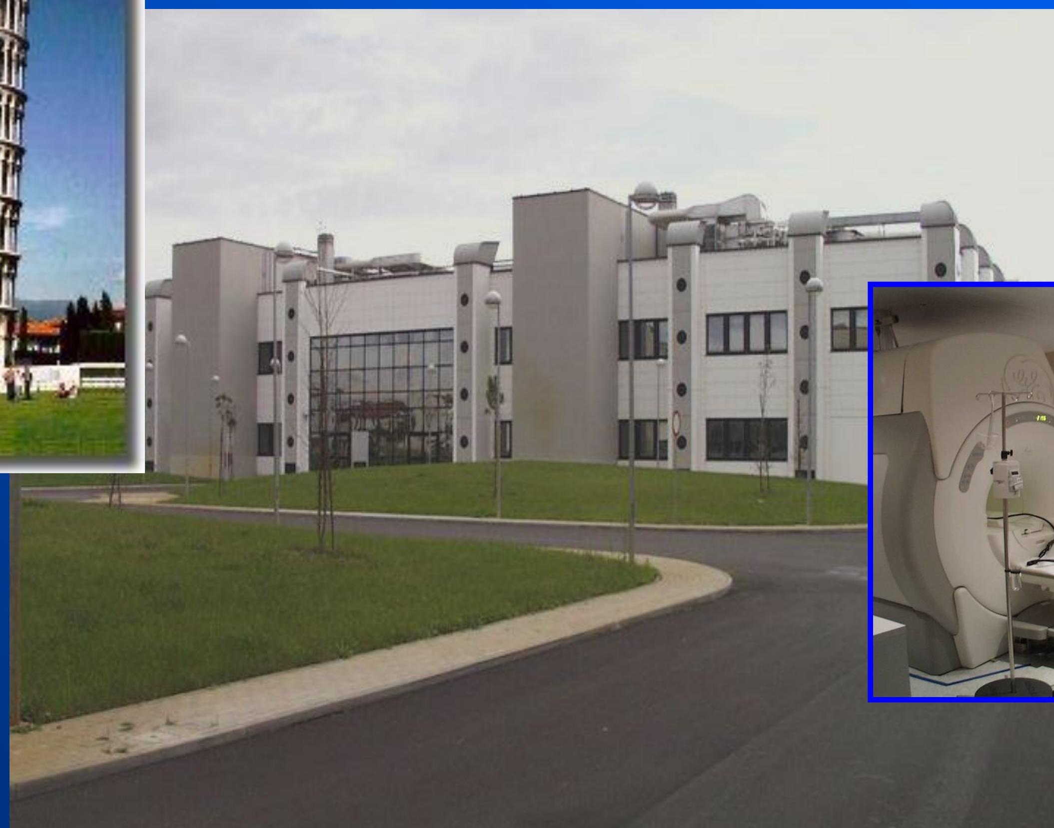
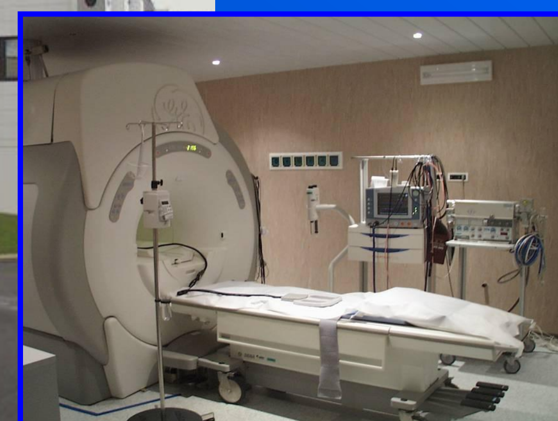
Principi fondamentali della produzione di immagini in RM e protocolli di acquisizione

G.D.Aquaro

Fondazione G.Monasterio Regione Toscana/CNR - Pisa

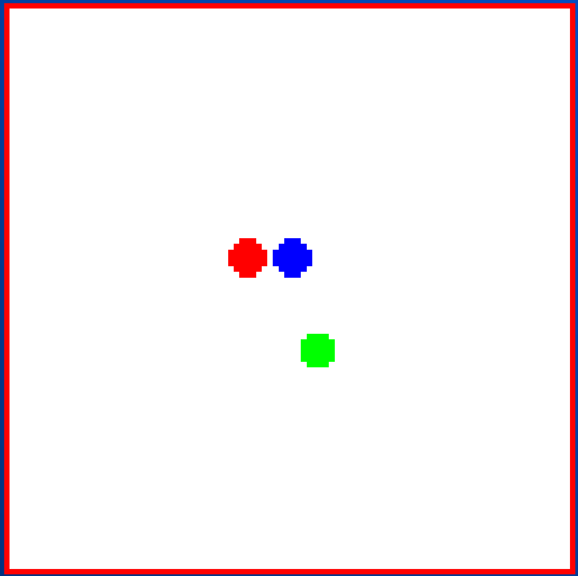


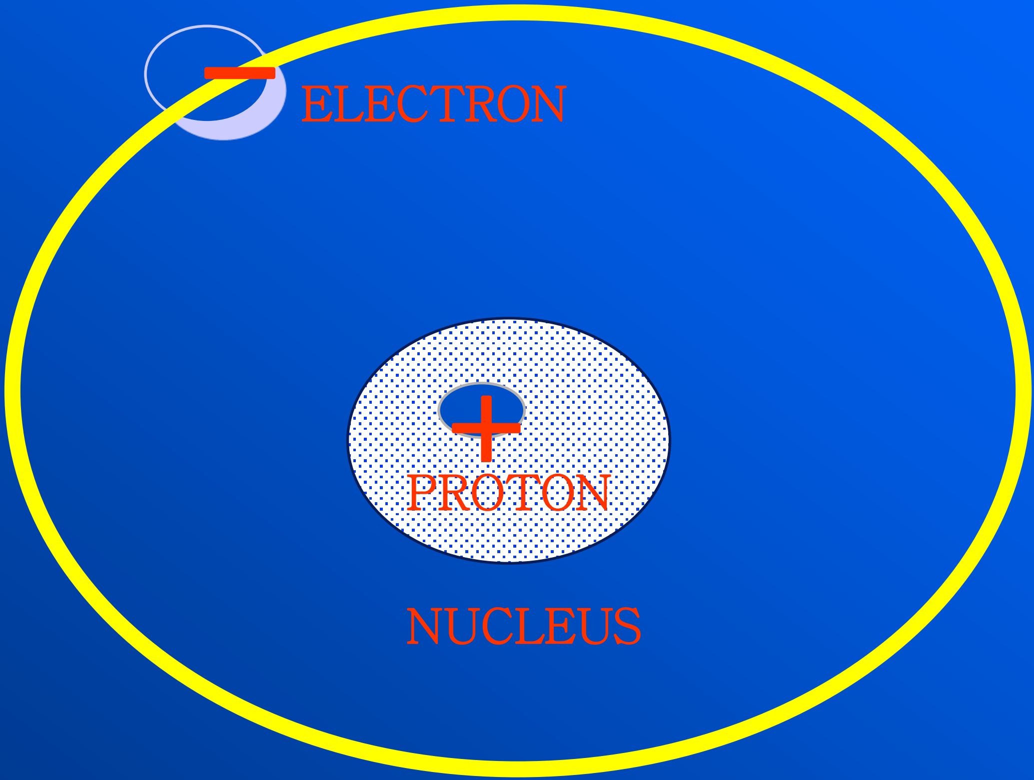


MRI-LAB

The phenomenon of Magnetic Resonance may be approached using different types of nuclei, however the atom of Hydrogen is generally utilized for creating MR images.

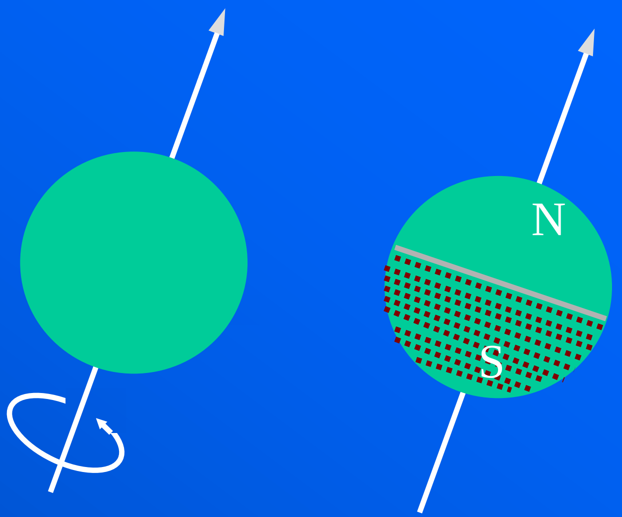
The atom of Hydrogen





Deuterium: 1 proton, 1 neutron, 1 electron

the nucleus is an electrically charged mass rotating on its own axis that generates a tiny magnetic field with its own direction and orientation. This phenomenon is called *"spin"* and is what gives the magnetic momentum μ to the nucleus.



Gyromagnetic ratio → γ

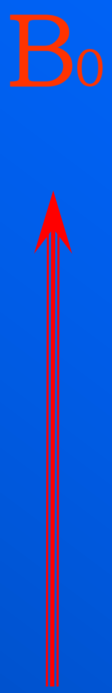
$$\gamma = \frac{\mu}{p}$$

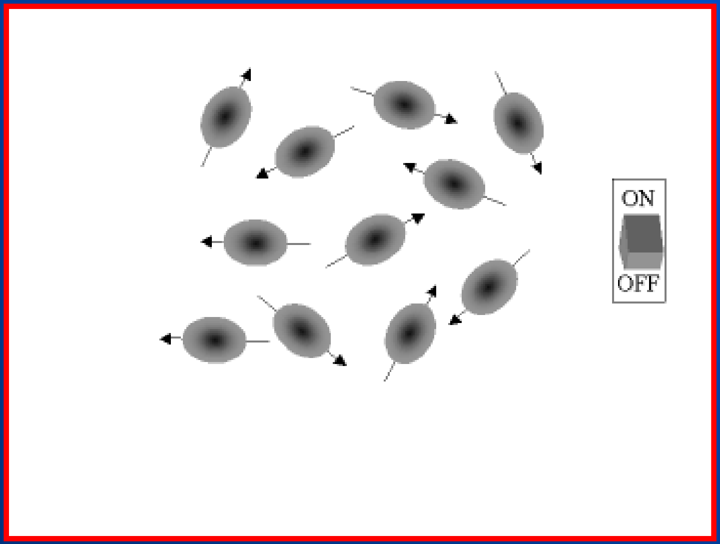
μ ← Magnetic momentum (due to a rotating electric charge)

p ← Angular momentum (due to a rotating mass)

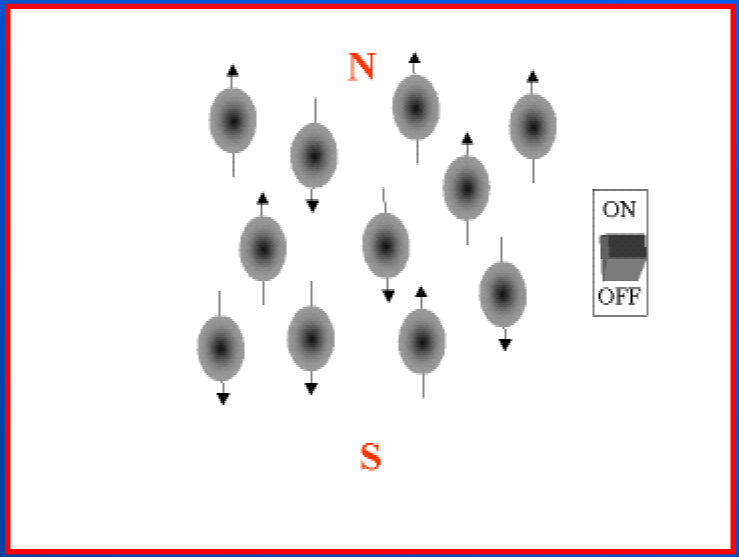
SPINS ORIENTATION

The spins in normal conditions are randomly oriented.
When we turn on a static magnetic field B_0 the spins align with that external field in parallel or anti-parallel position.





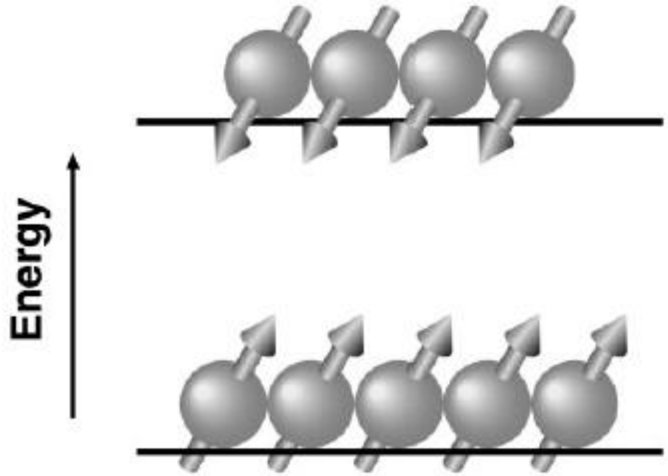
Without B_0



With B_0

Polarizzazione

In condizioni di equilibrio termico c'e' una lieve vantaggio energetico in direzione up=>down
quindi N^- saranno lievemente minori di N^+



Thermal equilibrium

$$P = \tanh\left(\frac{\gamma \hbar B_0}{2 k_B T}\right)$$

γ costante giromagnetica dell'atomo

$\hbar$ costante di Planck

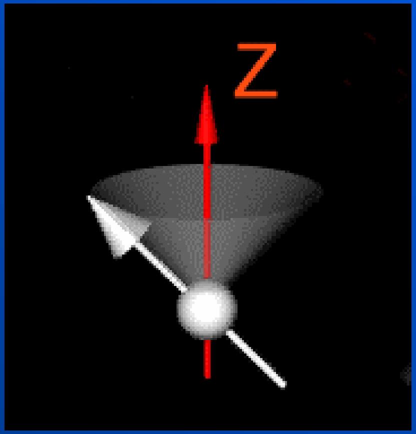
B_0 campo magnetico

k_B costante di Boltzmann

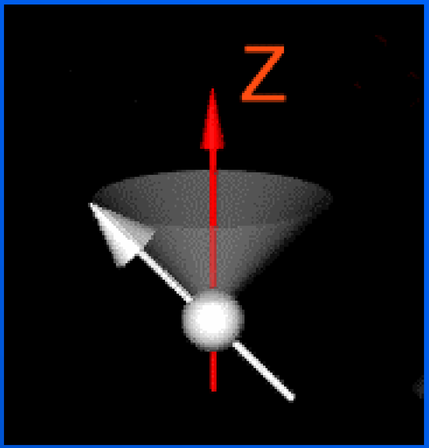
T temperatura

a 1.5 T 7/1000000 per ^1H (SNR di una singola ripetizione 0.0007%)

MRI: PRECESSION FREQUENCY



B_0



B_0

LARMOR FREQUENCY:

$$\omega = \gamma B_0$$

Frequency of precession (ω)

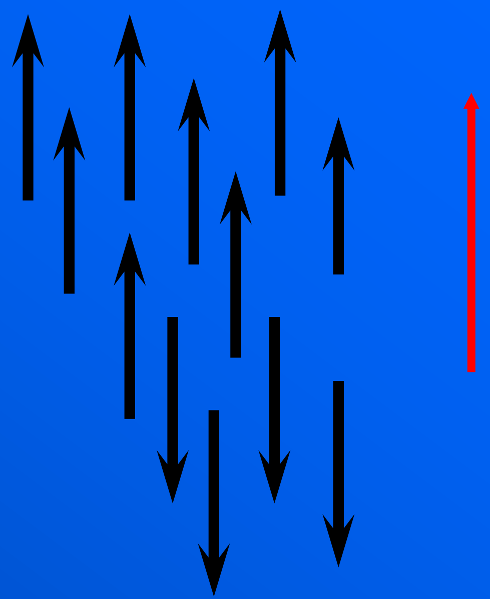
Gyromagnetic ratio (γ)

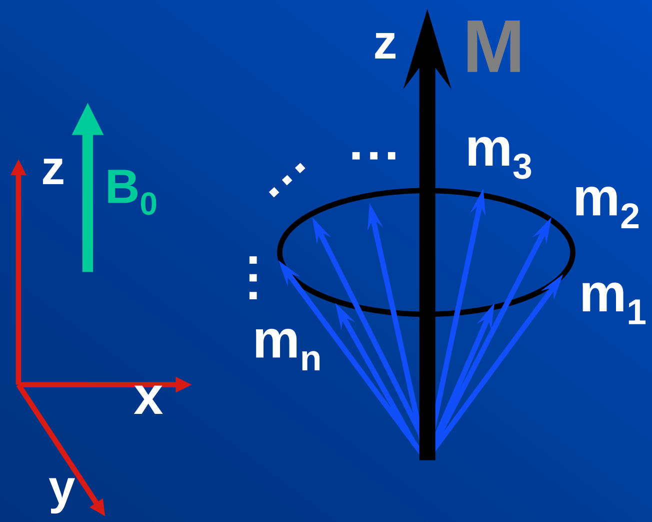
Static magnetic field (B_0)

ω = 42.58 x 1.5 = 63.87 MHz: we are in the radiofrequency domain (RF)

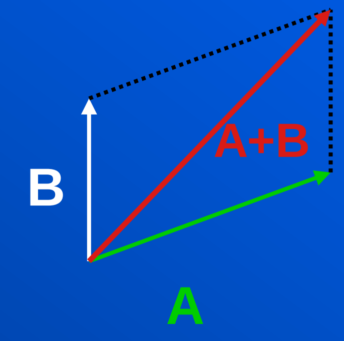
1 Tesla is = 10.000 Gauss.
(1 Gauss =intensity of the earth magnetic field)

It is given by the vectorial summation of the single magnetic moments of the spins.



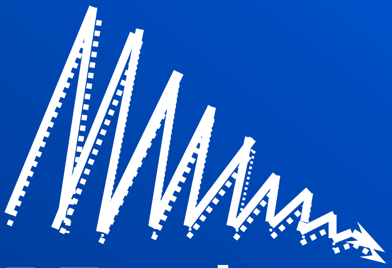


Sum of two vectors A+B:

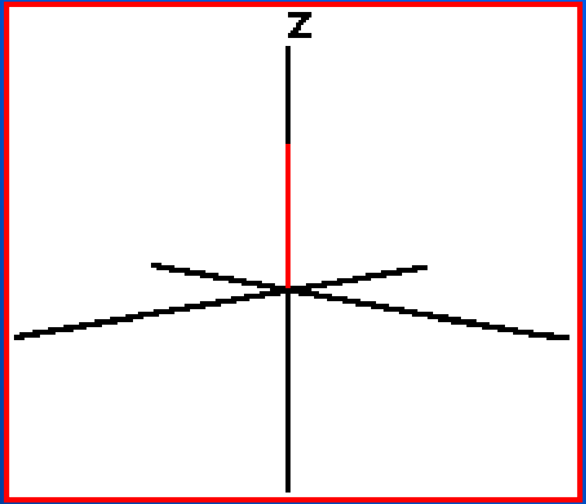


MAGNETIC RESONANCE

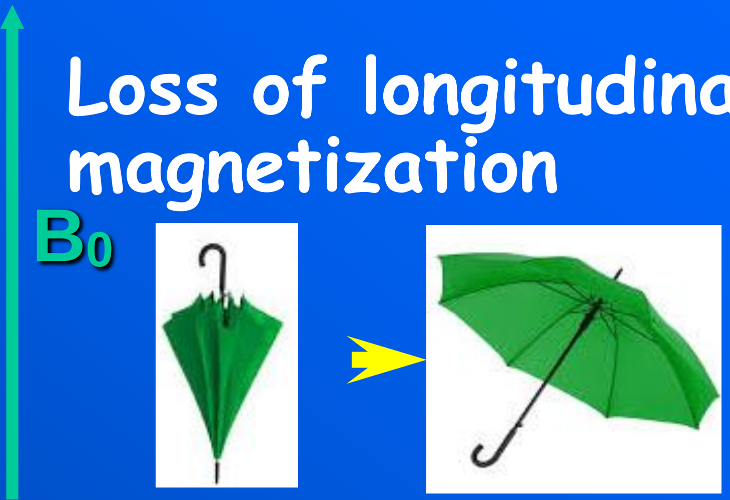
If the protons aligned in a static magnetic field B_0 are excited by a RF pulse at the frequency of precession (Larmour Frequency) we have the phenomenon of nuclear magnetic resonance.



