MRI – pulse sequence

Zdroj: https://predmety.fbmi.cvut.cz/cs/doktorske-bme

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Operační program Výzkum, vývoj a vzdělávání

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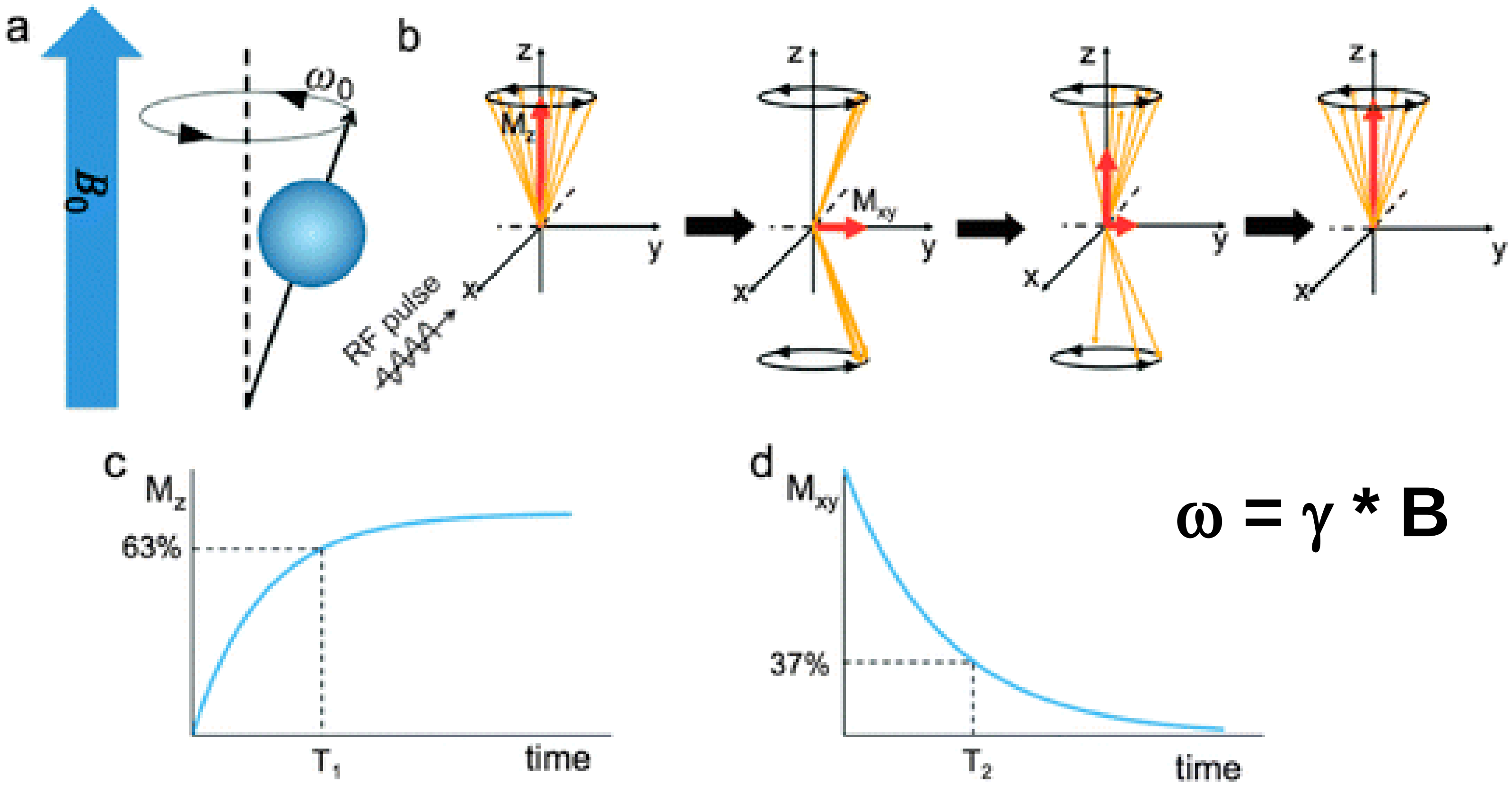
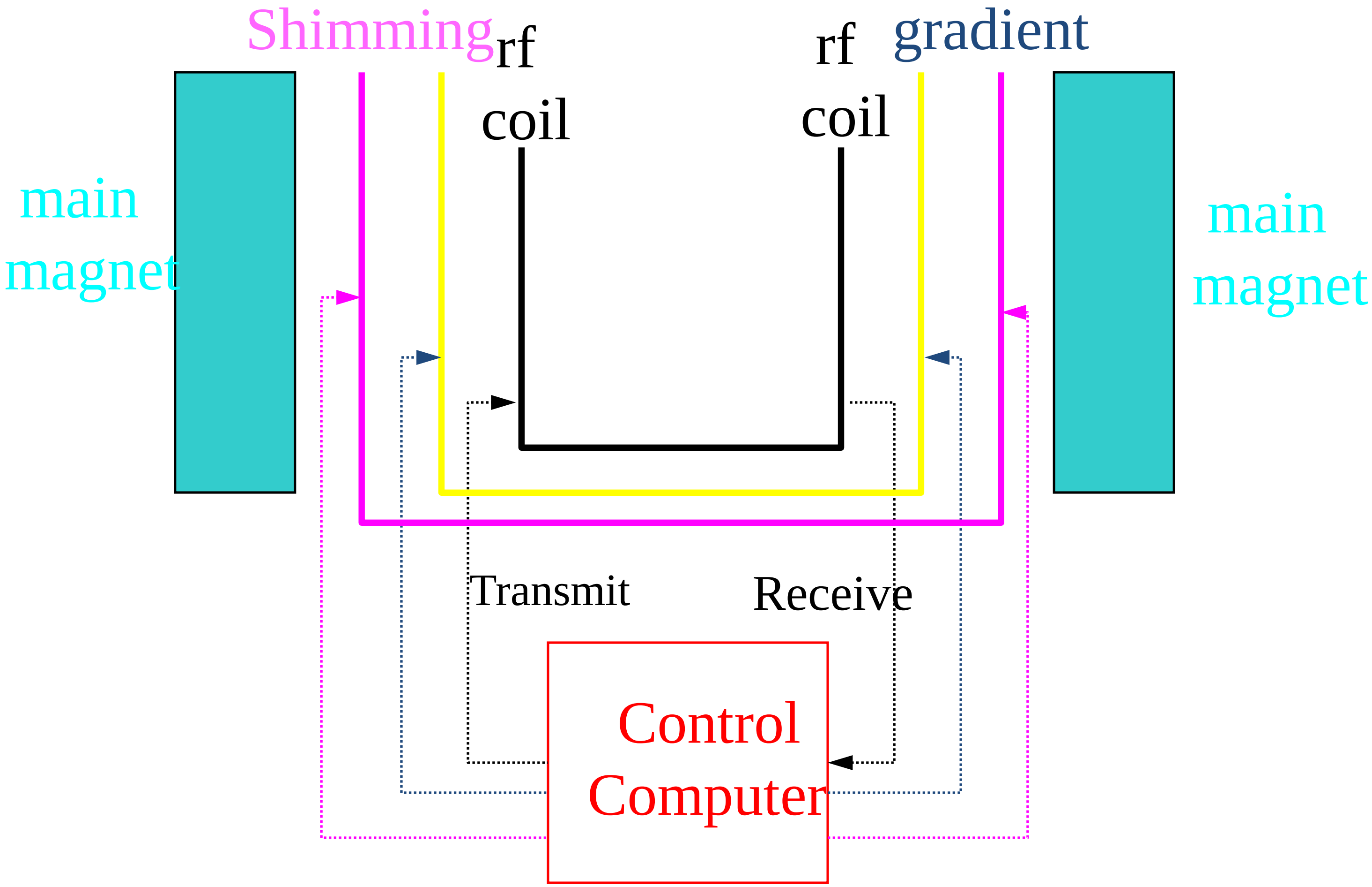
MRI Principle



