The Mystery of MRI

Yuchen Wu

Professor Huburt Bray

Mathematics in the universe

Duke University

07/24/17

Introduction:

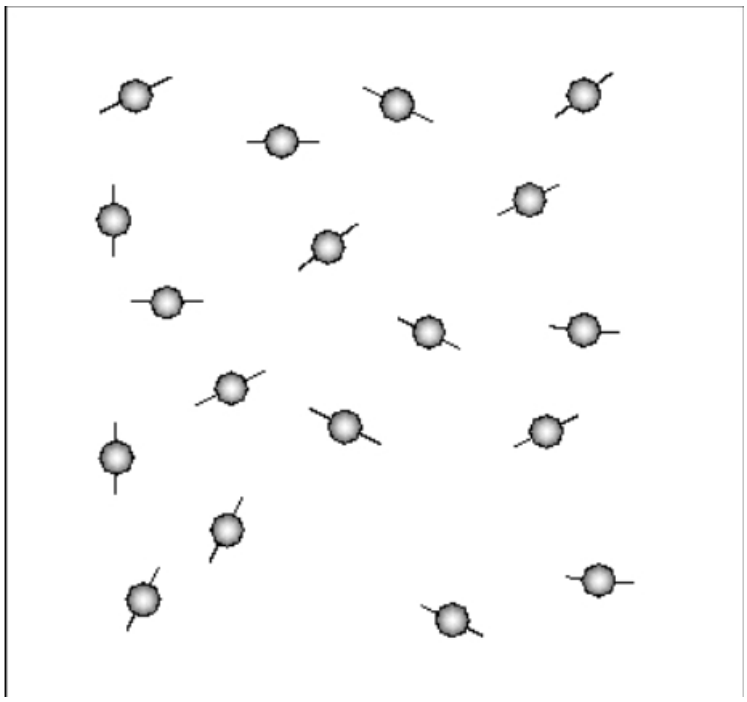
Nowadays, with the development of the medical technology, doctors and scientists are trying to find the diseases as fast and precise as possible. For this purpose, a new kind of image tech called MRI has become more and more popular since its accuracy and the non-invasion. It is really fancy for me so that I would like to take a research paper on this topic. In this paper, I will discuss about the operating principle of the machine, the differences between MRI and other imaging technologies, and the reason why it is so expensive.

The basic principles of MRI

The reason why MRI can create the images of our body is based on the directional magnetic field, or moment, associated with charged particles in motion. [1] The nucleus which contains an odd number of protons or neutrons has a characteristic motion or precession, and since the protons are positively charged particles, this precession produces a small magnetic

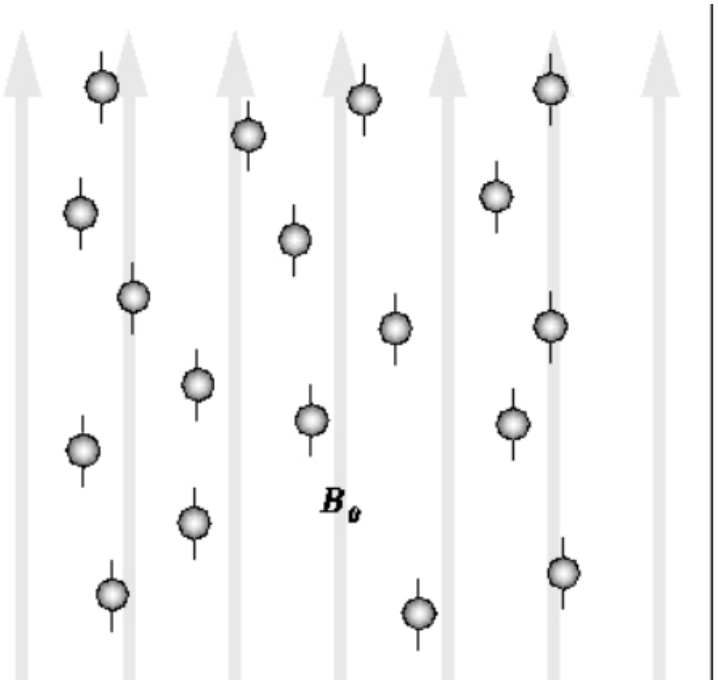
moment.

Since 70% percent of our body is made of water so the MRI depends mostly on the hydrogen in the water. The atoms themselves are randomly distributed normally, like picture A.



