Structural MRI Module

Introduction to MRI physics & hardware

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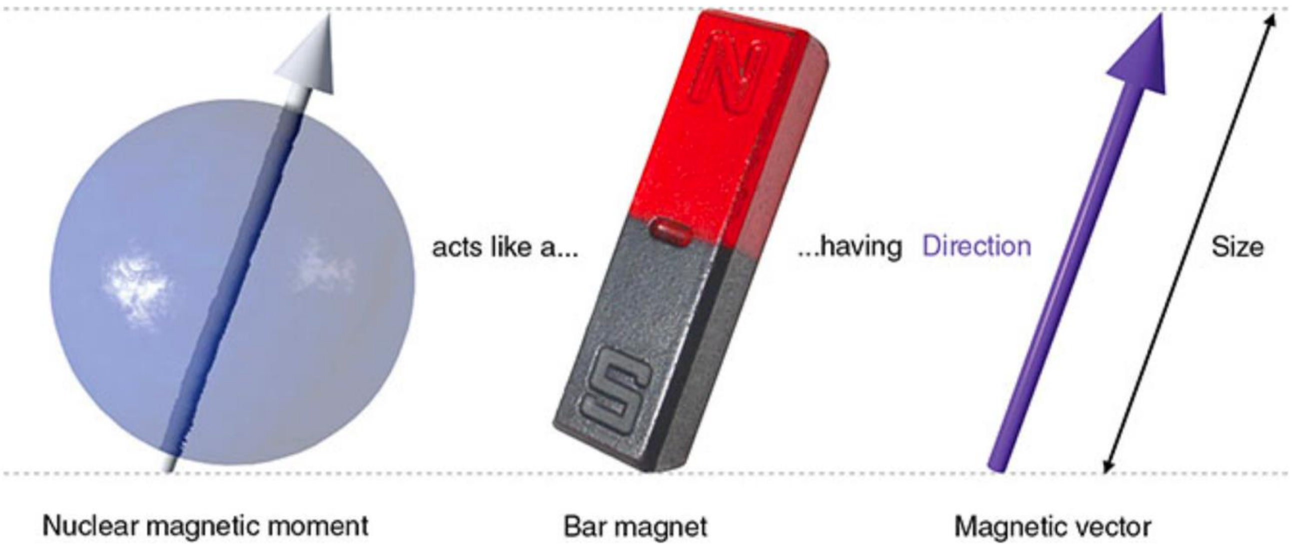
Outline

1. Basic principles of MRI
2. MRI hardware – what's inside the scanner
3. Safety considerations
4. Making an image
5. What's the deal with 7 Tesla?
6. Why we use MRI

