Basic Principles (How MRI Works?)

By

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Computer Applications 466

Monday, October 11, 2010
How MRI Works?

- Magnetic theory.
- Resonance.
- Relaxation.
- Contrast.
A picture is worth a thousand words
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Magnetic theory

* Creation of magnetism: 3 ways...

1- Through the imbalance between the spinning electrons in two different directions in a magnetic element.
   - e.g. An iron atom has 9 electrons spinning in its outer shell clockwise and 5 electrons anticlockwise. This imbalance between the two directions gives iron the potential for magnetism.

2- Through the imbalance between the protons and neutrons within the nucleus. This imbalance is too weak unless aided with special instrumentation.

3- Through the spinning proton in hydrogen atom, which is the only atom without any neutrons.
Magnetic theory

- The Hydrogen Atom:
  * The proton within the hydrogen atom is similar to a tiny bar magnet with two poles (north and south).
  * The spinning proton creates a magnetic field that’s too weak to detect, BUT…
  * The billions and billions of hydrogen protons in the body spin in random directions in neutral environment, BUT…
Magnetic theory

- The Hydrogen Atom:
  * The spinning of the protons into two different directions creates two opposite magnetic fields one parallel and one anti-parallel to the main magnetic field known as \( B_0 \), BUT…
  * The parallel protons do NOT spin exactly in the same direction of \( B_0 \), BUT…
  * The rate of the precession or wobbling depends on the strength of the magnetic field.

- e.g. The precession rate of protons at 1 Tesla = 42.570 MHz
Magnetic theory

- **The Hydrogen Atom:**
  
  * The precession of hydrogen proton continues but its strength or speed fades until another RF pulse is applied.
  
  * This precession depends on the characteristic of the element as well as on the strength of magnetic field ($B_0$).
Resonance

- The electromagnetic spectrum consists of different components with Radiofrequency (RF) being the most important component in MR imaging.
Resonance

* The RF applied at Larmor frequency in MRI has low energy, but it is sufficient enough to cause the parallel protons to oppose the main magnetic field.

* Larmor frequency is defined as the frequency at which the nucleus will absorb energy, altering protons alignment.

<table>
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<th>Long Wavelength</th>
<th>Aircraft and Shipping Bands</th>
<th>Small Frequency (Low Energy)</th>
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<td>AM Radio</td>
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<td>Shortwave Radio</td>
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<td>Microwaves and Radar</td>
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<td>Infrared Light</td>
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<td>Short Wavelength</td>
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- Large Frequency (High Energy)
- Small Frequency (Low Energy)
- Long Wavelength
- Short Wavelength
Resonance

* Since RF pulse is part of the electromagnetic spectrum, it posses both electrical and magnetic fields. Therefore, when applied to the hydrogen nuclei a second external magnetic field is formed and this is abbreviated as (B1).

** What does B1 magnetic field do to the main magnetic field B₀?

1- Gives sufficient energy to parallel protons to oppose B₀.
2- Decreases the amount of longitudinal magnetization since protons cancel each other out.
3- Increases magnetization in the transverse plane and eventually causing transverse magnetization.
4- Causes the MR signals to decay (free induction decay “FID”) after it is stopped. This will eventually produce what is known as relaxation.
5- Causes a deflection angle that’s known as flip angle.
Resonance

Precession

Decay

Recovery

Longitudinal

Transverse
RF pulse causes slowly protons to alter from longitudinal plane to transverse plane. Depending on how long the RF pulse is applied, protons will shift entirely from the longitudinal to transverse plane, creating a transverse magnetization.
Resonance

• Relaxation:
  * There are two common flip angles used in most MRI pulse sequences:
    1- 90° flip angle, causing magnetization to flip into the x-y plane or transverse plane.
    2- 180° flip angle, causing magnetization to flip back into the z plane or longitudinal plane.

  * Other flip angles may be used for fast spin echo and functional MRI, such as the 45° used in a FLASH pulse sequence.
Longitudinal magnetization is demonstrated prior to applying the 90° RF pulse.

The 90° flip angle applied by the RF pulse causes a shift in magnetization from longitudinal to transverse magnetization.
Relaxation

* The process in which protons try to return back to equilibrium by realigning to the direction of the main magnetic field $B_o$ after the RF pulse is switched off.

* Type of relaxation determines the type of image generated:
  1- T1 relaxation (Longitudinal relaxation).
    - The return of longitudinal magnetization to equilibrium ($B_o$), also known as T1 recovery.
  2- T2 relaxation (Transverse relaxation).
    - The return of transverse magnetization to equilibrium, also known as T2 decay.
Relaxation

• **Longitudinal Relaxation (Spin-Lattice or T1):**
  - Re-growing or recovering of 63% of longitudinal magnetization after signals decay.

Initial equilibrium state of T1

MR signal starts to decay after applying RF pulse

Re-growth of T1 to equilibrium after termination of the RF pulse
• **Longitudinal Relaxation (Spin-Lattice or T1):**
  - An input of energy is required to align all the protons in the direction of the main magnetic field.
  - Extra energy is provided when the RF pulse is applied. BUT once this RF pulse is over, there is a dissipation of this energy into the surrounding atoms. This is called T1 relaxation.
  - This release of energy is accomplished when the forced antiparallel protons relax back into a parallel state. The affect of T1 relaxation is a decrease in the transverse plane and an increase in the longitudinal plane.
Relaxation