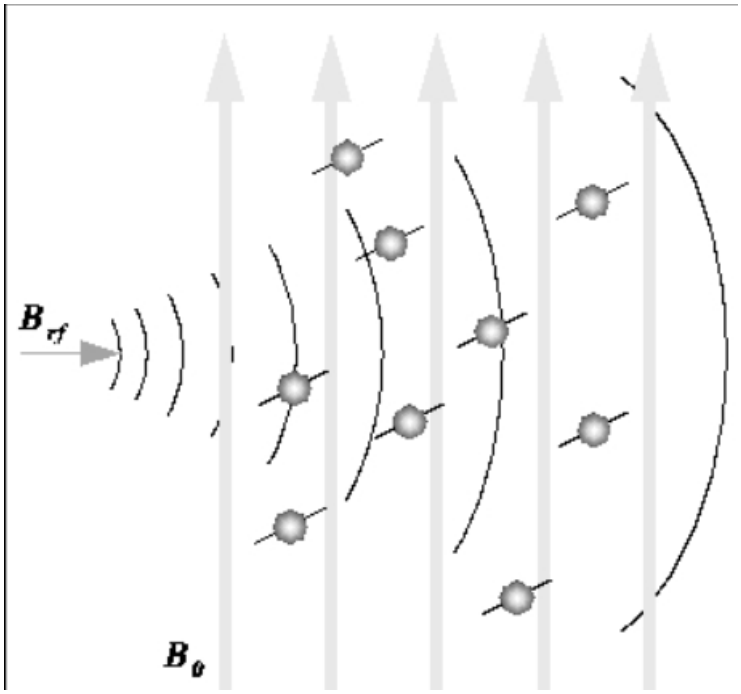
Picture A

But when we put the atom of hydrogen in the magnetic field, plenty of the nucleuses align themselves with the direction of the magnetic field, like picture B



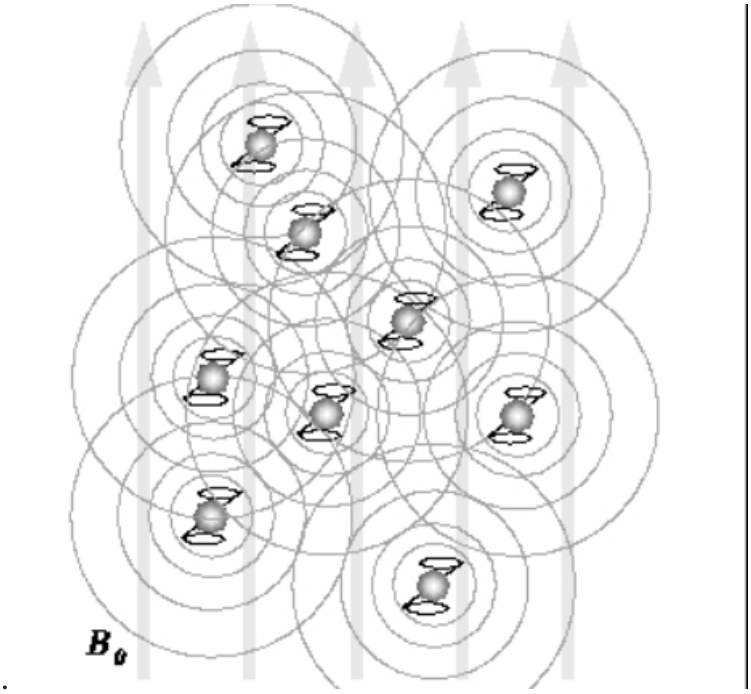
Picture B

Then the nucleus will present a particular behavior called Larmor precession, which is the procession of the magnetic moment of an object about an external magnetic field since the field exerts a torque on the magnetic moment. The frequency of Larmor precession is proportional to the applied magnetic field strength as defined by the Larmor frequency. And then a ratio-frequency pulse with the same frequency with the Larmor frequency is applied perpendicular to the origin magnetic field B_0 to make the moment tilt away from B_0 as the picture C.



PICTURE C

When the radiofrequency (RF) source is switched off the magnetic vector returns to its resting state, and this causes a signal (also a radio wave) to be emitted as picture D.



Picture D

It is this signal which is used to create the MR images. Receiver coils are used around the body part in question to act as aerials to improve the detection of the emitted signal. The intensity of the received signal is then plotted on a grey scale and cross sectional images are built up. Multiple transmitted radiofrequency pulses can be used in sequence to emphasis particular tissues or abnormalities.

