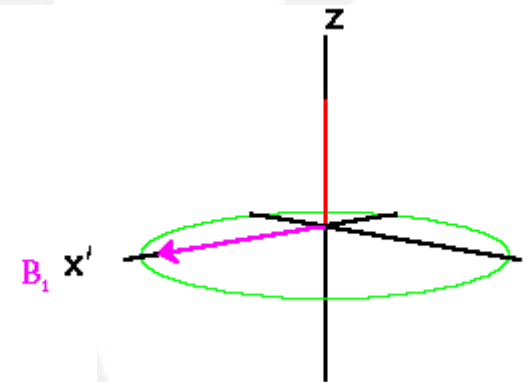
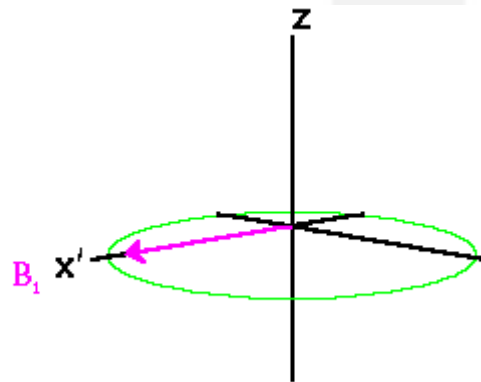
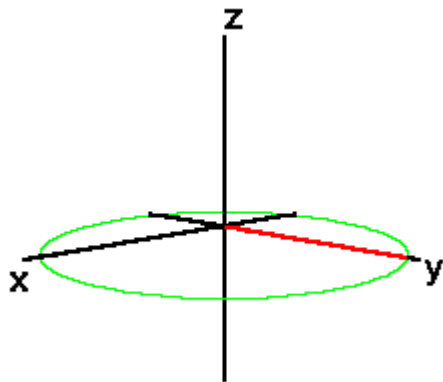
RF gerjesztés: excitáció



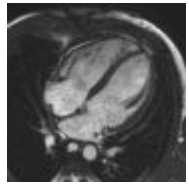


RF gerjesztés: excitáció

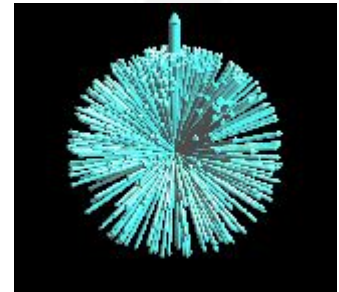
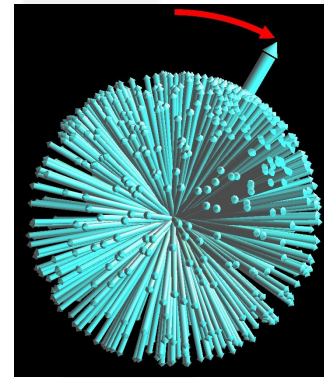
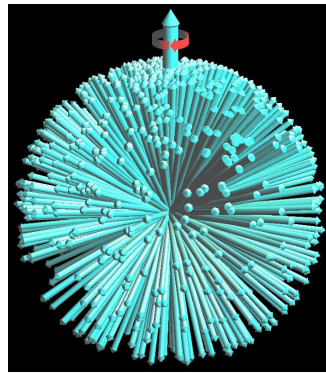
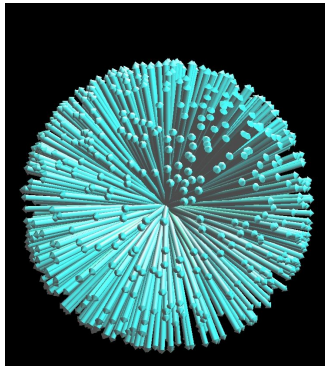
- $\theta = 2\pi \gamma \tau B_1$, ahol
 - θ : a rotációs szög, τ : pedig a gerjesztési idő

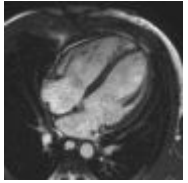


RF gerjesztés: excitáció



- Kvantummechanikailag azért nem ilyen





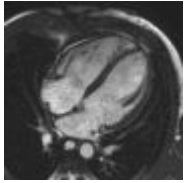
Bloch egyenletek

- Az MR-ben lejátszódó folyamatok elemi lépésenként követhetők

$$\frac{dM_{x'}}{dt} = (\omega_o - \omega)M_{y'} - \frac{M_{x'}}{T_2}$$

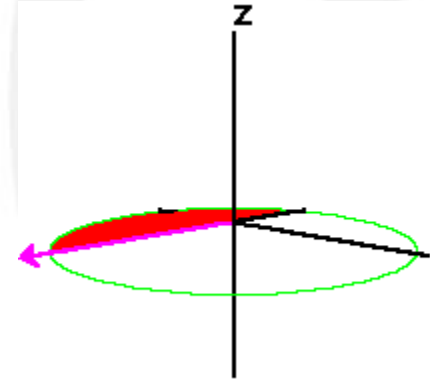
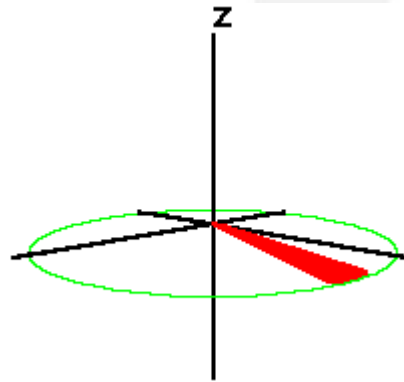
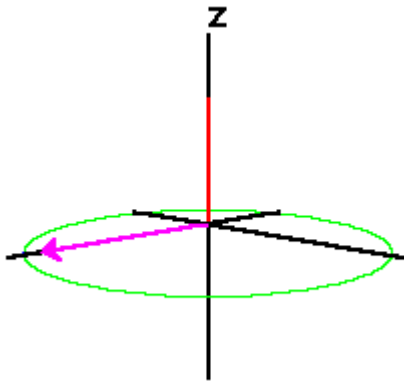
$$\frac{dM_{y'}}{dt} = -(\omega_o - \omega)M_{x'} + 2\pi\gamma B_1 M_z - \frac{M_{y'}}{T_2}$$

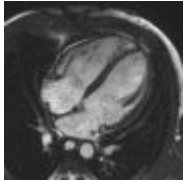
$$\frac{dM_z}{dt} = -2\pi\gamma B_1 M_{y'} - \frac{(M_z - M_{z_o})}{T_1}$$



Spin echo szekvencia

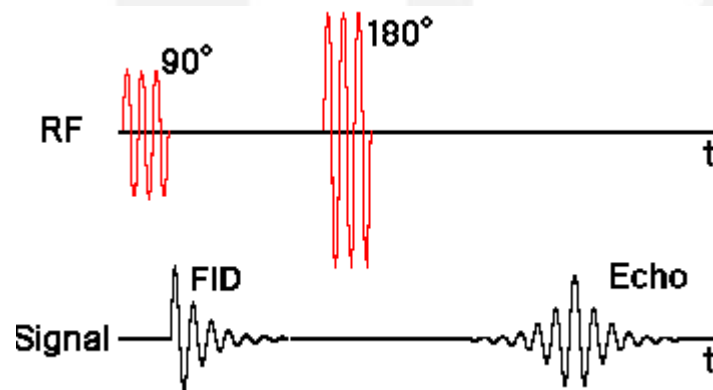
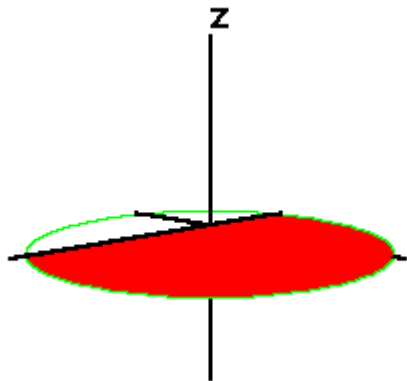
- Hahn: 1950 – Echo, Carr: 1954 – SSFP
– CPMG: Carr-Purcell-Meiboom-Gill

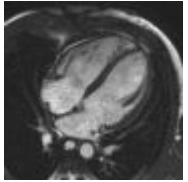




Spin echo szekvencia

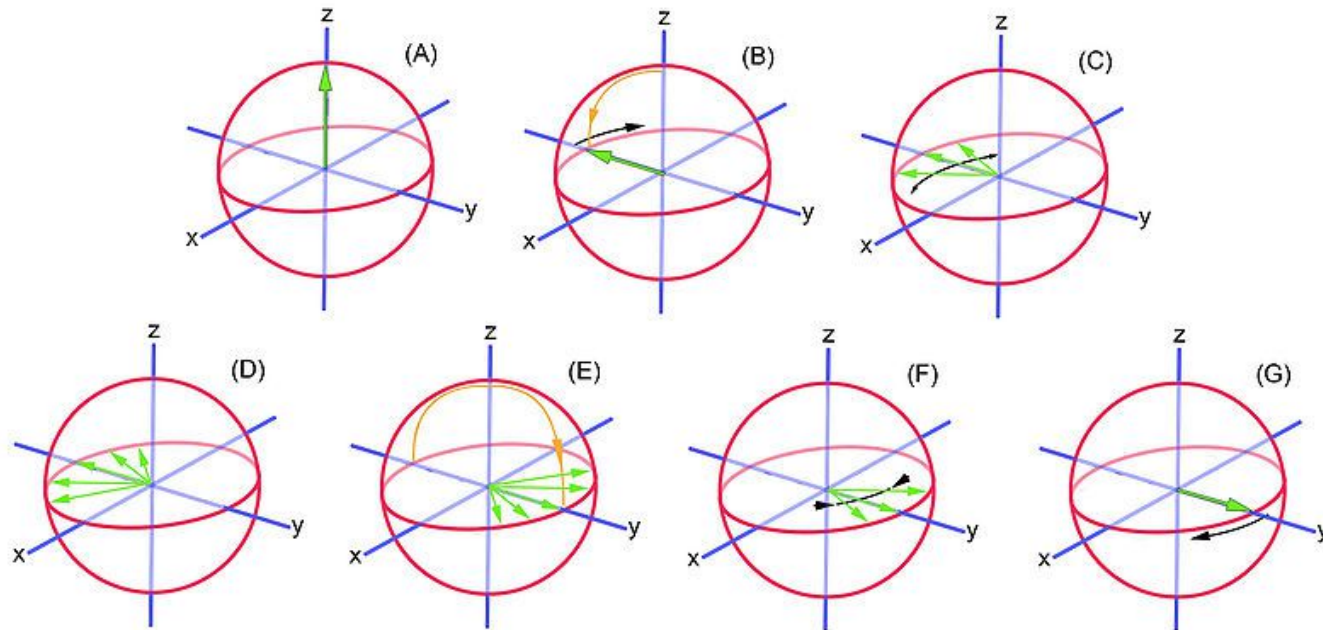
- $S = k \rho (1 - e^{-TR/T1}) e^{-TE/T2}$, ahol
 - a szignál mind a T1, mind a T2 időtől függ

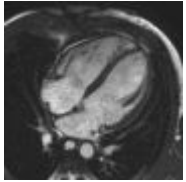




Spin echo szekvencia

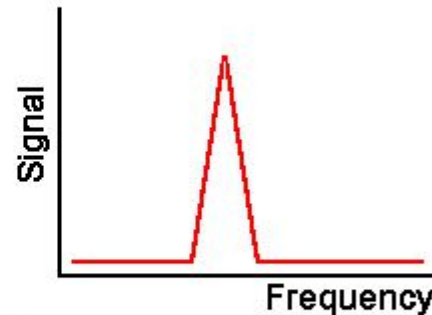
- Hahn: 1950 – Echo, Carr: 1954 – SSFP
– CPMG: Carr-Purcell-Meiboom-Gill

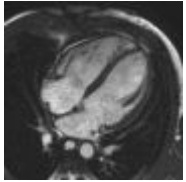




Lokalizáció

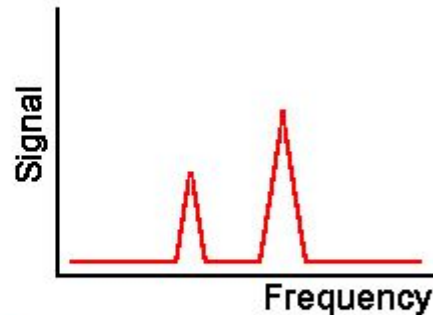
- $\nu = \gamma B_0$, ahol
 - ν : rezonancia frekvencia
 - γ : gyormágneses együttható (H: 42.6 MHz/T)

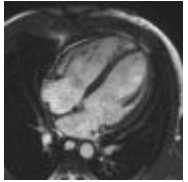




Lokalizáció

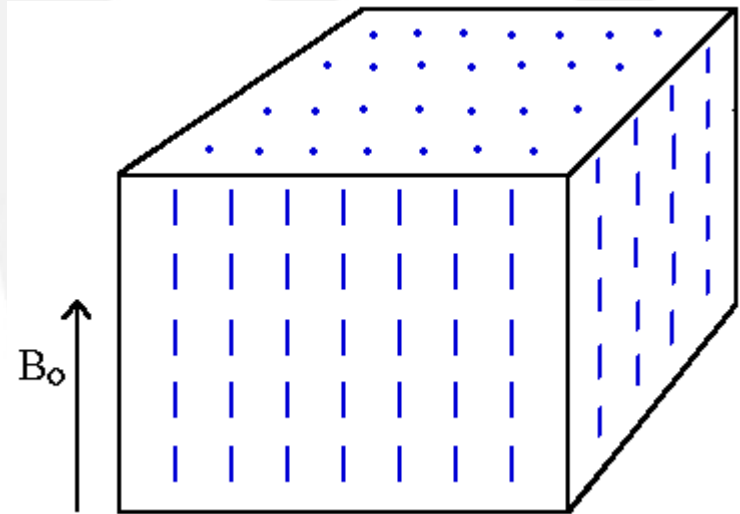
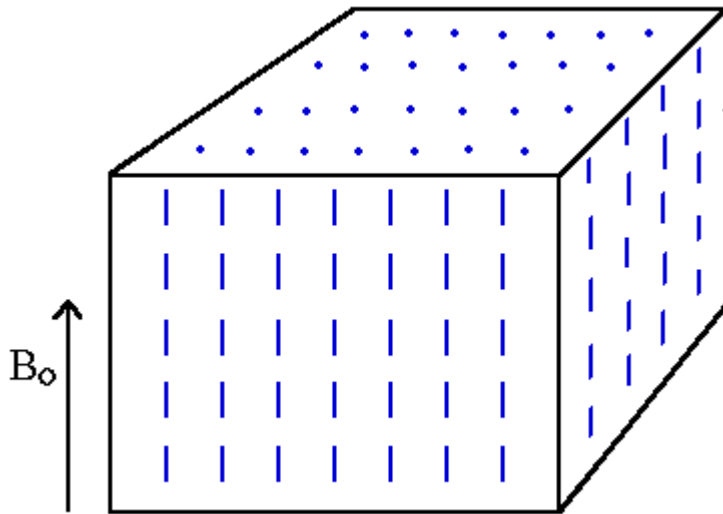
- $\nu = \gamma (B_0 + x G_x) = \nu_0 + \gamma x G_x$
 - Amiből: $x = (\nu - \nu_0) / (\gamma G_x)$



