MRI – “What we have here is a failure to communicate.”

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Lack of communication can certainly be the case if you are not familiar with how magnetic resonance images are formed and are not familiar with the terminology used to describe the images and the pathology associated with them. I hope to provide the entry level understanding of MRI to instill confidence when viewing the images as a beginner and to provide a basis for further understanding with practice and experience.

Fundamental Concept - magnetic resonance images are made up of a signal that is dependent on the magnetic spin properties of hydrogen nuclei and how these nuclei recover after excitation with radiofrequency waves

Big Advantage of MRI over Computed Tomography - greater sensitivity to subtle differences in tissue types especially normal vs. pathologic

Main Components of an MRI System

1) large magnet - produce the strong (or main or external) static magnetic field
2) gradient coils - induce small magnetic field superimposed over static magnetic field to aid in localization of signal received from patient
3) transmitter coil - transmits radiofrequency energy into the patient
4) receiving coil - receives signal from patient
5) computer system - process signal data and convert into images
6) operating console - technologist uses to select sequence parameters
7) archival system - image is stored digitally and/or radiographic film

Image Production Process - 4 Main Steps

I. Alignment of hydrogen protons
- A. Accomplished by strong magnetic field formed by permanent or superconductive magnet
  1. strength of magnetic field measured in Tesla (T) or gauss (10,000 gauss = 1T)
  2. examples of magnetic field strength used are .35T, .5T, 1.5T
  3. Earths magnetic field about .5 gauss
- B. Hydrogen protons can be thought of as behaving like a small bar magnet
  1. the direction of individual magnetization vector of the protons is random
  2. when placed in strong magnetic field a small percentage of the hydrogen nuclear magnetization vectors line up parallel with the main magnetic field

II. Excitation of protons

A. Radiofrequency (RF) wave is transmitted into the patient

1. RF wave is similar to FM radio wave - MR room is copper lined so that extraneous radiowaves will not interfere with signal from the patient
2. radiofrequency wave selected is at a particular frequency unique to hydrogen in that particular field strength (called the Larmor Frequency) and is transmitted into the patient
3. the hydrogen protons absorb the radiofrequency energy and then a short time later re-emit this RF energy (process of transfer of vibrating energy from one system to another is termed resonance)
4. the absorption of RF energy causes the small magnetic field created by the hydrogen protons to be tilted a certain number of degrees (usually 90) away from the main magnetic field.

III. Formation of Signal

A. Signal formed when the RF wave is terminated

1. the signal is strongest when the magnetic field caused by the hydrogen protons is perpendicular to the main magnetic field
2. the hydrogen protons release the absorbed energy and return to original alignment with the external magnetic field
3. this process of releasing the energy and returning to alignment with the main magnetic field is termed relaxation - there are two types of relaxation called T1 and T2, the times these take to occur are called T1 and T2 relaxation times, respectively
4. the T1 and T2 relaxation times are unique to different tissues
5. the T1 relaxation times are influenced by strength of external magnetic field (T1 times increase with increasing main magnetic field strength)

B. T1 relaxation time (longitudinal relaxation)

1. transfer of energy to surrounding tissue as the protons resume original direction in alignment with main magnetic field
2. indicates how quickly a specific tissue will be ready to absorb RF energy (short T1 time means it is ready quickly, long T1 time means it will take longer)

C. T2 relaxation time (transverse relaxation)

1. when protons are in alignment with external magnetic field they are not in exact alignment but rather they are spinning around the main direction of the static magnetic field at a certain angle
2. this movement is analogous to that of a spinning top that is tilted due to the influence of gravity

3. all of these hydrogen protons are spinning at the same frequency but are in different phases (when viewed end on)
4. the RF pulse not only tilts the magnetic vectors of these spinning protons but causes them to spin in phase
5. the greatest amount of signal is produced when they are spinning in phase and are perpendicular to static magnetic field
6. when RF pulse is stopped the spins begin to go out of phase and signal decreases
7. the movement out of phase is called T2 relaxation time

D. Number of protons present and T1 and T2 relaxation properties of tissues are primary factors that determine strength of signal