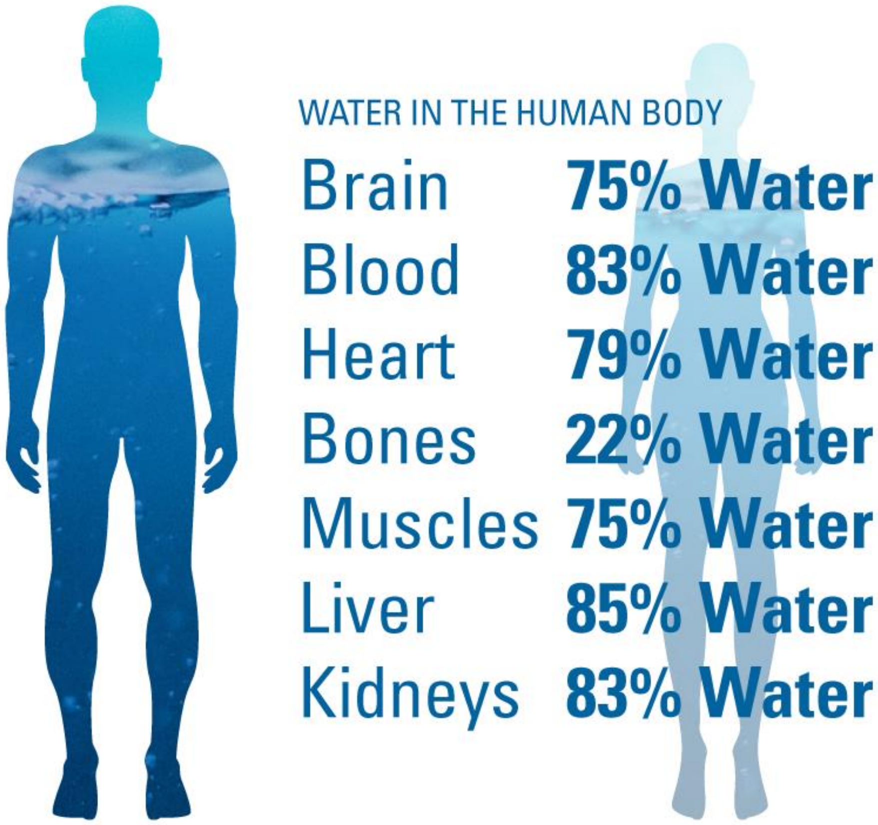
Basic Principles of MRI

Your body is full of water

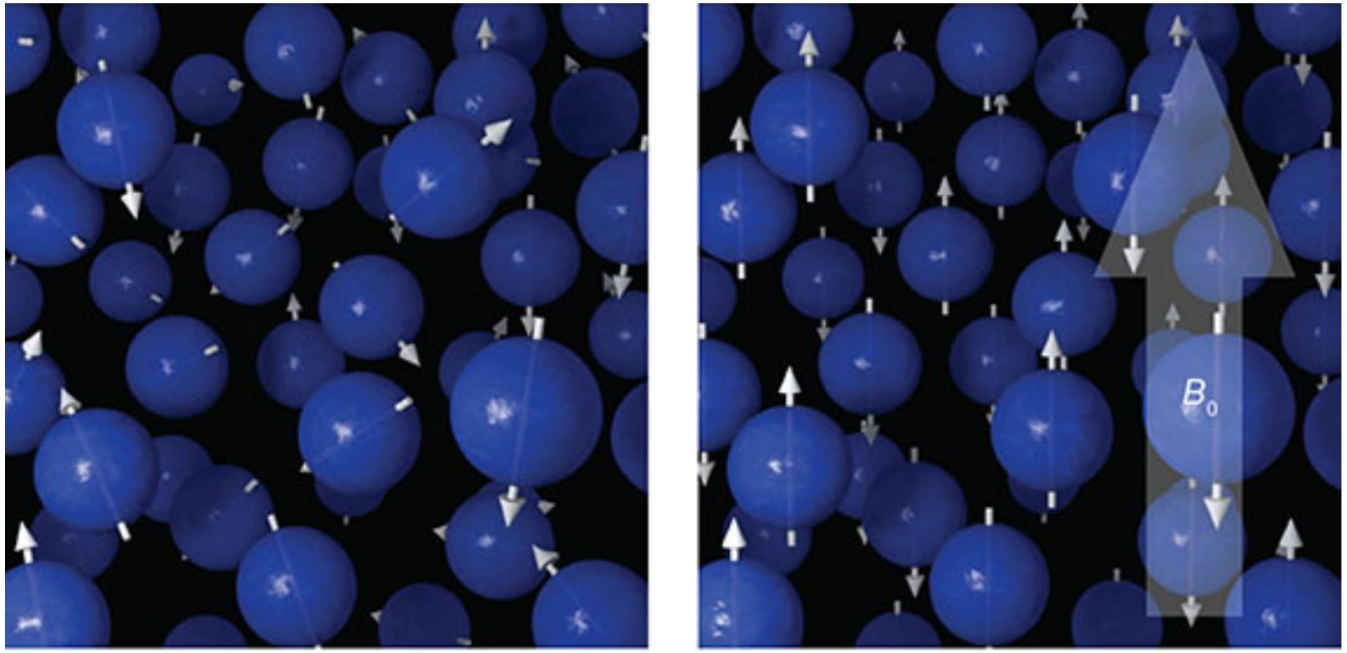
- Specifically, hydrogen atoms
- Hydrogen atoms have a **magnetic moment**