• Longitudinal Relaxation (Spin-Lattice or $T_1$):
Relaxation

- **Longitudinal Relaxation (Spin-Lattice or T1):**
  - The strength of the longitudinal signal can not be directly detected to create images. So why do we care about it to begin with??.
  - The value of T1 differs from one tissue to another and therefore, it has an extremely important diagnostic value. **BUT how do we measure it??**
  - The longitudinal magnetization just before a second RF pulse affects the strength of the new transverse signal. Thus, if another RF pulse is given before full T1 relaxation occurs, the height of the subsequent signal will be smaller, allowing T1 to be calculated by subtraction.
• **Transverse Relaxation (Spin-Spin or T2):**
  - Re-phasing of the MR signals or protons from the longitudinal magnetism (plane) to the transverse magnetism (plane) after applying a 90° RF pulse.
  - T2 relaxation or decay is the result of the exchange of energy between spinning hydrogen nuclei, and therefore it is referred to as "spin-spin" relaxation.
  - T2 relaxation time is the time required for transverse magnetization to decay to 37% of its initial value via irreversible process.
  - T2 relaxation occurs at a shorter or equal time to T1 relaxation, but never longer.
• **Transverse Relaxation (Spin-Spin or T2):**
  - The T2 and T1 times are approximately the same, 2-3 seconds. However, in biological materials, the T2 time is considerably shorter than the T1 time.
    --- For example: CSF, T1=1.9 seconds and T2=0.25 seconds. For brain white matter, T1=0.5 seconds and T2=0.07 seconds (70 msec).
  - The more efficient the exchange of energy in the hydrogen, the shorter the T2 time and vice versa.
    --- The T2 time of fat= 80ms, whereas the T2 time in water= 200ms.
  - In light of this, it’s crucially important to know what T2 value an area of interest has when imaging to determine the appropriate imaging parameters.
Relaxation

• **T2* Relaxation:**
  - A rapid decay or loss in transverse magnetization due to inhomogeneities in the magnetic field as well as local inhomogeneities within the tissue.

  - Although T2* is not used and may be considered not useful in structural MRI since transverse magnetization is lost rapidly, T2* is used in ....... Because ..... 

  - To recover the rapid loss of the transverse magnetization another 180° is applied at the end of the first 180°.
Relaxation

• T2 Relaxation Vs. T2* Relaxation:

![Diagram showing T2 and T2* relaxation processes](image)

- RF
- 90° pulse
- 180° pulse
- T2* decay
- T2 decay
- Echo
- TE
Relaxation

- **Transverse Relaxation (Spin-Spin or T2):**

  90° RF pulse is applied and MR signals start to shift from longitudinal to transverse magnetization.

  Initial equilibrium state of magnetization prior to applying the 90° RF pulse.

  T2 relaxation starts to dephase after termination of the 90° and MR signals return to longitudinal magnetization or equilibrium.
A picture is worth a thousand words

Longitudinal magnetization. Protons aligned to the main magnetic field ($B_0$) during which $T_1$ relaxation is in equilibrium.

Transverse magnetization. Protons dephase from the main magnetic field ($B_0$) after applying a $90^\circ$ RF pulse during which $T_2$ relaxation is in equilibrium.
T1 Relaxation Vs. T2 Relaxation

• The difference between spin-lattice and spin-spin relaxations.

• The difference in time between T1 recovery and T2 decay.

• The difference in magnetization direction between T1 relaxation and T2 relaxation.

• The role of RF pulse application in T1 relaxation and T2 relaxation.
Contrast

• **Image Contrast:**
  - The characterization of tissues using shades of gray is known as **image contrast**.
  - Effects from T1 and T2 relaxation times are opposite (because one affects the longitudinal relaxation and the other affects the transverse relaxation). This is a problem because many pathological conditions (i.e. Adema, inflammation, cystic and tumorous growths) increase T1 and T2 at the same time due to increases in free water in the area. Therefore, **image contrast can not** be distinguished. **So what can we do about it??**
  - I got it, woohooooo. **Proton Density**.
Contrast

• Image contrast:
  - The contribution of proton density to the image contrast depends on how many water molecules are present in the tissue being scanned.
    -- Tissues with high proton density (i.e. high free water as in fat, fluids, and edema).
    -- Tissues with low proton density (i.e. low free water as in cortical bone, fibrous tissue, or in air).
  - Materials that have low proton density will appear dark gray or black on all kinds of scans because varying the T1 or T2 weighting will not affect their signal strength.
  - This allows differentiation of bone, tendons, and air pockets possible regardless of any other weighting changes.
Contrast

- **Image contrast:**
  - Protons in water and other pure fluids like cerebrospinal fluid (CSF) have both long T1 and T2 relaxation times while protons in fat tend to have both short T1 and T2 times.
  - To obtain a T1-weighted image (an image where the T1 relaxation is the dominant source of signal), the TR value is reduced and the TE value is set far below a T2 relaxation echo time.
  - To obtain a T2-weighted image (an image where the T2 relaxation is the dominant source of signal), the TR value is increased while the TE value is set close to the T2 relaxation time.
Contrast

- **Image contrast:**
  
  - T1-weighted image has good tissue contrast and the CNS fluid in the ventricles and sulci appears dark.
  
  - Fluids have long T1 and T2 relaxation times, setting low TE and TR values produce images where fluid has a low signal and appears dark in T1-weighted images, but vice versa in T2-weighted images.
  
  - Tissues and other solids tend to have low T1 and T2 relaxation times, setting low TE and TR values produce images where tissue signal is high and appears bright in T1-weighted images, but vice versa in T2-weighted images.
  
  - The principle of image contrast is used in tissue characterization.
A picture is worth a thousand words

**T1TB Vs. T2TD**

T1-weigthed images with fluid dark and Tissue Bright

T2-weigthed images with fluid bright and Tissue Dark
Relaxation Time

- Develop a new idea on how to enhance medical imaging technology by the advent of computer and its applications.
- The internet project should be in 5 double space typed pages with a mini research build up style.
- Groups should be of 3 students or less.
- The deadline is 30/12/2010.