GLOBAL MRI ACADEMY

MRI Physics Made Simple

A Practical Guide for MRI Students & Technologists

Physics • Image Contrast • Pulse Sequences • Parameters • Artifacts • Image Quality

Global MRI Academy

Educate • Empower • Excel

Educational resource — not a substitute for institutional protocols, manufacturer instructions, or clinical supervision.

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1. MRI Physics: The Big Picture

MRI creates images by manipulating the magnetic behavior of hydrogen nuclei, especially the abundant hydrogen in water and fat. The scanner uses a strong static magnetic field, radiofrequency (RF) energy, and magnetic field gradients to produce spatially encoded signals.

Key idea: MRI signal comes from the behavior of hydrogen nuclei in a magnetic field—not from X-rays.

- Main components: static magnetic field (B0), RF system, gradient system, receiver coils, computer, and patient table.
- B0 aligns hydrogen spins and establishes the main magnetic environment.
- RF energy changes the orientation of net magnetization and produces measurable signal.
- Gradients provide spatial information so the system can determine where the signal originated.
- Image contrast depends on tissue properties and sequence parameters such as TR, TE, TI, flip angle, and diffusion weighting.

2. The Magnet and Magnetic Field

The main magnetic field is called B0. Modern clinical systems commonly operate at 1.5T or 3T, although other field strengths are used. A stronger field generally increases available signal but can also increase susceptibility effects and some safety/technical considerations.

- Tesla (T) is the unit used to describe magnetic field strength.
- The B0 field is always present in a superconducting MRI system, even when no scan is running.
- The magnetic field extends beyond the scanner room, which is why controlled access and MRI safety zones are important.
- Ferromagnetic objects can become dangerous projectiles near the magnet.

3. Hydrogen Protons and Net Magnetization

Hydrogen is ideal for MRI because it is abundant in the human body and has a nuclear property called spin. In the presence of B0, individual proton magnetic moments preferentially occupy lower-energy alignment, creating a small net magnetization.

Remember: longitudinal = along B0; transverse = perpendicular to B0.

- Longitudinal magnetization points primarily along the B0 axis.
- Transverse magnetization is the component that produces the measurable MR signal.
- At equilibrium, longitudinal magnetization is much larger than the net transverse component.
- RF excitation tips net magnetization away from the longitudinal axis.

4. RF Excitation and the Larmor Frequency

Hydrogen nuclei precess around the B0 field at a frequency called the Larmor frequency. The frequency is proportional to magnetic field strength.

- The Larmor relationship is commonly written as $\omega 0 = \gamma B0$.
- For hydrogen, the approximate frequency is 42.58 MHz/T.
- At 1.5T, hydrogen resonates at roughly 63.9 MHz; at 3T, roughly 127.7 MHz.
- An RF pulse at the appropriate frequency transfers energy to the spins and changes net magnetization.
- The flip angle describes how far the net magnetization is tipped by the RF pulse.

5. Relaxation: T1 and T2

After RF excitation, the spins return toward equilibrium. Two fundamental relaxation processes are T1 recovery and T2 decay.

Easy memory aid: T1 = recovery along the main field. T2 = loss of transverse coherence.

- T1 (longitudinal recovery): recovery of longitudinal magnetization toward equilibrium.
- T2 (transverse decay): loss of phase coherence among spins in the transverse plane.
- T1 recovery is generally faster in fat than in free fluid.
- T2 decay is generally longer in fluid-rich tissues than in fat.
- T2* includes true T2 decay plus additional dephasing from field inhomogeneity and susceptibility.

6. TR, TE and Image Contrast

Two of the most important timing parameters are repetition time (TR) and echo time (TE). Changing them changes how much T1 and T2 weighting contributes to the image.

- TR = time between repeated RF excitations of the same slice or imaging unit.
- TE = time from the RF excitation to the center of the measured echo.
- Short TR and short TE tend to produce stronger T1 weighting.
- Long TR and long TE tend to produce stronger T2 weighting.
- Long TR and short TE reduce both T1 and T2 weighting, producing relatively proton-density-weighted contrast.
- The exact appearance depends on the sequence, tissue properties, flip angle, and other parameters.