MRI In Practice, Westbrook 5th edition



Basic Principles of MRI



Random alignment
No external field

Alignment
External magnetic field

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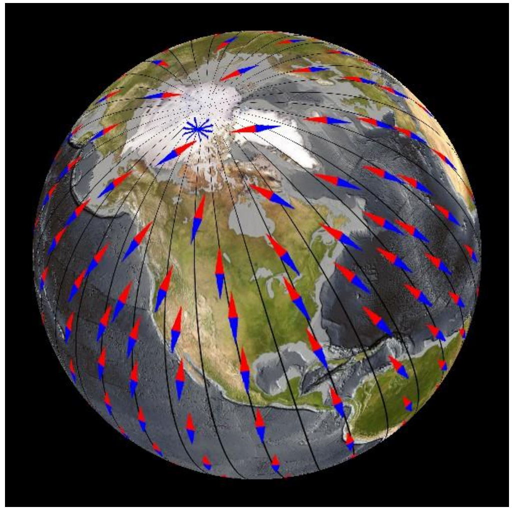
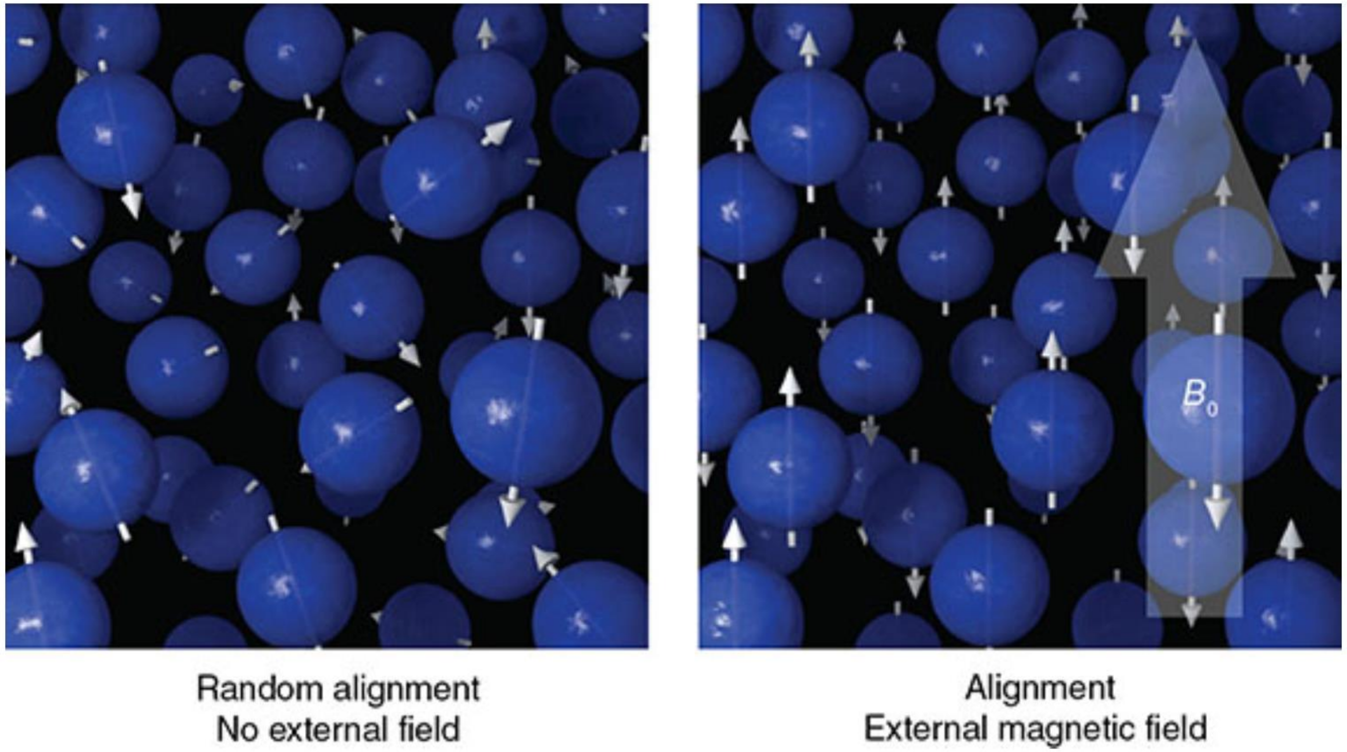
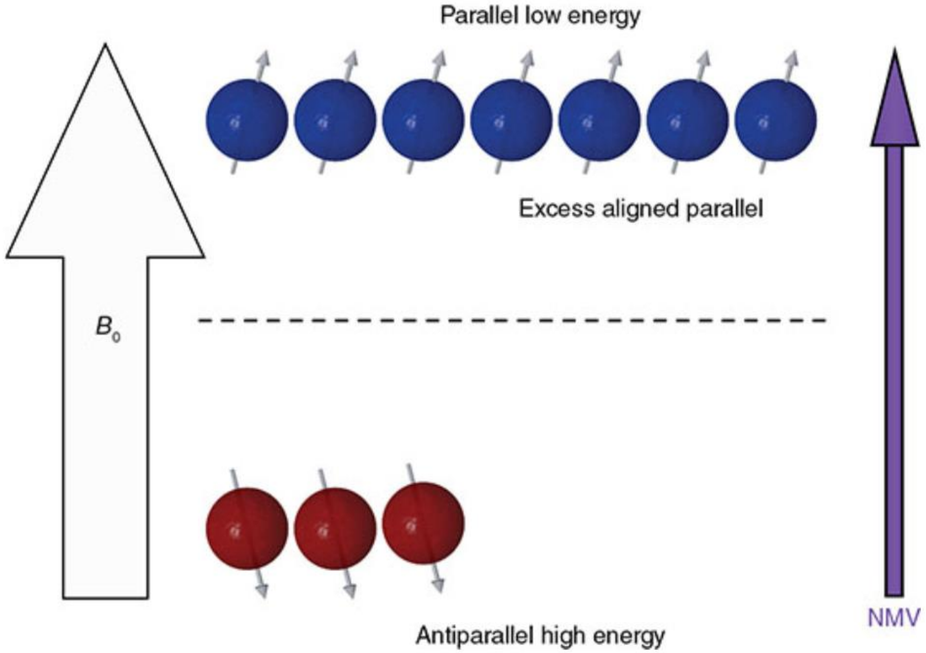
Similar to a compass needle aligning with Earth's magnetic field