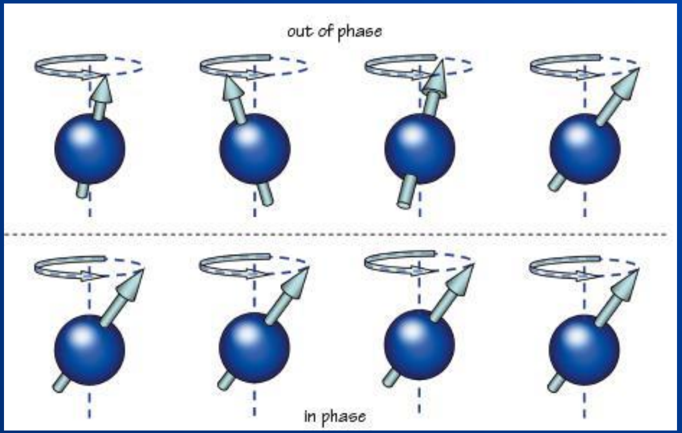
RF pulse

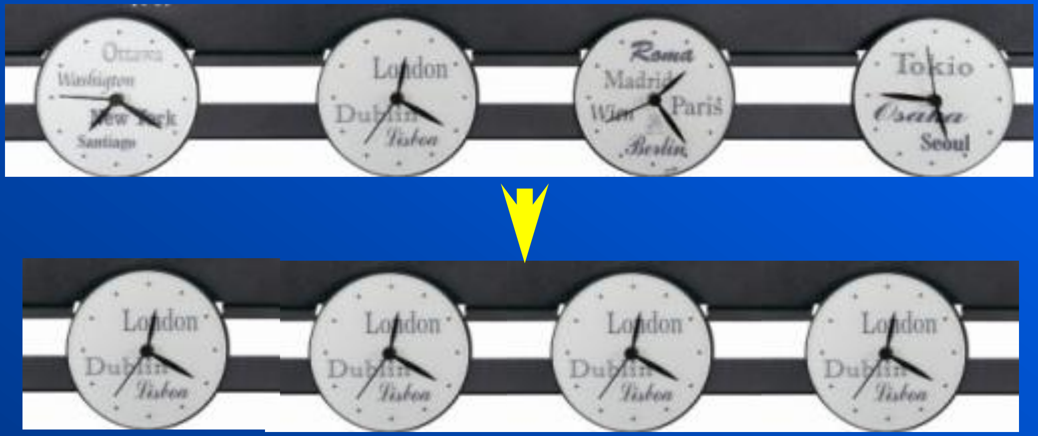


Loss of longitudinal magnetization



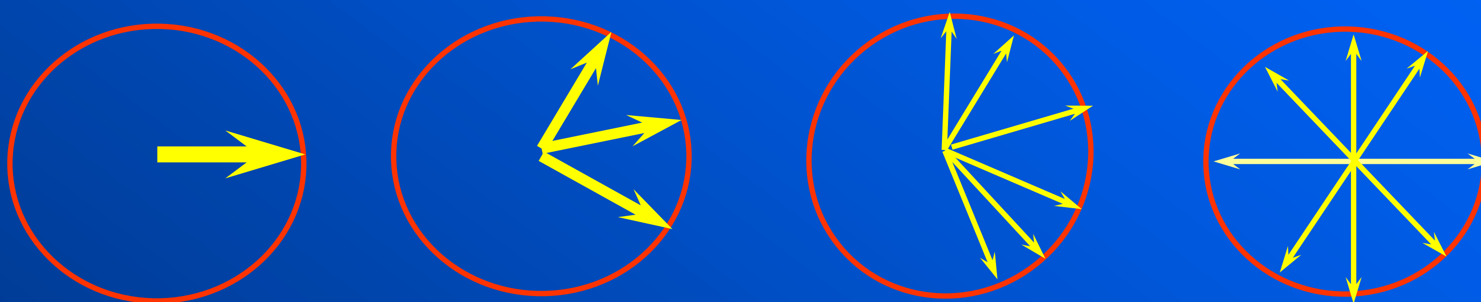
Phase coherence



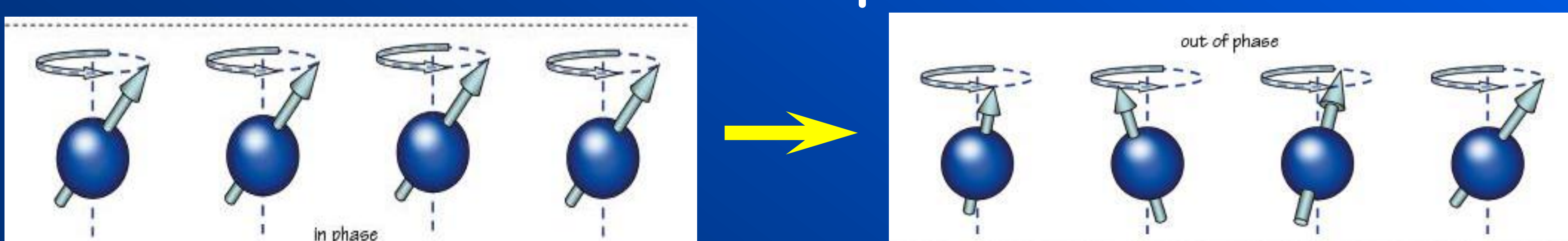


T_2 = spin-spin relaxation

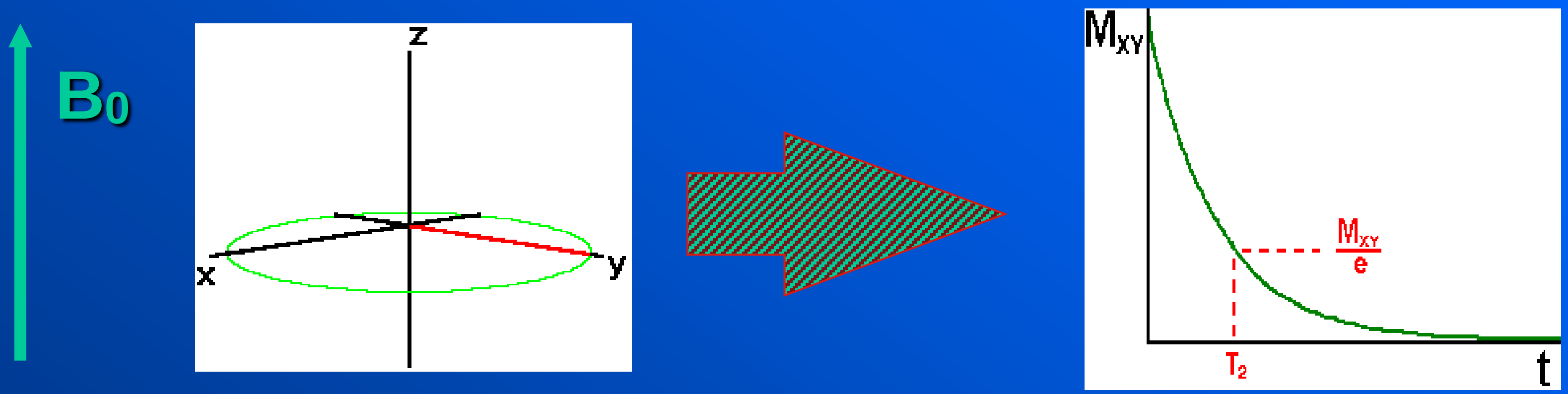
The spin-spin relaxation is caused by the interaction between nuclear magnetic moments.



These spin-spin interactions cause a change in the precessing frequencies of each nucleus.
The results is is a loss in phase coherence.



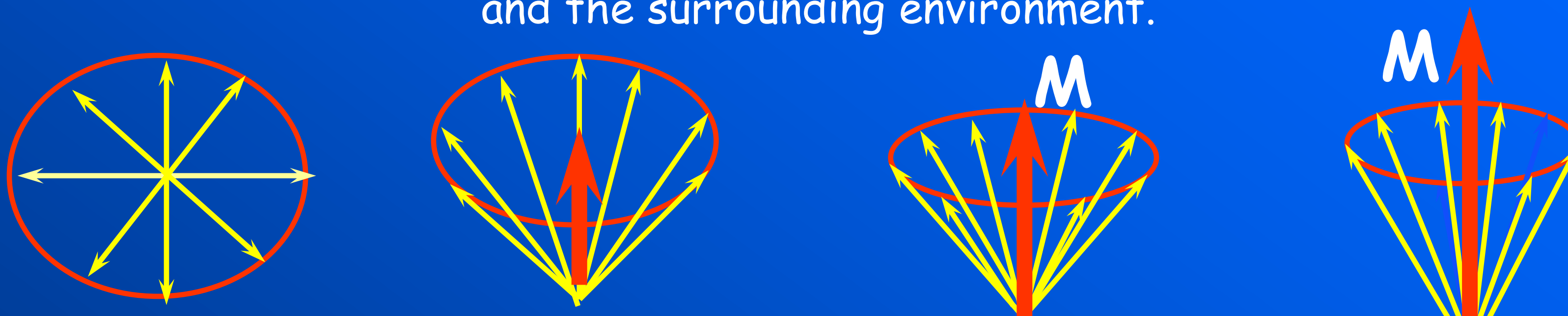
TRANSVERSE RELAXATION TIME T2



The constant of the transverse relaxation time is given by T2, that is the time necessary to reduce the value of M_{XY} by 63%.

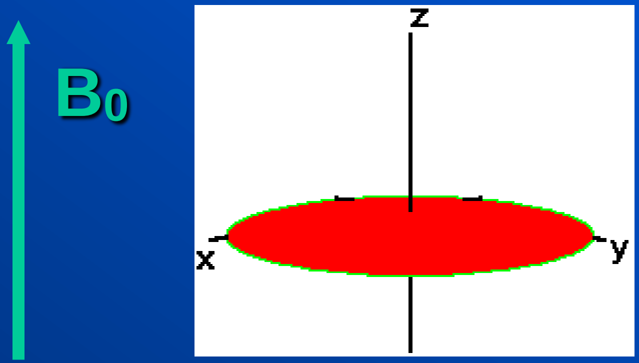
LONGITUDINAL RELAXATION TIME T1

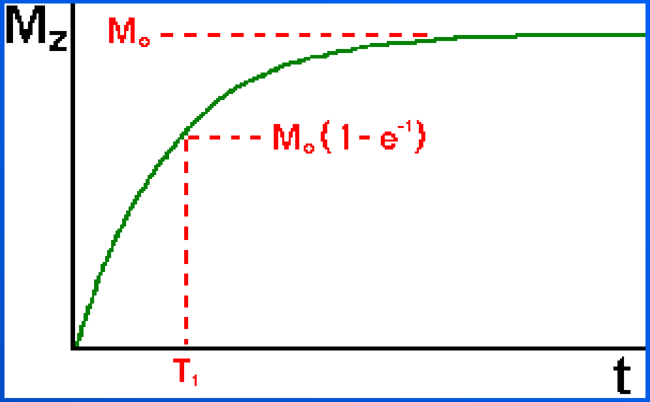
The spin-lattice relaxation is caused by the exchange of energy between spins and the surrounding environment.



The magnetic moments gradually realign with B_0

LONGITUDINAL RELAXATION TIME T1

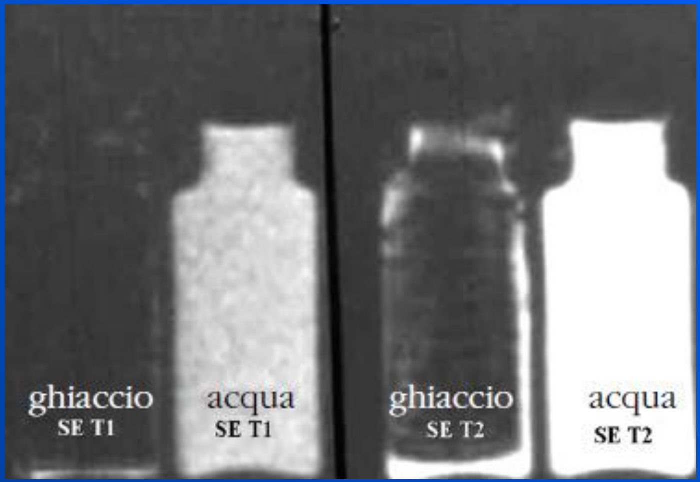




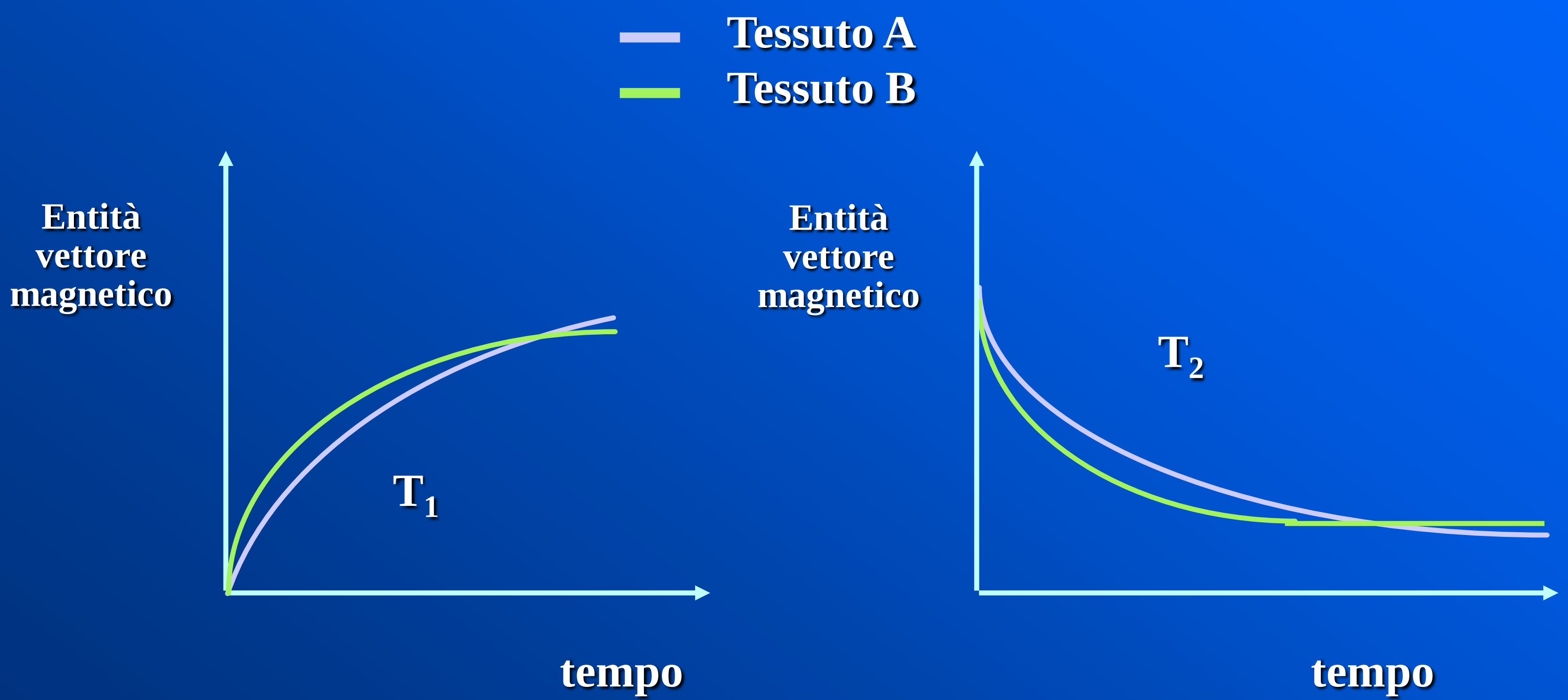
T1 is the time needed for 63% of Mz to return to equilibrium M0 after a 90° RF pulse.

MRI - parameters

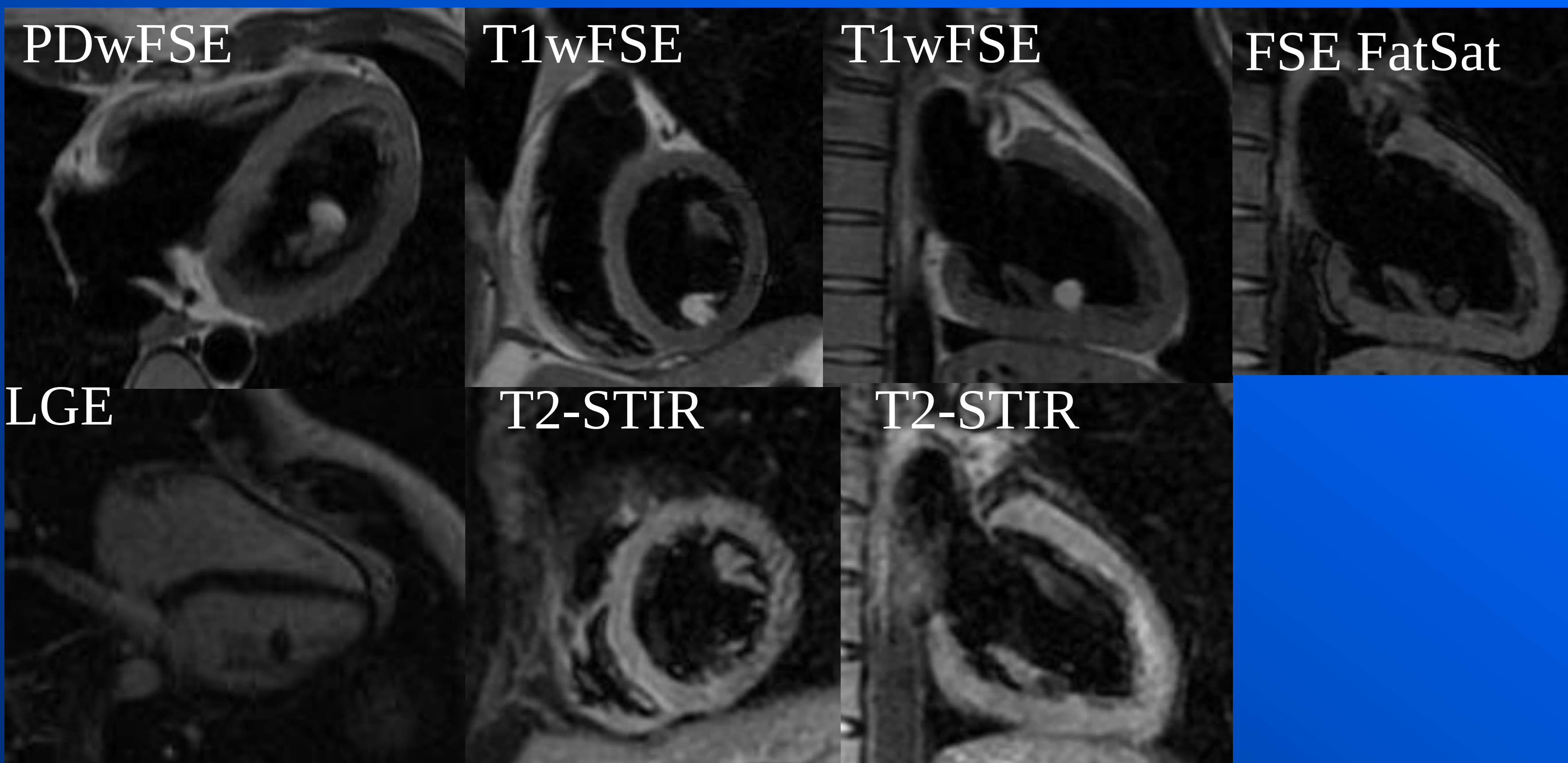
- Longitudinal relaxation time, or spin-lattice relaxation time: T_1
- Transverse relaxation time, or spin-spin relaxation time: T_2 (T_2^*)
- Proton density: PD



Longitudinal and transversal Relaxation

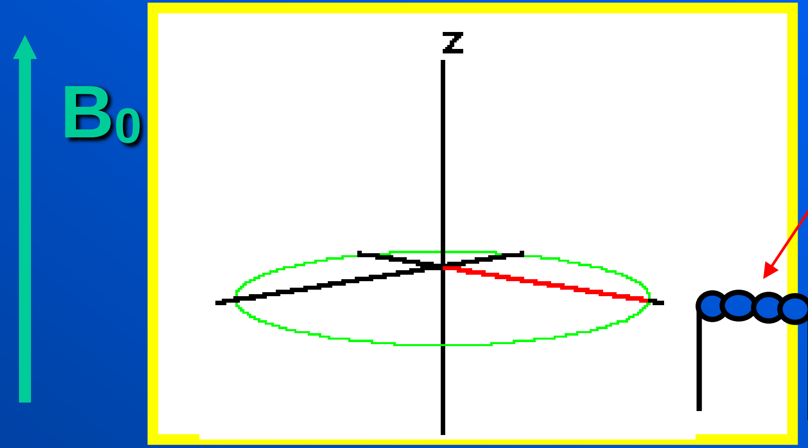


WEIGHTED IMAGES



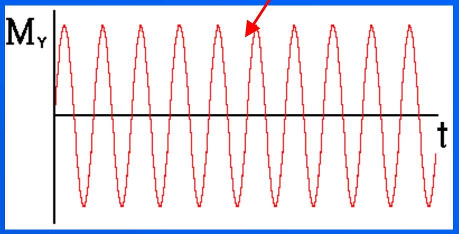
THE SIGNAL

In a perfect world.....