Typical goal	TR	TE	General tendency
T1-weighted	Short	Short	T1 contrast emphasized
T2-weighted	Long	Long	T2 contrast emphasized
Proton density	Long	Short	Less T1/T2 weighting

7. Pulse Sequences: SE, FSE, GRE, FLAIR and STIR

Pulse sequences are organized patterns of RF pulses, gradients, timing, and signal acquisition. Different sequences emphasize different tissue properties.

- Spin Echo (SE): uses a 90° excitation pulse followed by a 180° refocusing pulse.
- Fast Spin Echo / Turbo Spin Echo (FSE/TSE): collects multiple echoes after one excitation, reducing scan time.
- Gradient Echo (GRE): uses gradient reversal for refocusing rather than a 180° RF refocusing pulse; often sensitive to susceptibility and T2* effects.
- FLAIR: uses an inversion recovery preparation to suppress fluid signal, especially useful for brain imaging.
- STIR: inversion recovery technique designed to suppress fat; useful for many MSK and body applications, but generally not used after gadolinium because it can suppress T1-shortened enhancing tissues.
- DWI: uses diffusion-sensitizing gradients to detect differences in water motion.

8. Spatial Encoding: Gradients, FOV, Matrix and Slice Thickness

MRI needs to determine where the received signal came from. Gradients alter the magnetic field in a controlled way to encode spatial position.

Practical relationship: smaller FOV + larger matrix → smaller in-plane pixels, but usually lower SNR.

- Slice-select gradient helps select the imaging slice during RF excitation.
- Phase-encoding gradient assigns spatial information in one direction and is repeated with different amplitudes.
- Frequency-encoding (readout) gradient encodes position during signal acquisition.
- FOV (field of view) is the physical area represented by the image.
- Matrix describes the number of pixels in the image (for example, 256 × 256).
- Voxel size is related to FOV, matrix, and slice thickness.
- Smaller voxels generally improve spatial resolution but reduce SNR.

9. SNR, CNR and Scan-Time Tradeoffs

Signal-to-noise ratio (SNR) describes how strong the desired MR signal is relative to background noise. Contrast-to-noise ratio (CNR) considers the difference between tissues relative to noise.

- Increasing the number of signal averages (NEX/NSA) increases SNR but increases scan time.
- Increasing voxel size generally increases SNR but reduces spatial resolution.
- Increasing receiver bandwidth can reduce chemical shift and some susceptibility-related effects, but may reduce SNR.

- Higher field strength can increase SNR, but image quality depends on the entire protocol and hardware.
- Parallel imaging can shorten scan time but often reduces SNR.
- Compressed sensing and other acceleration methods can shorten acquisition time, with tradeoffs that depend on implementation.

10. SAR and Patient Safety

Specific absorption rate (SAR) describes the rate at which RF energy is absorbed by the body, expressed in watts per kilogram (W/kg). SAR is important because RF energy can cause tissue heating.

Safety principle: MRI physics and MRI safety are inseparable. Always follow the site's current safety policy and the device manufacturer's conditions.

- SAR can increase with higher field strength, certain RF pulse designs, shorter TR, higher flip angles, and some fast spin-echo protocols.
- The scanner monitors and manages RF exposure according to applicable limits and system settings.
- Patient screening remains essential for implants, devices, foreign bodies, and other hazards.
- Prevent conductive loops and skin-to-skin contact that can contribute to RF burns.
- Use appropriate padding and positioning, follow manufacturer conditions for implants, and maintain communication with the patient.

11. Diffusion MRI and ADC

Diffusion-weighted imaging (DWI) is sensitive to microscopic water motion. It is especially important in neurologic imaging, including evaluation of suspected acute ischemic stroke.