$$\omega = \gamma * B$$

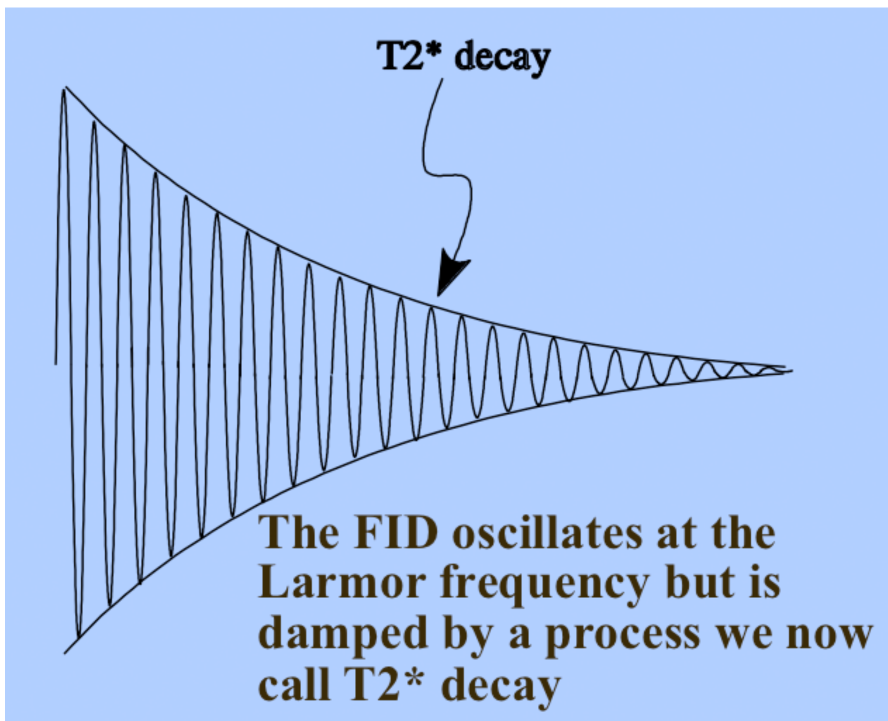
Magnetic resonance imaging

Components of MRI



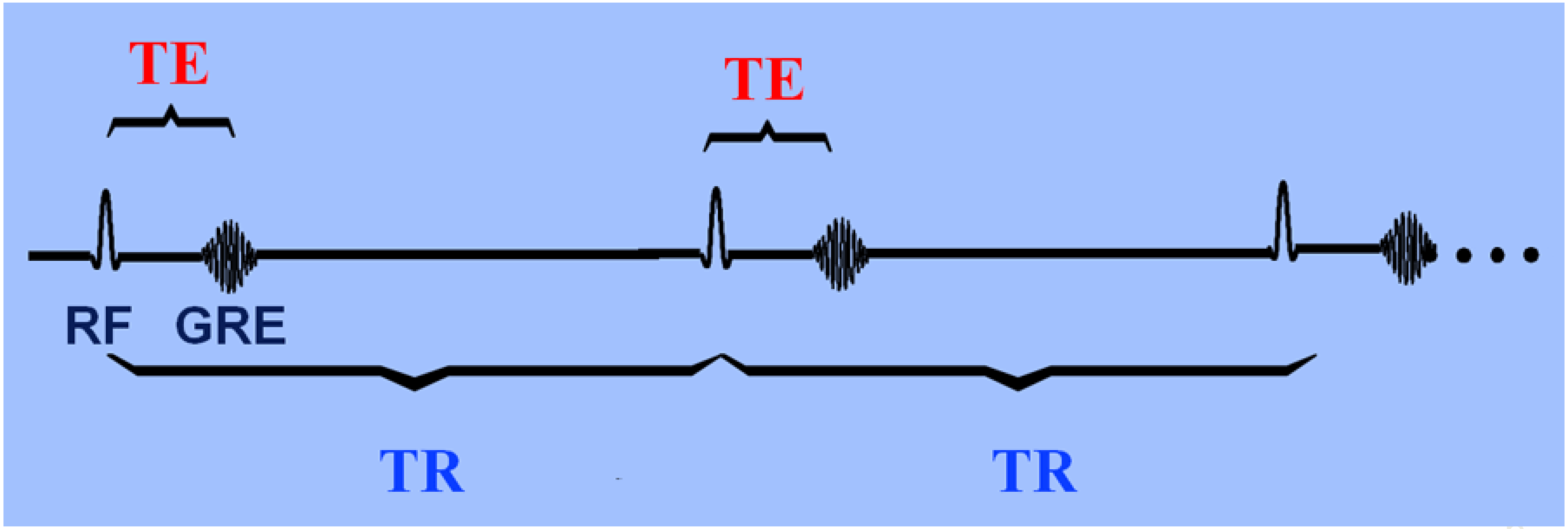
Free Induction Decay - FID

The FID has an underlying frequency of a sine wave oscillating at the Larmor frequency damped by exponential decay with time constant ***T2* ("T2-star")***. T2* reflects the effects of true T2 due to molecular mechanisms as well as phase dispersion due to magnetic field inhomogeneities.



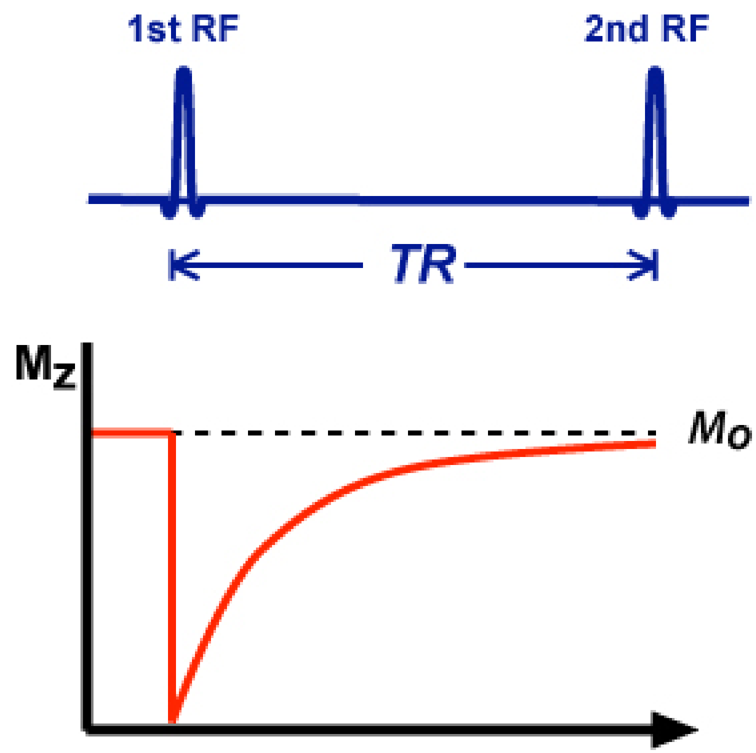
TR and TE

TR and ***TE*** are basic pulse sequence parameters and stand for ***repetition time*** and ***echo time*** respectively. They are typically measured in milliseconds (ms). The echo time (*TE*) represents the time from the center of the RF-pulse to the center of the echo. For pulse sequences with multiple echoes between each RF pulse, several echo times may be defined and are commonly noted *TE1*, *TE2*, *TE3*, etc.



