MRSO Exam Prep Course

Module 10

The MRI Process

Image 10.1

So, let's start pulling together what we have learned thus far. First, let's start with the MRI Scanner and its essential components. The MRI scanner will have:

- A powerful magnet to produce a static magnetic field (B_o)
- A three-coil gradient system for producing linear field distortions in the x, y, and z axes and the accompanying amplifiers
- An RF transmitter with a transmit coil integrated inside the scanner
- An RF receiver with great sensitivity for picking up and amplifying the MR signal
- Imagers might also employ a single RF coil that switches between transmit and receive modes
- More coils, either receive or transmit/receive
- Several computers are used to operate the scanner and gradients (control computer), create MR pictures (array processor), and coordinate all operations (main or host computer, to which the operator's console and image archives are attached)
- Other peripheral devices, such as a patient table control, ECG, and respiration monitors to trigger customized MR sequences, a cooling system for the magnet, a second operator's console, a film exposure device, or a PACS (picture archiving and communications system)

Section 10.1 Steps to Performing a Scan

MR personnel must follow the following steps to perform the MRI process properly:

1. **Patient preparation and screening**: Before the MRI process begins, the MRI personnel screen the patient for any metallic objects or devices in their body, such as pacemakers, which could interfere with the imaging process. The patient's health conditions and allergies are also reviewed, and informed consent is obtained for the procedure, including using gadolinium if required. The technologist explains the scanning procedure

to the patient and ensures any questions are answered. Once the patient is ready, they are led into the scanner room for the scan.

2. **Patient positioning:** The patient is placed on the gantry table, usually lying flat on their back (supine). Specialized receiver imaging coils are placed around the body part scanned, such as the head, chest, or knee. These devices are attached now if an electrocardiogram (EKG) or respiratory gating is necessary. A specific anatomical structure, such as the bridge of the nose or the umbilicus, is identified as a landmark using laser guidance, and its position is correlated with the table's position by pressing a button on the gantry.
3. **Protocol selection:** Most MRI facilities have developed an extensive list of imaging protocols for different diseases and clinical situations. Each protocol contains several pulse sequences focused on different anatomical planes and parameter weightings. For example, protocols for cranial imaging could include "Routine Adult Brain," "Routine Infant Brain," "Epilepsy Brain," "MR Angiogram Circle of Willis," and others. The technologist selects the appropriate protocol from the library to begin scanning. Additionally, generic sequences in the scanner library can be adjusted for specialized views or techniques.
4. **Localizer scans**: A set of three-plane, low-resolution localizer scans with a large field of view is obtained, equivalent to "scout views" in CT. These localizer images are used to plot slices.
5. **Calibration scans for parallel imaging**: A coil sensitivity calibration scan may be needed if parallel imaging is performed. This blurry image is not used for diagnosis but is often displayed as a separate series.
6. **Positioning slices and saturation bands:** At this stage, the exact positions and angles of the slices are graphically specified. Protocol parameters, such as field-of-view, phase- and frequency-encoding directions, and slice thickness, can be adjusted for the specific patient's anatomy. If saturation bands are required, they are also positioned at this time. Once the slices and bands are specified and parameters are optimized, the "Scan" button is pressed, and the image acquisition process begins.
7. **Automatic pre-scan:** When the scanning begins, the scanner first goes through a brief (10-20 sec) calibration procedure known as pre-scan. This procedure includes quick higher-order shimming, coil tuning/matching, center frequency calibration, transmitter and receiver gain adjustments, and dummy cycle stimulation. Although it's a fully automated process, manual adjustments are sometimes necessary.
8. **Image acquisition:** Finally, the desired pulse sequence is run, and the images are produced. Steps 6 through 8 are repeated until all sequences in the protocol have been completed.
9. **Post-processing:** Advanced sequences, including MR angiography, vascular and CSF flow studies, cardiac imaging, diffusion tensor imaging, functional MRI, and spectroscopy, may require additional post-processing. This can be done on the central scanner console or a separate workstation.
10. **Data archiving**: The images and processed data are stored on a Picture Archiving and Communication System (PACS) or another archival system. Once the necessary images and processed data have been saved, raw data is often discarded.

