The magnetic resonance imaging biology essay

Science, Biology

CHAPTER 4

Introduction And Overview

Magnetic resonance imaging (MRI) is a medical imaging process that uses a magnetic field and radio frequency (RF) signals to produce images [] of various organs of the human body. MRI produces images that are distinctly different from the images produced by other imaging modalities such as X-Rays and CT scans. The image and resolution produced by MRI is quite detailed and can detect any minute changes of structures within the body []. The contrast agents such as gadolinium are used in some procedures to increase the accuracy of the images. The cutaway view of an MRI machine is shown in Figure 4. 1. Figure 4. 1Cutaway view of an MRI machineMRI process can selectively image several different tissue characteristics which makes it different from other modalities. A potential advantage of this is that if a pathologic process does not alter one tissue characteristic and produce contrast, it might be visible in an image because of its effect on other characteristics. This causes the MRI process to be more complex than most other imaging methods. For optimizing an MRI procedure for a particular clinical examination, the user must have a good knowledge of the characteristics of the magnetic resonance (MR) image and how these characteristics can be controlled. In this chapter, we present a basic knowledge and overview of the MR image, how the image relates to specific tissue characteristics, and how image quality characteristics can be controlled.

The MR Image

MRI is based on the principle of nuclear magnetic resonance (NMR). The principle of NMR for medical imaging was first demonstrated by Raymond Damadian in 1971 and Paul Lauterbur in 1973 []. The MR image displays certain physical characteristics of human tissue. The MR image is the display of radio frequency (RF) signals that are emitted by the tissue during the image acquisition process. The source of the signals is a condition of magnetization that is produced in the tissue when the patient is placed in the strong magnetic field as shown in Figure 4. 2. The tissue magnetization depends on the presence of magnetic nuclei in it. The specific physical characteristics of a tissue or fluid that is visible in the image depends on how the magnetic field is being changed during the acquisition process. An image acquisition consists of an acquisition cycle, such as a heartbeat, which is repeated number of times. For every cycle, the tissue magnetization is forced with a series of changes. Different tissues and fluids progress through these changes at different rates. The RF signal intensity and the brightness of the tissue depends on the level of magnetization during the " picture snapping time". The specific tissue characteristics and the blood conditions are the prime source of contrast with which the MR images are identified in general. The tissue magnetization level, as well as contrast at the picture snapping time, determines these characteristics. The imaging protocol set by an equipment operator, determines the image type. Figure 4. 2 Gradient Magnetic Parts of the MRIThere are three categories of characteristics that are generally used as a source of contrast of image. Tissue magnetic characteristics are the first one among them. It is the most, widely; used one. Characteristics of fluid (usually blood) movement fall in the second category. The spectroscopic effects related to molecular structure form the third category.