Pulse train with long TR

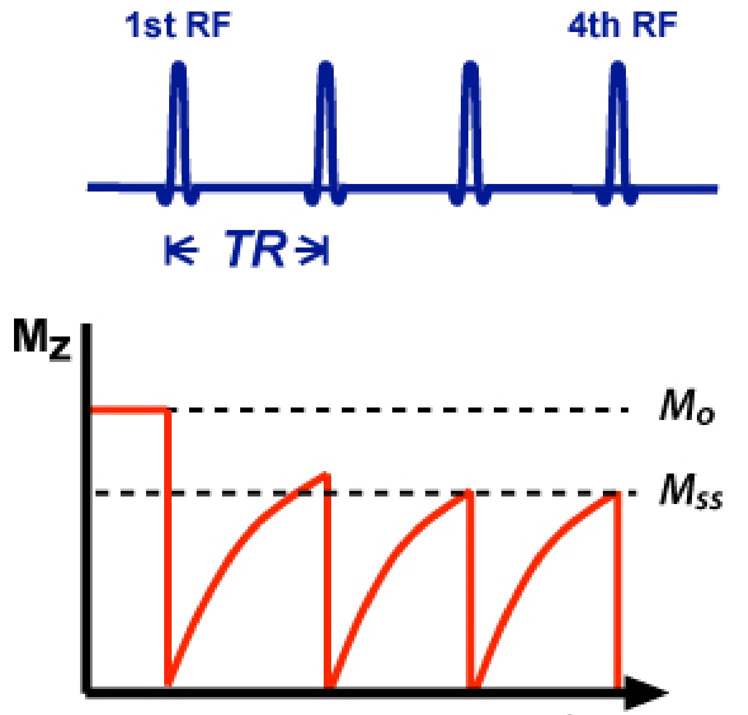
Each RF-pulse rotates some (or all) of **Mz** into the transverse plane. During the *TR* interval, **Mz** will regrow in an exponential fashion with time constant T1. If *TR* is sufficiently long (the usual requirement is *TR* > 4-5x T1), **Mz** will have time to completely recover and be restored to its full initial magnetization *Mo*.



When *TR* >> T1 there is complete recovery of $\mathbf{M_z}$ back to M_o before the 2nd RF-pulse.

Pulse train with medium TR

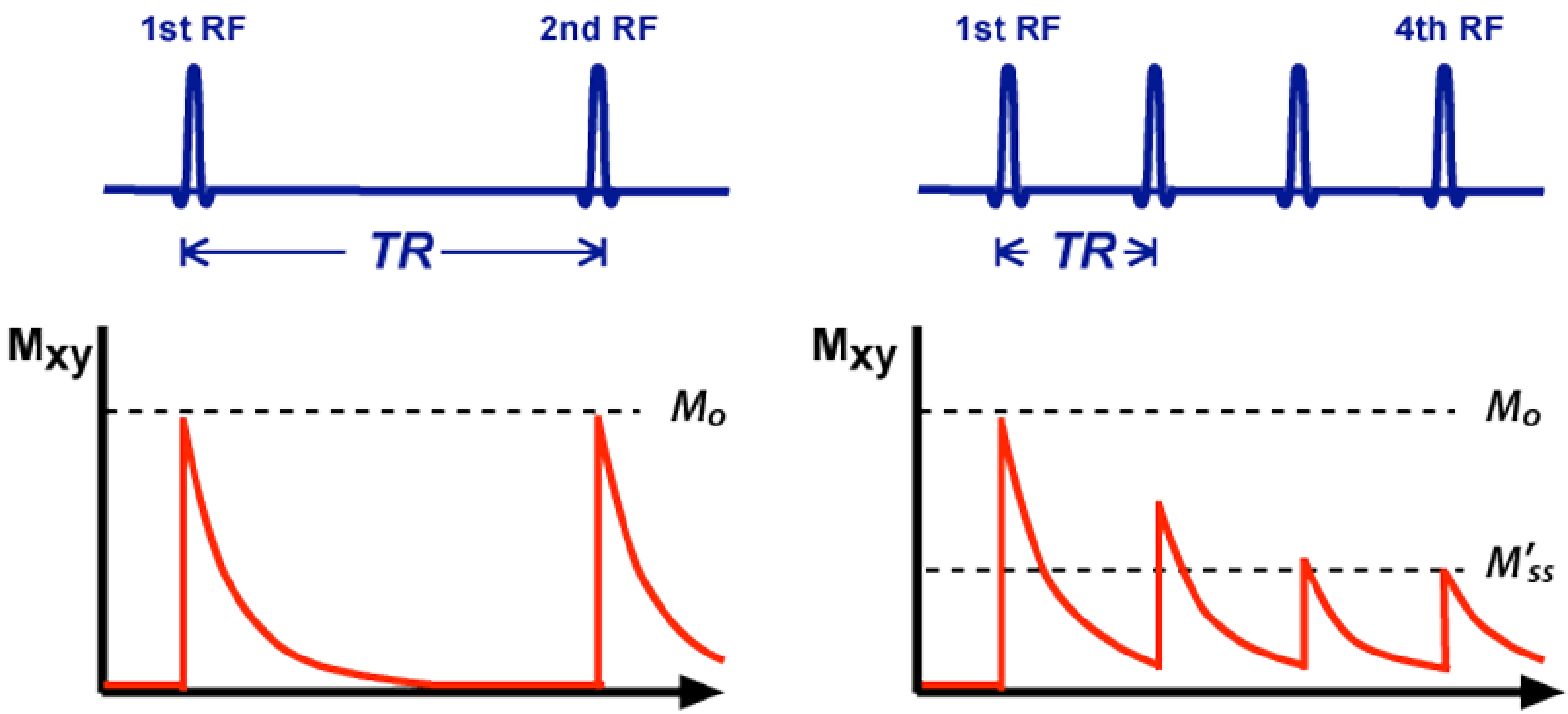
TR is now the same or shorter than T1. Here the second and subsequent pulses occur before Mz has returned to its initial value (Mo). After a few pulses a new steady-state longitudinal magnetization (Mss) will be established, where Mss < Mo. This phenomenon is called partial saturation, meaning that the spin system has not fully relaxed back to its equilibrium condition.



When $TR \leq T1$, partial saturation occurs with development of steady-state magnetization $M_{ss} < M_o$.