A different emphasis occurs because different tissues relax at different rates when the transmitted radiofrequency pulse is removed. The time taken for the protons to fully relax is measured in two ways. The first is the time taken for the magnetic vector to return to its resting state and the second is the time needed for the axial spin to return to its resting state. The first is called T1 relaxation; the second is called T2 relaxation. An MR examination is thus made up of a series of pulse sequences. Different tissues (such as fat and water) have different relaxation times and can be identified separately. [2]

Tissue	TI(msec)	T2(msec)
Water	4000	2000
Gray matter	900	90
Muscle	900	50
Liver	500	40
Fat	250	70
Tendon	400	5

Since most of the diseases manifest themselves by an increase in water content, MRI is a sensitive test for the detection of the diseases. And there is particular “fat suppression” pulse sequence which will remove the signal emitted by the fat, leaving only the signal from any abnormalities lying with it.

And there is also a simple way to explain the operating principle of MRI which is that when a human body is placed in between two large magnets, the hydrogen atoms like tiny magnets now obey the large one and change their orientation with respect to the magnetic field just like how small children obey their PT master in school.This change in position of the hydrogen atoms in the body picked up by sensitive devices and converted into digital images with the help of a computer.

However, the exact nature of the pathology can make it more difficult to ascertain the diseases. For example, infections and tumors can in some cases look similar (well when gets sick nobody wants to get a tumor so nobody expect to get confused by the image). At this time, a careful analysis of the images by a radiologist will often be necessary. Anyway, with the systematically trained, correct answer will easily be yielded; therefore, MRI is definitely a perfect way to detect the diseases.

Contrast with other imaging tech

Today there are three kind of imaging technologies which are used the most in medical industry——X ray, CT, and the leading actor of this article, MRI.

X-ray uses a small amount of radiation that passes through the body to quickly capture a single image of your anatomy to assess injury (fractures or dislocations) or disease (bone degeneration, infections or tumors). Dense objects, such as bone, block the radiation and appear white on the X-ray picture. Radiologists review the pictures and create a report with their findings to aid in diagnosis.

X-ray is good for:

- Assessing injury
- Offering a low-cost, first-look exam

CT(Computed Tomography) is a rapid, 5-20 minute painless exam that combines the power of X-rays with computers to produce 360 degree, cross-sectional views of your body. CT is able to image bone, soft tissue and blood vessels all at the same time. It provides the radiologist with details of

bony structures or injuries, diagnosing lung and chest problems, and detecting cancers.

The technology has a tube design but is slim from front to back, seldom creating anxiety or claustrophobia. A person who is very large may not fit into the opening of the CT scanner or may be over the weight limit for the moving table. While it is a painless process, there is radiation exposure with CT scans. CT is generally not recommended for pregnant women or children unless absolutely necessary.

CT is good for:

- Imaging bone, soft tissue and blood vessels at the same time
- Pinpointing issues with bony structures (injuries)
- Evaluating lung and chest issues (see lung scan image to the right)
- Detecting cancers
- Imaging patients with metal (no magnet)

Magnetic Resonance Imaging (MRI) combines a powerful magnetic field with an advanced computer system and radio waves to produce accurate, detailed pictures of organs, soft tissues, bone and other internal body

structures. Differences between normal and abnormal tissue is often clearer on an MRI than CT. There is no radiation exposure with MRI machines.

An MRI scan can typically last from 30 minutes to an hour since images are taken as cross sections or "slices" of the body part being scanned, as well as other factors such as the type of technology used (high-field versus open or open upright MRI), what the MRI is looking for and if the patient moves. Patients with claustrophobia typically get anxious in a traditional bore scanner due to having to stay still on a hard table for a long period of time. The machine also makes loud knocking sounds. A comprehensive patient screening procedure is followed as due to the magnetic field, special precautions are made or exams may be canceled for patients with cardiac pacemakers, tattoos and metal implants. A person who is very large may not fit into the opening of a traditional tube MRI scanner or may be over the weight limit for the moving table.