Principles of MRI

NMR is a phenomenon of magnetic systems that possesses both magnetic moment and an angular moment. All materials are made of atoms. Atoms consist of nuclei which contains protons and neutrons. Nuclei with odd number of these components possess a nuclear spin and a magnetic moment such as 1H, 2H, 13C, etc. Protons and neutrons combine with opposite spins to form nucleus. So when there is an even number of protons and neutrons, then there is no net spin where as odd occurrences possess a net spin. The Hydrogen nucleus which has single proton possesses a net spin. The fat and water present in the human body contain many hydrogen atoms. The NMR signal, arising from the body tissue's hydrogen nuclei are captured in MR images. The net spin of the nucleus gives an angular moment which results in a current loop. This current generates a magnetic field. The combined effect of the angular moment and the magnetic field provides a magnetic dipole moment to the proton. When a material having net magnetic moment is placed within a magnetic field, a proton having magnetic dipole moment precesses around the field axis as shown in Figure 4. 3. The frequency of precession is called as Larmor frequency, . This frequency is proportional to the strength of the applied magnetic field which is defined by(4. 1)where stands for the gyromagnetic ratio and http://www. cs. sfu. ca/%7Estella/papers/blairthesis/main/_4056_tex2html_wrap5292. gif is the applied magnetic field's strength. is a nuclei specific constant. The gyromagnetic ration for hydrogen is 42. 6MHz/Tesla. The object is positioned within the uniform magnetic field , with a value between 0. 5 to 3. 0 Tesla. Because of this, the hydrogen nuclei object aligns with the magnetic field. It creates a net magnetic moment http://www. cs. sfu. ca/%7Estella/papers/blairthesis/main/_4056_tex2html_wrap5180. gif, parallel tohttp://www. cs. sfu. ca/%7Estella/papers/blairthesis/main/_4056_figure87. gifFigure 4. 3. (a). Alignment of odd magnetic moment of hydrogen nuclei in theabsence of a strong magnetic field. (b) Alignment of the hydrogennuclei when the strong magnetic field, , is applied aboutthe direction of the field. A radio-frequency (RF) pulse, , is applied in a direction perpendicular to . This causes M to tilt away from . Some energy and a measurable RF signal is gained by the nuclei in the realignment. The nuclei realign when RF signal is removed. The net magnetic moment of the nuclei (http://www. cs. sfu. ca/%7Estella/papers/blairthesis/main/_4056_tex2html_wrap5180. gif), is in parallel with . This process of returning to equilibrium is called as relaxation. The nuclei emitt their own RF signal and lose energy during this time. This is shown in Figure 4. 4. This signal is called as the free-induction decay (FID) response signal. A conductive field coil placed around the imaging object measures the FID response signal. This measurement is used to obtain the 3D grey-scale MR images. http://www. cs. sfu. ca/%7Estella/papers/blairthesis/main/_4056_figure97. gifFigure 4. 4. (a) The net magnetic moment of the nuclei, http://www. cs. sfu. ca/%7Estella/papers/blairthesis/main/_4056_tex2html_wrap5180. gif, tilted away from bythe RF pulse, ,(b) Returning of nuclei to equilibrium such that http://www. cs. sfu.

ca/%7Estella/papers/blairthesis/main/_4056_tex2html_wrap5180. gifis again parallel to .

4. 4 Components of MRI system

Figure 4. 5 shows a schematic depiction of the major components of a magnetic resonance imager. The magnet produces the strong magnetic field for the imaging process. There are gradient coils, inside the magnet which produces a gradient in in all the three X, Y, and Z directions. The RF coil is placed within the gradient coils. The RF coil produces the magnetic field. It is necessary for rotating the spins by 900, 1800, or any other value which is selected by the pulse sequence. The signal coming from the spins within the body is detected by the RF coil. The patient is placed within the magnet with the help of computer controlled patient table. The table has 1mm positioning accuracy. The RF shield surrounds the scan room. This shield prevents the possibility of RF pulses from radiating out of the hospital. It also prevents the detection of other RF signals, from television and radio stations, by the imager. Figure 4. 5 Schematic representation of MRI scannerThe heart of the imager is a computer. All components on the imager are controlled by it. The RF components such as radio frequency source and pulse programmer are under the control of this computer. A sine wave of the desired frequency is produced by the source. The RF pulses are shaped into apodized sine pulses by pulse programmer shapes. The pulse power is increasedfrom millli watts to kilo watts by the RF amplifier. The gradient pulse programmer sets the shape and amplitude of the gradient fields. It is also controlled by the computer. The gradient coils are driven by the gradient pulses. The gradient amplifier increases the power of these pulses to a sufficient level. Fourier

transform can be performed in fractions of a second in two-dimension (2D) by the image processor. The Fourier transform is off loaded to this faster device by the computer. A control console is used to provide input to the computer by the operator of the imager. An imaging sequence can be selected and also customized from the console. The images can be seen on a video/image display by the operator or hard copies of the images can be made on a film printer. A typical MRI suite with main components like MRI scanner, image acquisition system, and movable table is shown in Figure 4. 6. Figure 4. 6 MRI scanner with movable table

Imaging coordinates and planes

The XYZ magnetic resonance coordinate system is not used in clinical imagers for collection and presentation of images. The anatomic coordinate system is used instead of this. The axes are referenced to the body as shown in Figure 4. 7. The three axes are left-right (L/R), anterior-posterior (A/P), and superior-inferior (S/I). Similarly, on clinical imagers the terminology XY, YZ, and XZ are not commonly used to indicate the imaged planes. Instead they are called as axial or transverse, sagittal and coronal respectively as shown in Figure. An axial plane is an imaged plane, which is perpendicular to the long axis (Z-axis) of the body. L/R and A/P are the sides of this plane. A plane that bisects the left and right sides of the body is called a sagittal plane. The sagittal plane is perpendicular to the X-axis and parallel to the field of gravity (g). S/I and A/P are the sides of this plane. A coronal plane is a plane that bisects the front of the body from the back. L/R and S/I are the sides of this plane. This plane is mutually perpendicular to both axial and sagittal plane. Figure 4. 7 Anatomical coordinates and planes