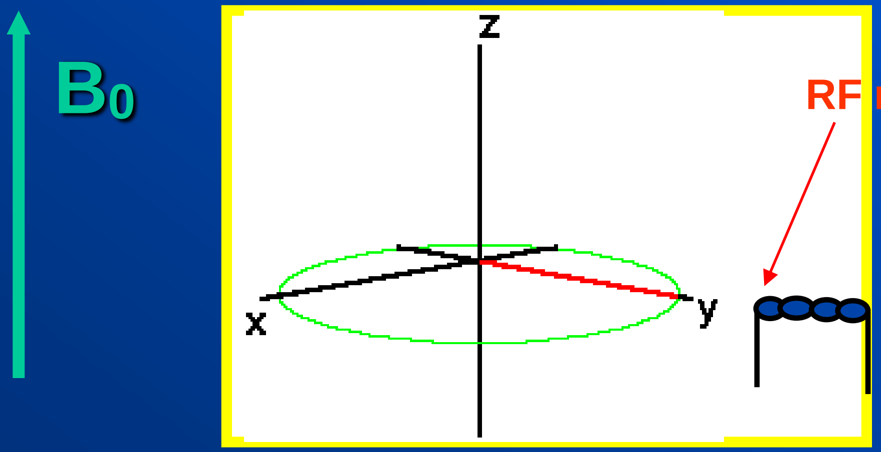


RF receiver coil

RF received signal

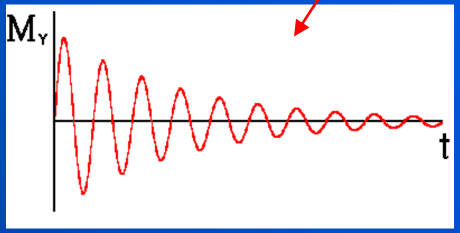


......in the real one FID Signal: Free Induction Decay



RF receiver coil

RF received signal (FID)



PARAMETERS OF ACQUISITION:

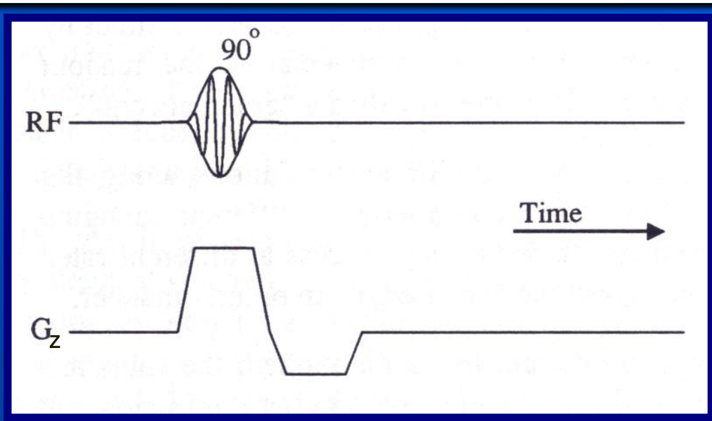
- FA - Flip Angle: the angle between B_0 e M; it is proportional with the duration of the RF pulse.
- TR – Time of Repetition: the time between an RF pulse and the next.
- TE – Time of Echo: the time between emission of the RF pulse and reception of the signal.

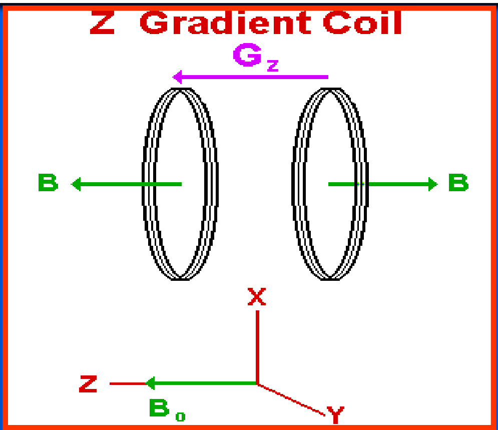
T1w = short TR (<800 ms) – short TE (<10 msec)

T2w =long TR (>1800)– long TE (>60 msec)