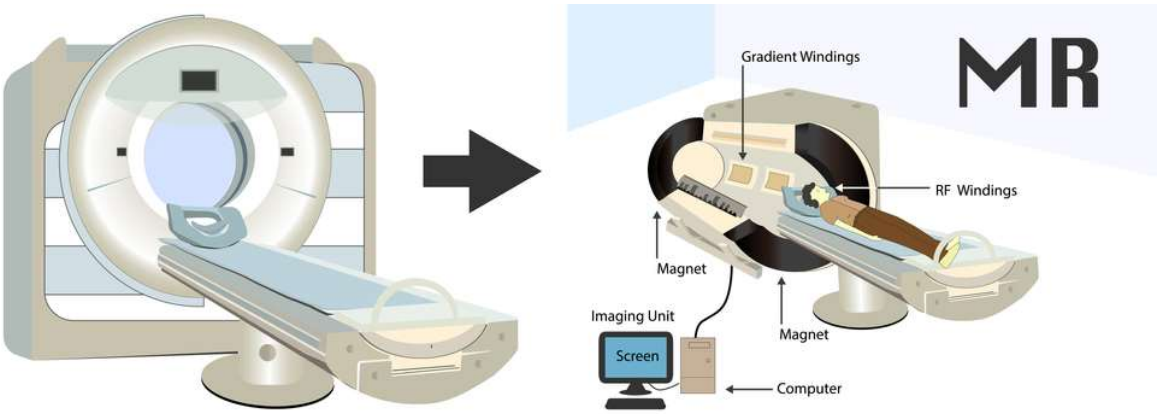

Image 10.2

10.1.1 Preparation

70% of the human body is comprised of water (H_2O). Hydrogen is a single proton that conveys a positive electric charge in water and other molecules in body tissues. The protons spin continuously and have their own magnetic fields. Without an externally applied magnetic field, their orientation is random. When patients enter the MRI unit's gantry, their bodies are introduced to the static magnetic field.

When an external magnetic field B_o is applied, they either align parallel or antiparallel to one another. Slightly more protons align in a similar direction (low-energy state) than in the antiparallel direction (high-energy state). The net magnetic vector produced by a small number of additional protons aligned parallel to the main magnetic field is the source of the MR signal and is used to generate MR images. Like the primary magnetic field, the longitudinal direction is designated the Z direction. The transverse plane, the X-Y Plane, is perpendicular to this direction. The protons rotate around a longitudinal axis like the precession of a spinning top at a frequency known as the Larmor frequency, which is directly proportional to the magnetic field strength. Specifically, 1.5T generates a Larmor frequency of 64MHz, and a 3.0T magnet will cause 128MHz.

10.1.2 Excitation

The scanner emits a radiofrequency (RF) pulse during the scanning procedure. An RF pulse typically lasts for 2-3 milliseconds. When the RF pulse is initiated, it disturbs or flips the protons simultaneously and moves them out of line with the main magnetic field. How much this turn, or flip, happens depends on how strong and long the RF pulse is. A 90-degree RF pulse will turn the net magnetization vector to the transverse plane (X-Y plane). 180-degree RF pulses change the direction of the net magnetization to the opposite direction (–Z plane). Only when

the RF pulse is tuned to the frequency of the electrons' precession can it upset the protons and move energy. In other words, the excitation process can only occur effectively if the RF pulse is in the same frequency as the primary magnet (64 MHz for 1.5T and 128 MHz for 3.0T). When it does happen, and excitation occurs at the same frequency as the electron's precession, this is defined as "resonance." Some low-energy protons switch to high-energy states when an RF pulse is given. This decreases the longitudinal magnetization, and the protons start to move in phase. So, the net magnetization vector moves to the transverse plane, which is the plane that is not parallel to the main magnetic field. This causes an electric current that is used to make the MR image. This electric current generated during this process is due to Faraday's Law of Induction.

When the RF Pulse is switched off, the protons start to move back to their original positions of low energy or balance, which is the direction of the main magnetic field. The word for this is "relaxation." There are two different types of relaxation: Relaxation T1 and Relaxation T2.

10.1.3 Relaxation T1

Relaxation T1 is when protons share energy with their surroundings to return to a low-energy state along the longitudinal line. This is done by restoring the longitudinal magnetization. T1 time is the time it takes to produce 63% of the original longitudinal magnetization**.** Different molecules in our bodies have other T1 relaxation times, depending on how tightly the hydrogen atom is bound to the molecule. For example, water has a long rest time and a dark signal, while fat has a short rest time and a bright signal. T1 weighted pictures are good for showing how the body is put together.