Imaging parameters

MRI signal intensity produced by a particular tissue depends on at least three intrinsic tissue parameters: the proton density, which determines , and the relaxation times T1 and T2. Hence, a number of MR imaging techniques(" weightings") are available to choose from, which accentuate some properties and not others. They are PD-weighted or PD, T1-weighted or T1, and T2 weighted or T2 images. Two more additional parameters that control the image contrast are repetition time (TR) and echo time (TE). The RF pulse is repeated at a predestined rate during MR image acquisition. TR is the period of the RF pulse sequence, which is measured in milliseconds. It is the TR which determines the amount of T1 relaxation for a particular type of nuclei in a given environment. If the TR is longer the longitudinal magnetization is also recovered more accordingly. Greater signal density is possessed by tissues having short T1 compare to those with longer T1 at any given TR. Magnetization can be recovered more in long TR which thus reduces differences in the image contrast in the T1 contribution. The FID response signals, within the TR interval, can be measured at various times. TE is the time between the application of RF pulse and the response signal. When a 180 degree, refocusing pulse is applied after a delay of TE/2 from the RF pulse, the spin echo occurs. This time is referred as TE. TE determines the amount of decay of the transverse magnetization that is allowed to occur before the signal is read. TE controls the T2 relaxation. The TR and TE control the relaxation times of local tissue, T1 and T2, affect the signal. The variation in contrast is due to the application of RF pulses at different TRs and receiving of signals at different TEs, in MR images. The contrast difference for various tissue types can be achieved by adjusting TR and TE. Table 4. 1 shows the set of conditions necessary to produce the MR weighted images in terms of TR and TE values[]. Table 4. 1 : MRI imaging techniques in terms of TR and TE

Weighting

TR value

TE value

T1 <= T1 < > T1>= T2PD>> T1 < Increase Parameters below

SNR

Resolution

Acquisition Time

Distance Covered

Max. Number of slices

FOV (Field of view)

+

-

ncncncNEX (Number of excitation or acquisition)

+

nc

+

ncncSlice Thick

+

-

nc

+

ncInter slice gap

+

-

nc

+

ncTR

+

nc

+

nc

+

TE

-

ncncnc

-

Matrix size

-

+

+

ncncBandwidth

-

ncncnc

+

Magnet strength

+

ncncncncIn MRI, the quality of image is generally described in terms of signal to noise ratio (SNR), spatial resolution, contrast and acquisition time. They all are interrelated and the change in one affects the others. Hence, a radiologist has to decide what factors are more important for an examination. The trade off between these factors are given in Table 2. This table shows the effect on the top row of parameters, of increasing the variables in the column on the right. A plus (+) sign indicates an increase, a minus (-) sign indicates a decrease, and (nc) indicates no change. Many of these parameters are interdependent. so we are looking at the direct effects of changes of single variables.

Image Types and Tissue Characteristics

Proton Density (PD) Images

One of the tissue characteristic is the concentration or tightness between protons (hydrogen) that can be imaged most directly. The image brightness can be determined by three factors such as magnetization of tissues, RF signal and proton density. The strong signals are generated by high proton density tissues and which produced brightest images. The Low signals are produced when low proton density and it generate dark images.