E. T2 is less than or equal to T1 of same tissue
1. T1 times in biological tissues range from 200-2000 msec
2. T2 times in biological tissues range from 50-500 msec
3. solids - short T2, long T1
4. pure liquids - long T2, long T1

F. Pulse sequences - differences in the number of protons (proton density), T1 and T2 relaxation times of different tissues can be maximized by varying a number of parameters
1. the RF energy wave is not pulsed just once but many times to acquire the signal
2. TR (repetition time) - time between one RF pulse and the next - allows protons to become aligned with direction of main magnetic field (the lower the TR the larger the number of protons that will become aligned and be available to absorb RF energy and therefore greater the signal intensity of the tissue)
3. TE (echo time) - time from the beginning of the RF pulse until the time the machine records available signal - allows time for RF energy to be released
4. varying the TR and TE times of the RF pulse sequences allows the operator to emphasize the difference in T1 relaxation times (T1-weighted images) or T2 relaxation times (T2-weighted images) in tissues
5. spin echo pulse sequence is commonly used
   a. images can be T1- or T2-weighted
   b. long TR and long TE yield T2-weighted images (means differences in signal intensities on the image are due primarily to differences in T2 relaxation times)
   c. short TR and short TE yield T1-weighted images (means differences in signal intensities on the image are due primarily to differences in T2 relaxation times)
   d. long TR and short TE yield proton density weighted images (means differences in signal intensities on the image are due primarily to differences in number of protons in the tissues)

e. short TR range is 100-1000 msec, long TR range is 2000-3000 msec

f. short TE range is 20-30 msec, long TE range is 80-105 msec

G. Signal localization (a MIRACLE is the best explanation)

1. each signal must be isolated to a specific region
2. this is accomplished by use of gradient coils that vary the magnetic field strength with position
3. utilizes 3 gradient coils that allow localization of signal to X, Y, and Z axes in a plane – by varying the sequence the gradient coils are applied, different planes (sagittal, dorsal or transverse) can be obtained

IV. Signal Conversion to Image

A. The complex signal received (consisting of many different frequencies) is converted into signal intensities by complex mathematical calculations called Fourier Transformation and are represented by gray scale in the final image

B. Image is presented as 2 dimensional plane partitioned into a grid of pixels

C. Intensity of each pixel represents strength of MR signal coming from that region

D. Each pixel has signal intensity that correspond to proton density and relaxation behavior of the protons in that pixel

Contrast Media

1) gadolinium based (Magnevist, Prohance)
2) alters proton relaxation time and therefore influences image indirectly
3) greatest effect on T1 relaxation time - shortens T1 relaxation time resulting in increased signal (brighter) on T1-weighted image
4) distributed throughout extracellular space analogous to iodinated radiographic agents
5) rapid renal excretion by glomerular filtration
6) some lesions may have signal intensities similar to surrounding tissue
7) highlights (enhances) areas of blood-train barrier breakdown and enhances vascular tissue
8) separates tumor boundaries from peritumoral edema in brain

Image Interpretation

General Principles:

1) typical lesion causes an increase in water content of tissue and therefore causes an increase in T1 and T2 relaxation times and an increase in number of protons
2) an increase in T1 time lowers signal intensity and an increase in T2 time and number of protons causes an increase in signal intensity
3) as TR increases - T1 effects are less prominent and T2 effects and proton density dominate (therefore a bright signal)
4) get T1-weighted image with short TR and short TE
5) get T2-weighted image with long TR and long TE
6) increased signal on T1-weighted image can be caused by fat, highly proteinaceous fluids, subacute hemorrhage, slow flowing blood, gadolinium, melanin
7) increased signal on T2-weighted image can be caused by inflammation (edema, infection, infarction), neoplasia, fluid collections such as CSF
8) decreased signal on T1 and T2-weighted images can be caused by air, cortical bone, fibrous tissue, calcification, and rapid flowing blood
9) T2-weighted images are good screening techniques due to high sensitivity to underlying pathological conditions
10) T1-weighted images of brain - CSF is dark and there is poor differentiation between gray and white matter
11) T2-weighted images of brain - CSF is bright and there is good contrast between gray and white matter