- DWI signal is influenced by diffusion weighting, commonly described by the b-value.
- Restricted diffusion often appears bright on DWI and relatively dark on ADC, but interpretation must consider the full imaging pattern.
- ADC maps help reduce confusion from T2 shine-through.
- High b-values provide stronger diffusion weighting but may reduce SNR.
- Technical factors such as motion, susceptibility, and eddy-current effects can affect diffusion images.

12. Common MRI Artifacts

Artifacts are unwanted features that can reduce diagnostic quality. Recognizing their appearance and cause helps the technologist choose an appropriate correction.

- Motion artifact: repeated signal displacement, often along the phase-encoding direction. Reduce with patient coaching, immobilization, faster sequences, or motion-correction methods when available.
- Chemical shift: frequency difference between fat and water can cause spatial misregistration. Higher bandwidth and appropriate fat-suppression strategies can help.

- Susceptibility artifact: prominent near metal, air-tissue interfaces, and blood products. GRE sequences are particularly sensitive.
- Aliasing (wrap-around): anatomy outside the selected FOV is mapped into the image. Increase FOV or use phase oversampling when appropriate.
- Gibbs/ringing: oscillating lines near sharp high-contrast boundaries; related to limited k-space sampling.
- Partial volume: different tissues occupy the same voxel and their signals are averaged. Thinner slices or smaller voxels can reduce the effect.
- RF interference: external radiofrequency sources can create lines or noise; check room integrity and equipment when appropriate.

13. Practical Parameter Guide

The best parameter choice depends on anatomy, clinical question, scanner, coil, patient, and institutional protocol. The following relationships are useful for understanding tradeoffs rather than replacing a clinical protocol.

Change	Typical effect	Common tradeoff
Increase FOV	Larger coverage / larger pixels if matrix unchanged	Lower spatial resolution
Increase matrix	Smaller pixels / higher in-plane resolution	Lower SNR and/or longer scan
Increase slice thickness	Higher SNR	Lower through-plane resolution
Increase NEX/NSA	Higher SNR	Longer scan time
Increase bandwidth	Less chemical shift, shorter readout	Lower SNR
Longer TR	More longitudinal recovery	Often longer scan time; less T1 weighting
Longer TE	More T2/T2* weighting	Lower signal and greater susceptibility

Clinical reminder: Never change a clinical protocol solely from a general rule in an educational book. Follow the radiologist-approved protocol, scanner manufacturer guidance, and site policy.

14. Quick Review & Exam Questions

1. What is B0?

Answer: The main static magnetic field of the MRI system.

2. What produces the measurable MR signal?

Answer: Transverse magnetization from precessing transverse components of magnetization induces signal in the receiver coil.

3. What does TR control?

Answer: It strongly influences longitudinal recovery and therefore T1 weighting, while also affecting scan time and signal.

4. What does TE control?

Answer: It strongly influences how much transverse decay occurs before the echo is measured, affecting T2/T2* weighting and signal.

5. Short TR + short TE generally produces what weighting?

Answer: T1-weighted contrast.

6. Long TR + long TE generally produces what weighting?

Answer: T2-weighted contrast.

7. What is SAR?

Answer: The rate of RF energy absorption by the body, expressed in W/kg.

8. Why is ADC useful with DWI?

Answer: It helps assess diffusion and helps distinguish true restriction from T2 shine-through.

9. What is one common way to reduce motion artifact?

Answer: Improve patient coaching/immobilization or use a faster or motion-corrected acquisition when appropriate.

10. What happens to SNR when voxel size is increased?

Answer: SNR generally increases, but spatial resolution decreases.

Final Study Checklist

- ■ I can explain B0, RF, gradients, and receiver coils.
- ■ I can distinguish T1, T2, and T2* relaxation.
- ■ I understand TR and TE and their effect on contrast.

- ■ I can describe the basic purpose of SE, FSE, GRE, FLAIR, STIR, and DWI.
- ■ I understand FOV, matrix, voxel size, SNR, CNR, and scan-time tradeoffs.
- ■ I understand why SAR and patient screening matter.
- ■ I can recognize common artifacts and name at least one correction strategy.

About Global MRI Academy

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