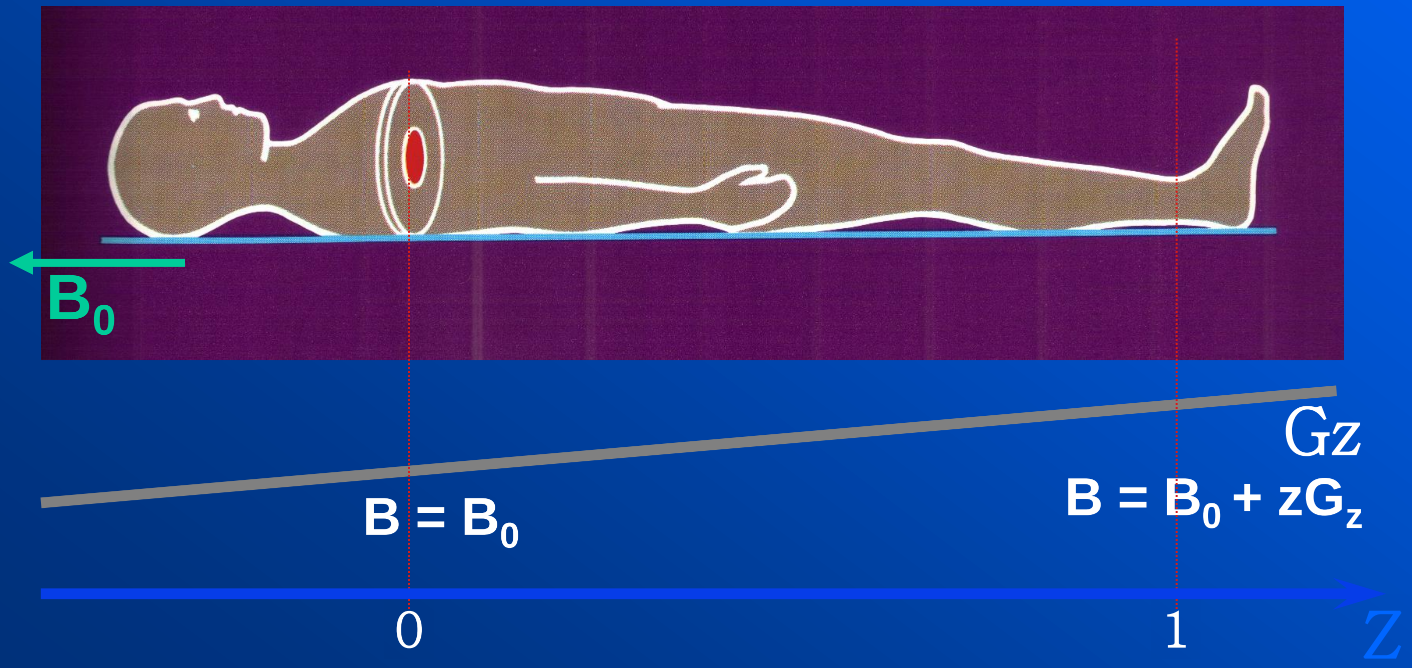
PDw =long TR – short TE

GRADIENT FOR THE SLICE SELECTION



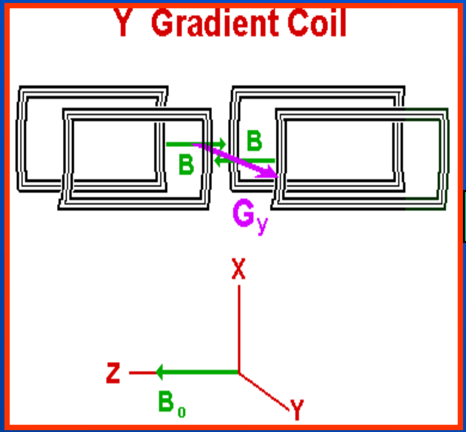


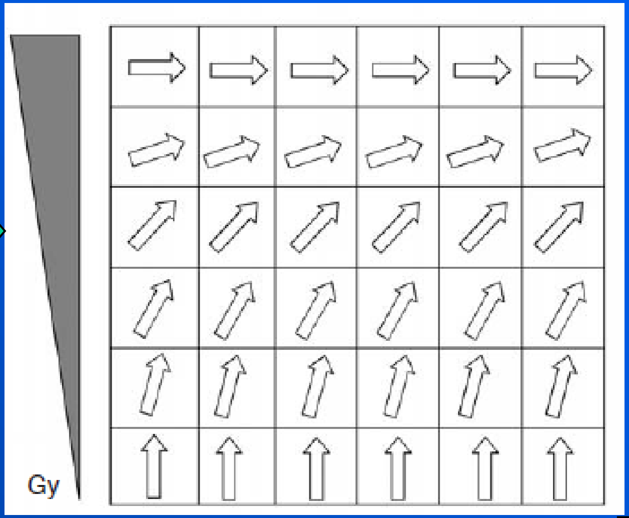
Gradient along B_0 - z

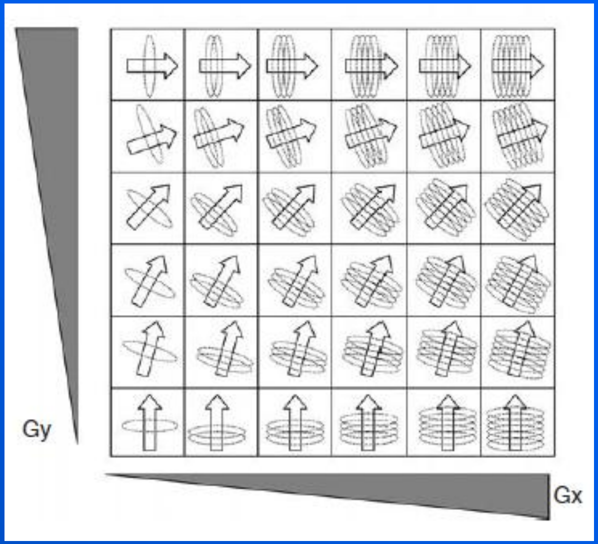


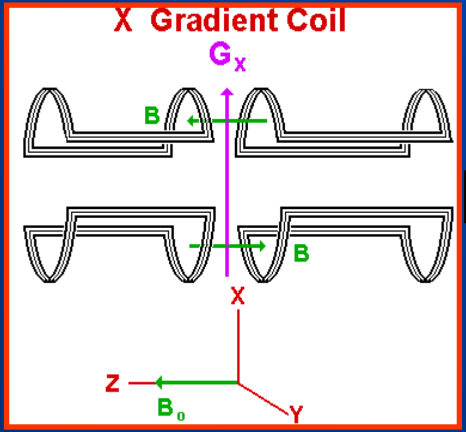
$\omega = \gamma B$

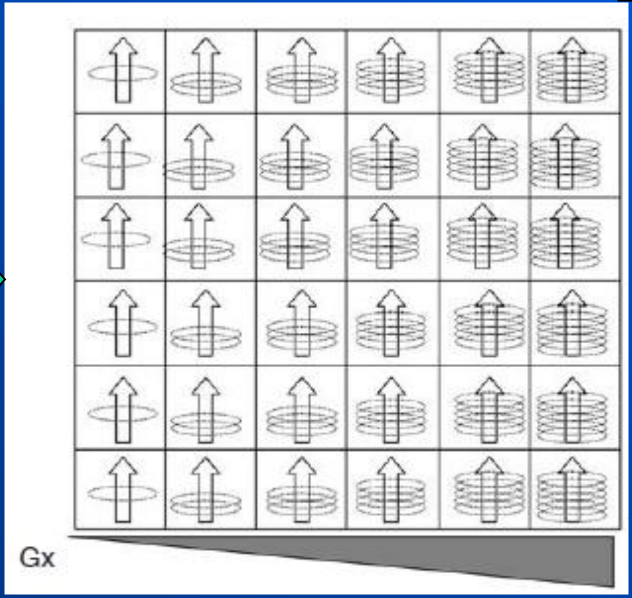
THE GRADIENT COIL

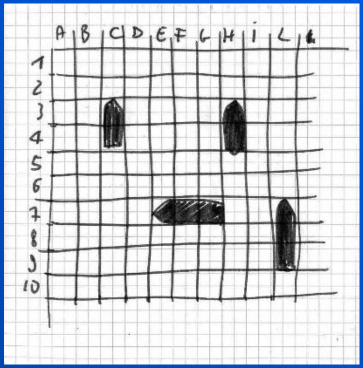






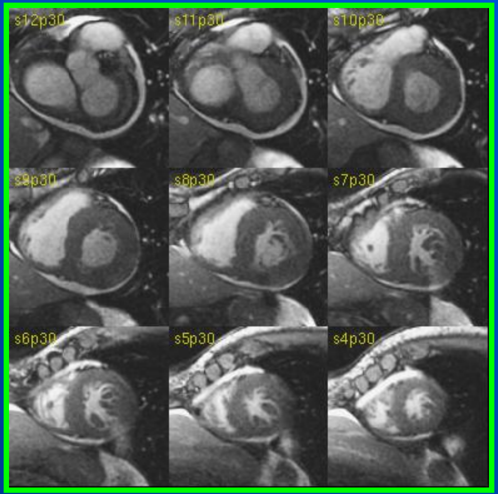


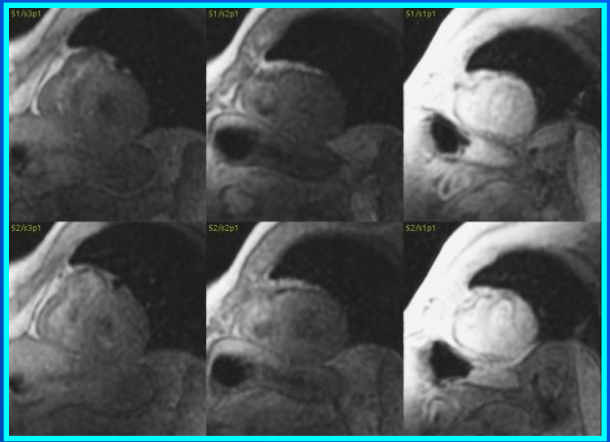




CMR PULSE SEQUENCES

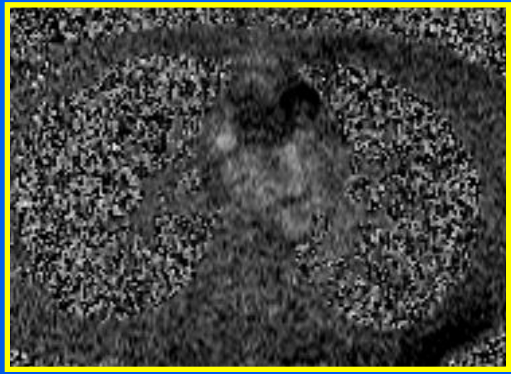
SSFP





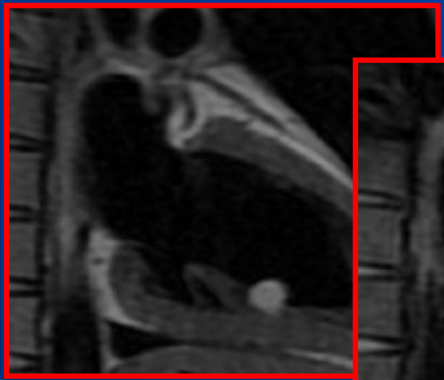
EPI ET

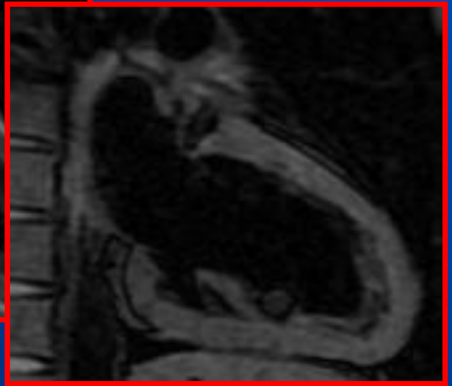
PC



IR GRE T1 post m.d.c
Delayed Enhancement

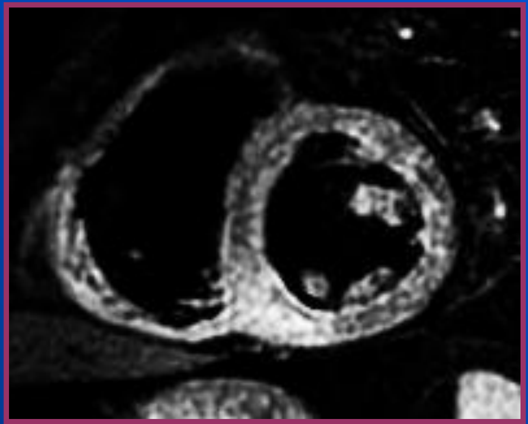
FSE or Double IR



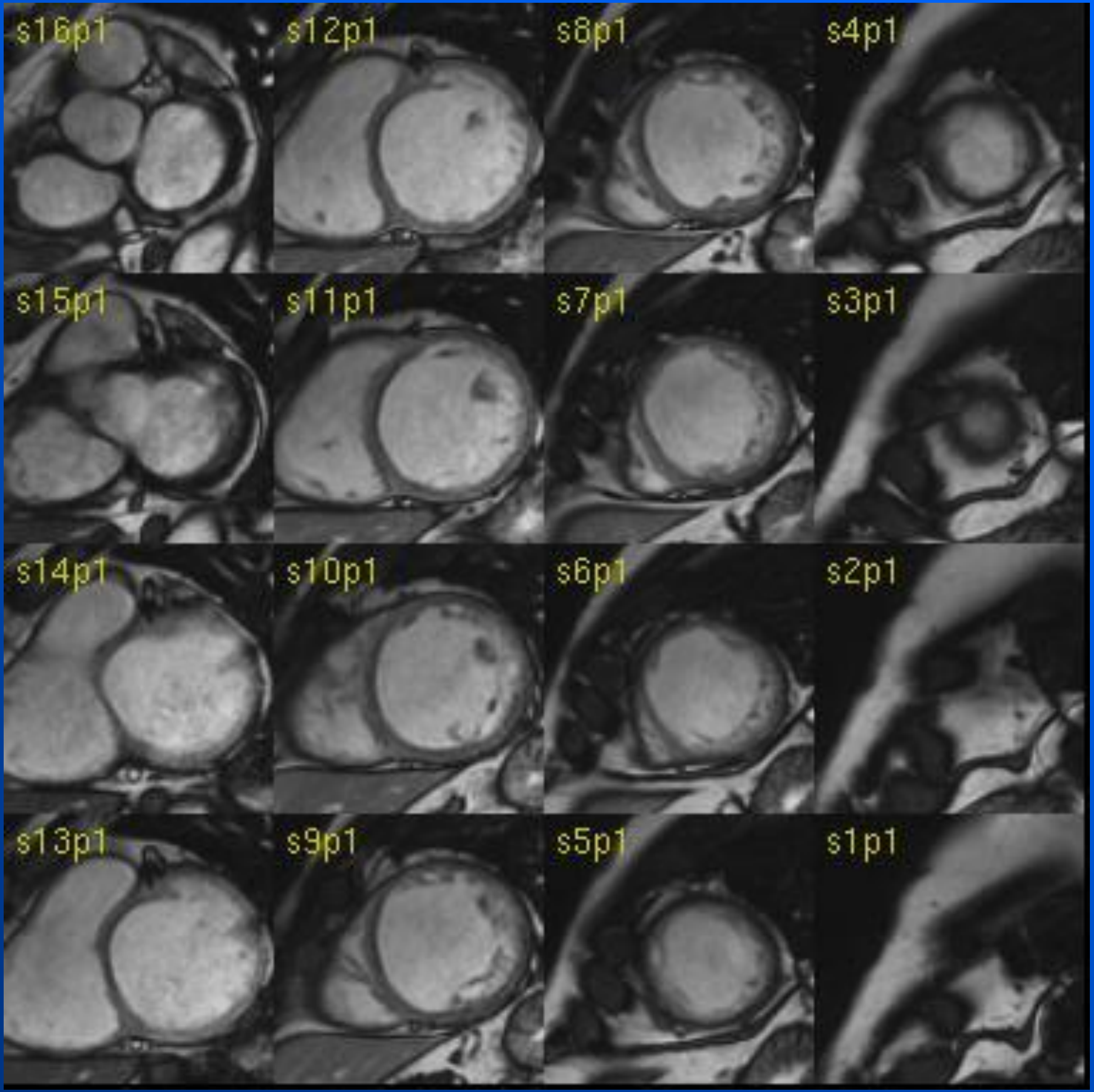


FSE or Double IR Fat sat

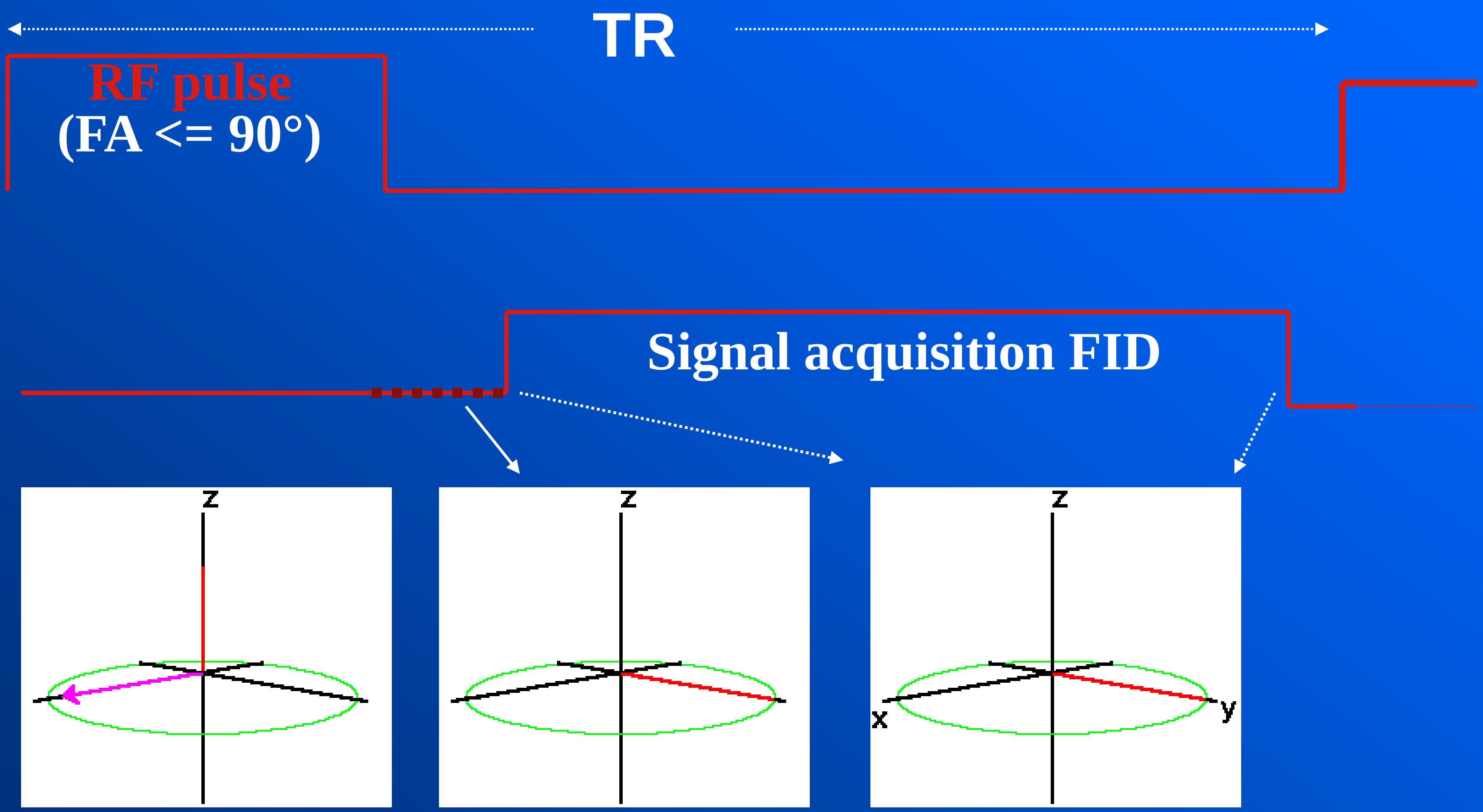
STIR



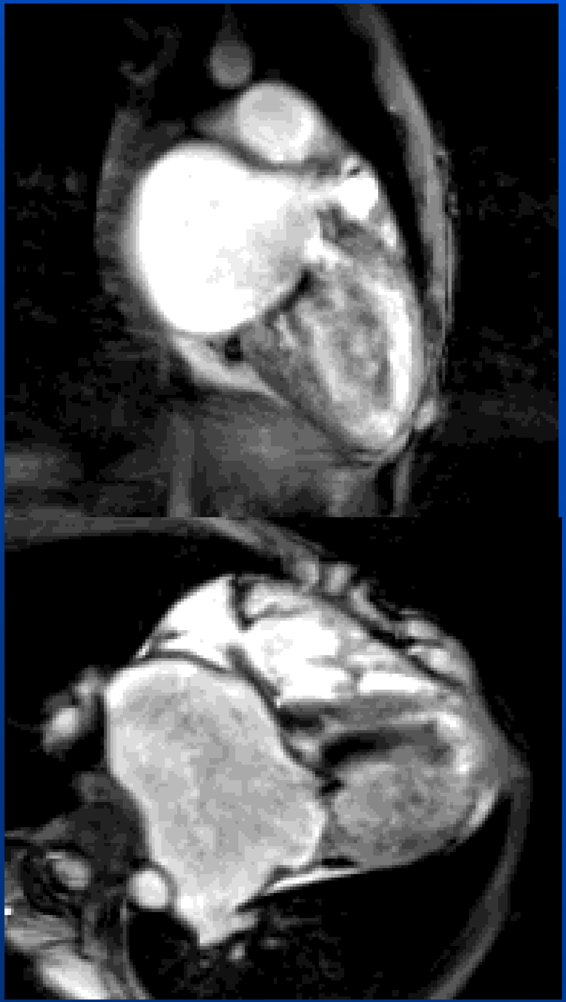
Cine-CMR: SSFP & GRE

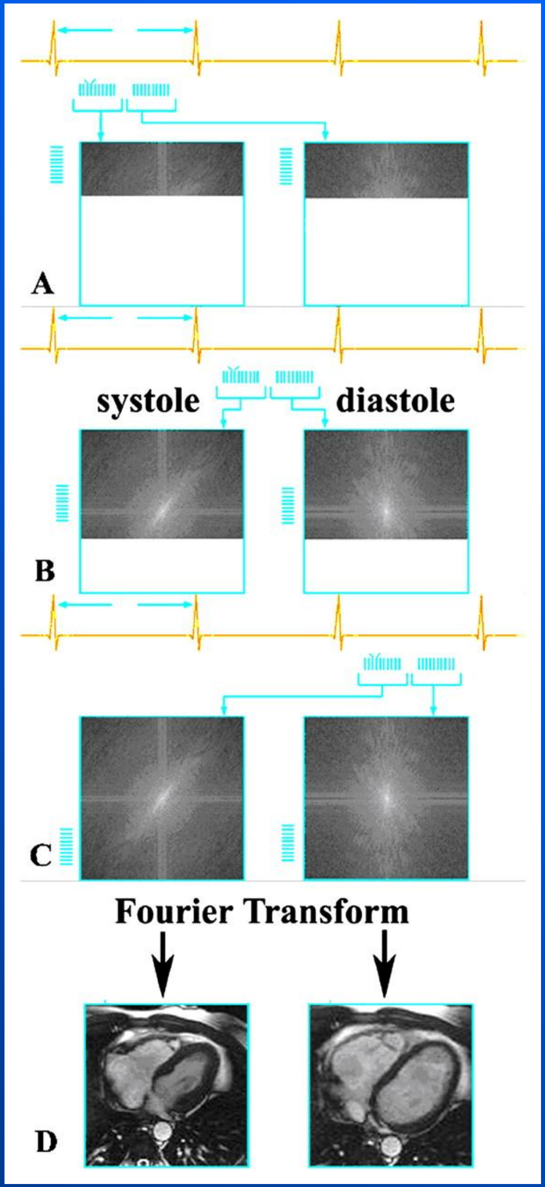


GRADIENT-ECHO

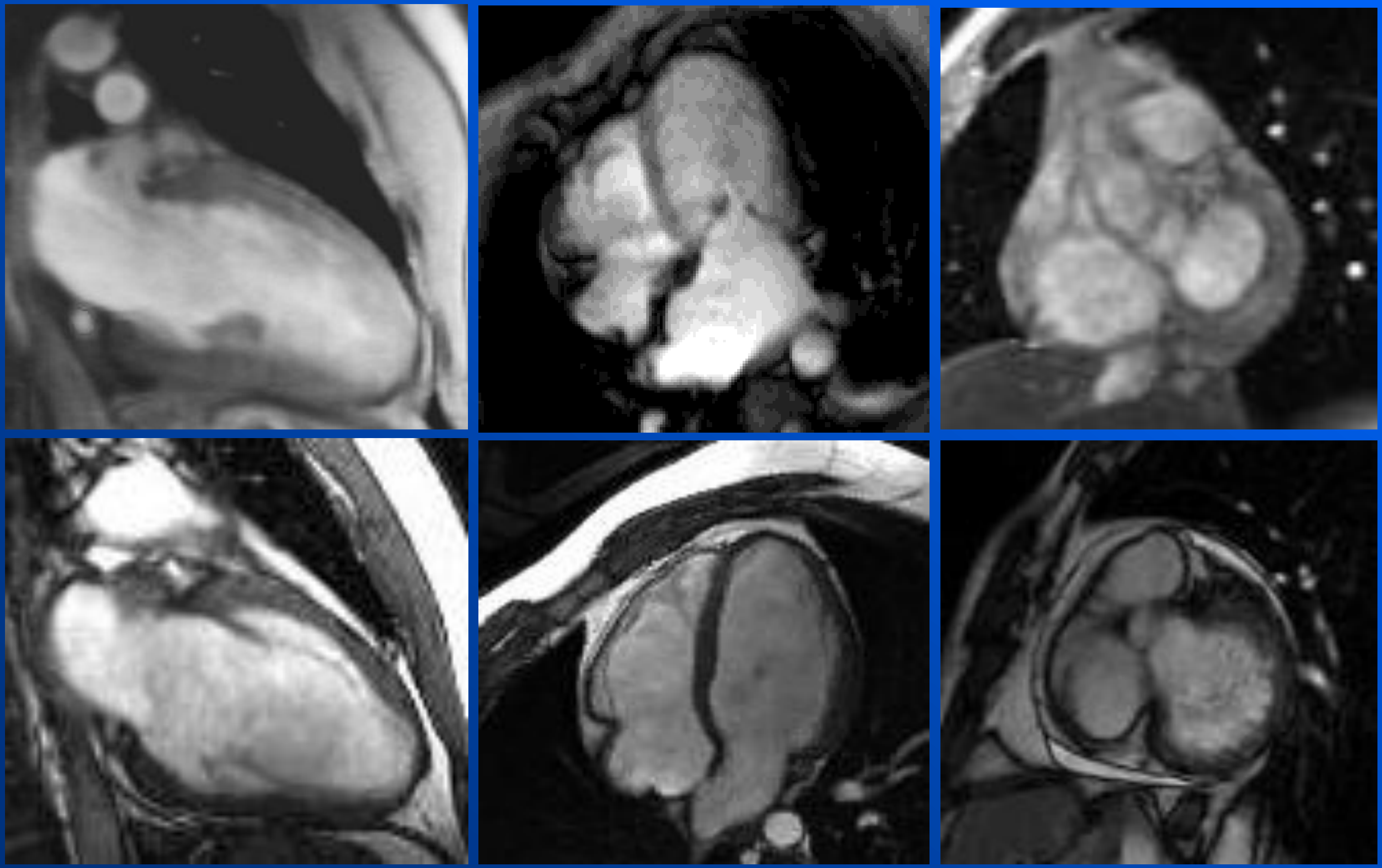


Cine –GRE (SPGR)

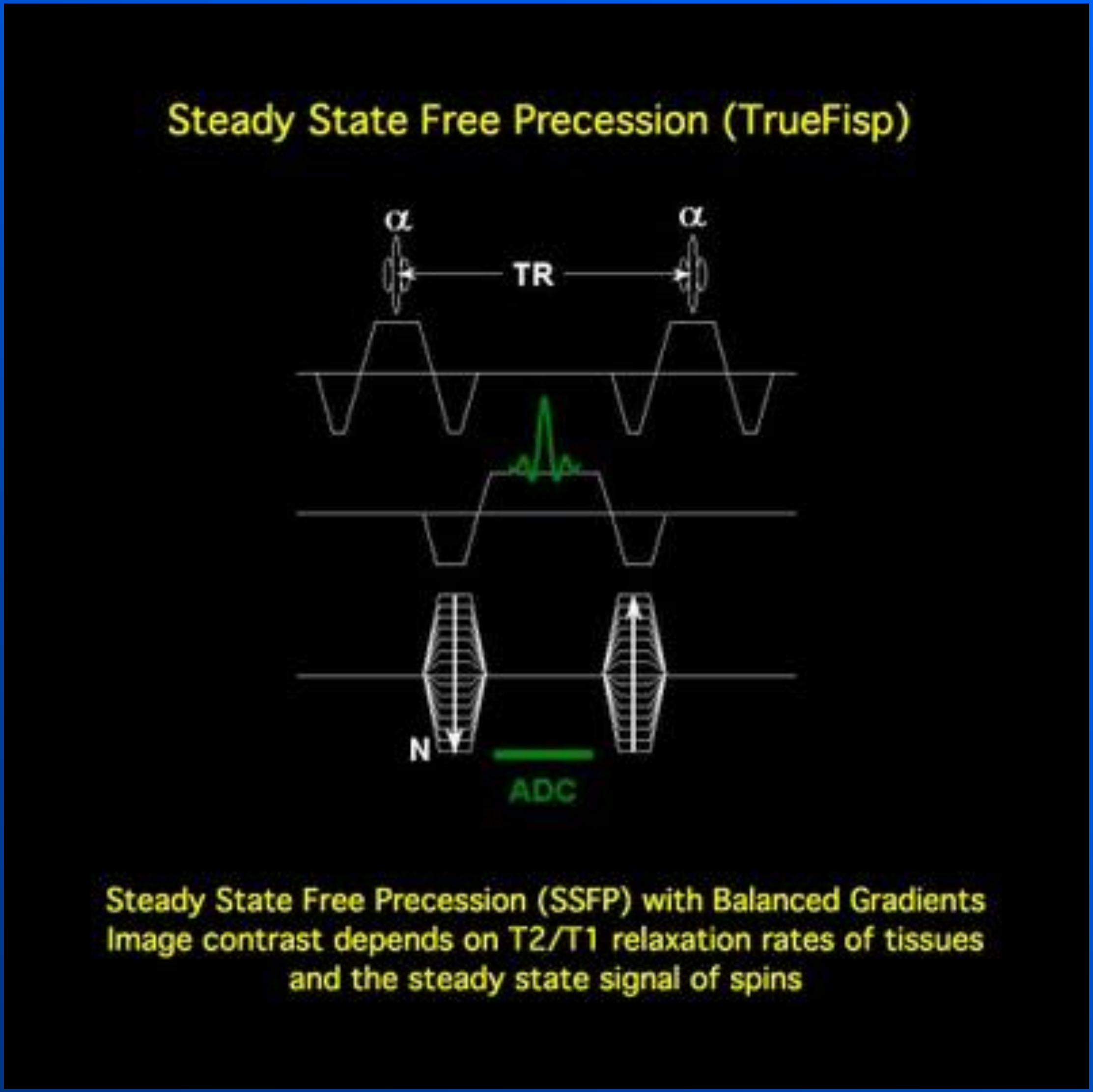




CINE-CMR

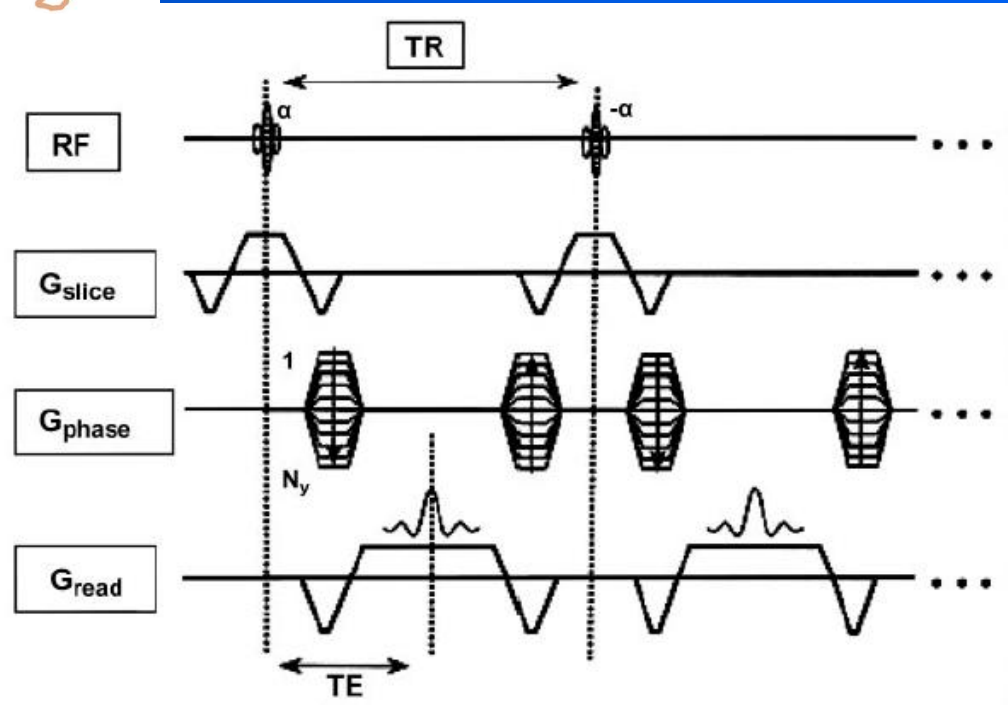


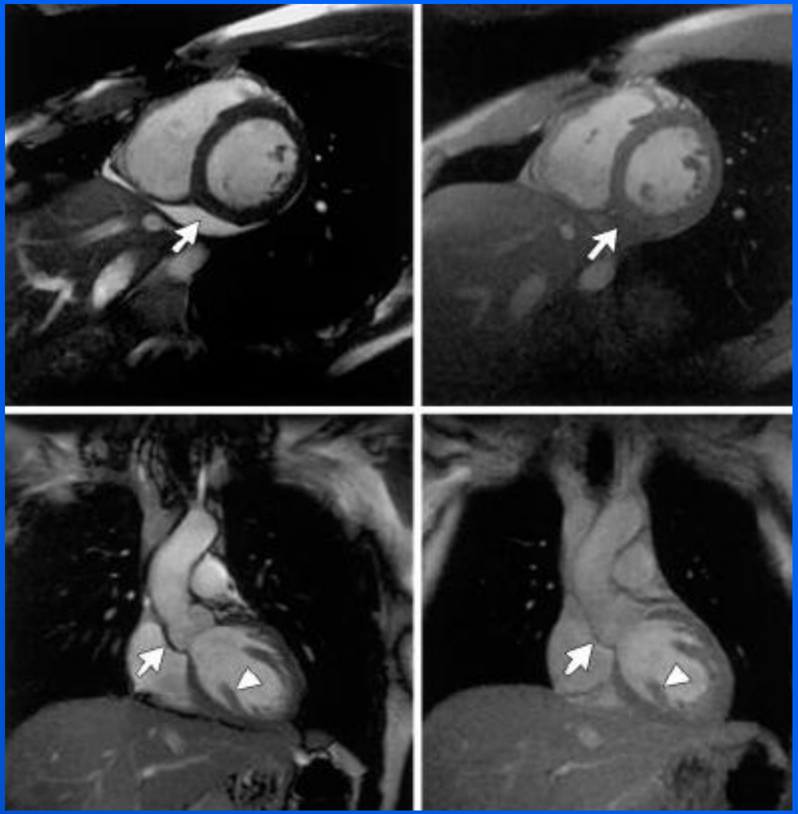
SSFP



Steady state: short TE and TR<10 msec → T2/T1w

SSFP

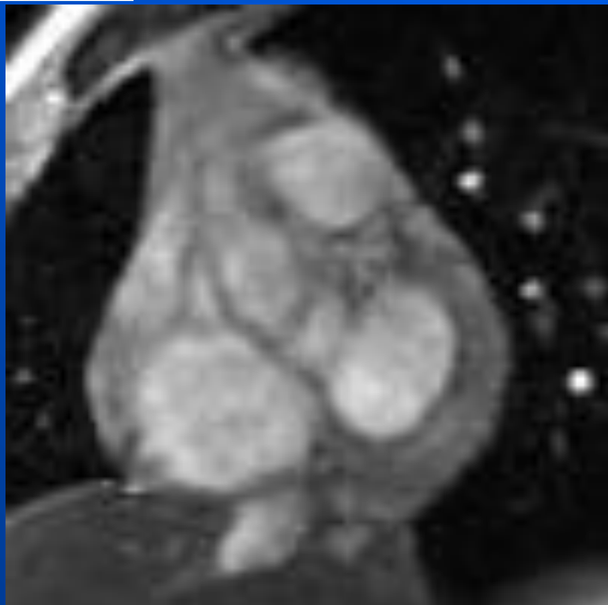




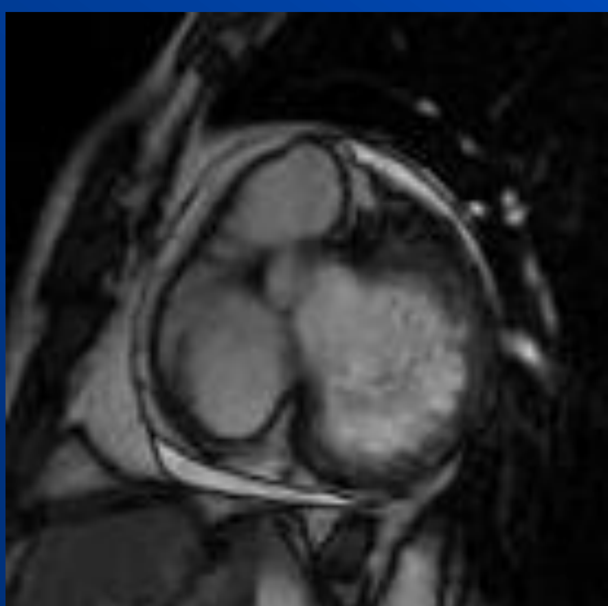
Gradients *(G)* are fully balanced along all three (section-selective, phase-encoding, and readout) axes.

The sum of positive gradient areas is exactly balanced by the sum of negative gradient areas. In this case, echo and readout occur midway between RF pulse.