Pulse train with short TR

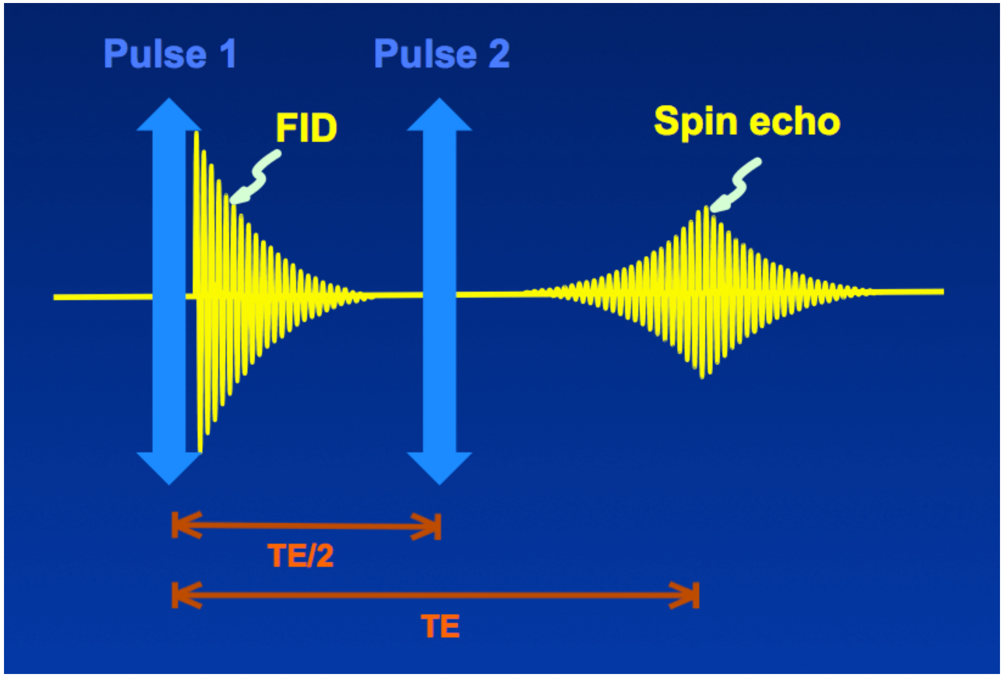
Similar to the graphs above for the longitudinal magnetization (Mz), the diagram below shows what happens to the transverse magnetization (Mxy) as TR is progressively reduced to the order of T2 or less.



TR ≤ T2 and Mxy does not fully decay to zero before next RF-pulse is applied. After a few pulses a new nonzero steady-state transverse magnetization (M'ss) is reached.

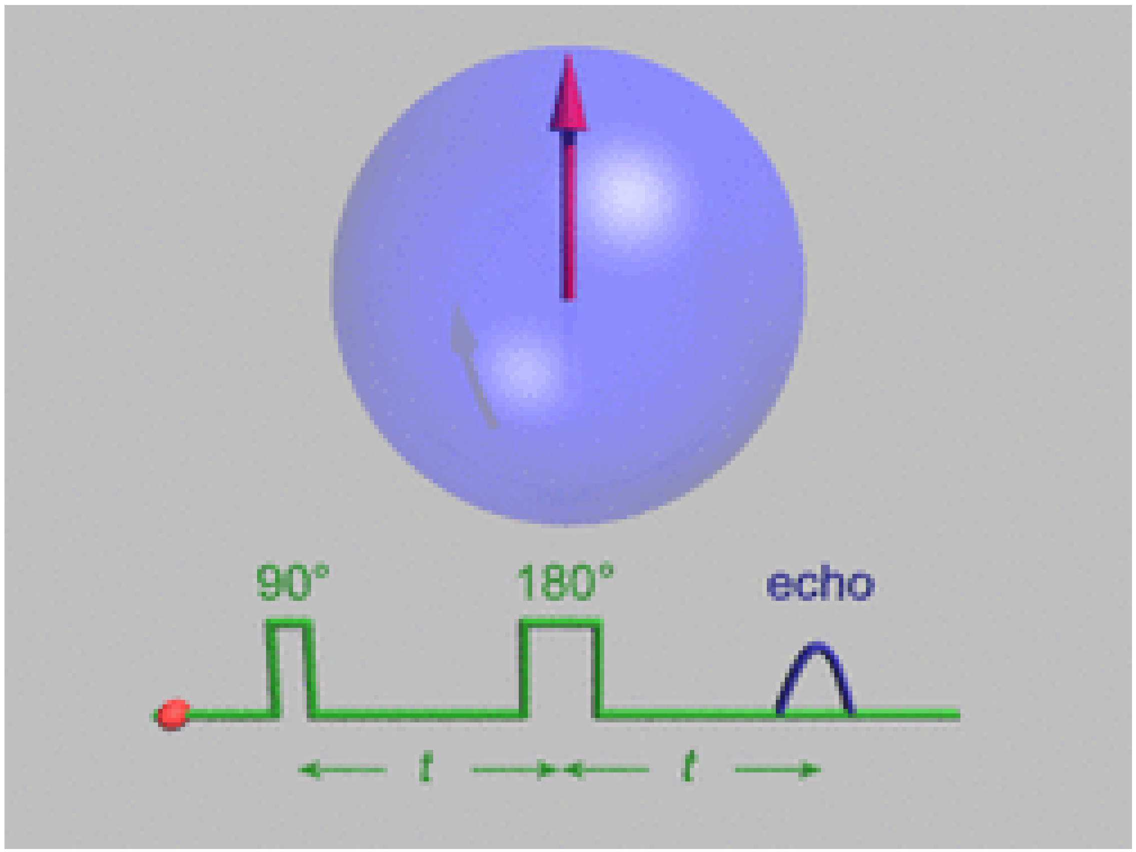
SPIN ECHO sequence

A single RF pulse generates a free induction decay (FID), but two successive RF pulses produce a spin echo (SE). The time between the middle of the first RF pulse and the peak of the spin echo is called the echo time (TE).



SPIN ECHO sequence

http://mriquestions.com/spin-echo1.html



Multi-echo Spin Echo

As long as T2-relaxation has not completely destroyed the MR signal, it is possible to stimulate the system with additional 180° -pulse(s) and generate additional echo(es). The amplitude of each echo is progressively smaller due to T2 decay.