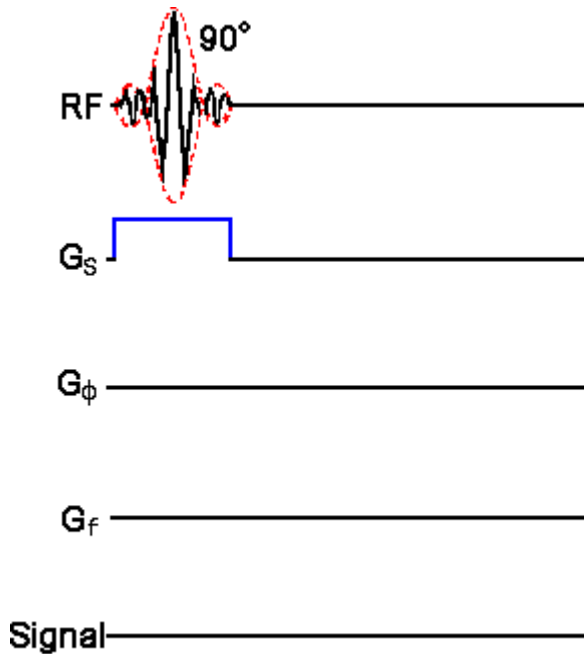
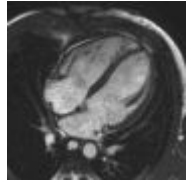


Szelet kiválasztás

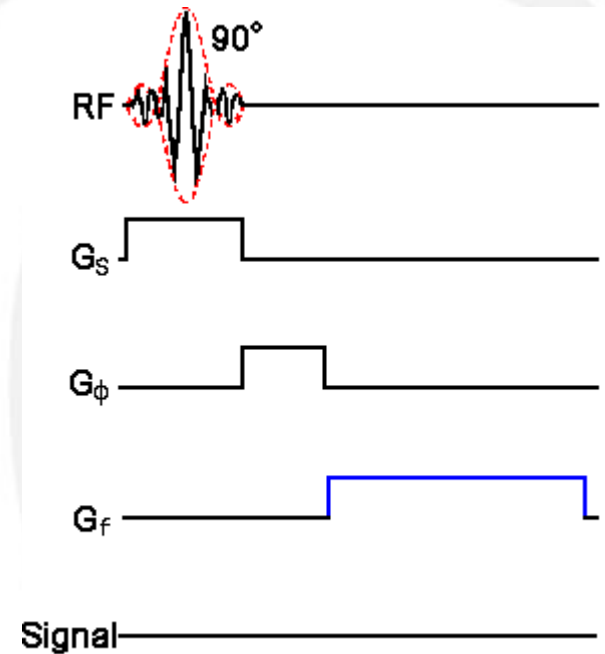
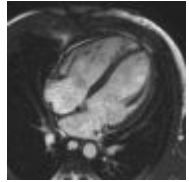
- $v = \gamma (B_0 + x G_x) = v_0 + \gamma x G_x$
 - Amiből: $x = (v - v_0) / (\gamma G_x)$



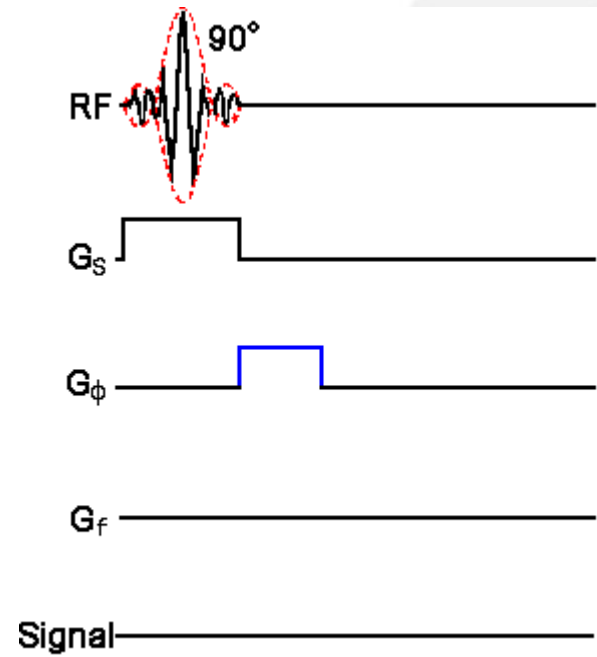
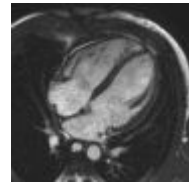
Szekvencia: szeletkiválasztás

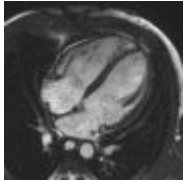


Szekvencia: frekvencia kódolás

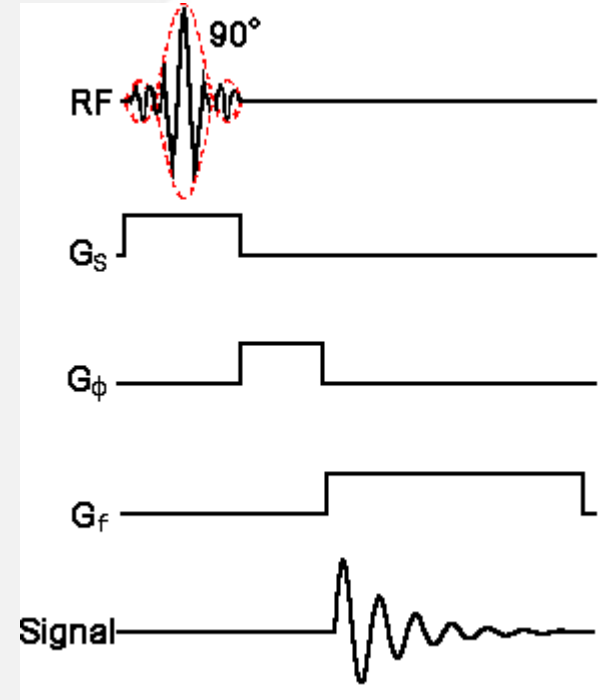
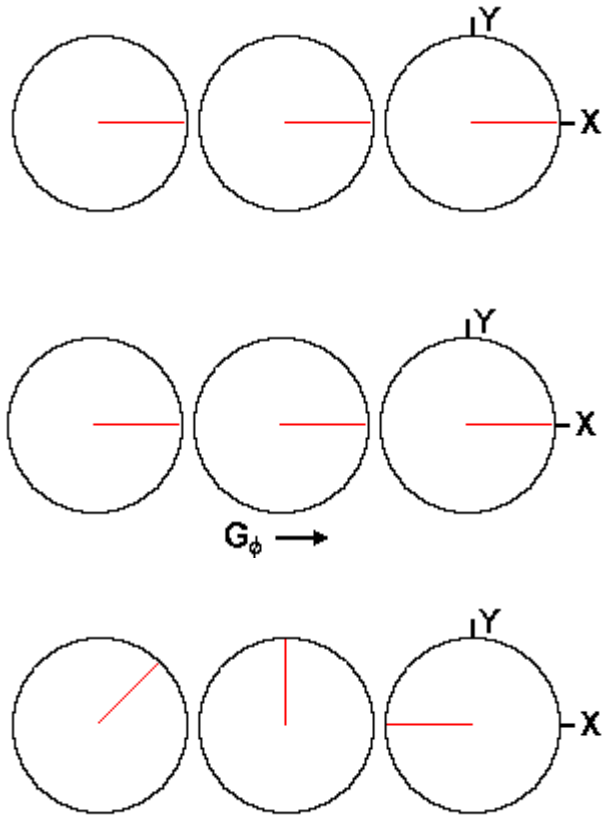


Szekvencia: fázis kódolás

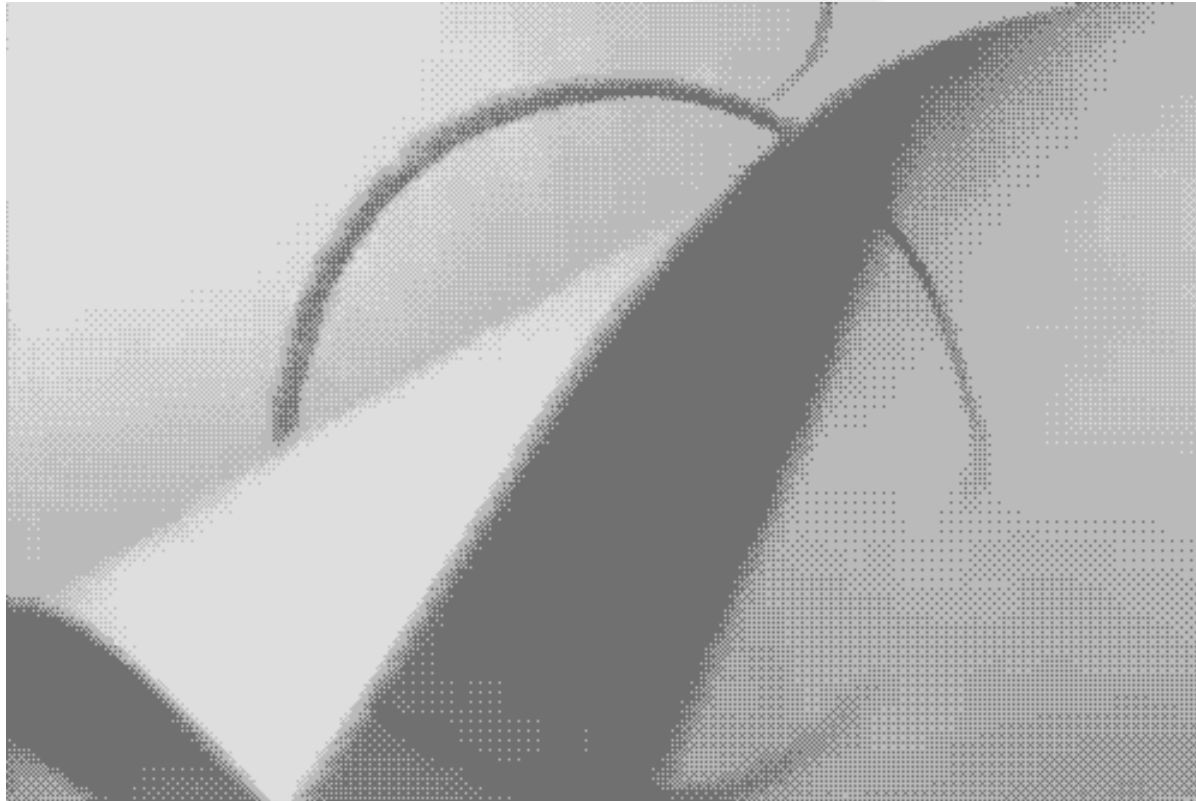
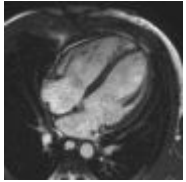


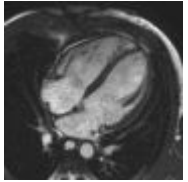


Szekvencia: fázis kódolás

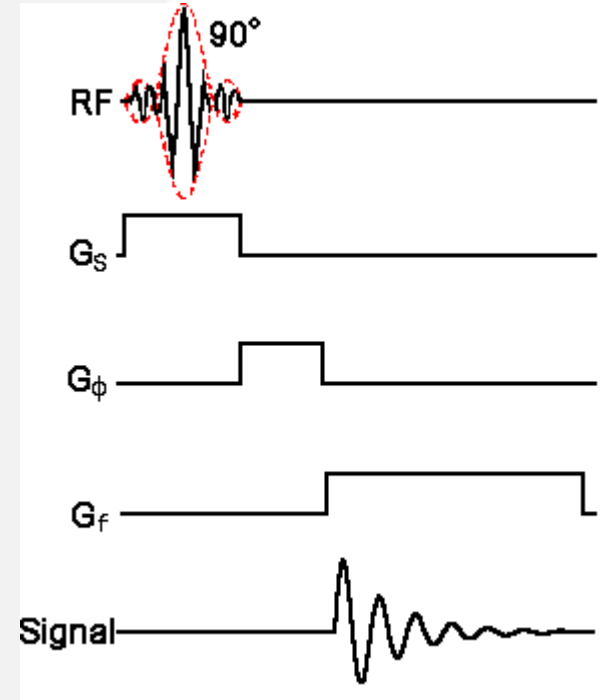
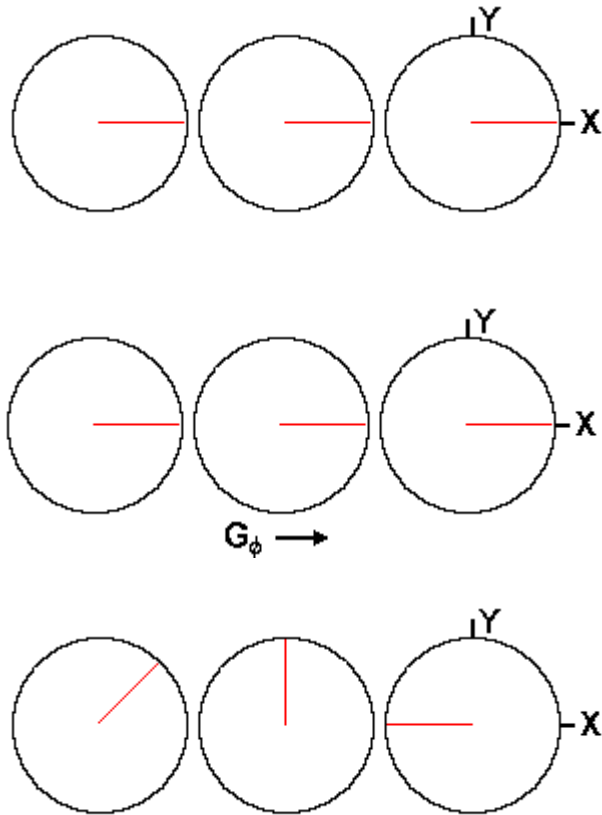


Fázisváltás üteme = frekvencia!