MRI: cine-pulse sequences



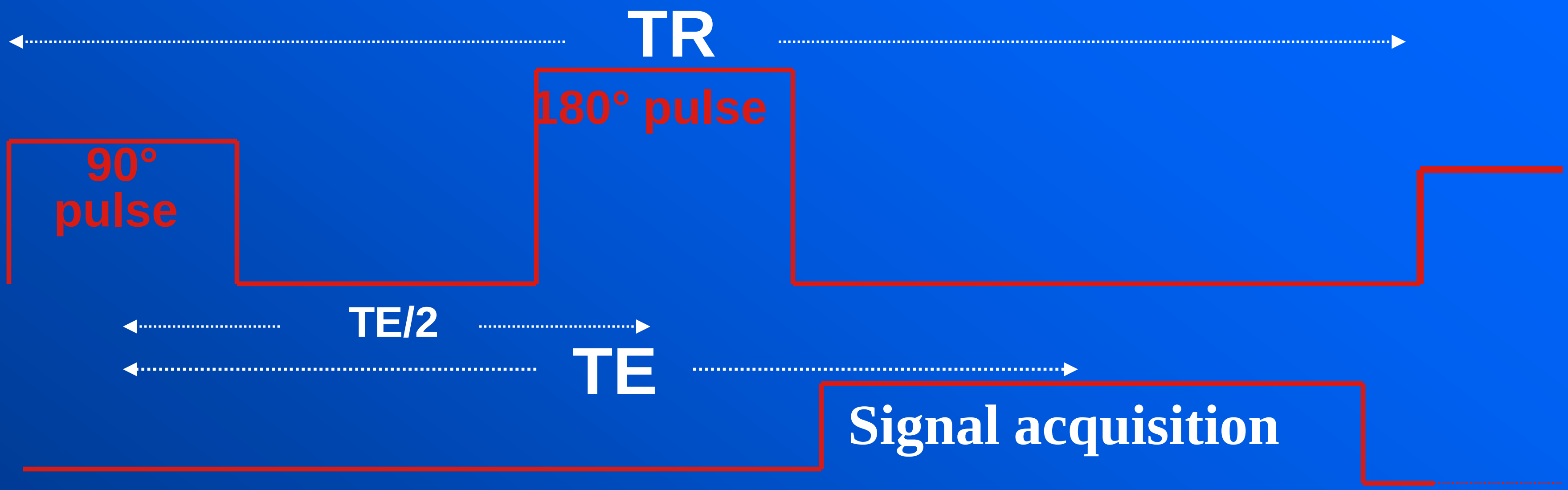
GRE

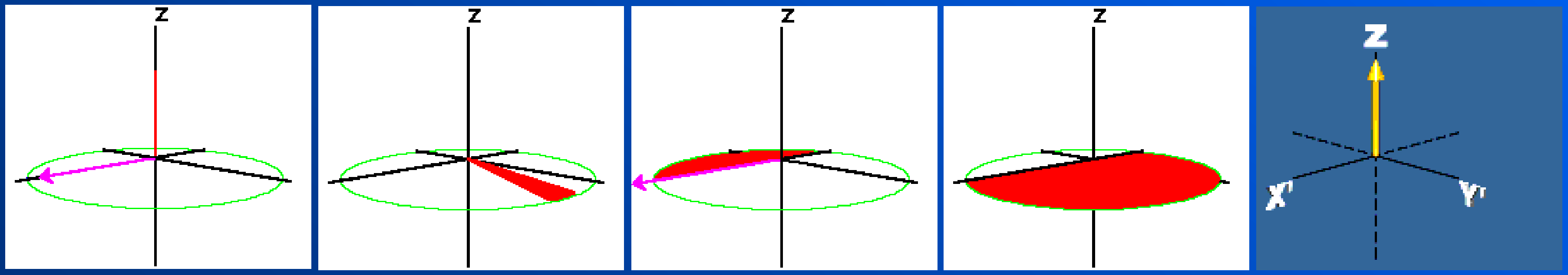


SSFP

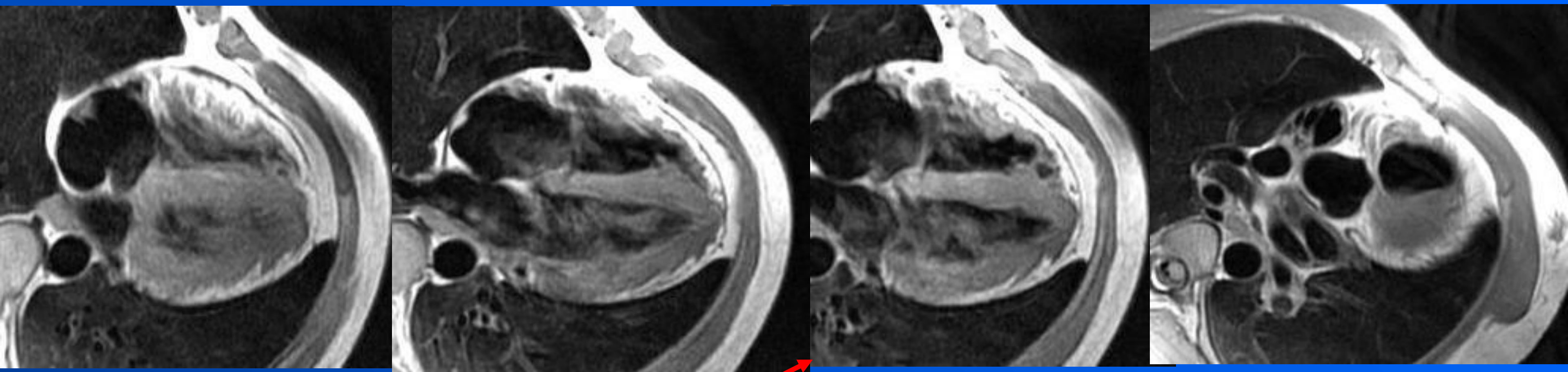
	SSFP
TE	Minimun
TR	HR depending
FLIP ANGLE	45° to 60°
RBw	125 kHz
FOV	20-40
THICKNESS	5-8 mm
SPACING	0.0
NEX	1+ (BH or FB)
N° Phase	30
View per segm.	8-16 to 30-32
R-R	1

SPIN-ECHO



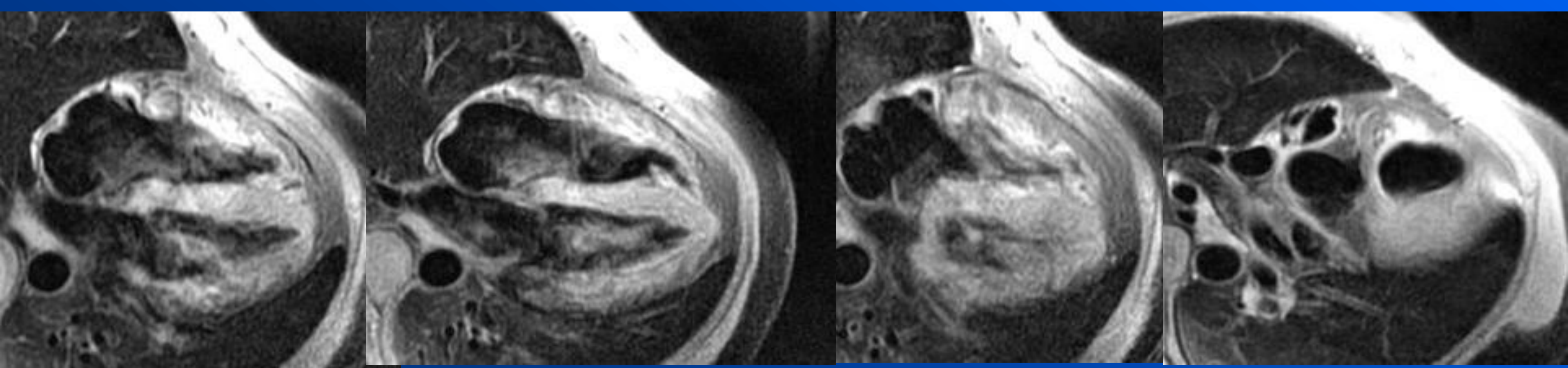


FSE BLACK BLOOD

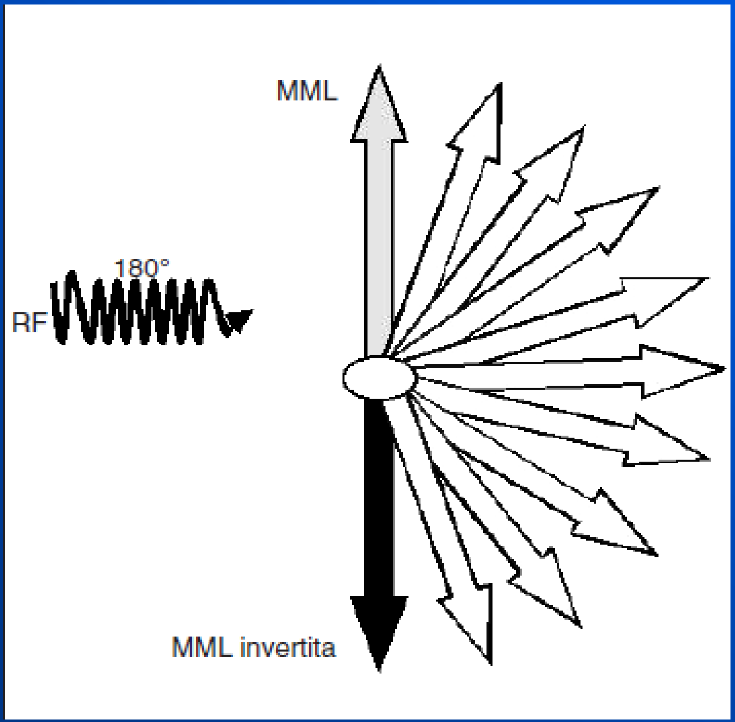


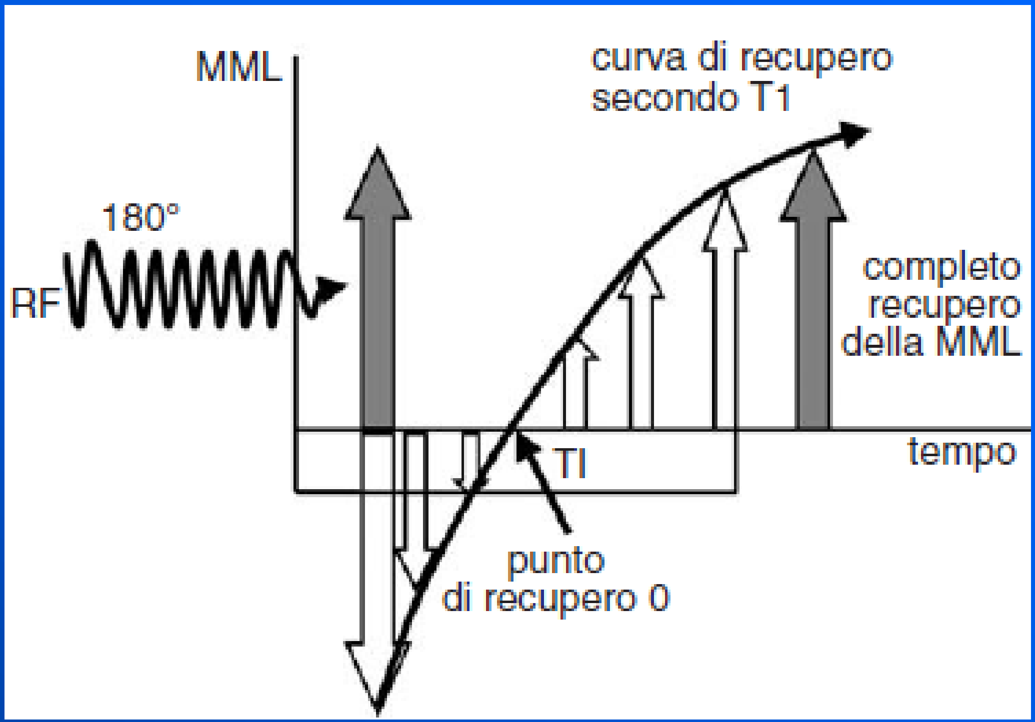
T1 weighted SpinEcho

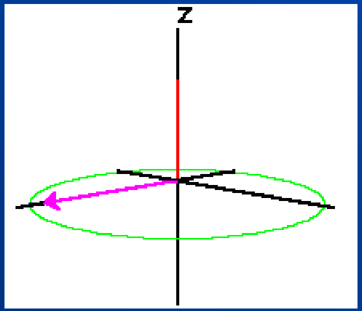
T1 weigthed Spinecho with fat saturation

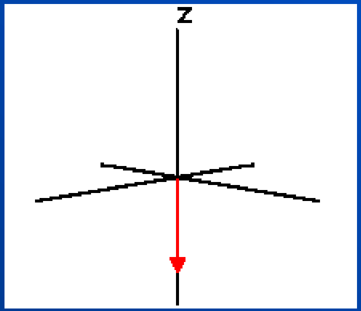


INVERSION RECOVERY: 180° RF

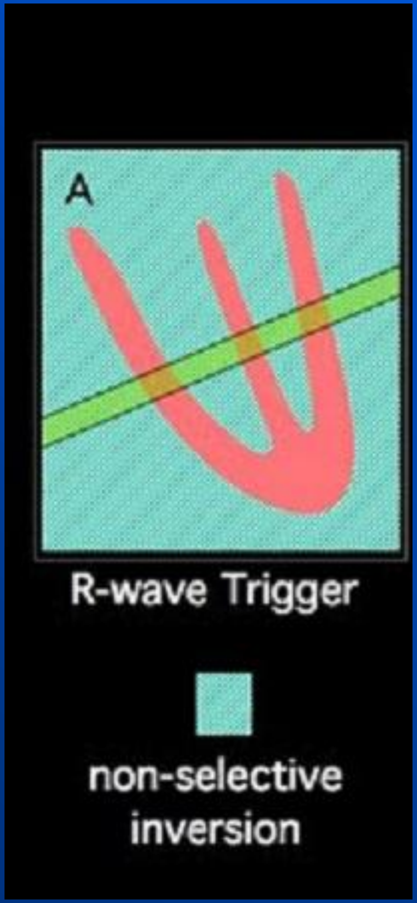








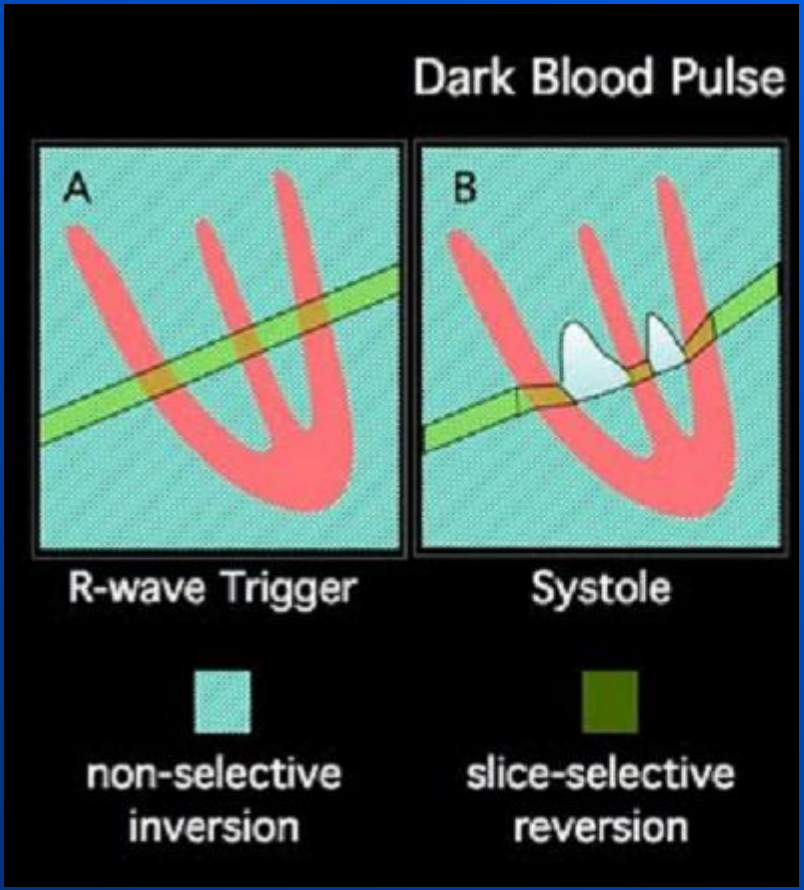
DOUBLE-IR



DOUBLE IR

A non-selective 180° inversion pulse excites all the tissues and blood within the entire heart when the R-wave trigger is detected at the beginning of the cardiac cycle

DOUBLE-IR

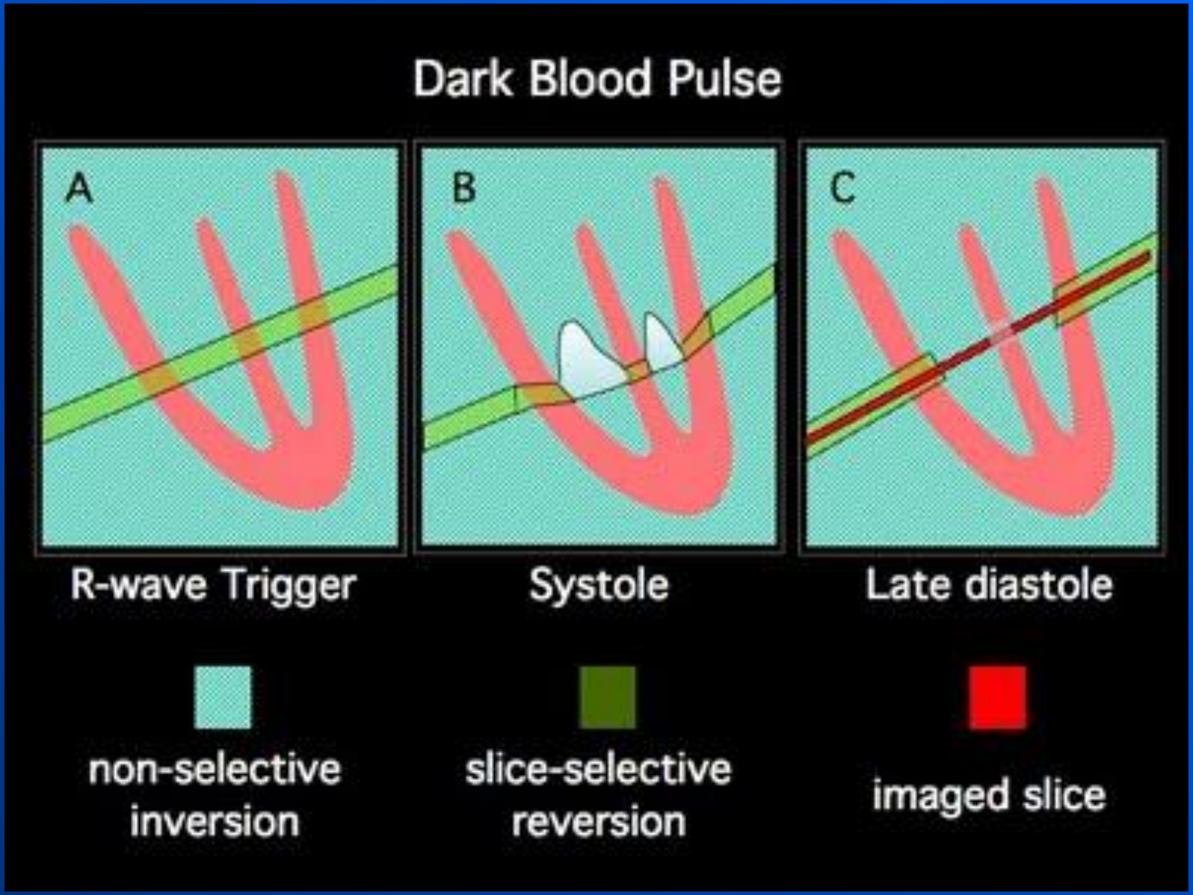


DOUBLE IR

Immediately following, a slice-selective re-inversion pulse excites only the tissues and blood within the image slice.

The net result is that everything within the slice is flipped back to normal because it experienced both the inversion and re-inversion pulses, whereas everything outside the slice remains inverted.