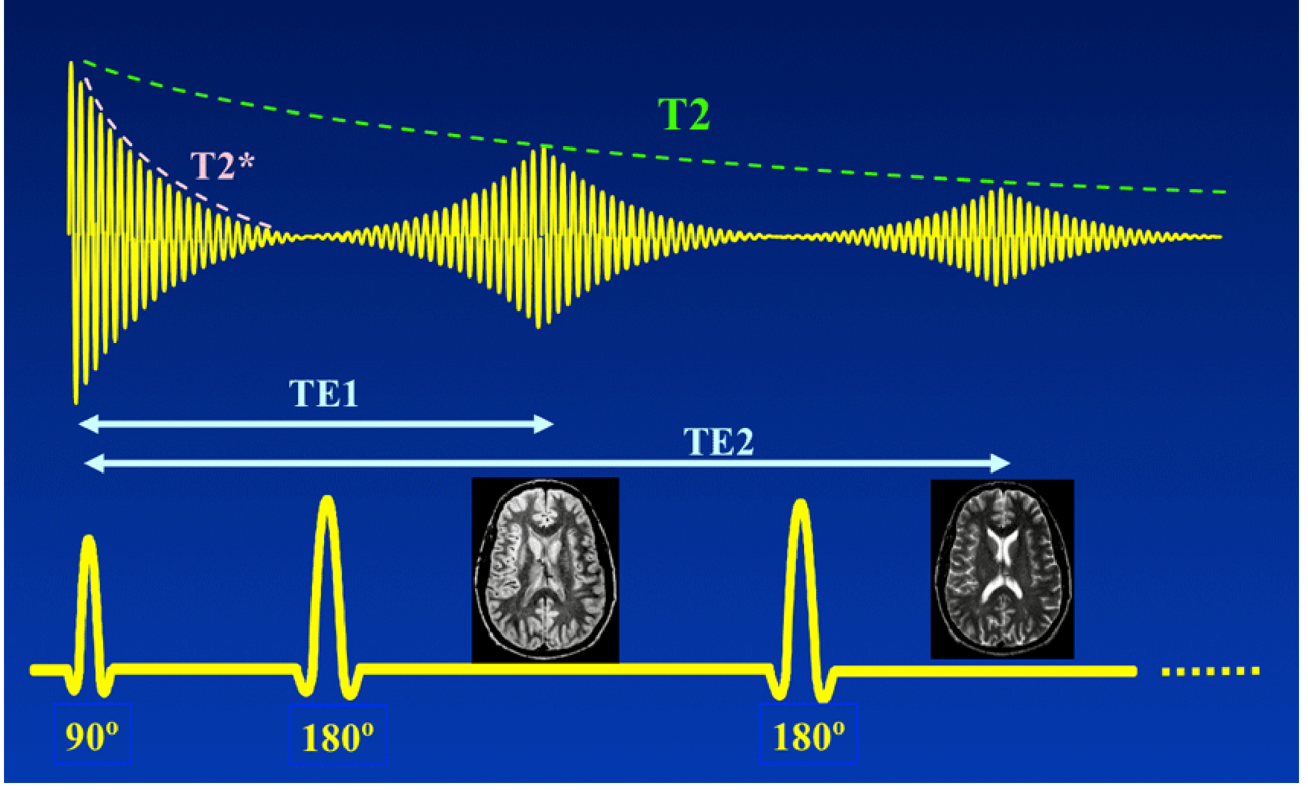


Image contrast

On spin-echo (SE) imaging, the repetition time (TR) and the echo time (TE) are used to control image contrast and the "weighting" of the MR image.