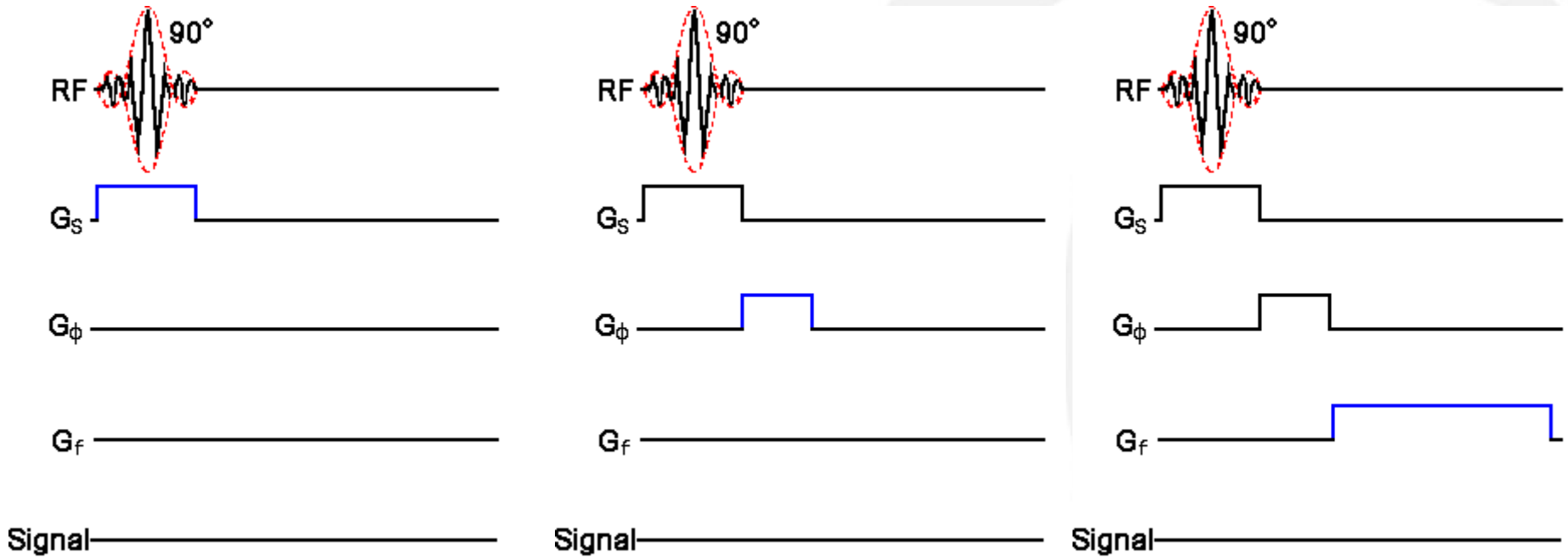
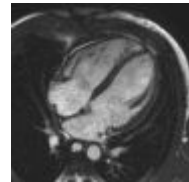




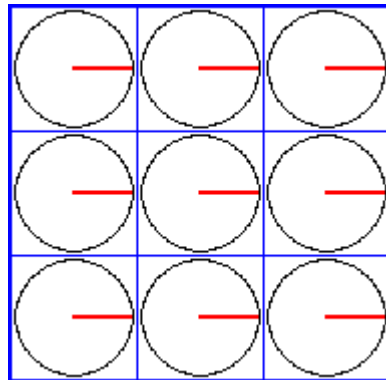
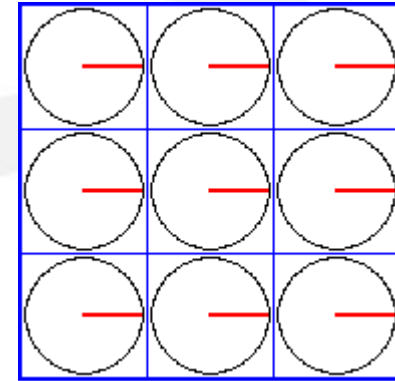
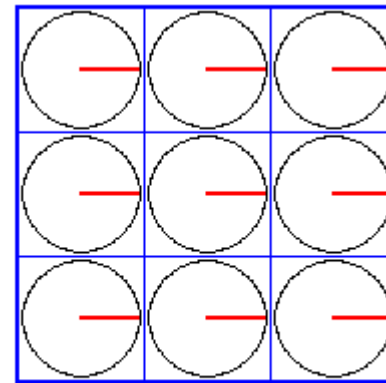
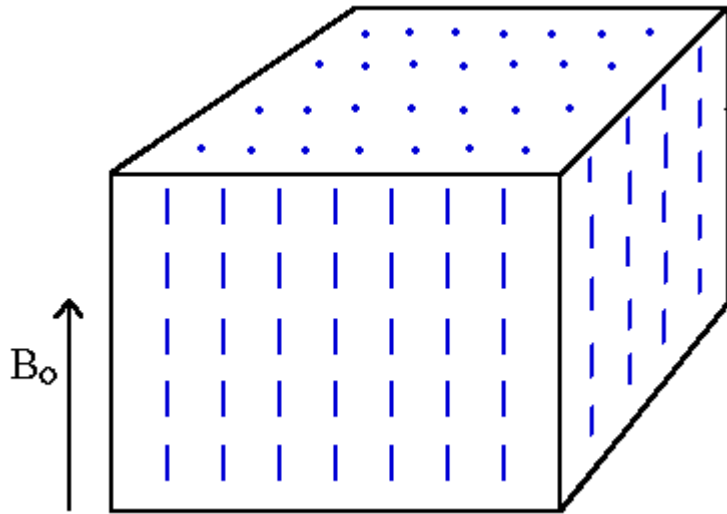
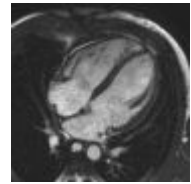
Fázisváltás üteme = frekvencia!



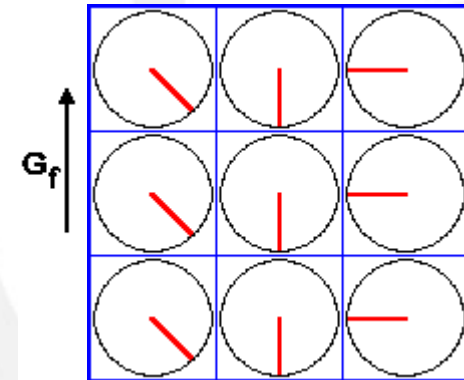
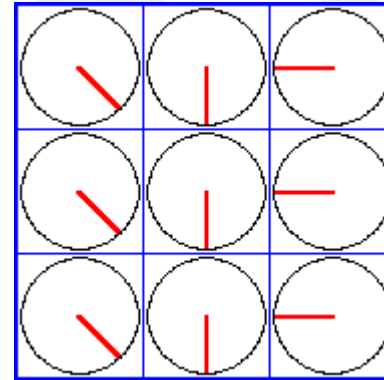
Szekvencia

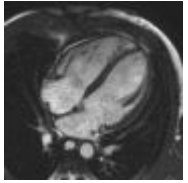


Szekvencia



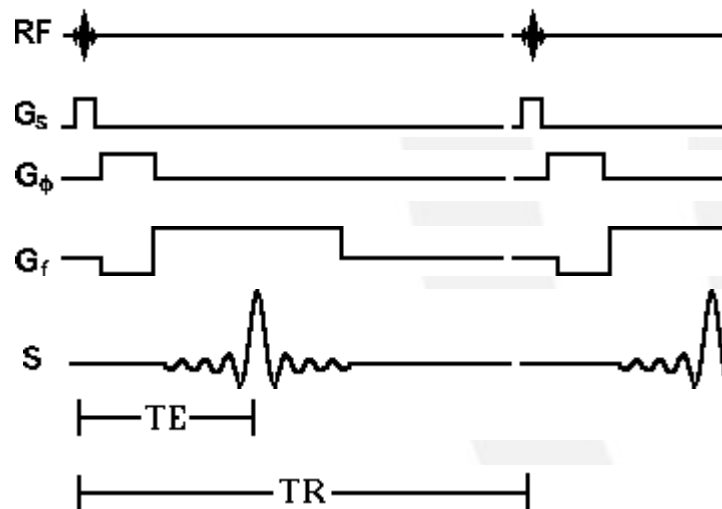
G_ϕ



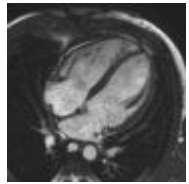


2D gradiens echo szekvencia

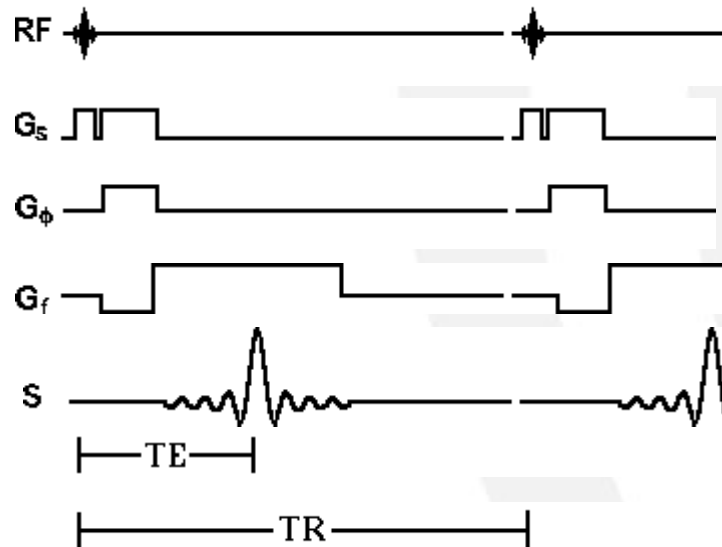
- $S = k \rho (1 - e^{-TR/T1}) e^{-TE/T2^*}$, ahol
 - a szignál mind a T1, mind a T2* időtől függ



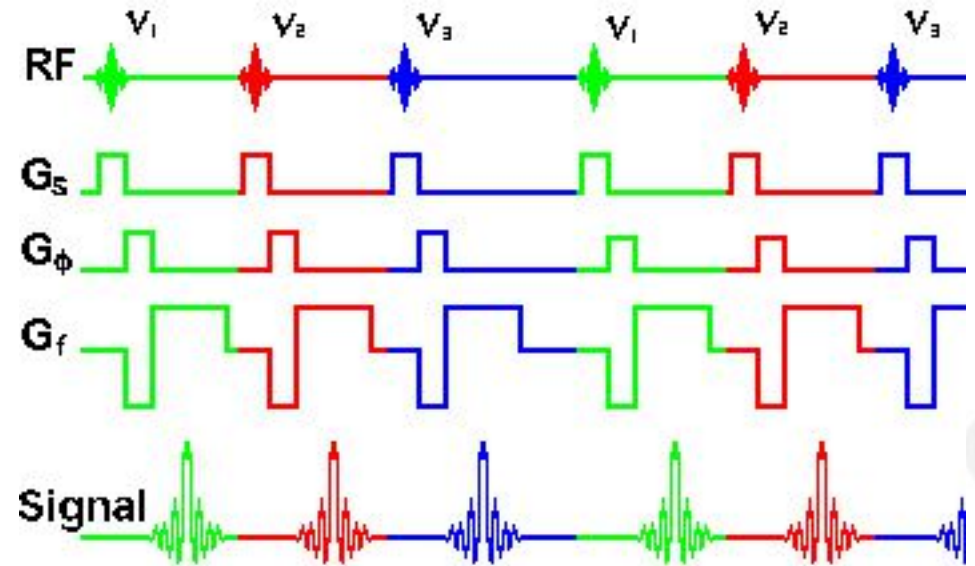
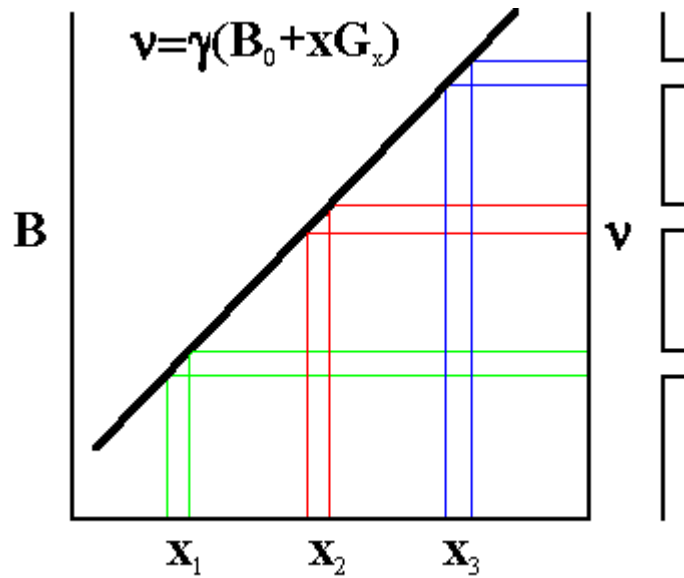
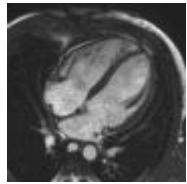
3D gradiens echo szekvencia



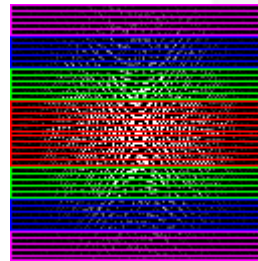
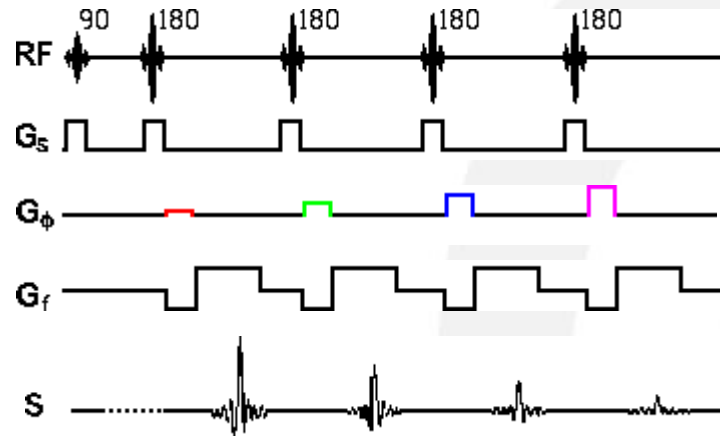
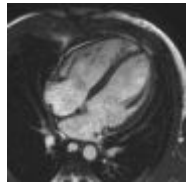
- Z irányban is fáziskódolás
 - Idő: TR Ny Nz