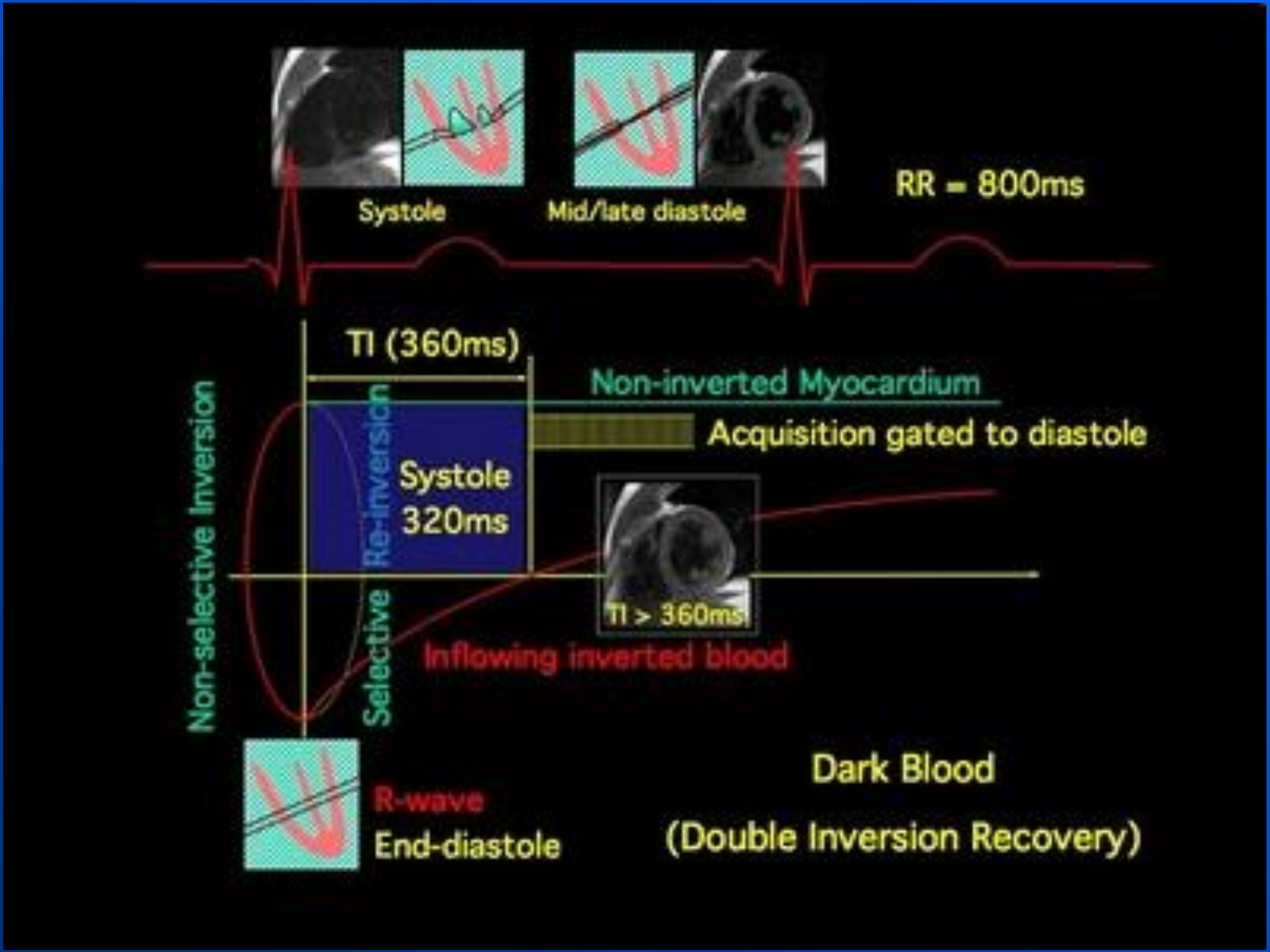
DOUBLE-IR



systolic contraction forces the blood within the slice to be replaced by blood from outside the slice.

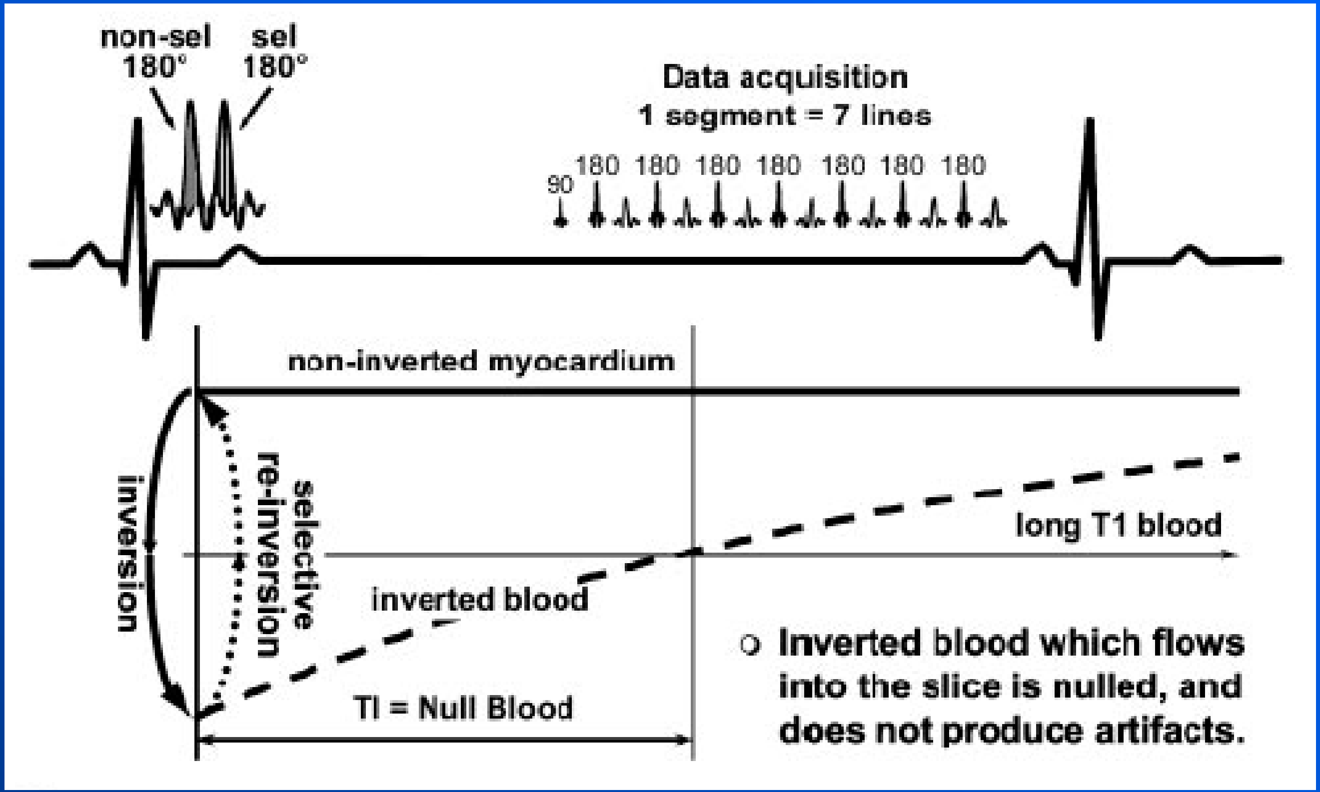
After enough time delay has occurred to allow the blood to be fully replaced within the slice, the image data is collected during mid to late diastole of the cardiac cycle.

DOUBLE-IR



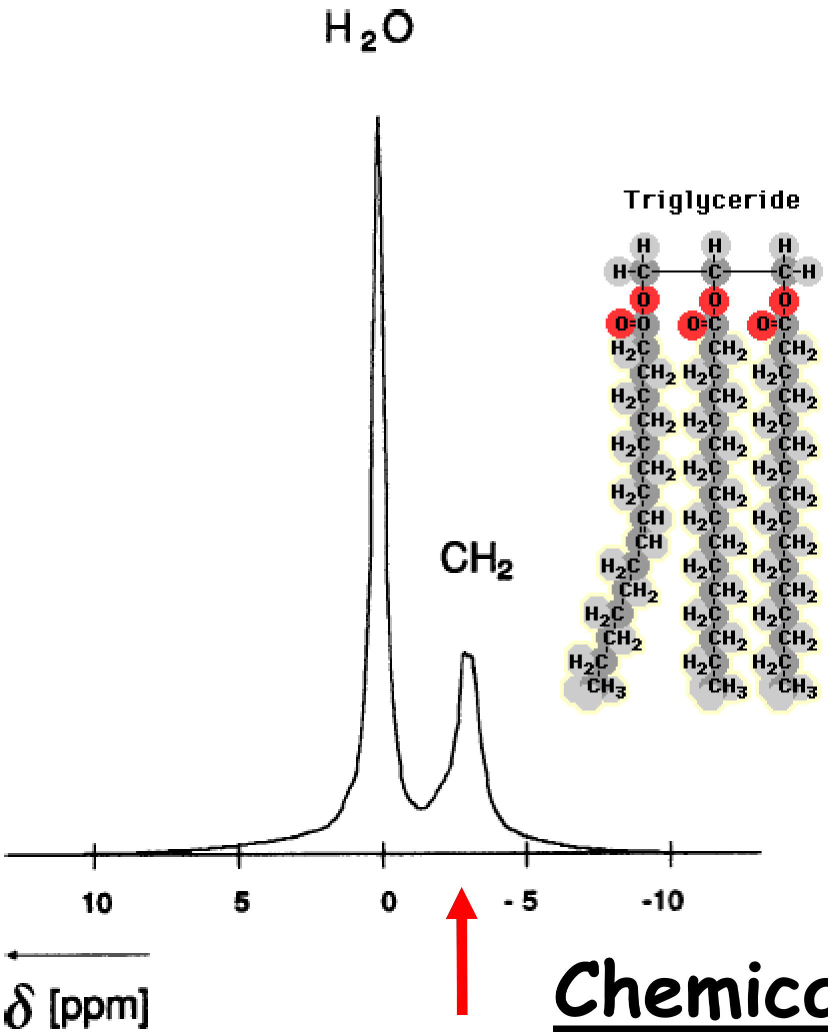
Systole
Mid/late diastole
RR = 800ms
TI (360ms)
Non-inverted Myocardium
Acquisition gated to diastole
Non-selective Inversion
Re-inversion
Selective
Systole
320ms
TI > 360ms
Inflowing inverted blood
R-wave
End-diastole
Dark Blood
(Double Inversion Recovery)

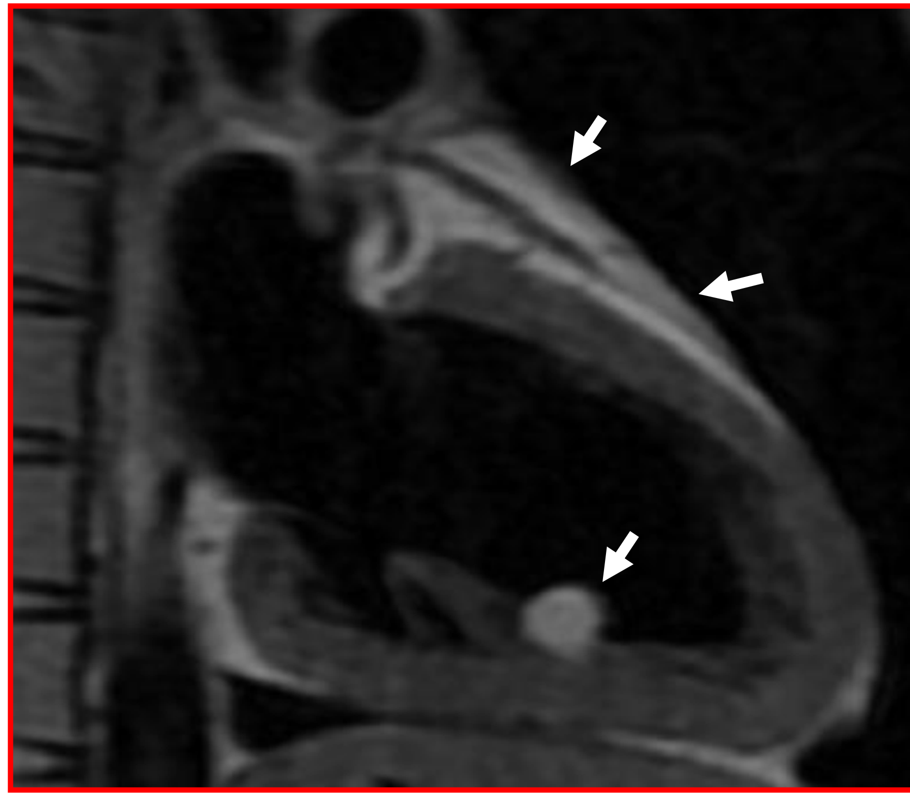
DOUBLE-IR



the readout module
(a 90° pulse followed by a train of refocusing 180° pulses)
is applied when blood is relaxing to zero, in-flowing blood produces no signal.