An important concept to remember from T1 Relaxation is the term Spin-Lattice Relaxation. The lattice field is the magnetic field made by the movement of atoms in the lattice caused by heat. The lattice field of a nucleus with less energy can combine with the lattice field of a nucleus with more energy. This causes the energy of the nucleus with more energy to be shared between the two nuclei. So, the energy that the nuclei receive from the RF pulse is lost as more significant vibration and spin within the lattice, which can slightly raise the temperature of the sample. Spin-lattice relaxation is when the spins return the energy from the RF pulse to the lattice around them. This brings them back to a state of balance. The big takeaway from this concept is that Spin-Lattice Relaxation can generate heat directly into our patient. The more energy put in the atoms, the more heat is generated within our patient once T1 Relaxation is initiated.

10.1.4 Relaxation T2

Relaxation T2 is the time constant for the loss of transverse magnetization caused by spontaneous atomic or molecular interactions. It is used to measure the natural processes at the atomic and molecular levels in the tissue or material of interest that contribute to the

transverse loss of the MR signal. So, T2 is the time it takes for the axial magnetization to drop to about 37% (1/e) of what it was at first. Transverse relaxation and spin-spin relaxation are both similar names for T2 relaxation.

T2* is utilized to consider both the regular T2 relaxation and the T2 relaxation caused by an uneven magnetic field. T2* can be thought of as an "observed" or "effective" T2, while the first T2 can be considered as the "natural" or "true" T2 of the tissue being scanned. T2* is always lower or the same as T2. Inconsistencies in the main magnetic field mainly cause T2*. These differences could be caused by flaws in the magnet itself or susceptibility-induced field changes caused by the tissue or other materials. We use this formula to describe their relationships:

$$\frac{1}{T2*} = \frac{1}{T2} + \frac{1}{T2'}$$

Section 10.2 Signal-to-Noise Ratio Influencing Factors

Image noise is caused by a variety of sources, including:

- Magnetic field inhomogeneities, RF coil thermal noise, and signal amplifier nonlinearity are all MR system flaws
- Aspects of the image processing process itself
- Factors affecting the patient result from body movement or respiratory motion

The signal-to-noise ratio describes the connection between the MR signal and the amount of picture noise present (SNR). The SNR is calculated by dividing the signal intensity obtained in a region of interest (ROI) by the standard deviation of the signal intensity in an area beyond the anatomy or object being scanned.

In MRI, a high SNR is desirable. The SNR is affected by the following factors:

- Receiver bandwidth and slice thickness.
- Viewing angle.
- The (picture) matrix's size.
- The total number of acquisitions.
- Scan settings (TR, TE, flip angle).
- The magnitude of the magnetic field.
- Coil selection for transmitting and receiving (RF coil).

10.2.1 Pulse Sequence

An MRI pulse sequence is a meticulously programmed set of changing magnetic gradients to create different types of contrast in MRI images. Each sequence consists of several parameters, and multiple sequences are organized into an MRI protocol.

Parameters

A pulse sequence is generally defined by multiple parameters, including:

- **Time to echo (TE)**: The time from the center of the excitation pulse to the peak of the signal received
- **Time to repetition (TR)**: The time from the start of one excitation pulse to the start of the next
- **Flip angle**: The angle by which the net magnetization is rotated at the time of excitation
- **Field of view and matrix size**: Determines the size and resolution of the image
- **Inversion pulse(s)**: Used in inversion recovery sequences to invert the longitudinal magnetization
- **Spoiler gradient(s) (crusher gradients)**: Dephase remaining transverse magnetization
- **Echo train length (ETL)**: The number of echoes acquired per excitation
- The spatial acquisition of k-space determines how the MR signal is sampled in the spatial frequency domain

Sequences

MRI sequences can be grouped in various ways. They can be categorized by the type of sequence (e.g., spin echo, inversion recovery) or by general image weighting (e.g., T1 or T2) and additional features (e.g., fat-suppressed, gadolinium-enhanced).

Pulse sequences can be broadly grouped as follows:

- Spin echo sequences
- Inversion recovery sequences
- Gradient echo sequences
- Diffusion-weighted sequences
- Saturation recovery sequences
- Echo-planar pulse sequences
- Spiral pulse sequences

Protocols

Multiple sequences are usually needed to adequately evaluate a tissue, and the combination of sequences is referred to as an MRI protocol. The radiologist tailors the pulse sequences to best address the clinical question the referring physician poses.