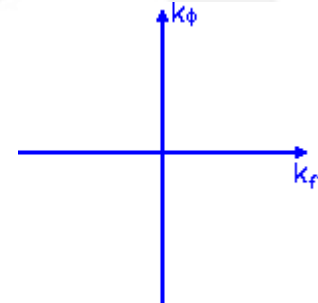
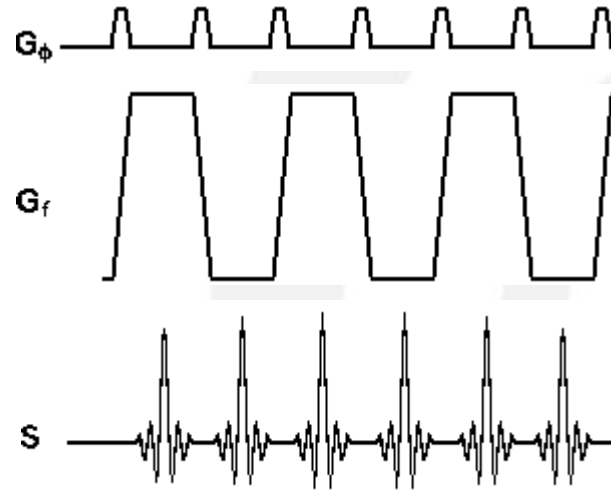
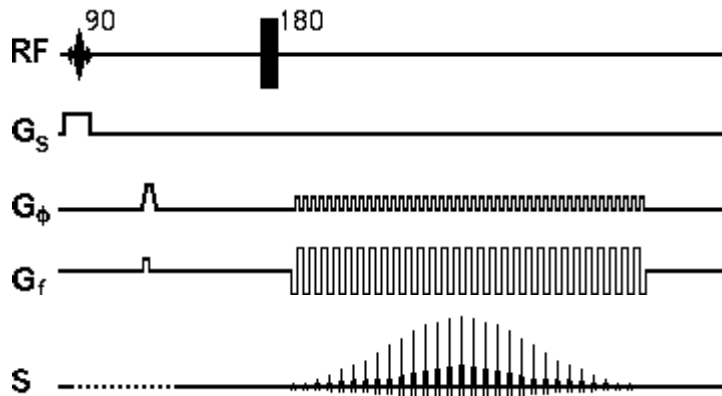
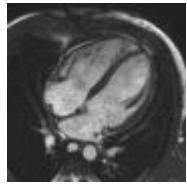
Többszeletes képképzés



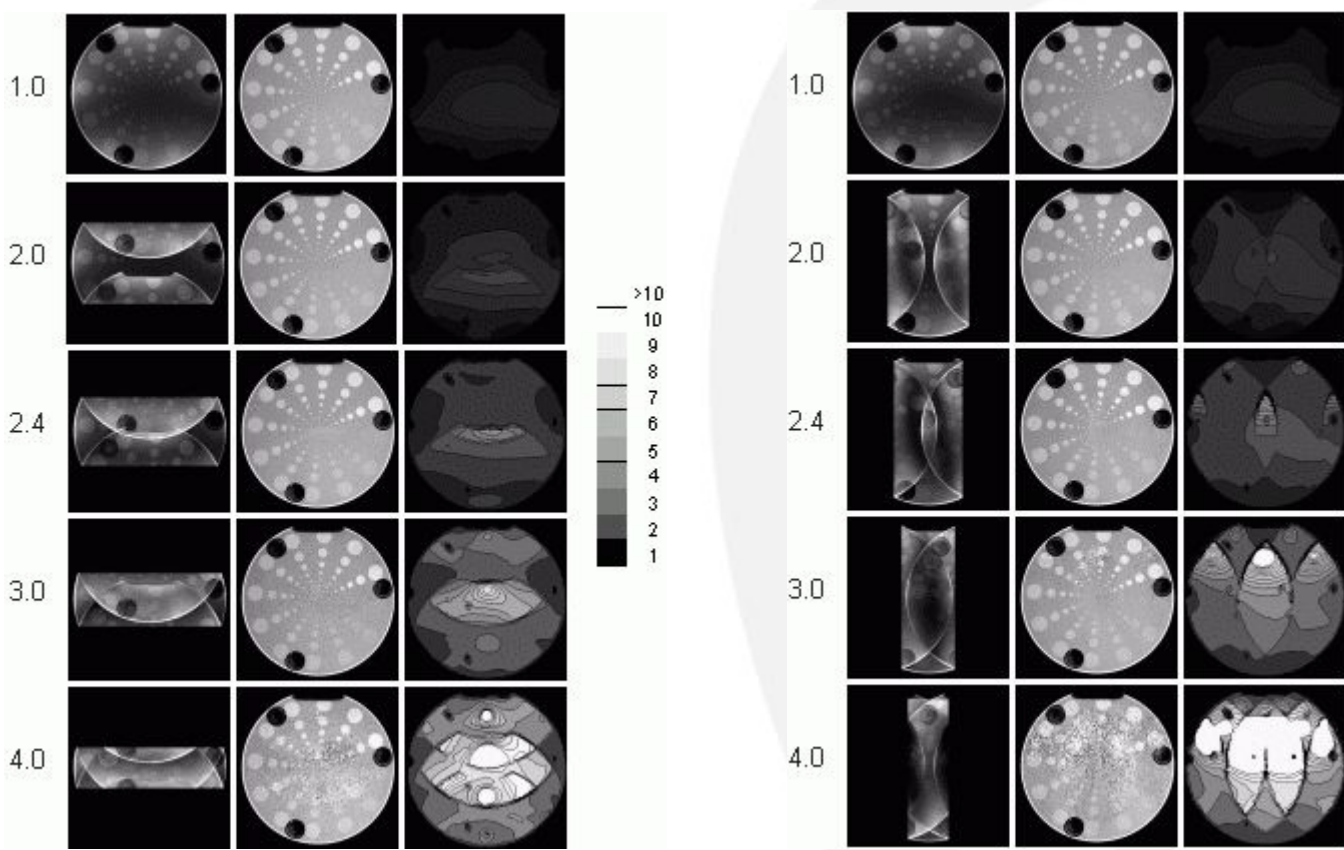
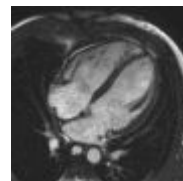
Fast spin echo – CPMG



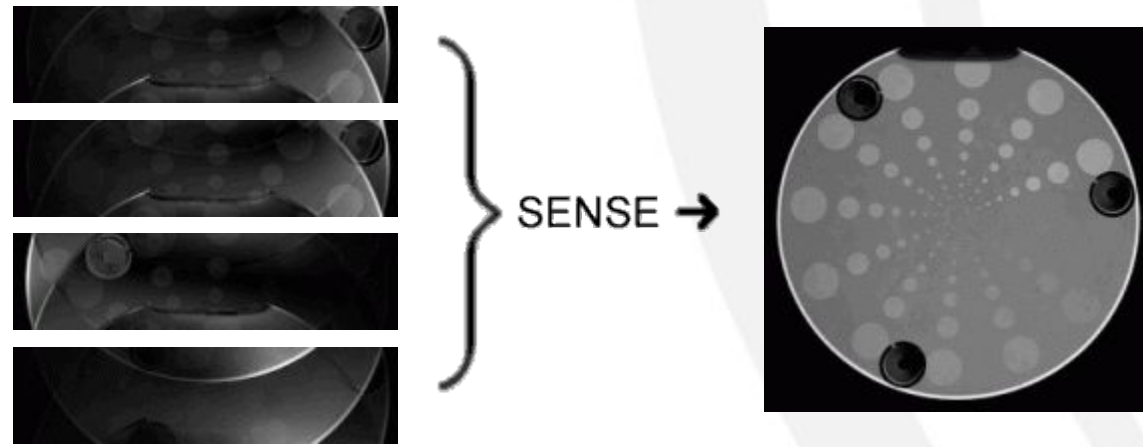
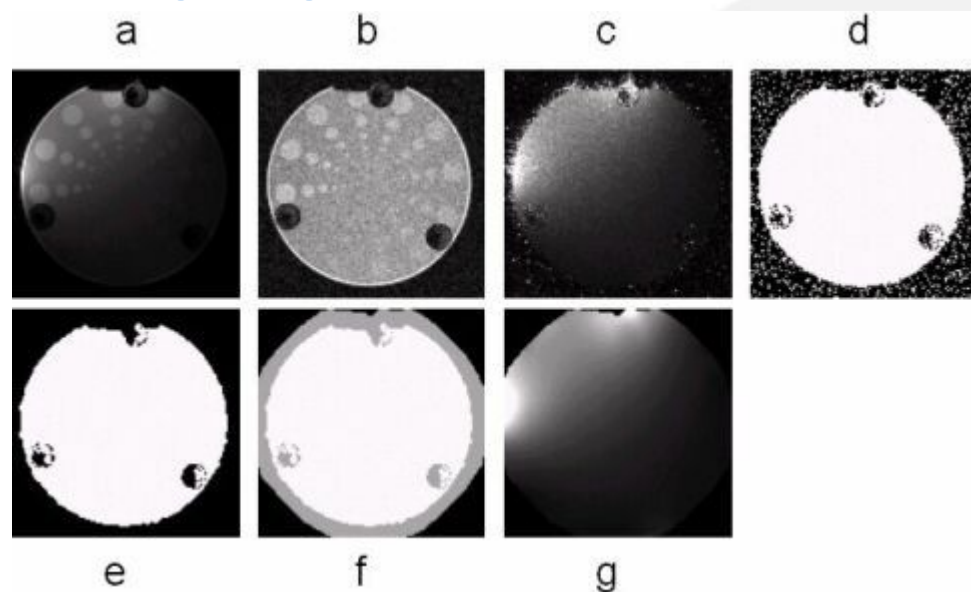
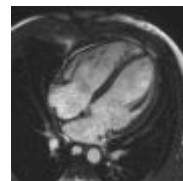
Echo-planar imaging (EPI)

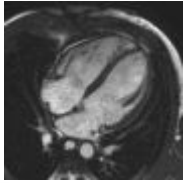


Parallel imaging: SENSE



Parallel imaging: SENSE





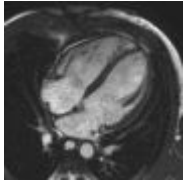
Fast gradient echo: band-ek

- T1 – súlyozott
 - Spoiling
 - RF (és/vagy grádiens)
- Kevert kontraszt
 - Sima: T1w és T2w
 - Fordított: T1w < T2w
 - T2/T1: balanced SSFP
 - Kiegyensúlyozott grádiensek
 - Alternáló RF gerjesztés

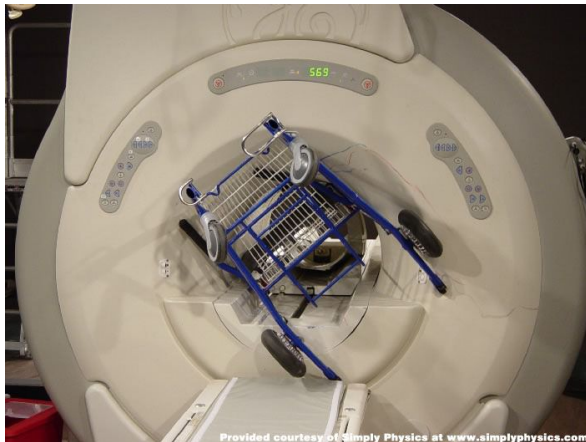
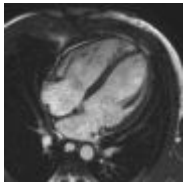
CT: forog – MR: nem forog



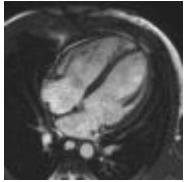
Biztonság 1/4



Biztonság 2/4



Biztonság 3/4



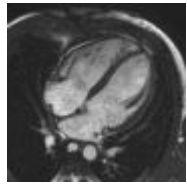
MR: oxigén palack – muriból



MR: szék eltávolítása – csörlő+



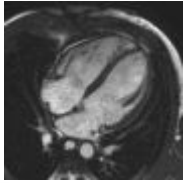
Biztonság 4/4



MRI-SIDE-EFFECTS.COM

Nationwide NSF Lawsuits ~ Call Toll Free 1-800-883-9858



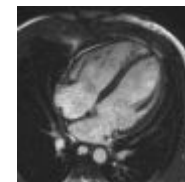


A mi MR-ünk

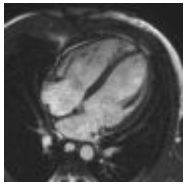
- Philips Achieva 1.5T
- Grádiens: Dual Nova HP (33/66, 180/90)
- Software: R2.6.3p4
 - Cardiac Specialist Pro
 - Coronary Specialist Pro
 - Neuro Specialist
- Szekvencia programozás: PARADISE (C)
- Posztprocesszing fejlesztés: PRIDE (IDL)



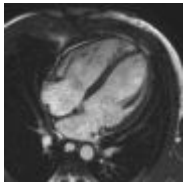
Mi MR-ünk



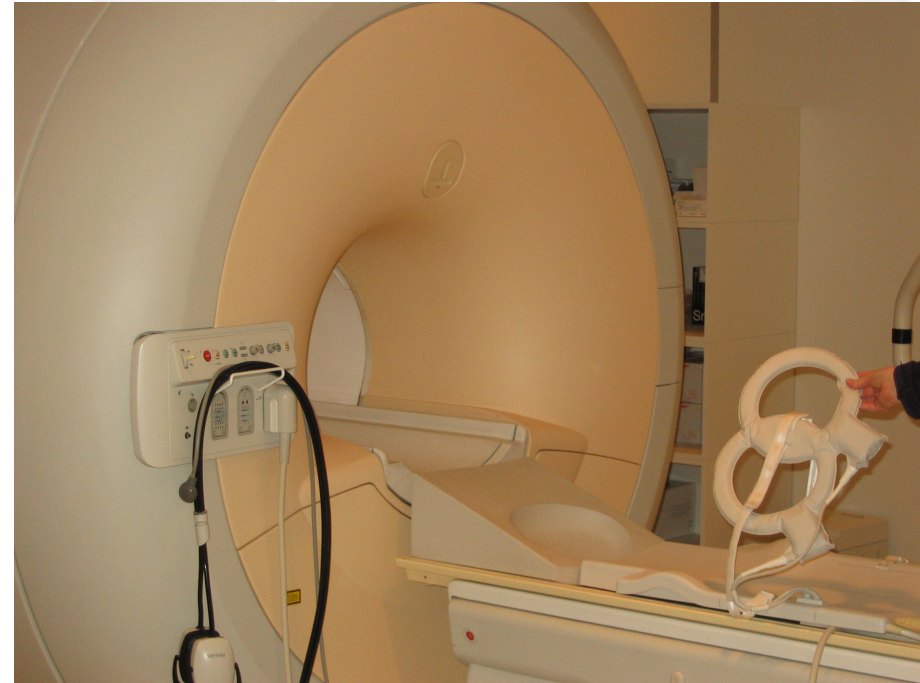
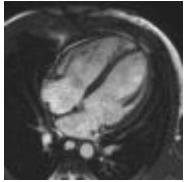
Mi MR-ünk