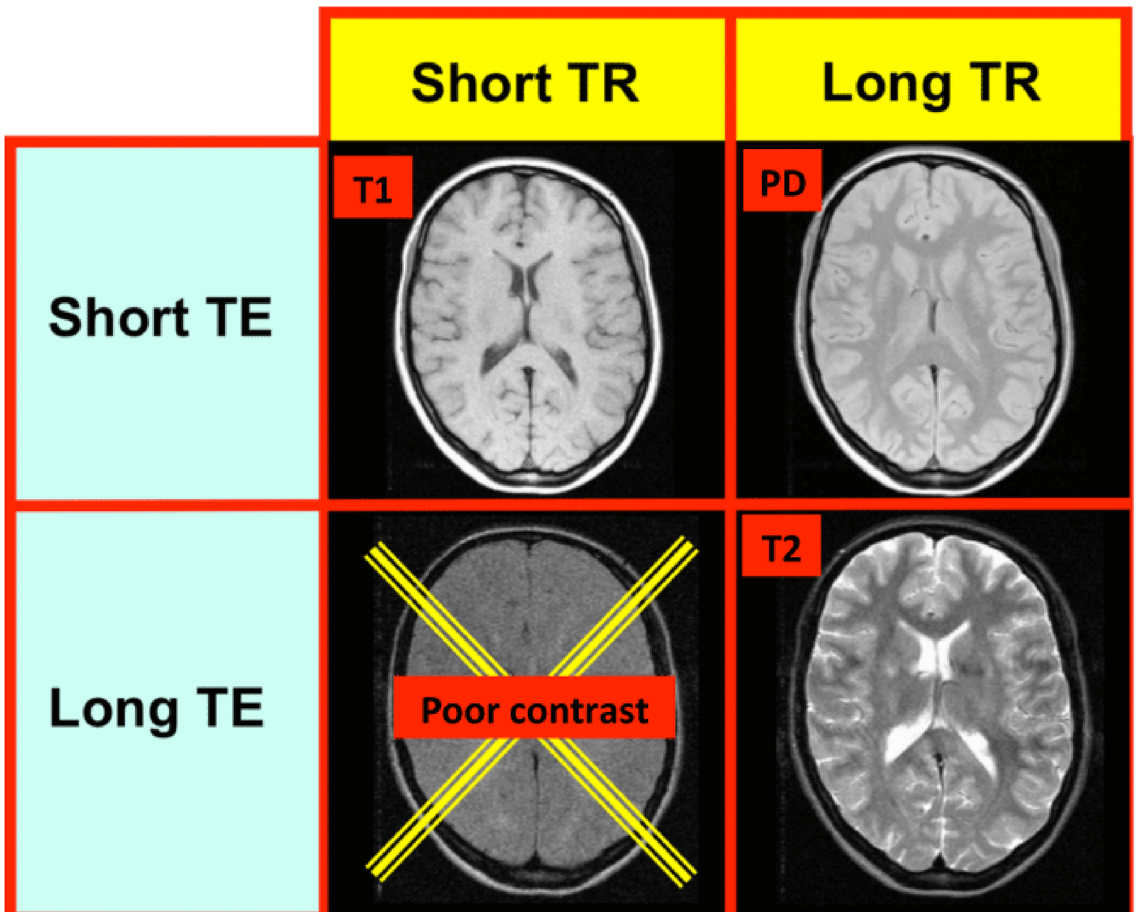


Image contrast

$$S = K \cdot [H] \cdot (1 - e^{-TR/T1}) \cdot e^{-TE/T2}$$

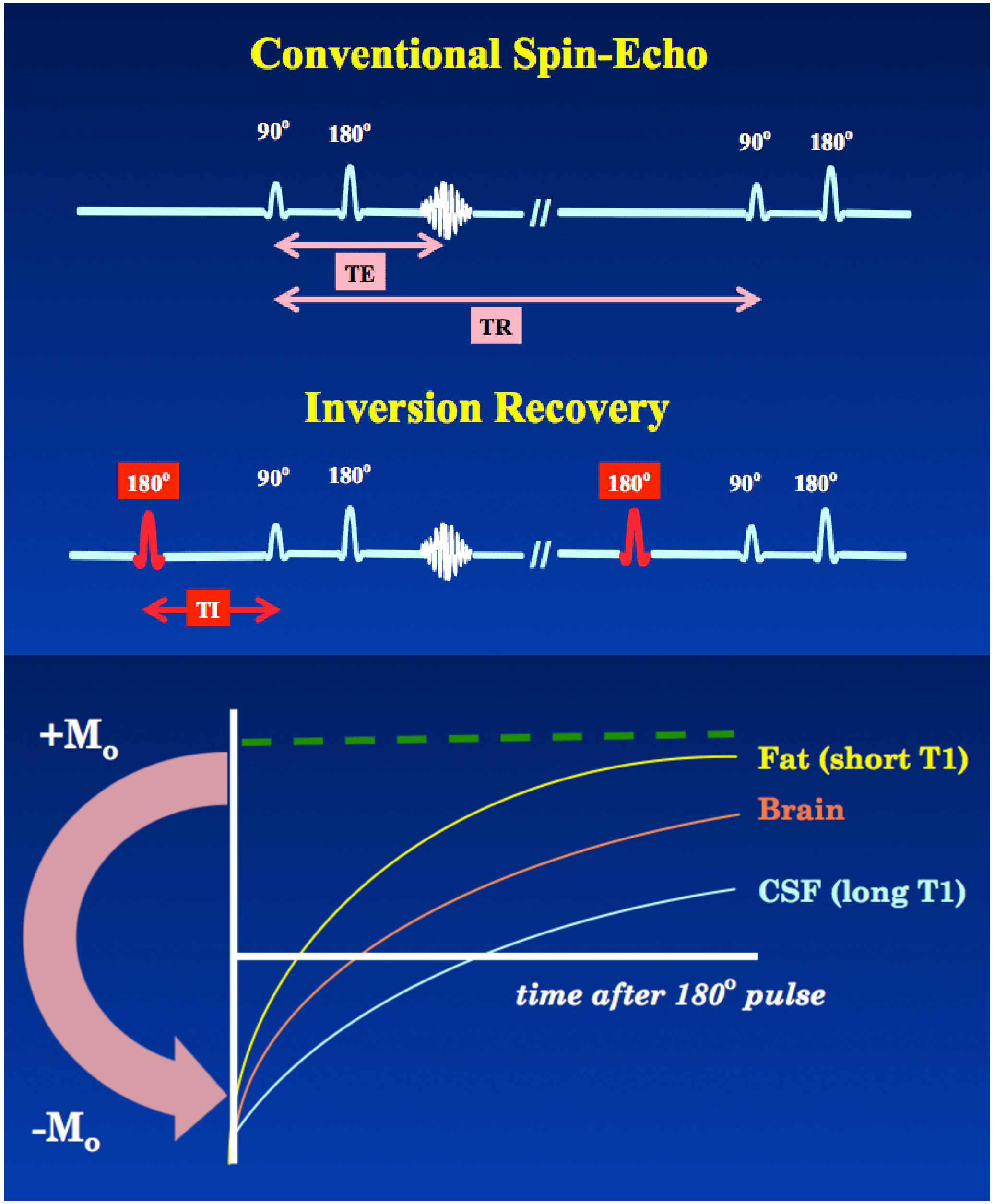
When *TE* is made short compared to T2, the ratio TE/T2 → 0, so the T2-weighting term $e^{-TE/T2} \rightarrow e^{-0} \rightarrow 1$. In other words, T2 effects largely disappear. Conversely, when *TE* is made long compared to T2, the importance of the exponential weighting term increases.

Another way to understand the effect of *TE* on T2-weighting is to consider the signals generated by two tissues with different T2 values. When *TE* is short, the echo occurs when there has been little time for T2-decay to have taken place and hence the tissues are not differentiated. If *TE* is long, the relative differences in signal decay between the two tissues become more noticeable, and hence more "T2-weighting."

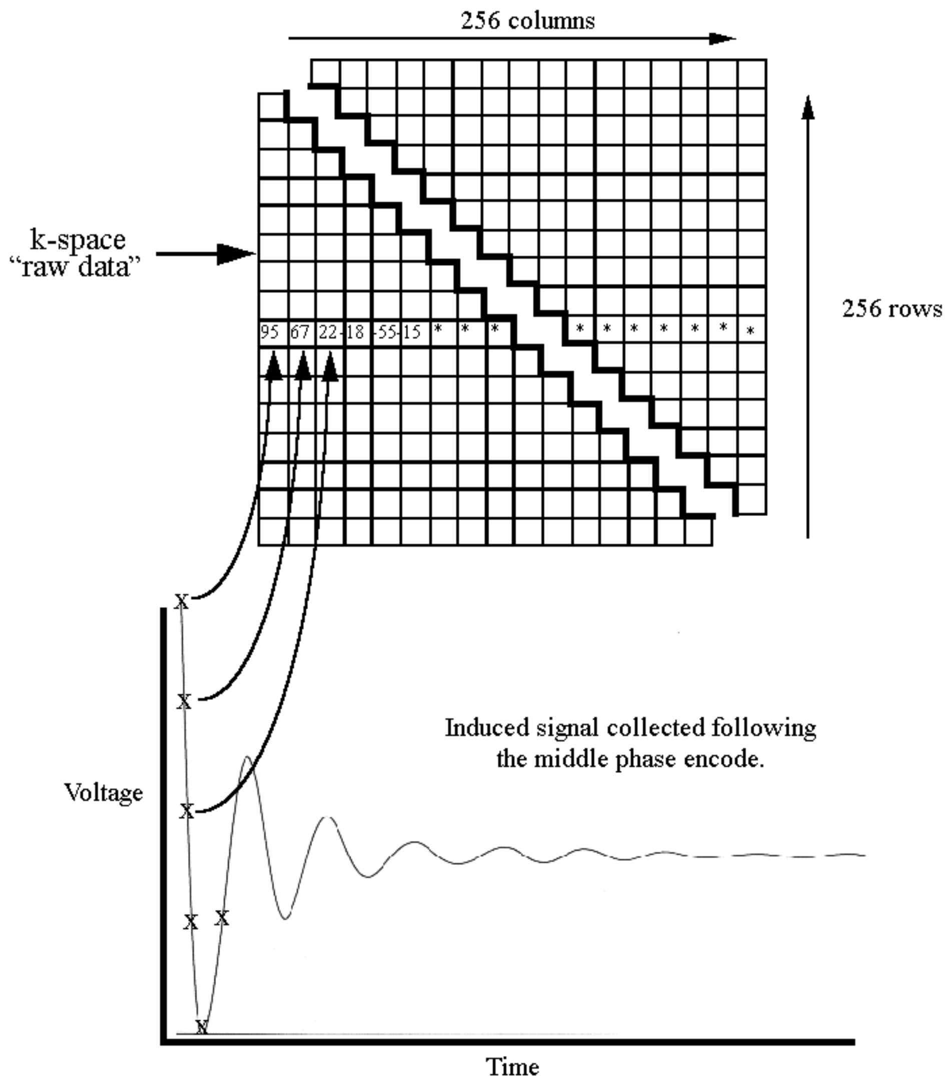
Similar arguments can be made for the interplay between *TR* and T1. When *TR* is long compared to T1, the T1-weighting term $e^{-TR/T1} \rightarrow 0$, so T1 effects disappear. At long *TR's* tissues with different T1 values have all had time to recover from the 90° excitation pulse, so their signals are not dramatically different. Conversely, short *TR's* accentuate "T1-weighting".

Finally, when *TR* is long and *TE* is short, both T1 and T2 effects are minimized. The only remaining factor is the spin-density [H], which becomes the dominant weighting for that combination of parameters.