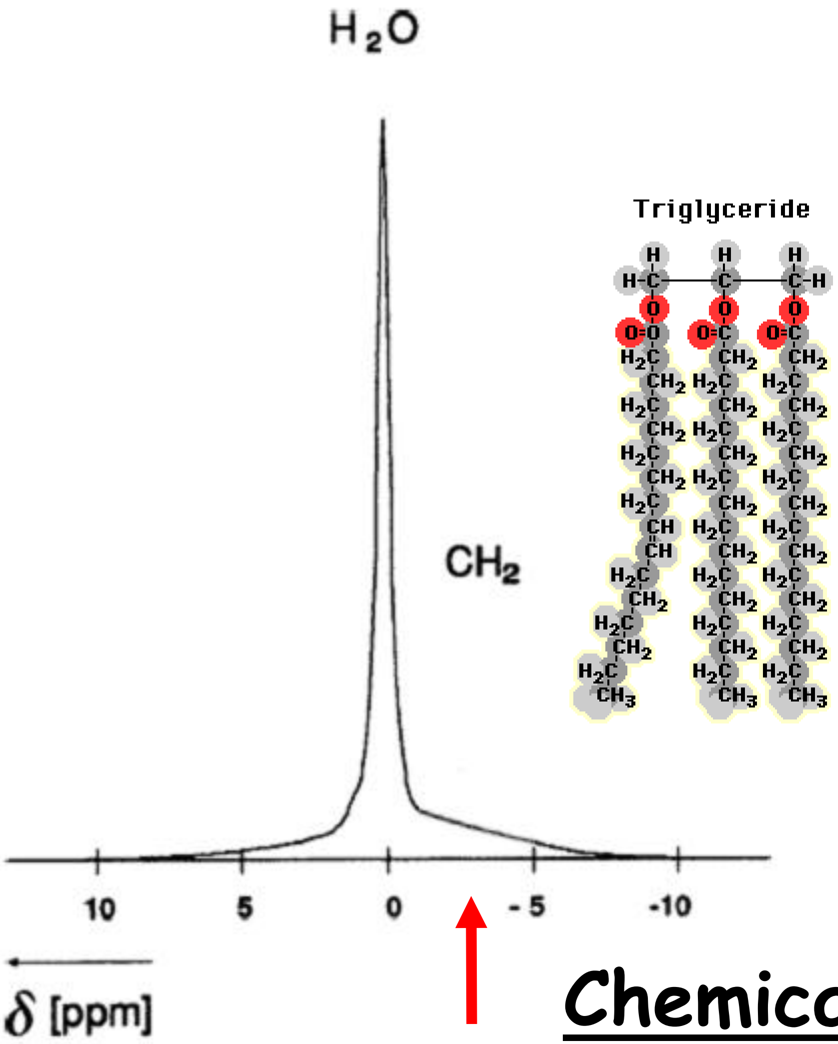
FSE and Double IR





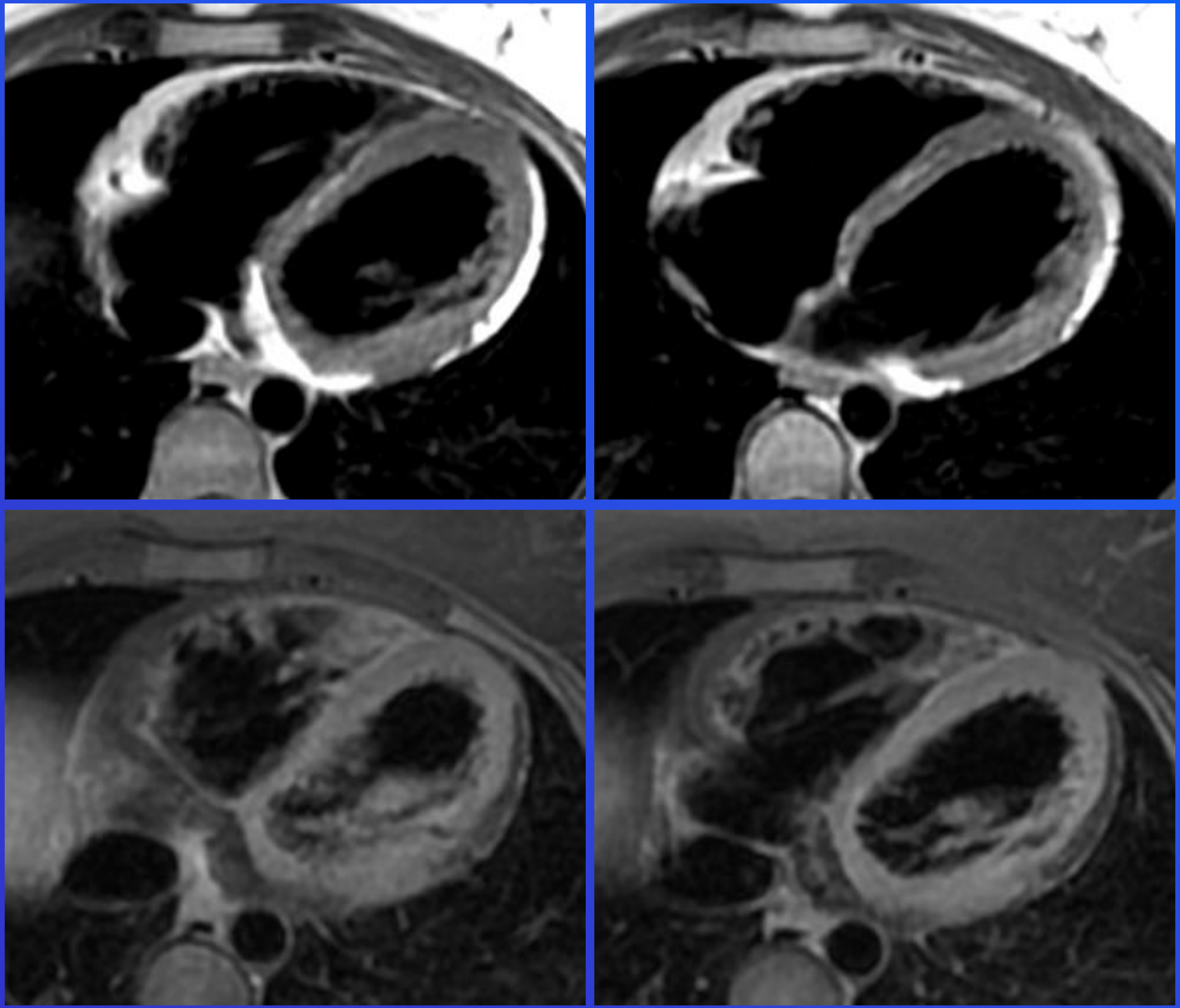
Chemical-Shift

FSE and Double IR



Chemical-Shift

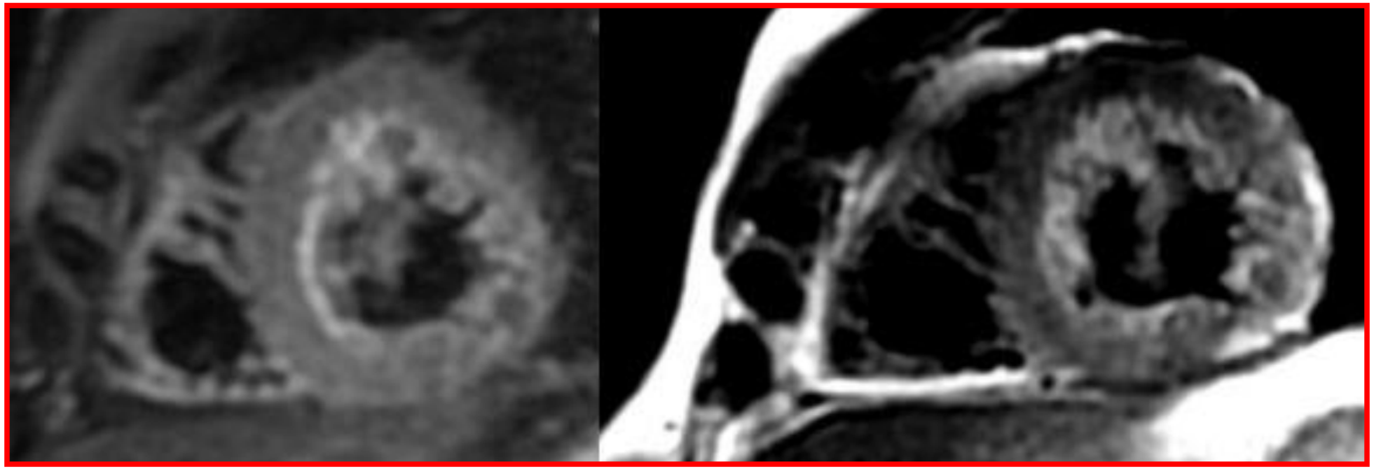
FSE and Double IR

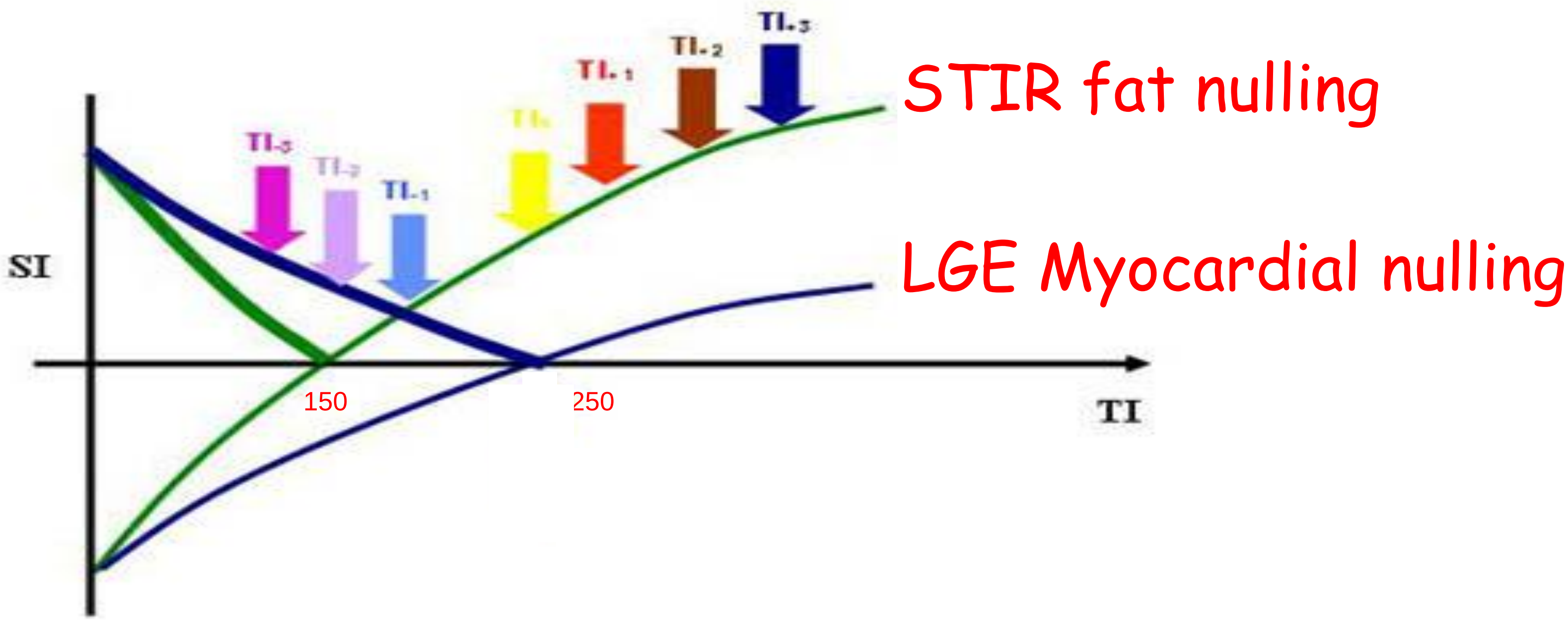


FSE

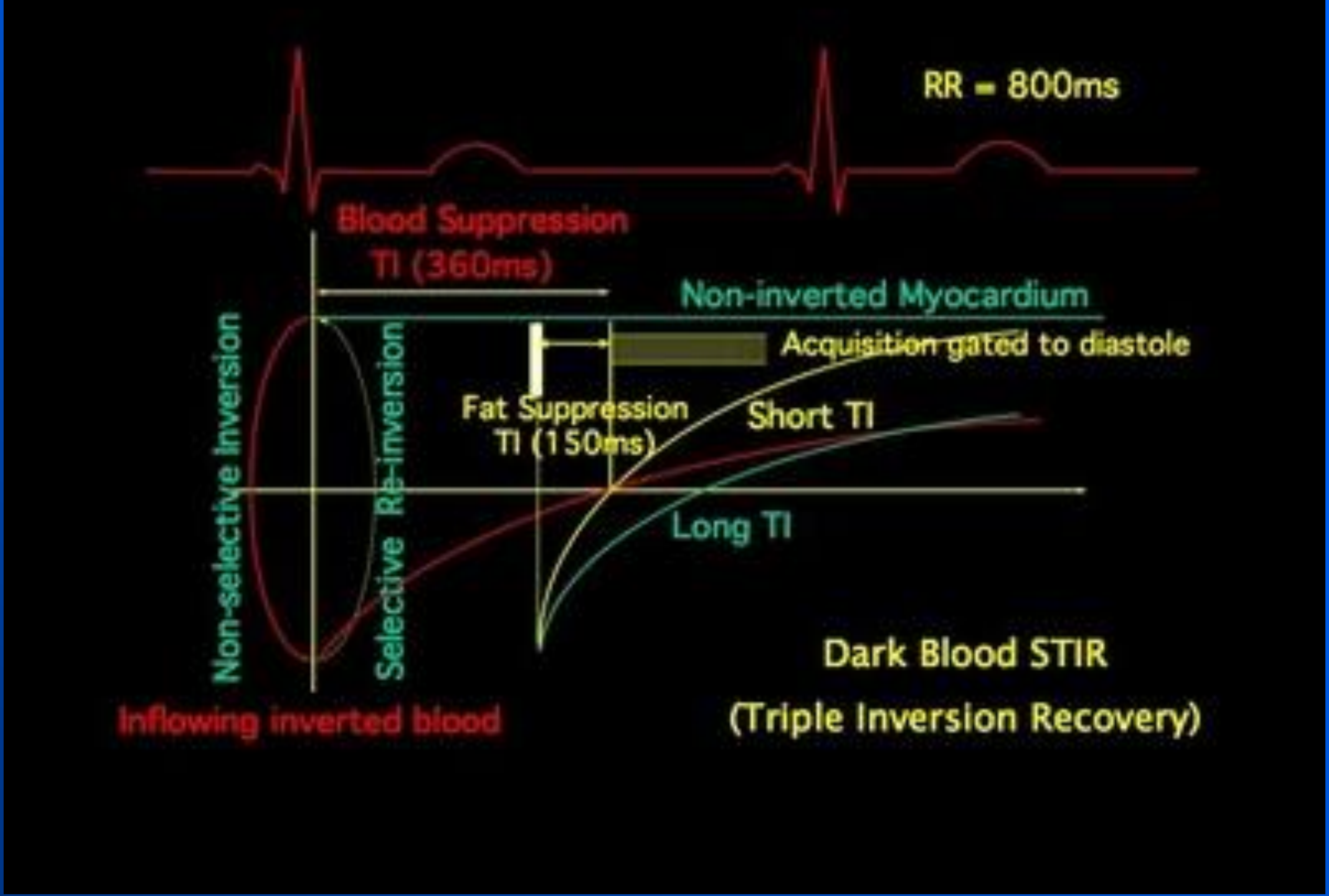
FSE FatSat

FSE and Double IR





STIR: TRIPLE IR



The third IR pulse and the fat signal are shown in yellow.
The delay time for fat to cross its null point is much shorter.
Both the blood and fat cross their null points at the same time that data is collected, both blood and fat will be dark in the image.

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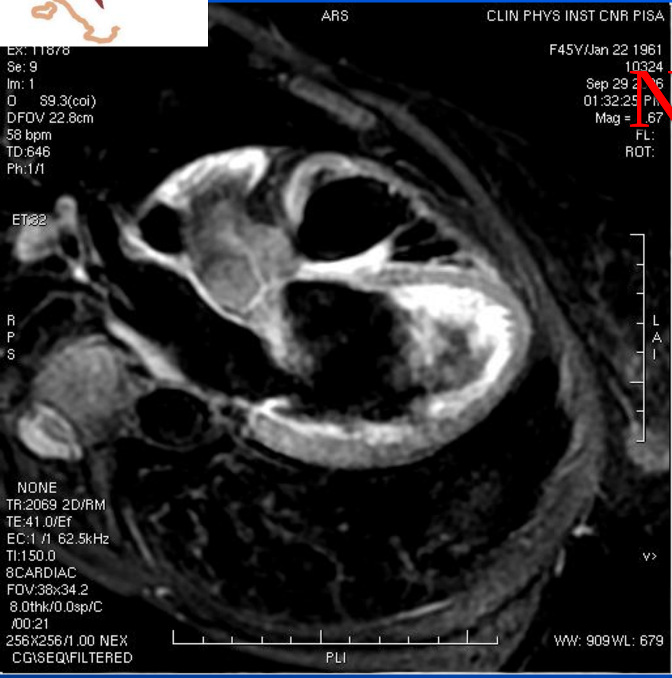
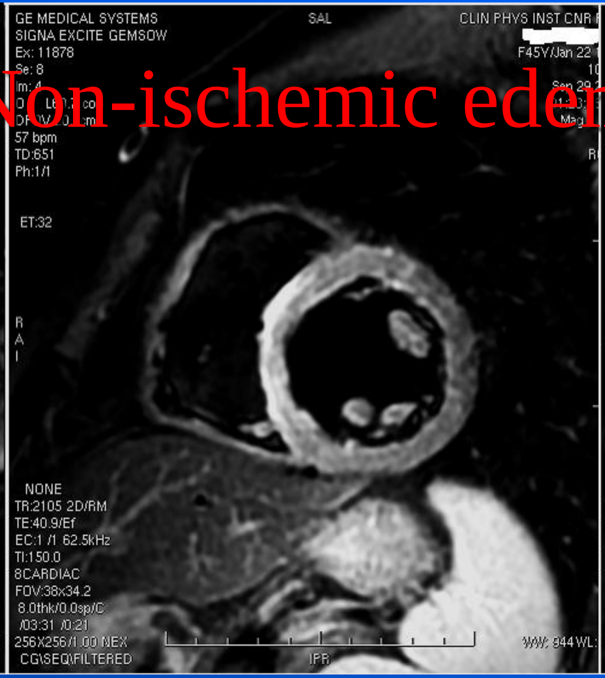
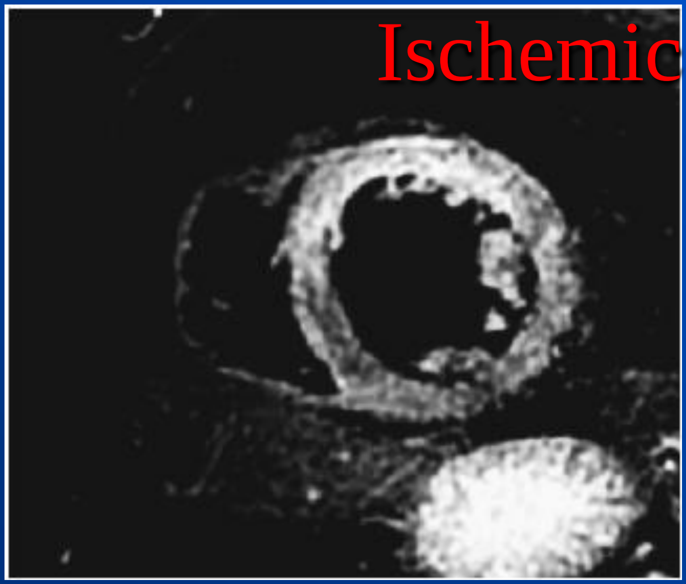
T2-STIR MYOCARDIAL EDEMA

Non-ischemic edema

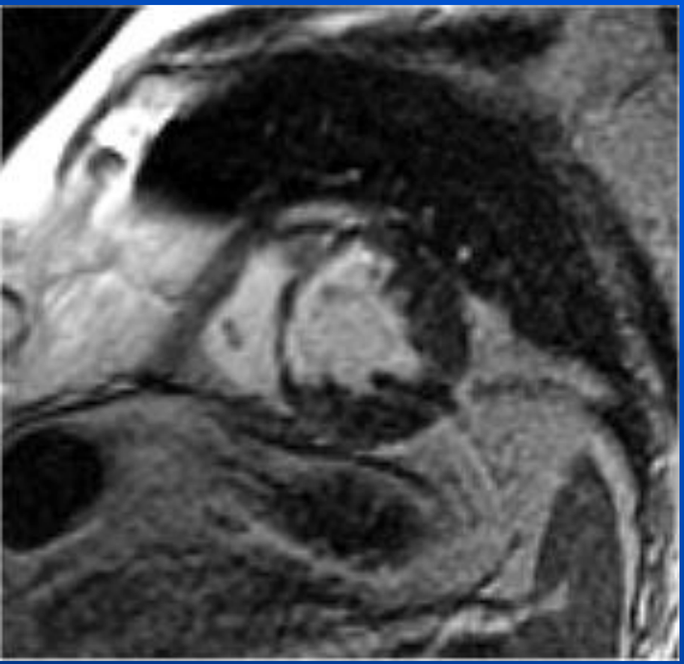


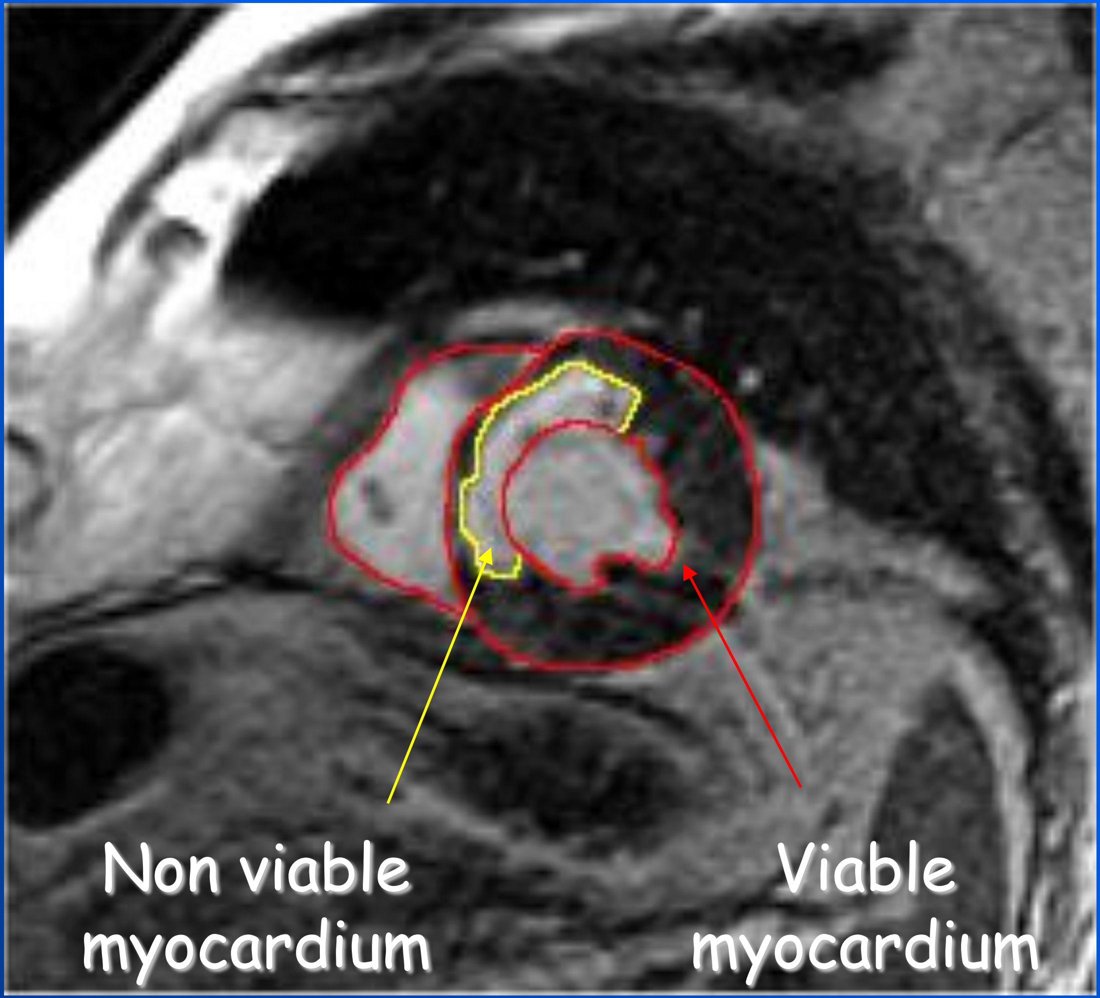


Ischemic edema



LATE GADOLINIUM ENHANCEMENT



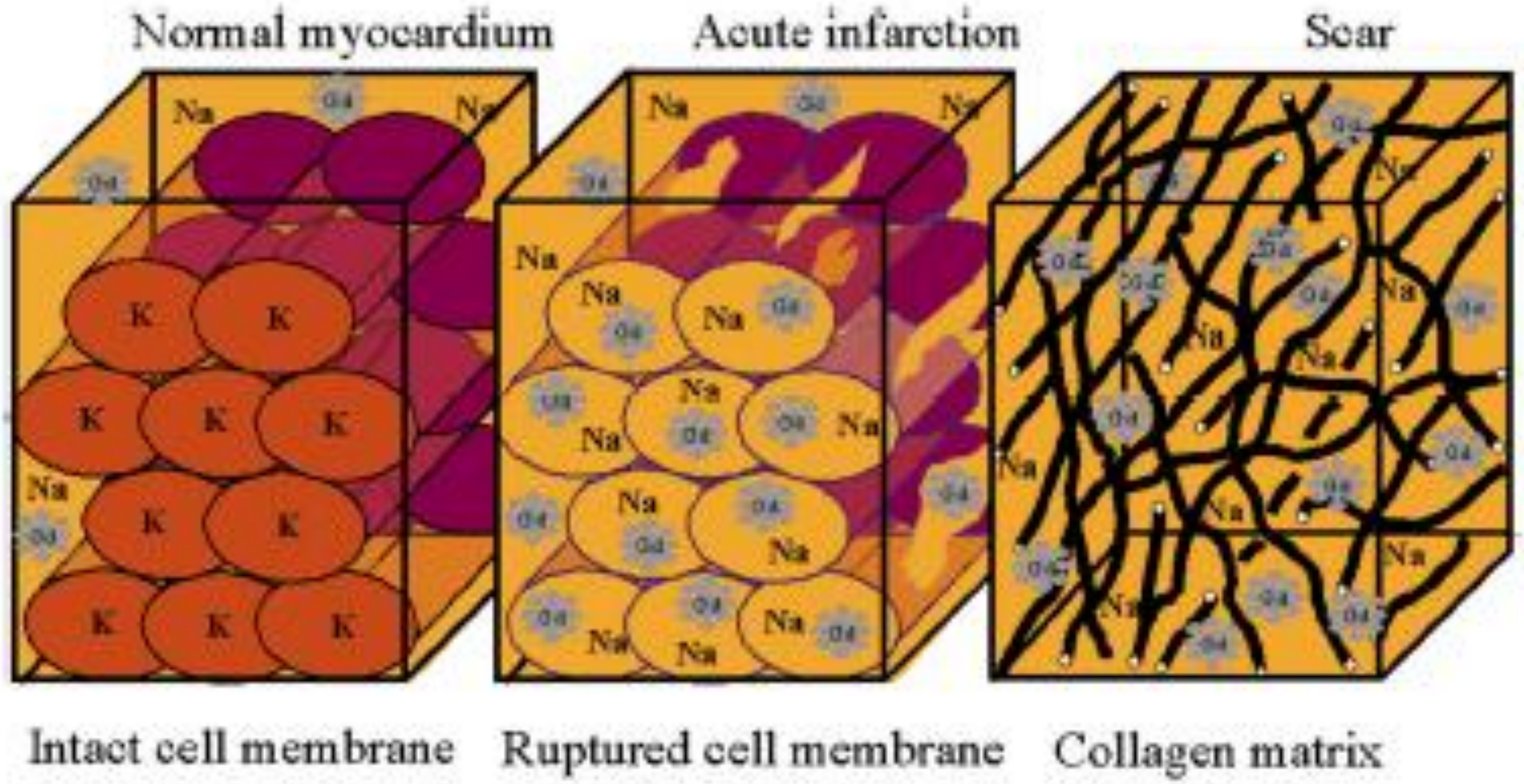


Inversion Recovery GRE T1w post mdc
TI to null myocardium

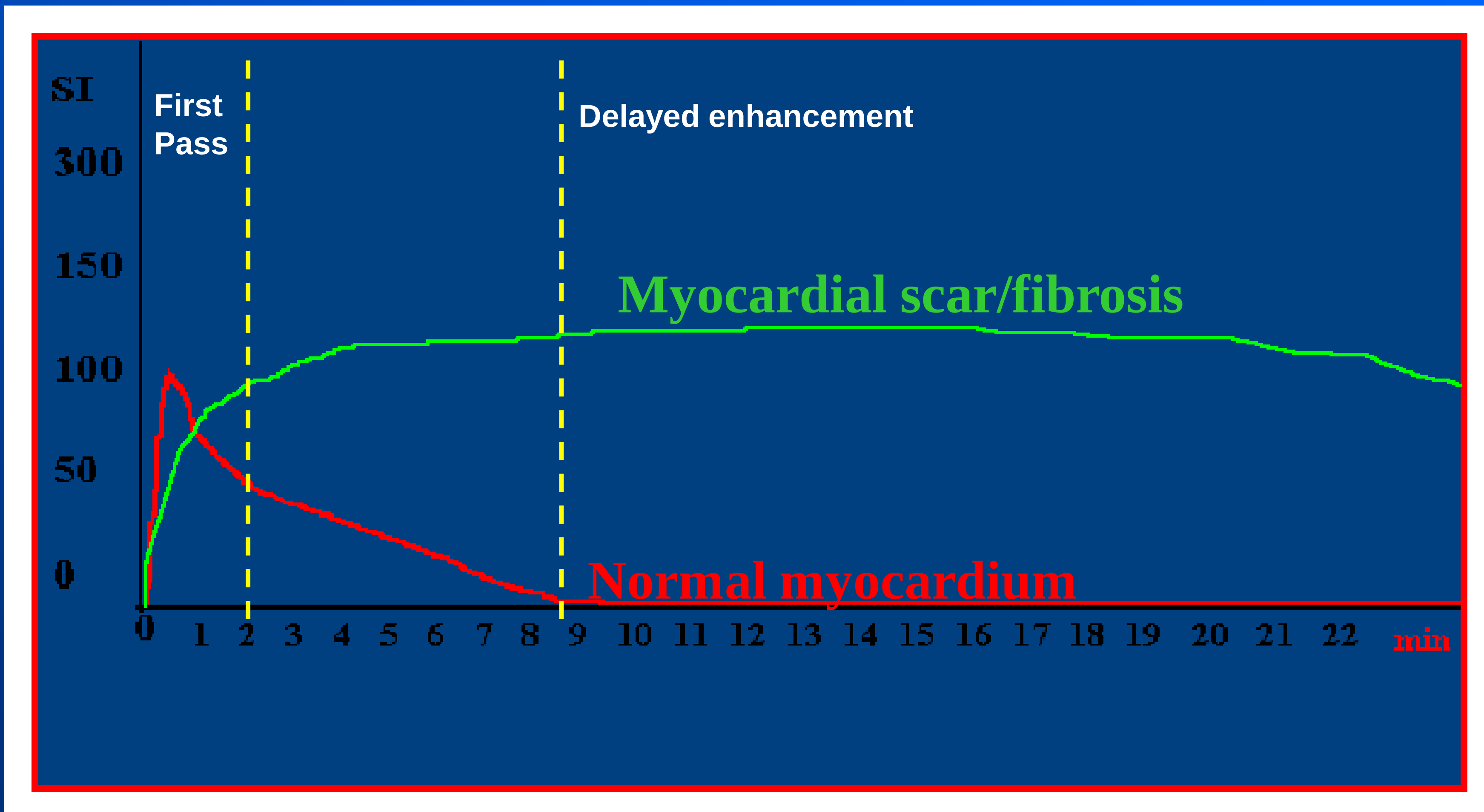
LATE ENHANCEMENT

The mechanism is a combination of:

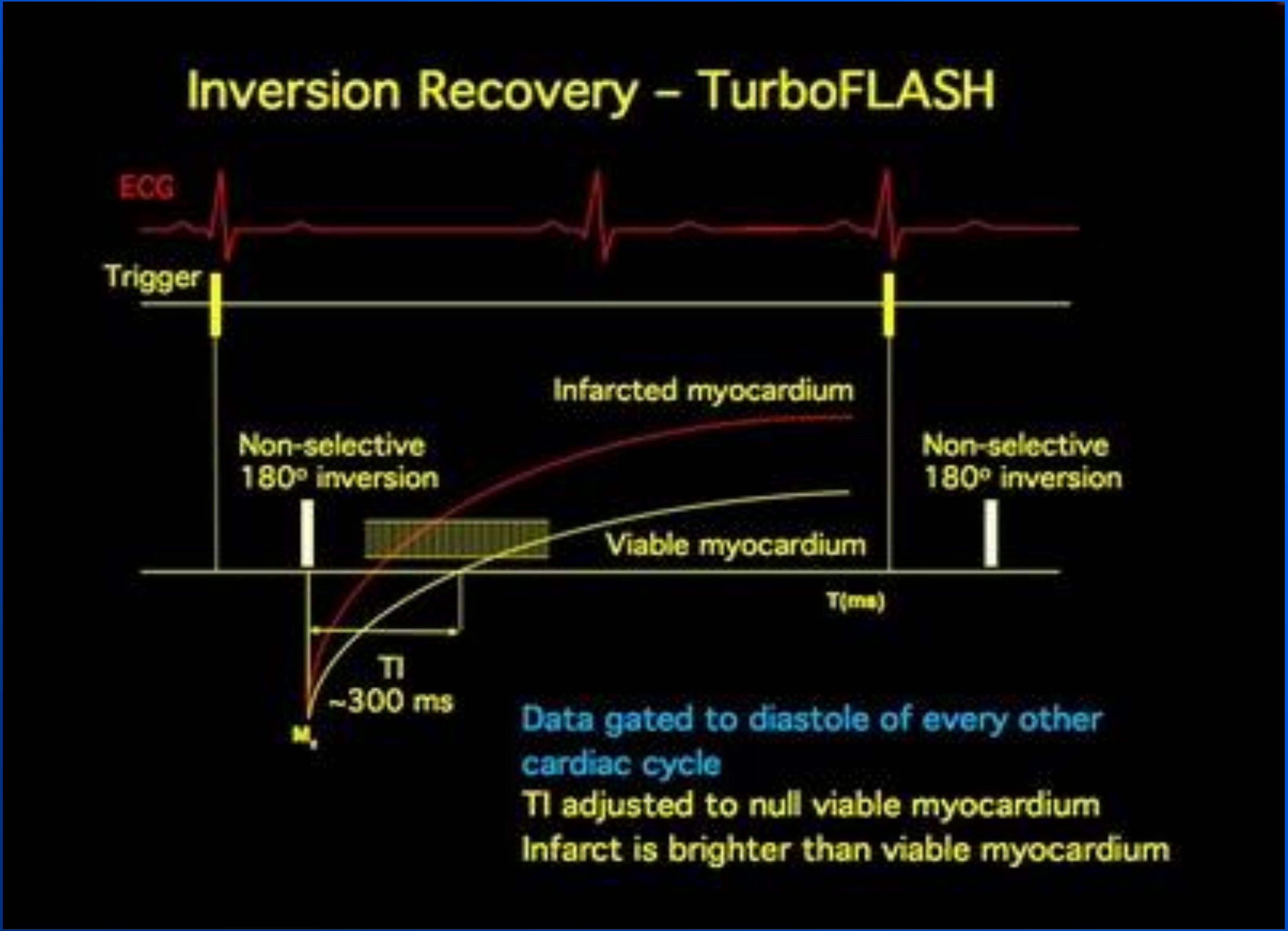
- delayed wash-in and wash-out kinetics of nonviable tissue
- acute and chronic disarrangement of interstitium
- different volumes of distribution of Gd in viable and nonviable tissue



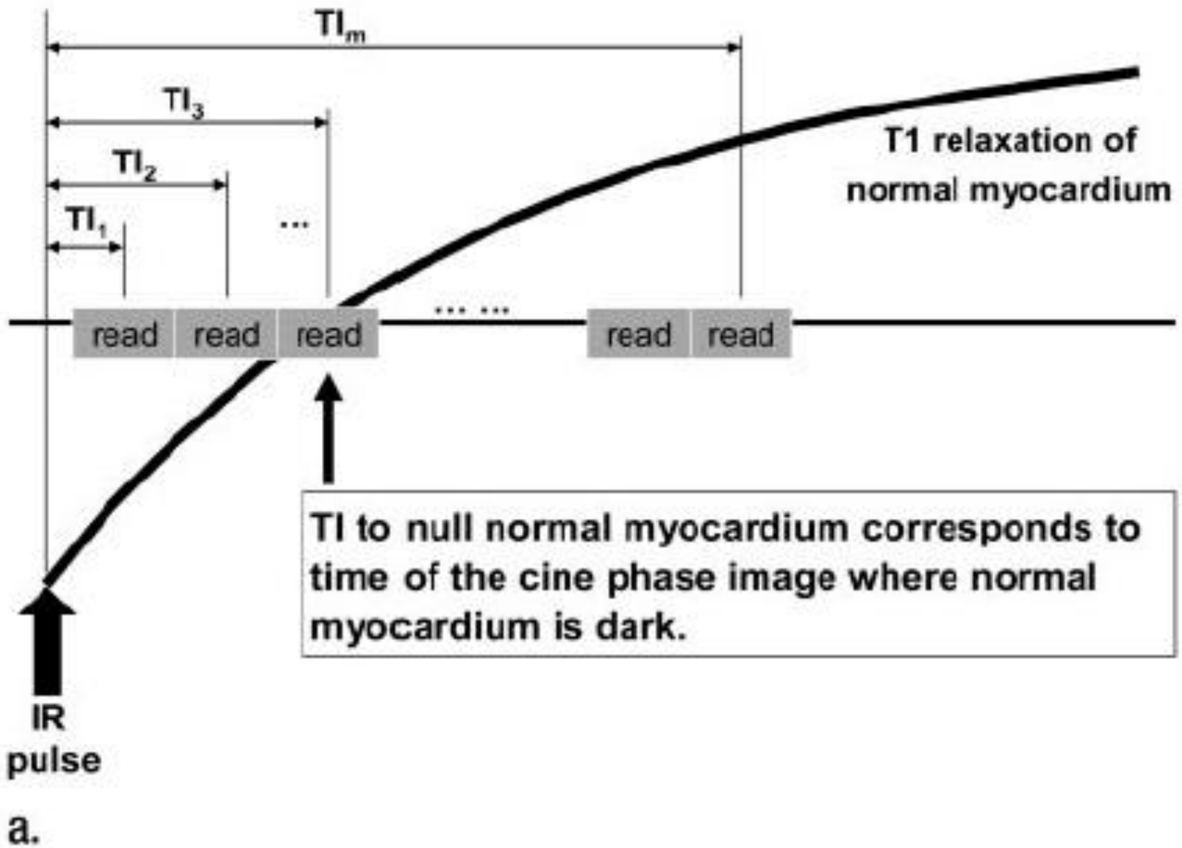
LATE GADOLINIUM ENHANCEMENT

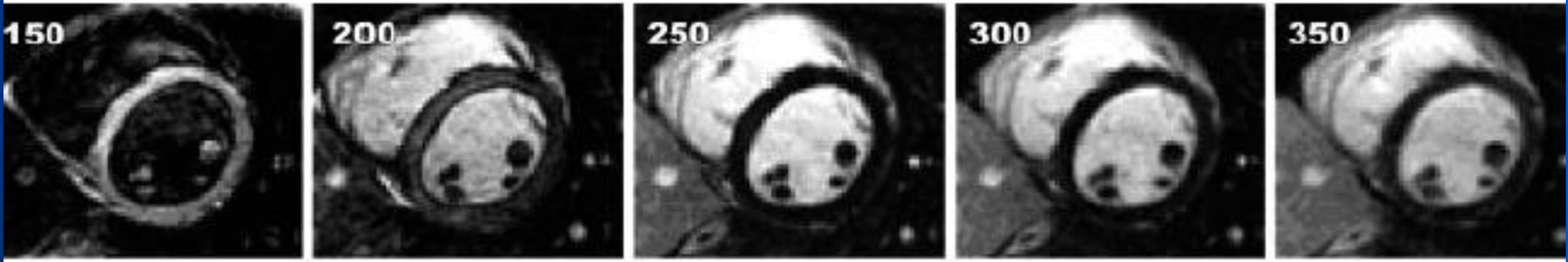


LATE GADOLINIUM ENHANCEMENT

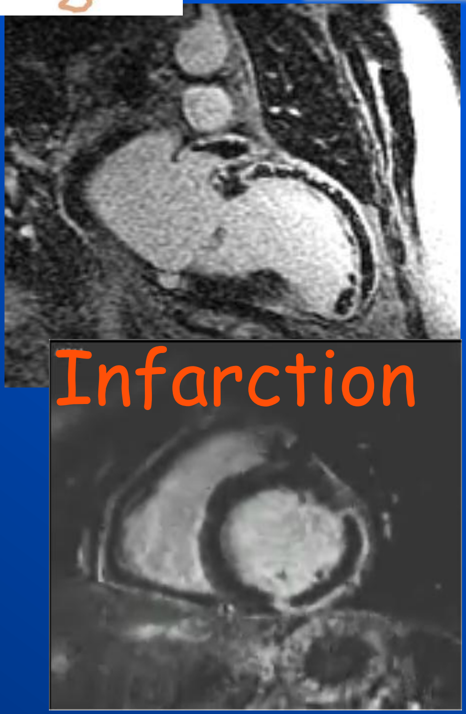


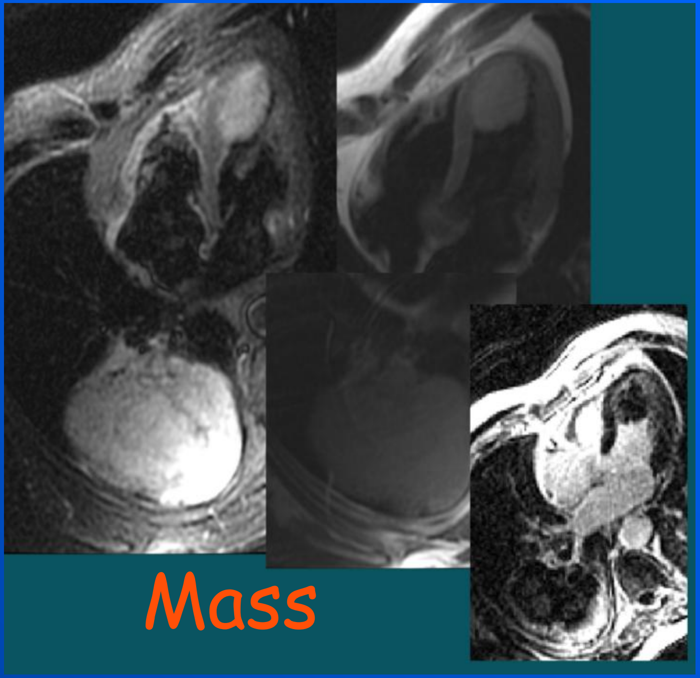
LATE GADOLINIUM ENHANCEMENT

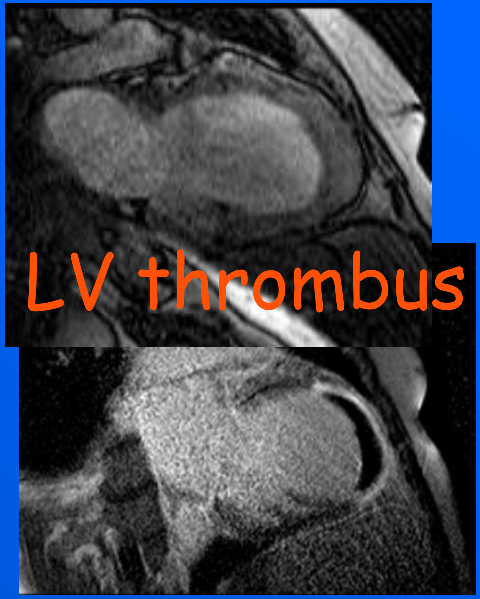


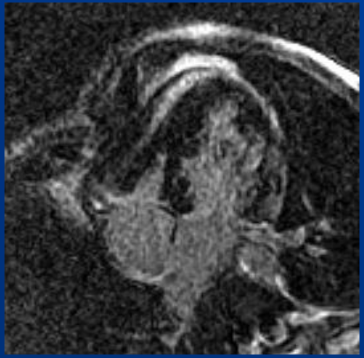


Applications of Late Enhancement

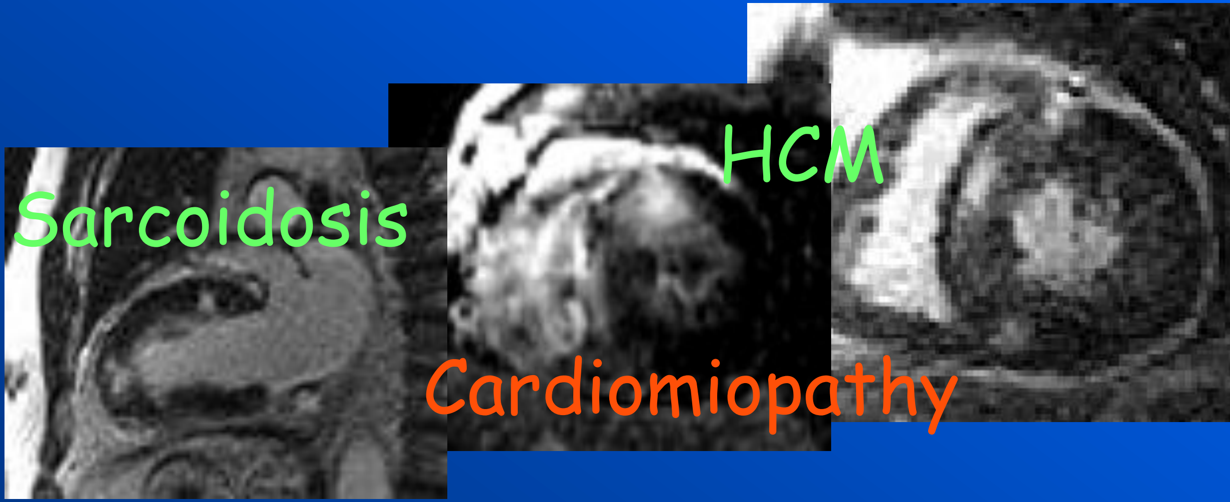








Myocarditis



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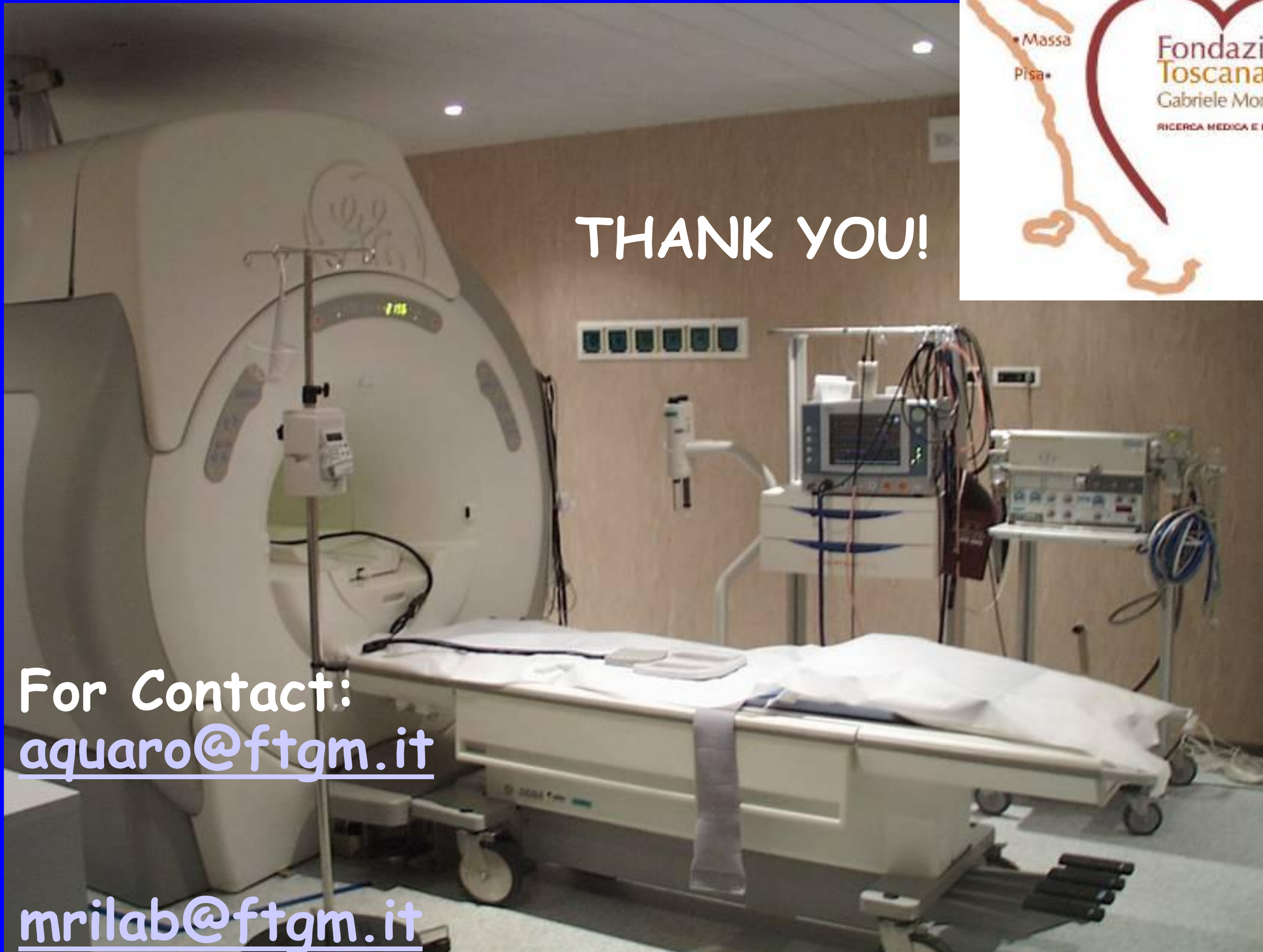
RICERCA MEDICA E DI SANITÀ PUBBLICA



THANK YOU!

For Contact:

aquaro@ftgm.it

mrilab@ftgm.it