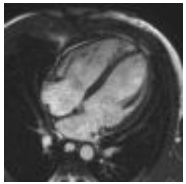
Mi MR-ünk



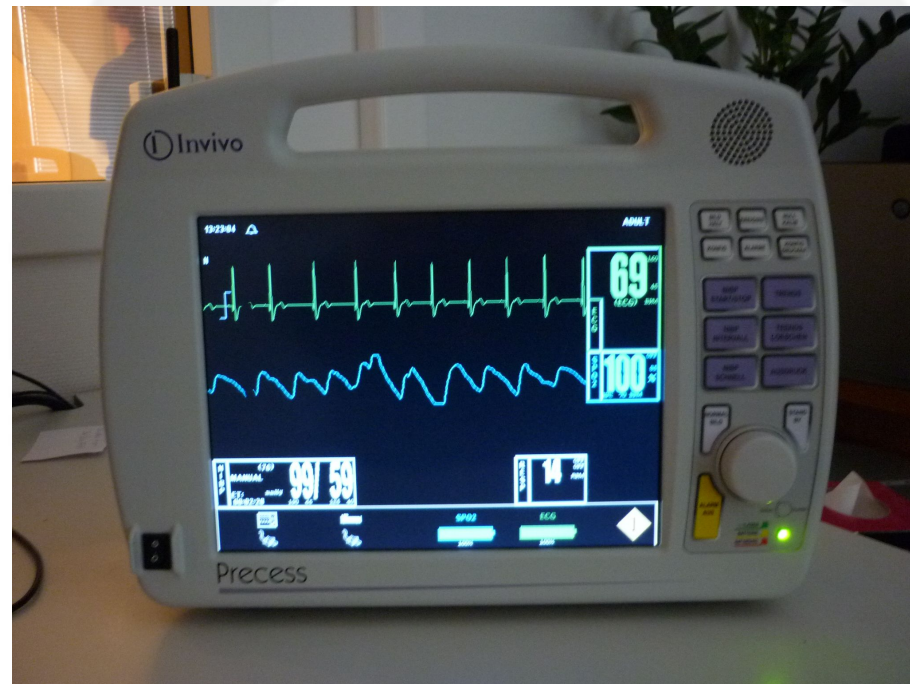
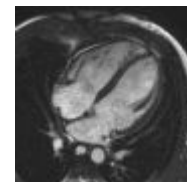
Mi MR-ünk



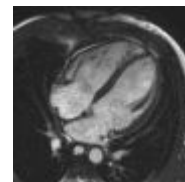
Mi MR-ünk



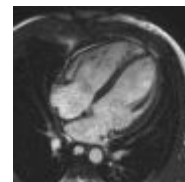
Mi MR-ünk



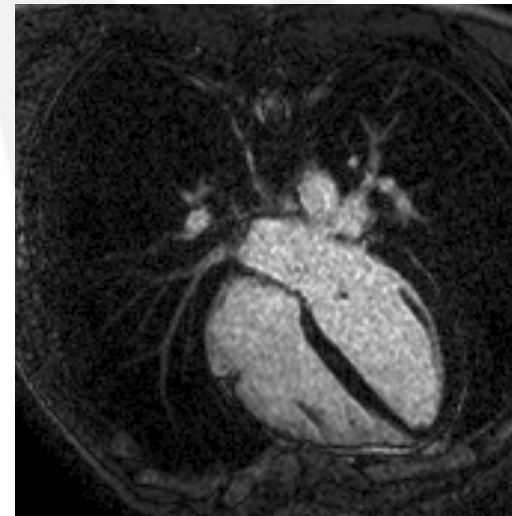
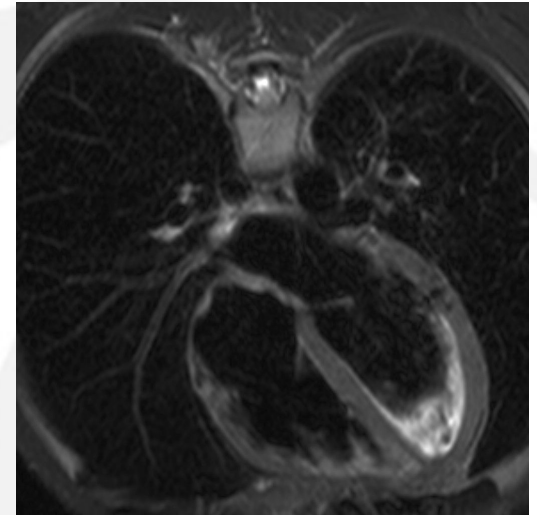
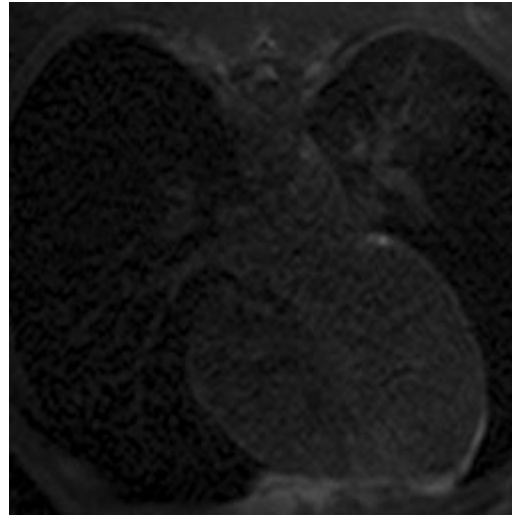
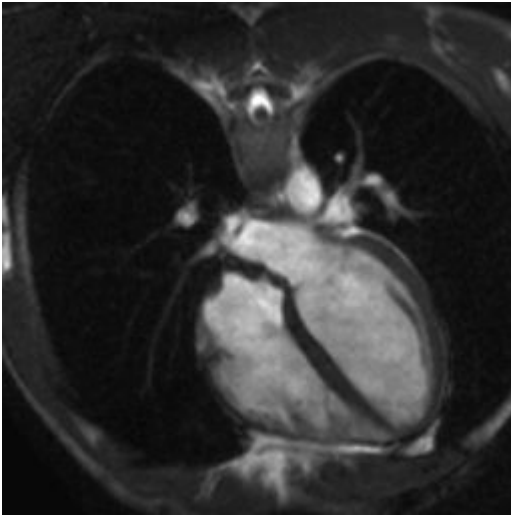
Mi MR-ünk



Mi MR-ünk



Spartathlonista



LVESVi 34, RVEF 51/55 RVEDVi 160/140

QMass MR 7.2

File Edit View Analysis Settings Tools Help

Study Matrix: Phases (25)

	ALL	1	2	3	4	5	6	7	8	9	ES	11	12	13	14	15	16	17	18	19	20	21	22	23	ED	25
15																										
14																										
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4																										
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2																										
1																										

Slices (15)

Active View

Scan Lines

S101 S301 S401 S501 S701 S801 S901 S1001 S1101 S1201 S1301 S1401 S1501 S1601

L 28,4, A 85,2, S, 72,5, Gray value=1

Start 1.D.J Naggy - Run, Zom... RDO Atoth - Belépés - M... QMass MR 7.2 mc [atoth@atoth].../vsave 18:57

LVESVi 34, RVEF 51/55 RVEDVi 160/140

QMass MR 7.2

File Edit View Analysis Settings Tools Help

Study Matrix: Phases (25)

ALL	1	2	3	4	5	6	7	8	9	ES	11	12	13	14	15	16	17	18	19	20	21	22	23	ED	25
15																									
14																									
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8																									
7																									
6																									
5																									
4																									
3																									
2																									
1																									

Slices (15)

3D Viewer (S801)

Basal

Post

Ant

Apical

Named Settings: Default

Movie Type: Phases

Movie Reload Print Preview Print Settings Close

L 24,5, A 84,5, S, 54,3, Gray value=0

Start 1.DJ Naggy - Run, Zom... RDO Atoth - Belépés - M... QMass MR 7.2 mic [atoth@atoth].../vsave 18:59

LVESVi 34, RVEF 51/55 RVEDVi 160/140

QMass MR 7.2

File Edit View Analysis Settings Tools Help

Study Matrix: Phases (25)

	ALL	1	2	3	4	5	6	7	8	9	ES	11	12	13	14	15	16	17	18	19	20	21	22	23	ED	25
15																										
14																										
13																										
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7																										
6																										
5																										
4																										
3																										
2																										
1																										

Slices (15)

Active View

Scan Lines

S101 S301 S401 S501 S701 S801 S901 S1001 S1101 S1201 S1301 S1401 S1501 S1601

L 37,7, A 68,7, S, 95,9, Gray value=4

Start 1.D.J Naggy - Run, Zom... RDO Atoth - Belépés - M... QMass MR 7.2 mc [atoth@atoth].../vsave 18:54

LVESVi 34, RVEF 51/55 RVEDVi 160/140

QMass MR 7.2

File Edit View Analysis Settings Tools Help

Study Matrix:

ALL	1	2	3	4	5	6	7	8	9	ES	11	12	13	14	15	16	17	18	19	20	21	22	23	ED	25
15																									
14																									
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7																									
6																									
5																									
4																									
3																									
2																									
1																									

Phases (25)

Active View

Scan Lines

3D Viewer (S801)

Basal

Sept

Lat

Apical

Named Settings: Default

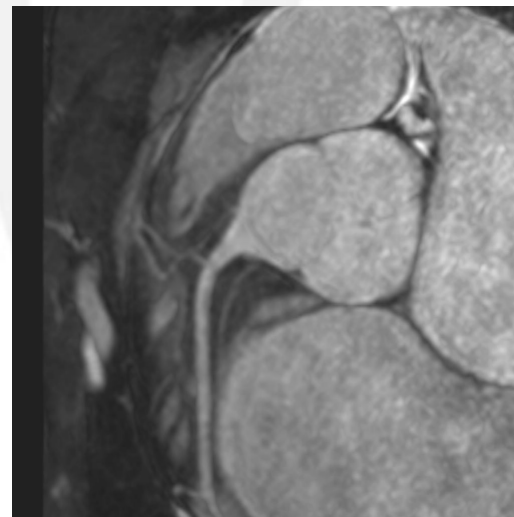
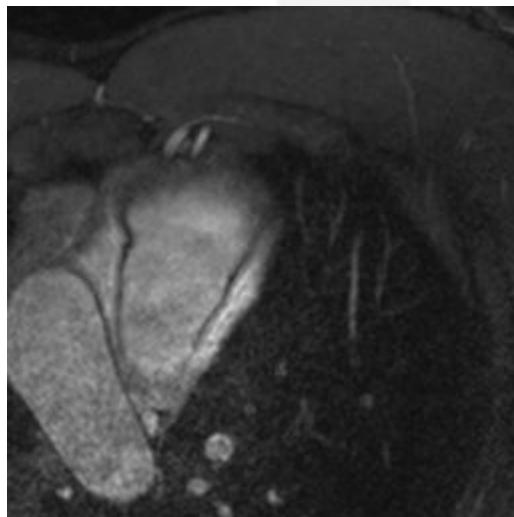
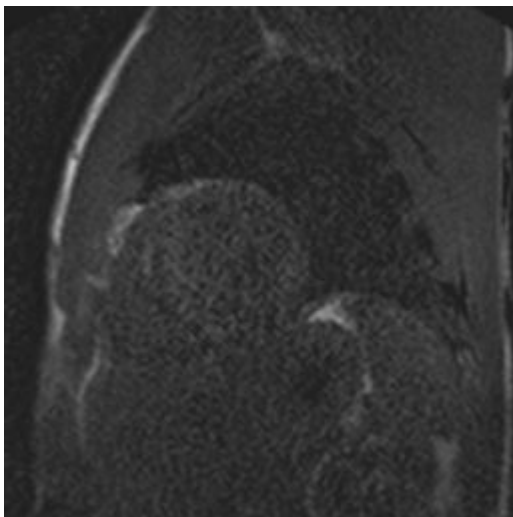
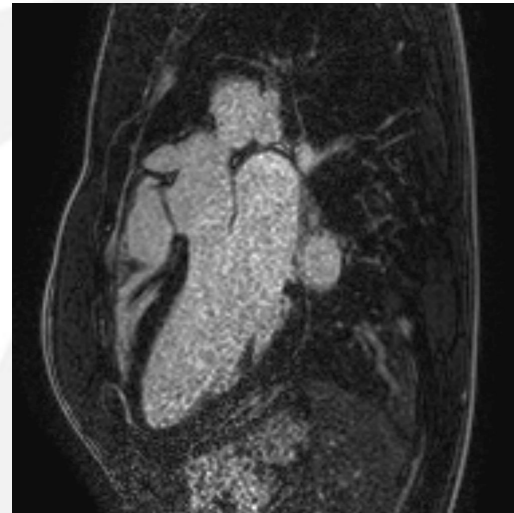
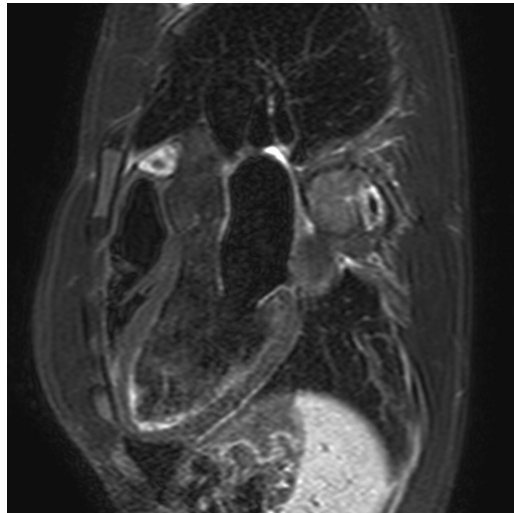
Movie Type: Phases