Inversion Recovery

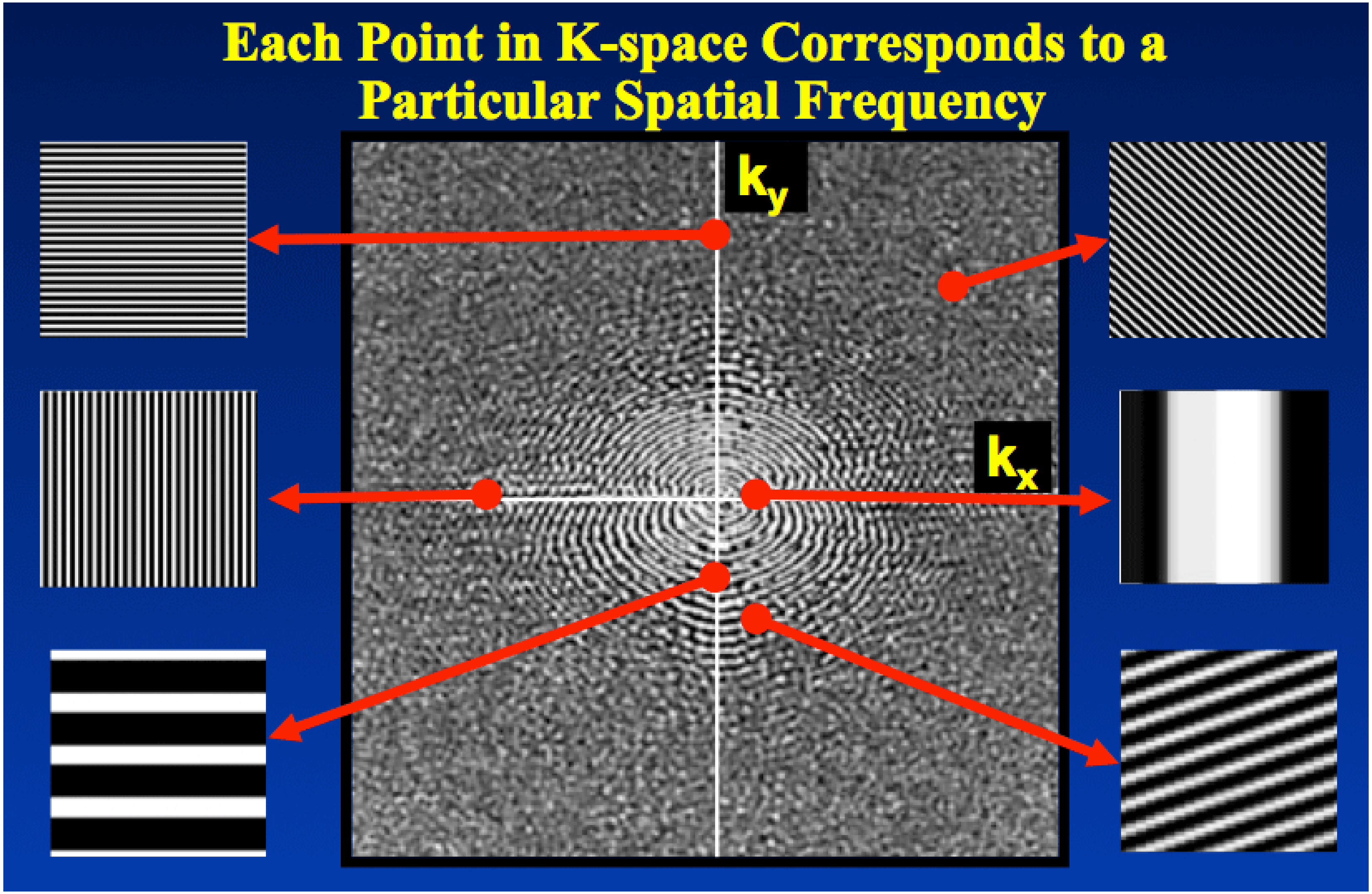


K-space



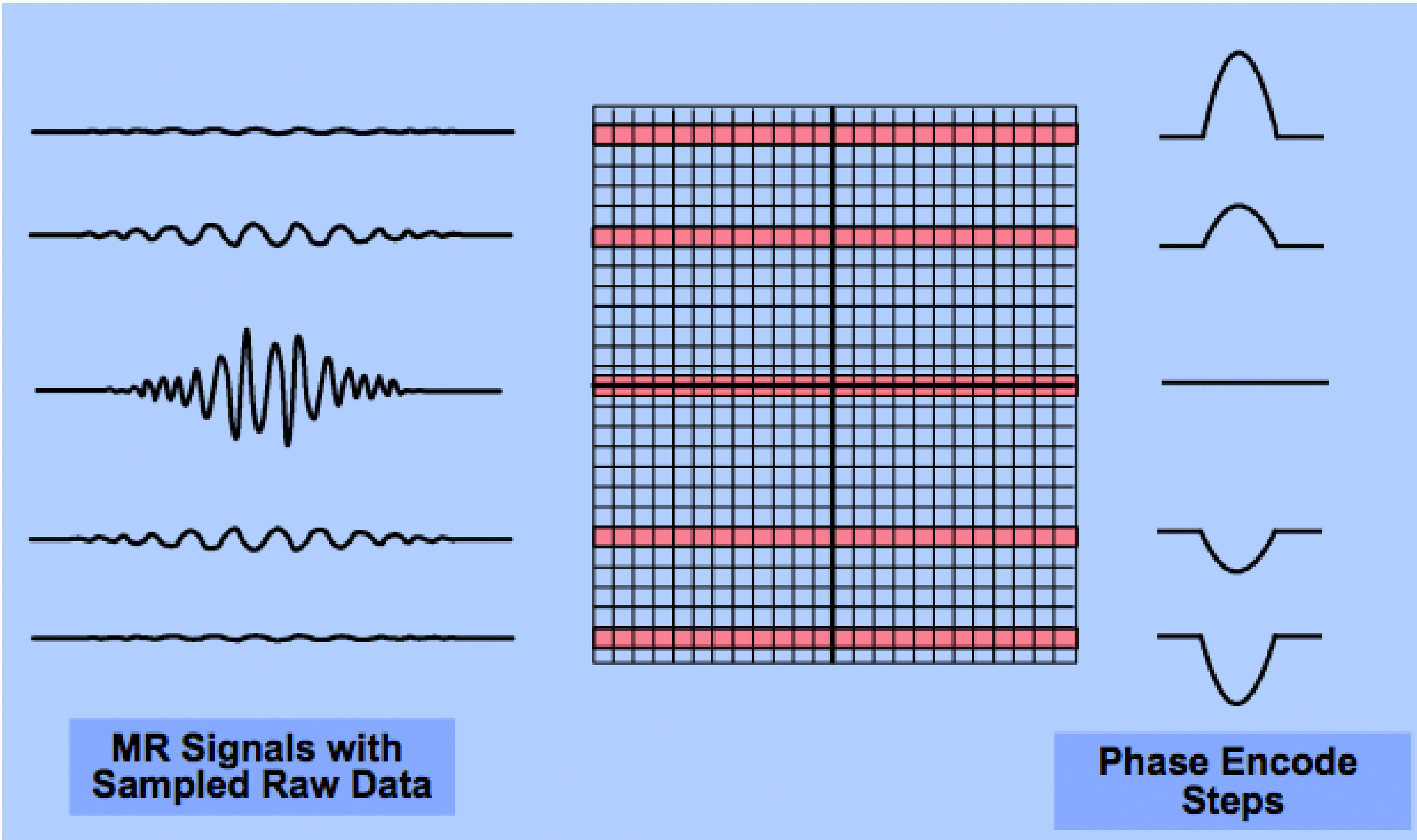
256 columns
256 rows
k-space
"raw data"
95 67 22 -18 -55 -15 * * * * * * * * * *
X
X
X
X X
X
Voltage
Time
Induced signal collected following
the middle phase encode.