MRI is good for:

- Imaging organs, soft tissue an internal structures (see spine scan image to the right)
- Showing tissue difference between normal and abnormal
- Imaging without radiation[4]

Conclusion:

The 3 kinds of techs each has their own advantages and disadvantages as well, for example, X-ray costs the least and it can help the doctors make the diagnose immediately after get injury. However, the accuracy of it may need the other 2 kinds of imaging techs to verify and correct. CT is good at detecting cancer but it is really harmful for the body since the radiation. MRI does no harm to the human body and it is quite good at tell the normal tissue and the abnormal one.

Why MRI so expensive

The MRI does provide accurate diagnose, but the high cost is always a puzzle for citizens. So what causes the high price of the MRI scan?

According to recently released Medicare pricing data analyzed by Nerd Wallet Health, the average cost of an MRI in the U.S. is $2,611. Here's what's behind that number.

The cost of the machine

The main cost of the MRI scanner is in generating this very large, very uniform magnetic field. And the way that we do is using super conducting wires. So super conducting materials has this unique property that they have no electrical resistance. It’s not nearly nothing, it’s absolutely nothing. So

once you start a current flowing through these coils that current will continue to flow essentially forever. So the main cost of the MRI scanner is this coil of wire, and to keep that coil of wire super-conducting, to keep it with zero resistance we have to keep it very cold. And we keep it cold using liquid helium. Liquid helium is four degrees above absolute zero, absolute zero is minus 273 degrees Celsius. And when you look at the MRI scanner itself, what you're looking at is a big tub that contains several thousand liters of liquid helium.[5]

Make Room for a Big Machine

Magnetic resonance imaging machines use magnets and radio waves to produce black-and-white images of bones and organs, usually to help with a diagnosis. Only five companies make MRI machines, and each specializes in a few magnet strengths, so there is relatively little competition when it comes time for a hospital or medical center to buy one.

Machines come in a variety of sizes and powers. Their imaging power is measured in magnetic field strength units called Teslas; low-field or open MRI machines measure 0.2 to 0.3, while the strongest currently on the market are 3 Teslas. Used low-field MRI machines can be as cheap as $150,000 or as expensive as $1.2 million. For a state-of-the-art 3 Tesla MRI machine, the price tag to buy one new can reach $3 million.

The room that houses the machine, called an MRI suite, can cost hundreds of thousands more. Safety features must be built in to protect those rights outside from the magnetic field. Add in patient support areas and installation costs, and a suite with just one machine can cost anywhere from $3 million to $5 million. Recouping these costs factors into your bill, but that alone does not tell the entire story.

Add in the Doctors and Hospitals

Charges for a single MRI scan vary widely across the country for reasons beyond startup costs. According to the recently released Medicare data, MRIs charges are as little as $474 or as high as $13,259, depending on where you go. (Another recent study of medical claims by Change Healthcare found that in-network prices for certain MRIs can run from $511 to $2,815.) That's because hospitals and medical centers can charge whatever they want, and in most cases they don't have to justify prices or even disclose them ahead of time.

Doctors can also charge whatever they want, and though the MRI facility probably sets the rates of their staff doctors, you'll be charged separately for a radiologist to read the MRI. Additionally, your ordering physician may ask for the MRI to be done with or without contrast dye, or both. This "dye" is actually a paramagnetic liquid that responds to the machine's magnet and

helps enhance certain abnormalities on the scan that would not have otherwise been visible, common in neurological MRIs.

This means that in addition to cost of the scan, your total bill for the MRI will include the radiologist fee, the contrast dyes, and the cost of the procedure itself. Depending on the medical center, these charges may be bundled together into one charge. Bundling is one type of common error on medical bills, so always check over an itemized statement before paying for any costly medical procedure. [6]

Conclusion

In this paper, we discuss about the basic principle of the MRI which depends on the magnetic fields and the molecules itself. And we talked about the difference between MRI and other kinds of imaging systems used in medical system. Then there is the discussion of why the MRI costs so much which is a complicated question the public care about.

Reference

[1] The paper by Blair Mickiewicz

[2] Adapted from Abi Berger," Magnetic Resonance Imaging."

[3] Data from Bottomley PA, et al. "A Review of Normal Tissue Hydrogen NMR Relaxation Times and Relaxation Mechanisms from 1-100 MHz: Dependence on Tissue Type, NMR Frequency, Temperature, Species, Excision, and age." Med Phys 1984; 11: 425-448 Science

[4]From CDI

[5] Dr Richard Watts from the Department of Physics and Astronomy at the University of Canterbury

[6] From NerdWallet Health, a website that empowers consumers to find high quality, affordable health care, and insurance