Movie Reload Print Preview Print Settings Close

L 17,2, A 83,3, S, 20,8, Gray value=1

Windows taskbar: Start, 1..DJ Naggy - Run, Zom..., RDO Atoth - Belépés - M..., QMass MR 7.2, mic [atoth@stoth].../vsave, 18:57

Mérések: férfi kajakos



Navigátor

PHILIPS

Patient System Help 19:11

1968 07 13 M
SURVEY_BFFE FOV 450
2009 11 12,18:12 Slice 16/20

Planscan

Geometry: Navigator A

Delete Copy

Volume Stack Slab

All midplanes 3PPS

System Ready 20

HC Screen HC Case
Compose Compose

Scan: 1

More... All

View Window RAL

VCG+Resp 5 s 63

3D_BTFE_BH

Remaining scan time: 00:00:59

56%

Autoview... Start Scan Stop Scan

Sc 18
B-TFE/M
SI 2
Td 800ms

Sc 1
B-TFE/M
SI 16

Sc 1
B-TFE/M
SI 4

HAJNI VIAB II(2) 00:03:45

Sequence	View	Plane
9,1	SA_movie	SA(1)
10,1	LL F8 TD150	LA(1)
SA_VIA-3D	SA(1)	
11,1	SA_VIA-3D	SA(1)
12,1	LA_LE_IR	LA(1)
13,1	LA_LE_IR	LA
14,1	SA_LE_IR	SA
15,1	IRTFE_3D_NA...	SA
16,1	BTFE_FB_50	4CH
17,1	3D_BTFE_WH	WH
18,1	BTFE_FB_50	LA
3D_BTFE_BH	CORON	
3D_BTFE_BH	CORON	

Parameter	Value	Unit
Coil selection	SENSE-Cardiac	
element selection	12345	
connection	d	
Dualcoil	no	
CLEAR	yes	
FOV FH (mm)	250	
AP (mm)	200	
RL (mm)	25	
Voxel size FH (mm)	1.1	
AP (mm)	1.1	
RL (mm)	1.1	
Recon voxel size (mm)	0.5	
Slice oversampling	default	
Reconstruction matrix	512	
SENSE	no	
k-tBLAST	no	
Overcontiguous slices	no	
Stacks	1	
slices	23	
slice orientation	sagittal (coronal)	
fold-over direction	AP (RL)	

Parameter	Value
Total scan duration	02:45.7
Ret. signal level (%)	100
Act. TR/TE (ms)	4.9 / 2.4
ACQ matrix M x P	228 x 182
ACQ voxel MPS (mm)	1.10 / 1.11 / 1.10
REC voxel MPS (mm)	0.49 / 0.49 / 1.10
Scan percentage (%)	98.9
TFE shots	172
TFE dur. shot / acq (ms)	270.9 / 112.5
TFE shot interval (beats)	1
Entered heartrate	63
Trigger delay max. / act...	904.8 / 630.0
Max. heart phases	1
Act. WFS (pix) / BW (Hz)	0.223 / 974.7
Min. WFS (pix) / Max. B...	0.222 / 980.4
SAR / whole body	< 32% / 1.3 W/kg
Whole body / level	< 1.3 W/kg / normal
B1rms [uT]	2.6
PNS / level	59% / normal
Sound Pressure Level (...)	14.5

3D_BTFE_BH

3D Balanced TFE coronary scan

Navigator Display

3D_BTFE_BH

Leading navigator, beam 1

artery and the
en the arteries
asure the precise

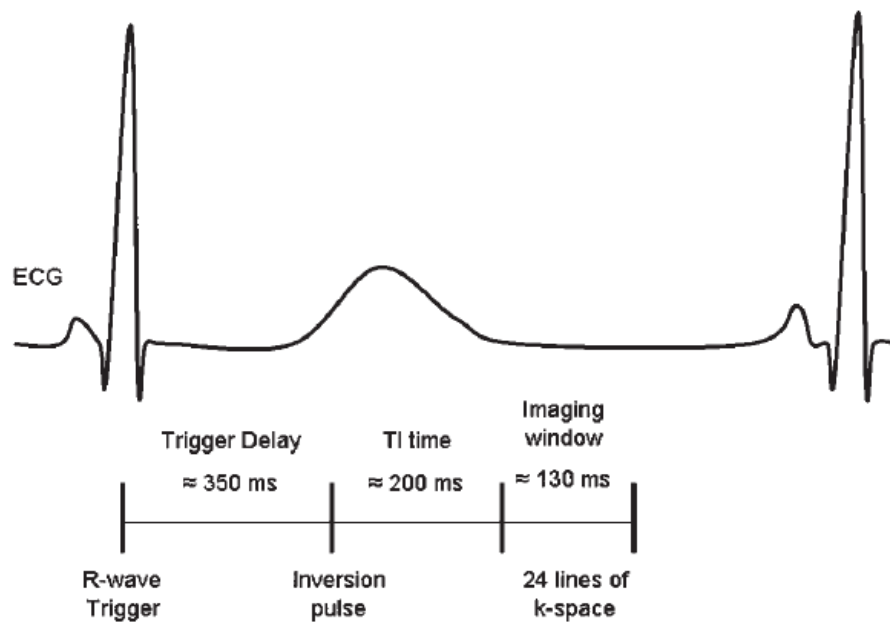
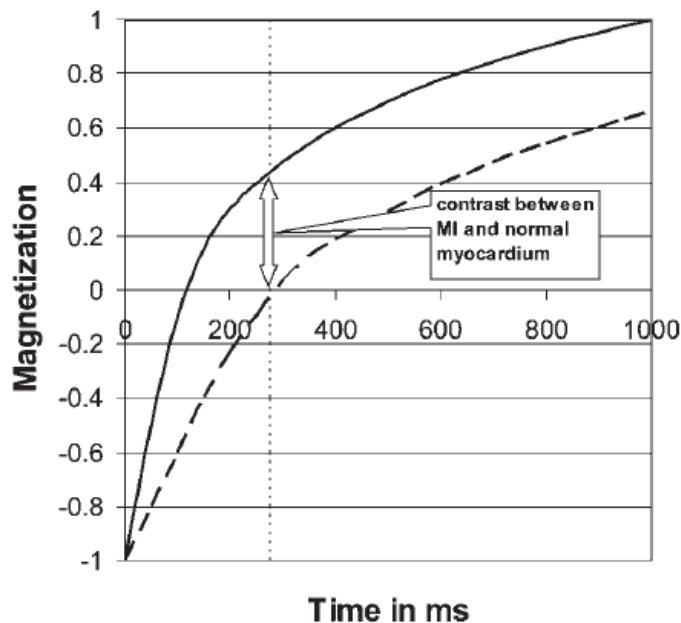
Save Hide

19:11 Gating efficiency is 57% over the last 60s.

RadioGraphics 26:795 (2006)

796 May-June 2006

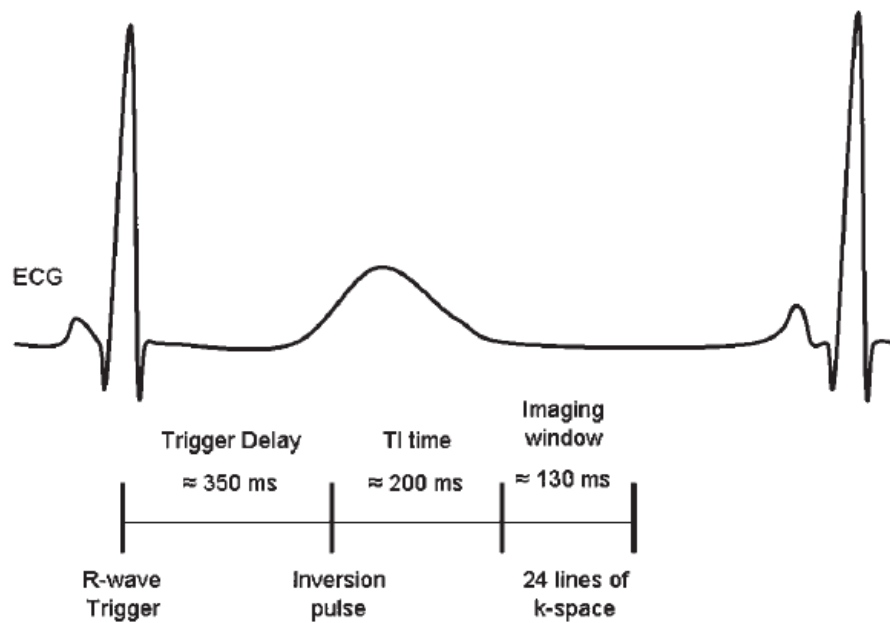
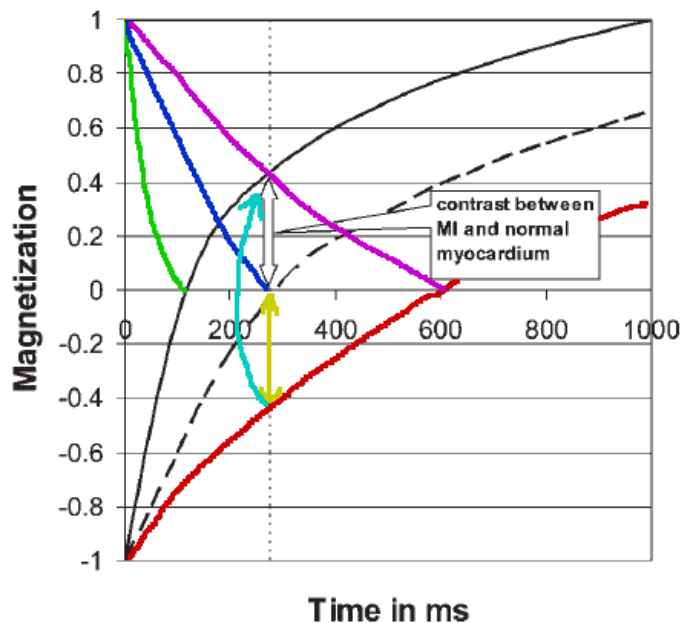
RG ■ Volume 26 • Number 3



a.

b.

Figure 1. (a) Relaxation of myocardium with delayed enhancement and normal myocardium. Optimal image contrast between myocardial areas of delayed enhancement (solid line) and normal myocardium (dashed line) is achieved by imaging at the null point of normal myocardium and adjusting the inversion time for each patient (3). In this example, the inversion time (dotted line) is 275 msec. *MI* = myocardial infarction. (b) Diagram of a delayed myocardial contrast-enhanced MR imaging sequence. The image acquisition starts after or around the center of the individually selected inversion time (*TI*), depending on the vendor. *ECG* = electrocardiogram.



a.

b.

Figure 1. (a) Relaxation of myocardium with delayed enhancement and normal myocardium. Optimal image contrast between myocardial areas of delayed enhancement (solid line) and normal myocardium (dashed line) is achieved by imaging at the null point of normal myocardium and adjusting the inversion time for each patient (3). In this example, the inversion time (dotted line) is 275 msec. *MI* = myocardial infarction. (b) Diagram of a delayed myocardial contrast-enhanced MR imaging sequence. The image acquisition starts after or around the center of the individually selected inversion time (*TI*), depending on the vendor. *ECG* = electrocardiogram.

Magn Reson Med 47:372 (2002)