K-space 1/2

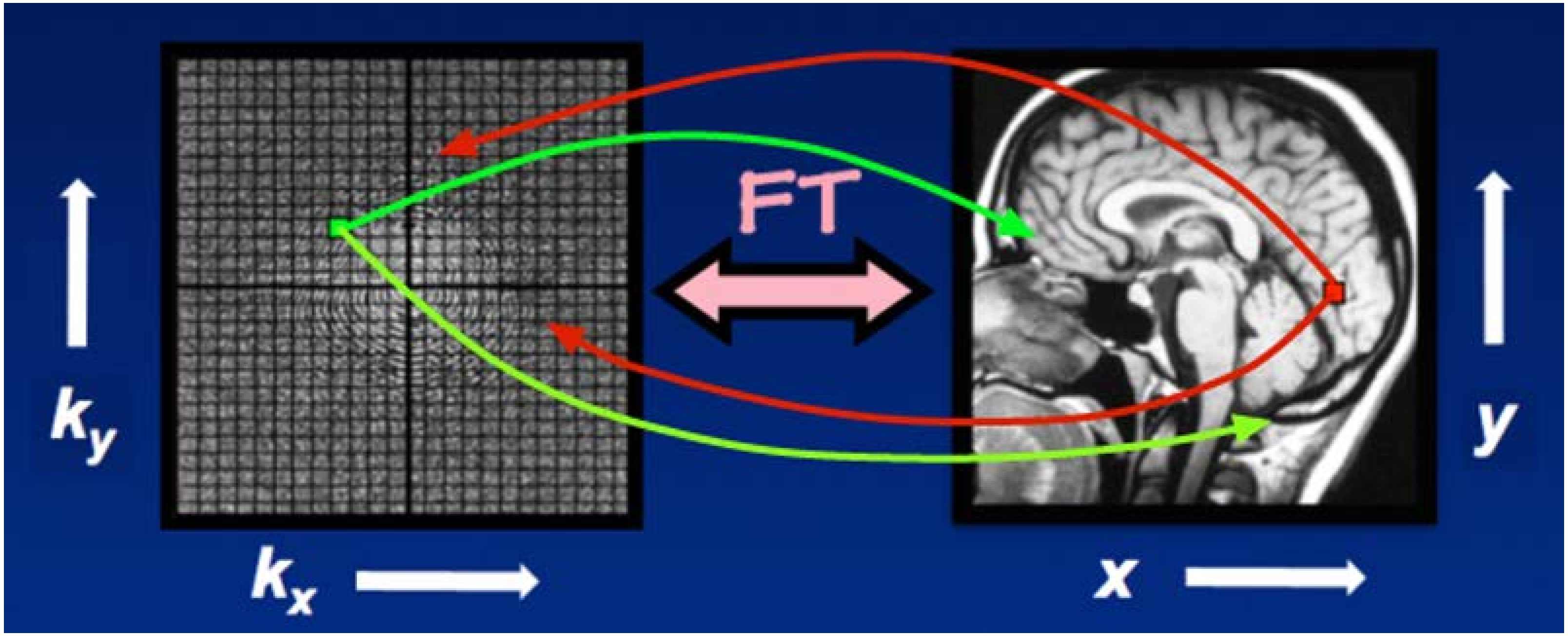


Each Point in K-space Corresponds to a Particular Spatial Frequency
ky
kx

K-space 2/2

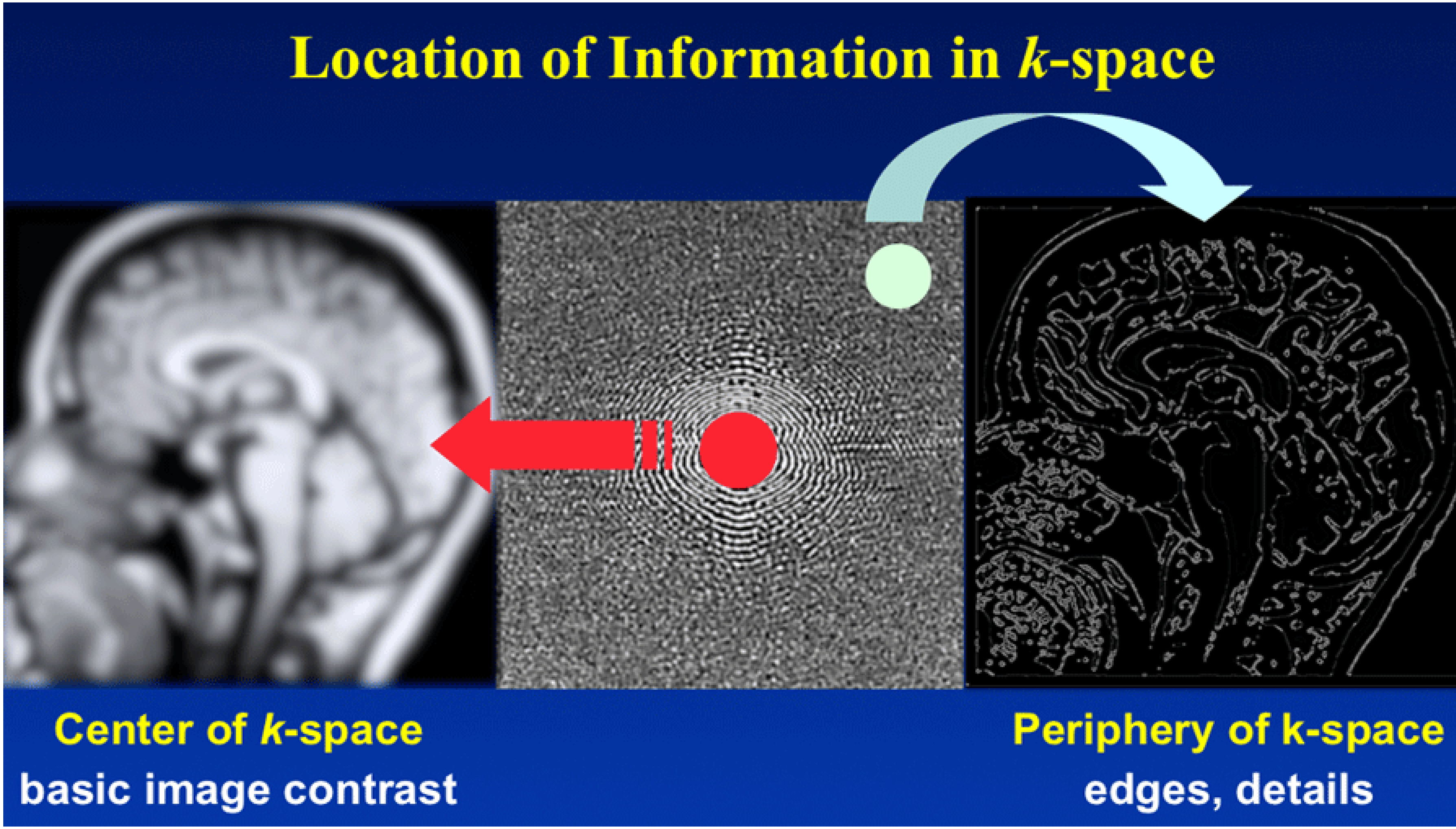


K-space v. Image 1/2



Each point in *k*-space maps to every point in the image, and vice-versa.

K-space v. Image 2/2



Reference

- MRI Questions, 2023 [online]. [cit. 29. 9. 2019]. Dostupné z: https://www.mriquestions.com/index.html
- Magnetic Resonance Imaging - Siemens Healthineers, 2023 [online]. [cit. 29. 9. 2019]. Dostupné z: https://www.siemens-healthineers.com/magnetic-resonance-imaging/
- BME 595 – Medical Imaging Applications Part 2: Introduction to MRI. 2023 [online]. [cit. 29. 9. 2019]. Dostupné z: https://www.slideshare.net/SanjeebSinha3/mri1ppt