Magnetic Relaxation Times

Magnetic relaxation time is time duration between proton comes from higher energy level to lower energy level. The protons are go to higher energy level when RF signals are given to that protons. The higher energy level is unstable one and it will come back to original position after RF signals are stopped. This process is known as relaxation. The time required for the magnetization to relax varies depending on the tissue type. This relaxation time is commonly used to differentiate (i. e., produce contrast) normal and pathologic tissues. Every tissue is characterized by two relaxation times: T1 and T2. T1 and T2 are the leading contrast . It is impossible to create images in which one of the tissue characteristics (e. g., PD, T1, or T2) is the only pure source of contrast. Usually, there is a mixing or blending of the characteristics. But, an image will be more heavily weighted by one of them. When an image is described as a T1-weighted image, it means that T1 is the predominant source of contrast. There is also some possible contamination from the PD and T2 characteristics and similarly for PD as well as T2. Figure 4. 5 shows 2d slices from the weighted MRI volumes. http://www. cs. sfu. ca/%7Estella/papers/blairthesis/main/_4056_figure119. gifFigure 4. 3. (a) A proton density (PD) weighted MR image slice. (b) The same T2-weighted slice.

T1

When the imaging protocol is set to produce a T1-weighted image, it is the tissues with the short T1 values that produce the highest magnetization and are the brightness in the image.

T2

When the imaging protocol is set to produce a T2-weighted image, it is the tissues with the long T2 values that are the brightest. This is because they have a higher level of magnetization at the picture snapping time.

Slices

A typical examination will consist of at least one set of contiguous slices. In most cases the entire set of slices is acquired simultaneously. However, the number of slices in a set can be limited by certain imaging factors and the amount of time allocated to the acquisition process. The slices can be oriented in virtually any plane through the patient's body. The major restriction is that images in the different planes cannot generally be acquired simultaneously. For example, if both axial and sagittal images are required, the acquisition process must be repeated.

Noise

Visual noise is a major issue in MRI. The presence of noise in an image reduces its quality, especially by limiting the visibility of low contrast objects and differences among tissues. Most of the noise in MR images is the result of a form of random, unwanted RF energy picked up from the patient's body. The amount of noise can generally be controlled through a combination of factors. However, many of these factors involve compromises with other characteristics.

Artifacts

Artifacts are undesirable objects, such as streaks and spots, that appear in images which do not directly represent an anatomical structure. They are usually produced by certain interactions of the patient's body or body functions (such as motion) with the imaging process. There are numerous kinds of artifacts that can occur in MRI. Some of them affect the quality of the MRI but some do not affect the diagnostic quality. Artifacts are categorized based on the source of cause presented in the Table 4. 3. Table 4. 3 : MRI artifacts

S. No

Artifact

Cause

1RF QuadratureFailure of the RF detection circuitry2B0 InhomogenityMetal object distorting B0 field3GradientFailure in a magnetic field gradient4RF InhomogenityFailure of RF coil5MotionMovement of imaged object during the sequence6FlowMovement of body fluids during the sequence7Chemical shiftLarge B0 and chemical shift difference between tissues8Partial volumeLarge voxel size that is averaged by many tissues9Wrap aroundImproper chosen FOV10Gibbs ringingLack of sampling dataThere is a selection of techniques that can be used to reduce the presence of artifacts.

Spatial

The general spatial characteristics of the MR image are described previously. However, when setting up an imaging protocol the spatial characteristics must be considered in the general context of image quality.

Image Acquisition Time

When considering and adjusting MR image quality, attention must also be given to the time required for the acquisition process. In general, several aspects of image quality, such as detail and noise, can be improved by using longer acquisition times.

Protocol Optimization

An optimum imaging protocol is one in which, there is a proper balance among the image quality characteristics described above and also a balance between overall image quality and acquisition time. The imaging protocol that is used for a specific clinical examination has a major impact on the quality of the image and the visibility of anatomical structures and pathologic conditions. Therefore, the users of MRI must have a good knowledge of the imaging process and the protocol factors and know how to set them to optimize the image characteristics. The five major image quality characteristics such as contrast sensitivity, detail, noise, artifacts, and spatial can be controlled to a great extent by the settings of the various protocol factors. MRI is a powerful diagnostic tool because the process can be optimized to display a wide range of clinical conditions. However, maximum benefit requires a staff with the knowledge to control the process and interpret the variety of images.

Advantages of MRI

MRI is preferred over other modalities especially for children and patients since it is not using ionizing radiationMRI can produce the image with greater detail thereby depicting the abnormalities with more sensitiveMRI is so flexible that it can image in any plane without altering the position of the patientMRI agents cause less harm compared with othersMRI can overcome the artifacts by bones in CT imagesSo, it is concluded that MRI is the best source for any of the clinical studies and researches related with medical science