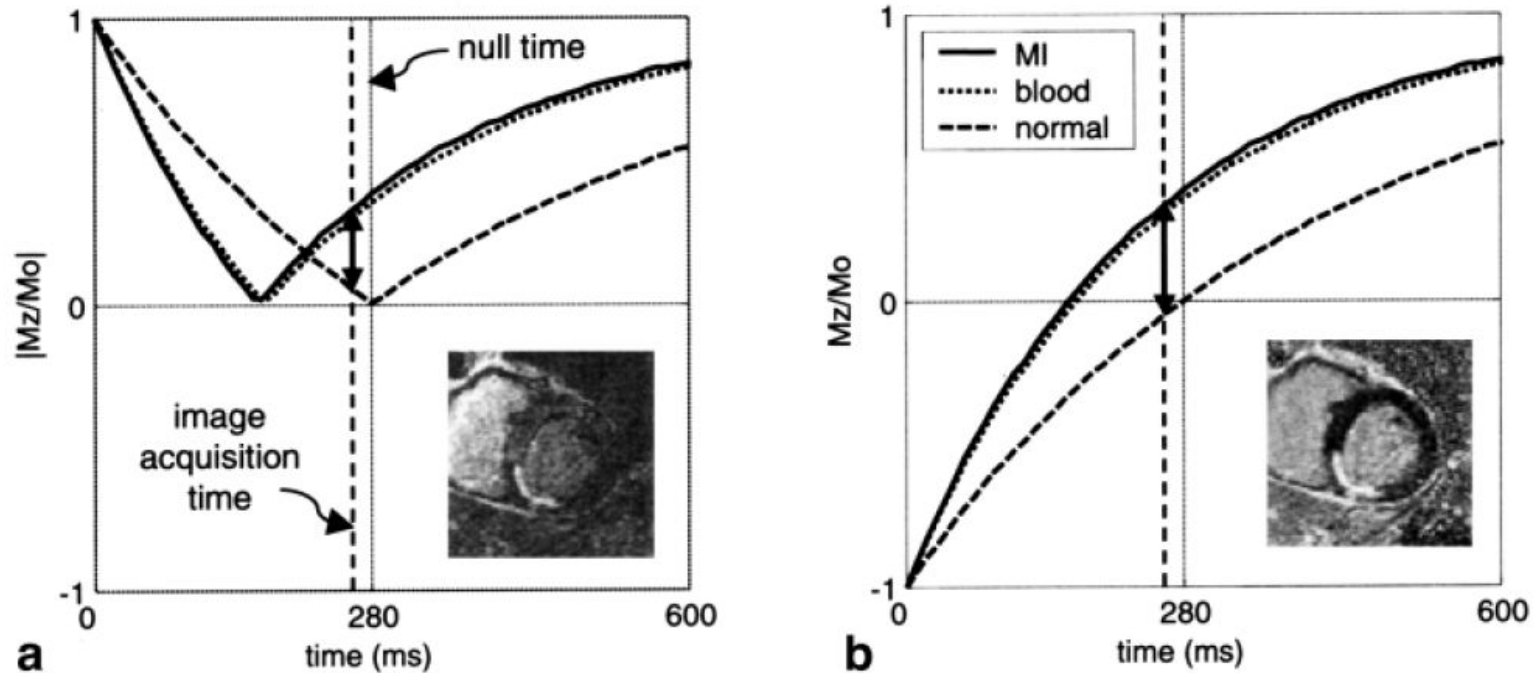
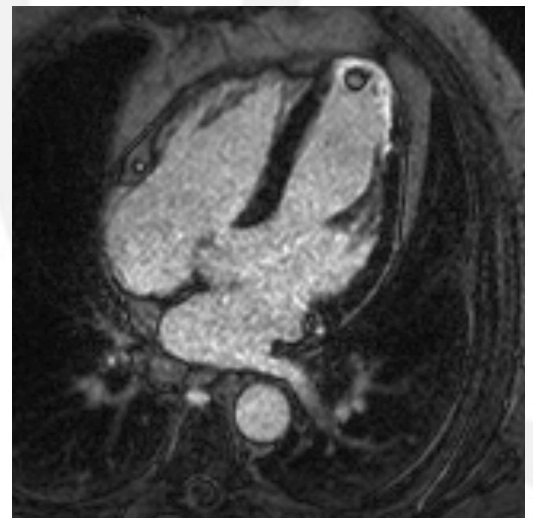
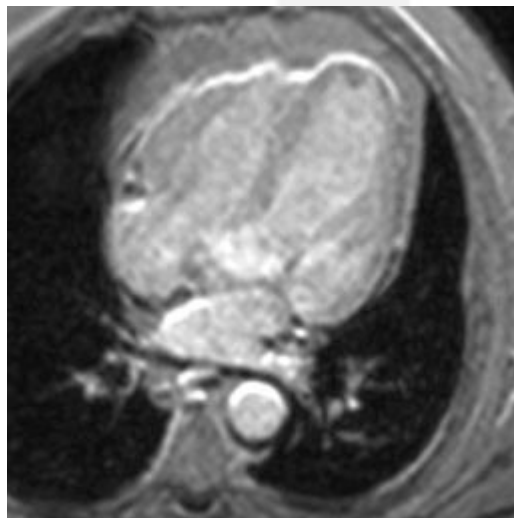
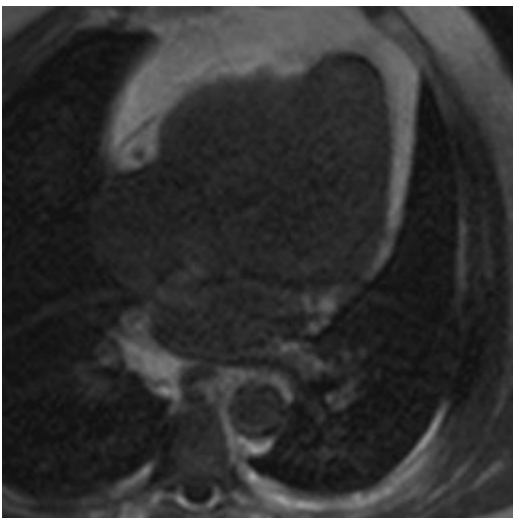
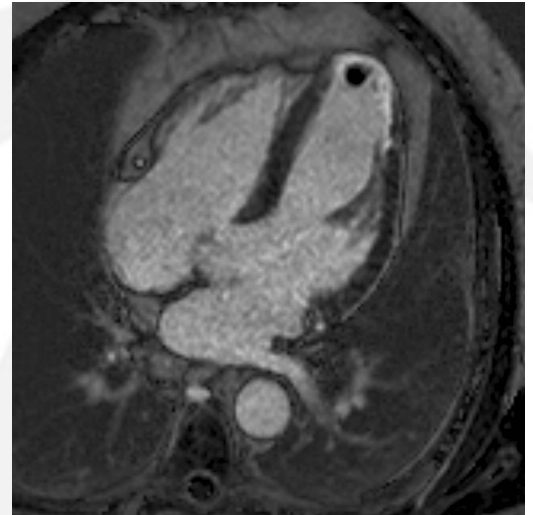
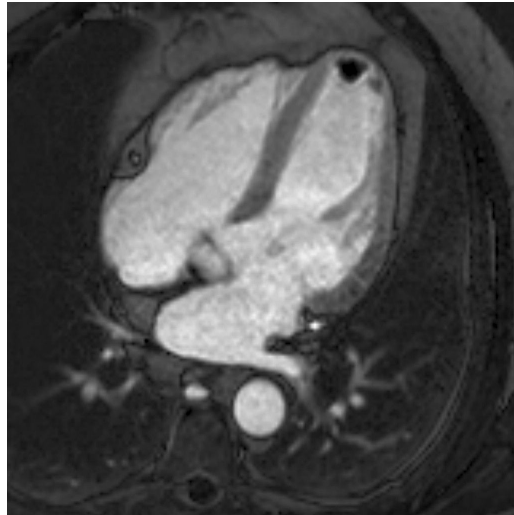
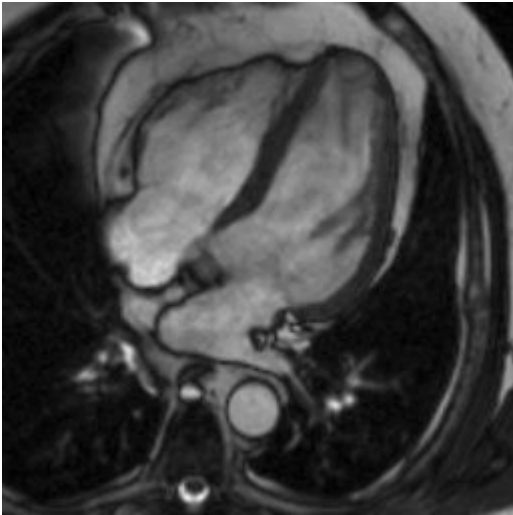
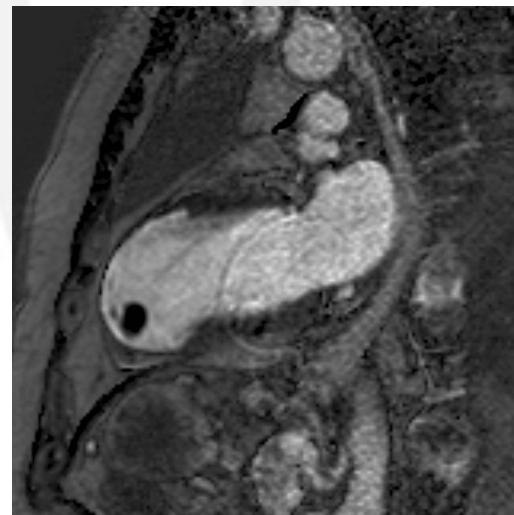
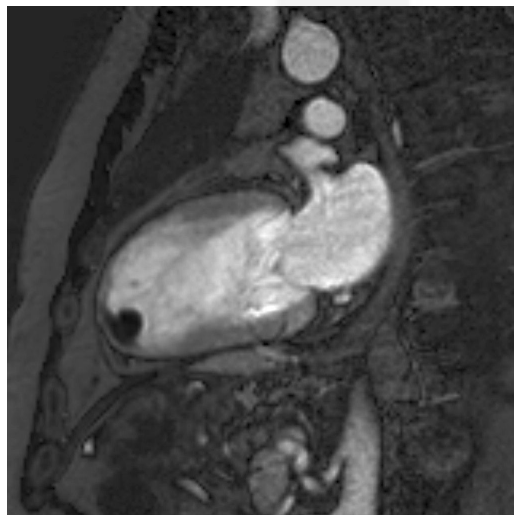
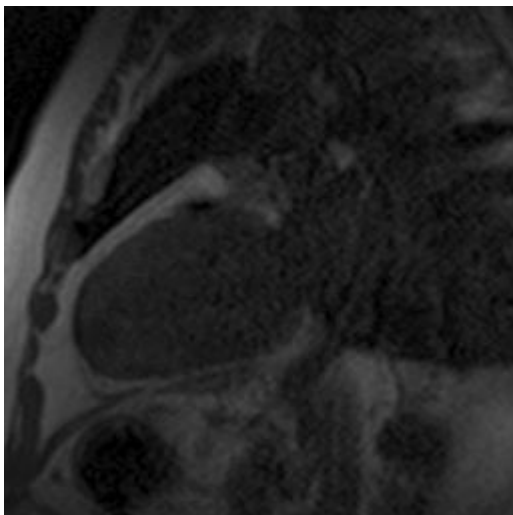
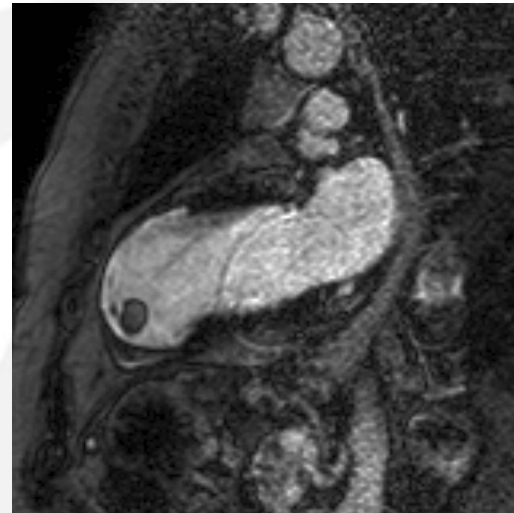
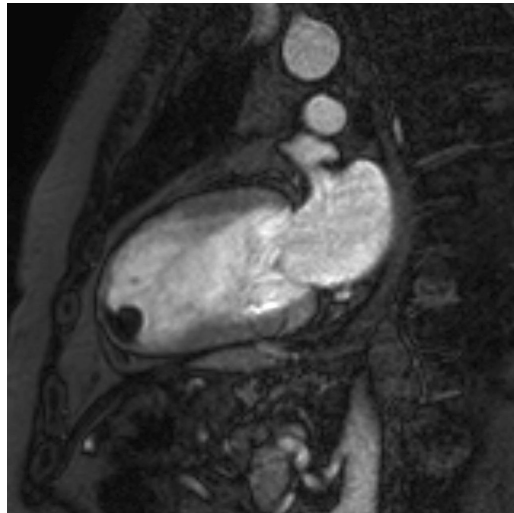
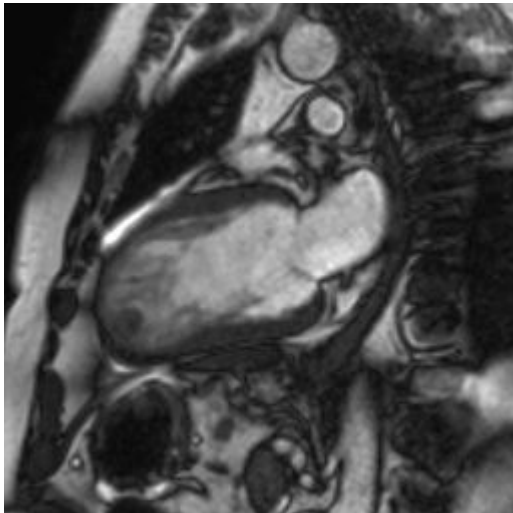


FIG. 1. Plots of signal intensity vs. TI for (a) magnitude and (b) phase-sensitive detection for MI (solid), blood (dotted), and normal myocardium (dashed), using nominal values of T_1 at 15 min following a double dose of contrast agent. Example images correspond to acquiring images earlier than the null time for normal myocardium. The solid lines with double arrows depict the contrast between the MI and the normal myocardium.

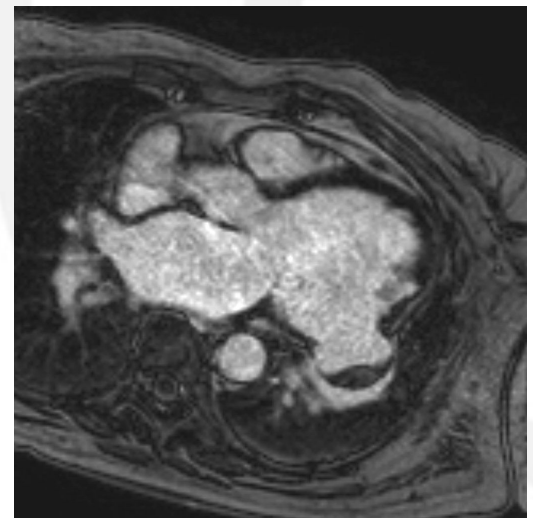
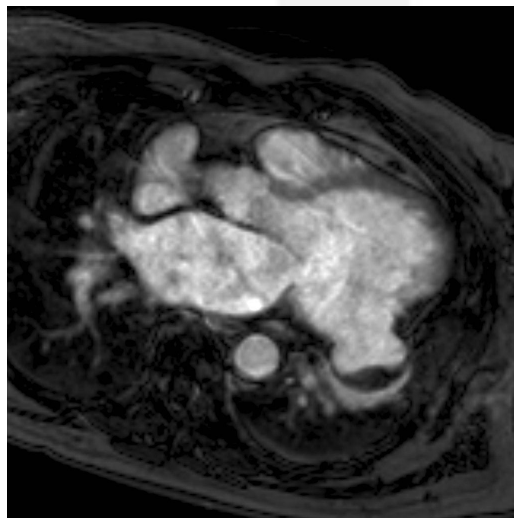
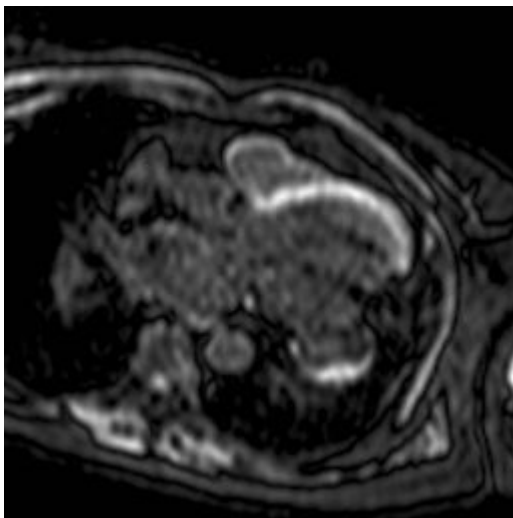
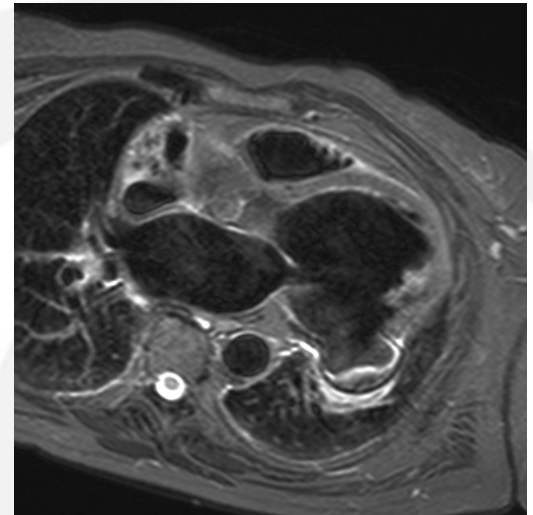
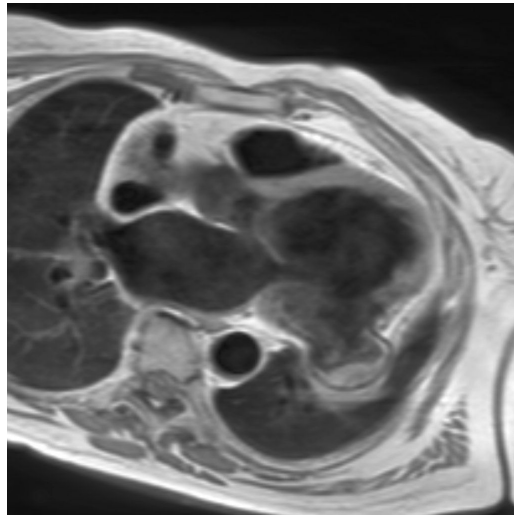
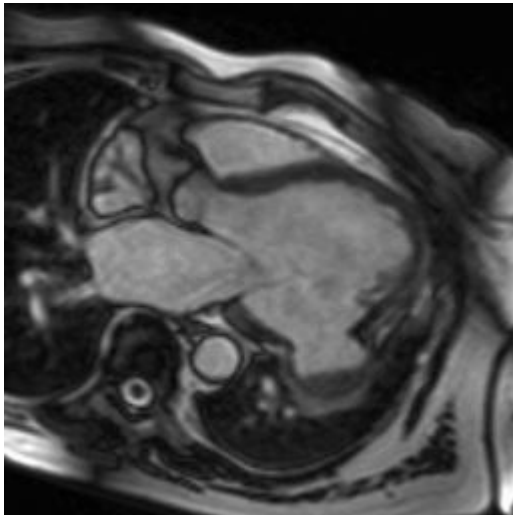
4CH



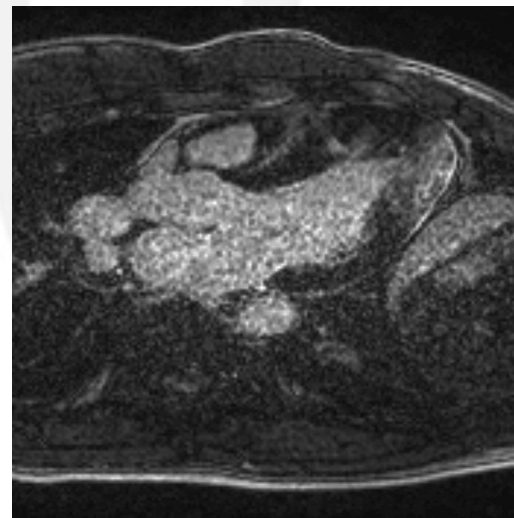
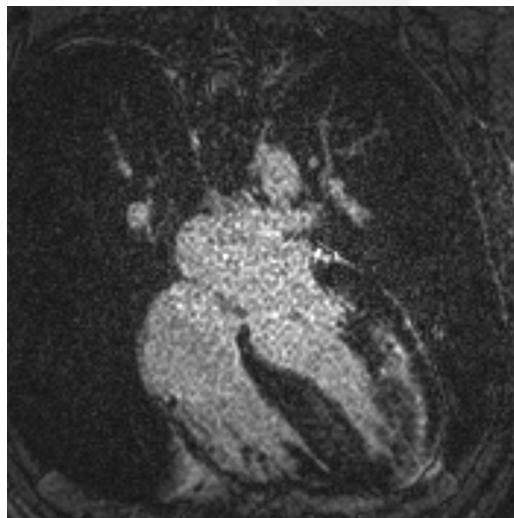
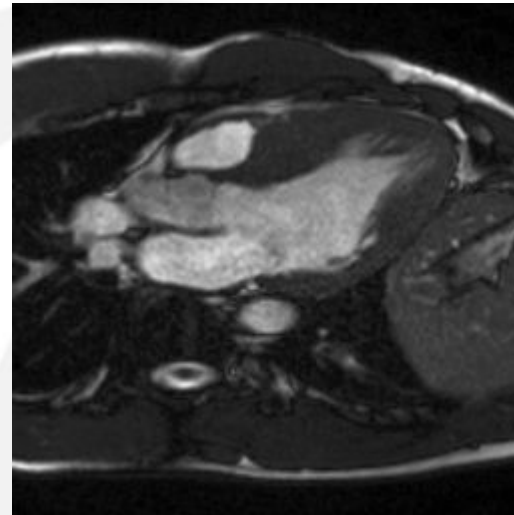
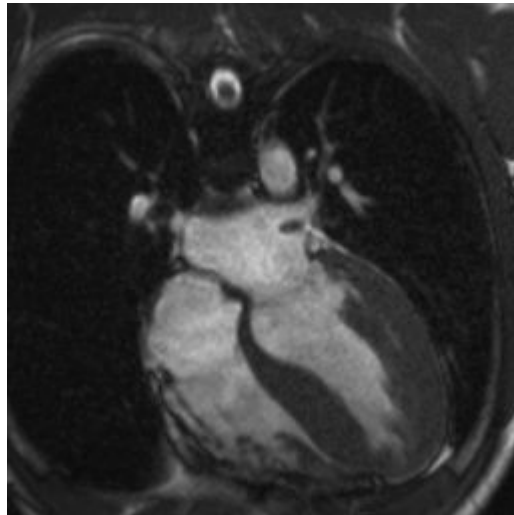
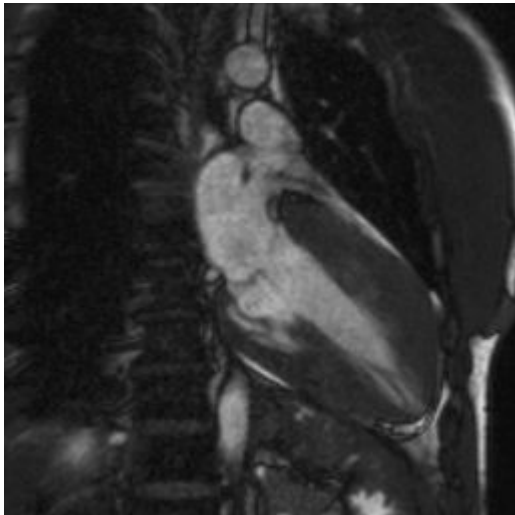
2CH



Cine, T1, T2-SPIR, LL, EE, DE



LA mozgókép és DE



DE quantification: 63g scar out of 360g

The screenshot displays the QMass MR 7.2 software interface. The main window shows a cardiac MRI scan with a red outline indicating the scar tissue and a green outline for the total myocardial mass. The software is in the 'Step 4: Specifying Transmurality Threshold and Placing Reference Point' stage. The 'Transmurality Threshold [%]' is set to 50. The 'Result Dialog' shows the following data:

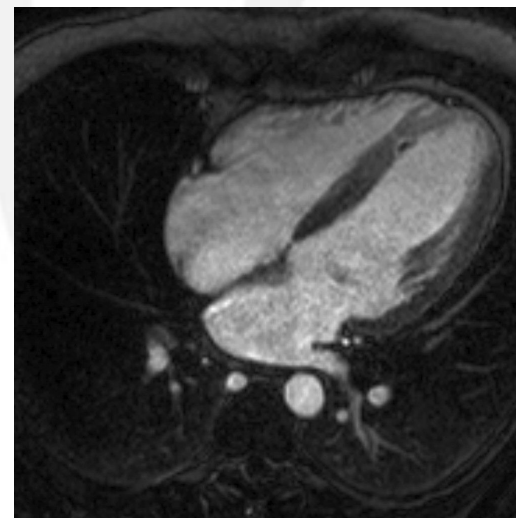
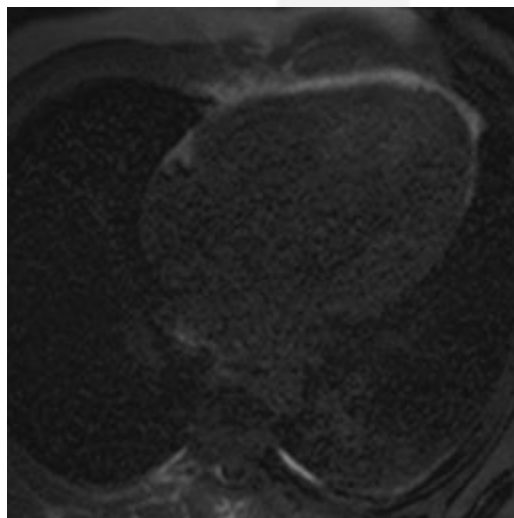
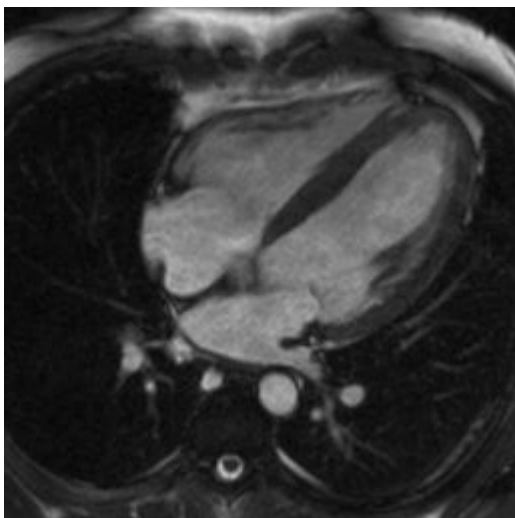
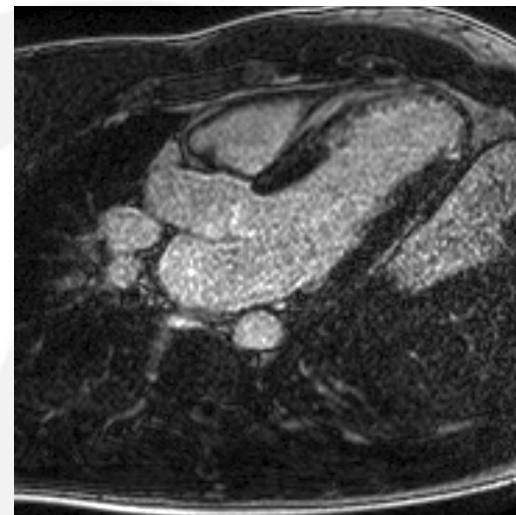
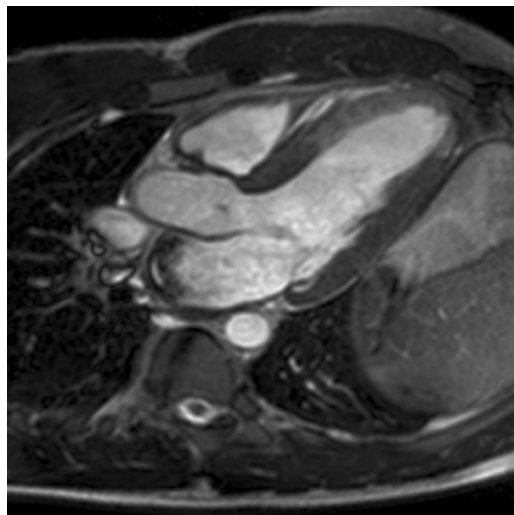
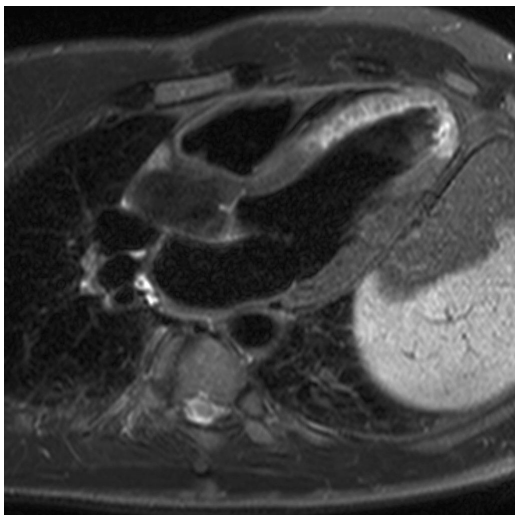
Parameter	Value
Total myocardial mass:	360.33 g
Scar tissue mass:	63.20 g
Scar tissue volume:	60.19 ml
Scar tissue percentage:	18 %
Nonviable mass:	5.33 g
Nonviable volume:	5.08 ml
Nonviable percentage:	1 %
Transmurality threshold:	50 %

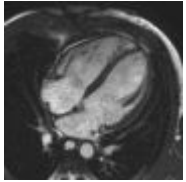
Technical parameters for the scan are listed in the bottom right of the main window:

- TR: 5.49ms
- TE: 2.52ms
- Ti: 0.00ms
- TD: 773ms
- SLs: 12
- PH: 1
- SP: 88.00mm
- SI th: 8mm

Additional information includes 'Total mass: 360.33g', 'Scar tissue: 63.20g / 18%', 'WW: 138', 'WL: 2 090', and 'Zoom: 175%'. The interface also shows a grid of 20 smaller MRI slices at the bottom, each with a green and red outline. The Windows taskbar at the bottom shows the Start button and several open applications, including 'Atoth SquireMail 1.4.1...', 'e-MedSolution - Mozilla F...', '1. Axion b2b Virtual xtc...', and 'mc [atoh@atoh]:~\jsa...'. The system clock shows 21:21.

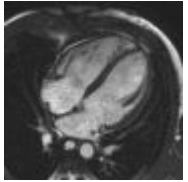
Összefoglalás: 21% non-viabilis





Köszönet

- Prof Merkely Béla, Prof Hüttl Kálmán
- Balázs György, Prof Simor Tamás
- Vágó Hajnalka
- Asszisztensek
- <http://atoth.sote.hu/radiol>



Ajánlott irodalom

- www.cis.rit.edu/htbooks/mri/
- users.fmrib.ox.ac.uk/~stuart/lectures/
- Haacke
- Vlaardingerbroek
- www.drcmr.dk/
- www.revisemri.com/tutorials/what_is_k_space/