Basic Principles of MRI





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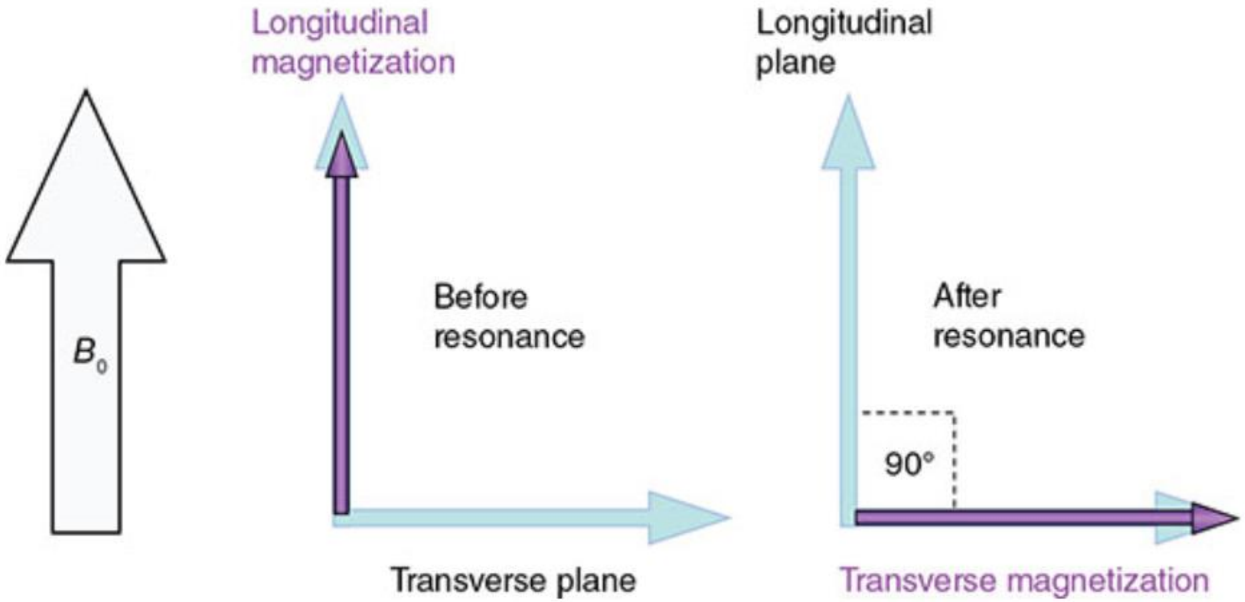
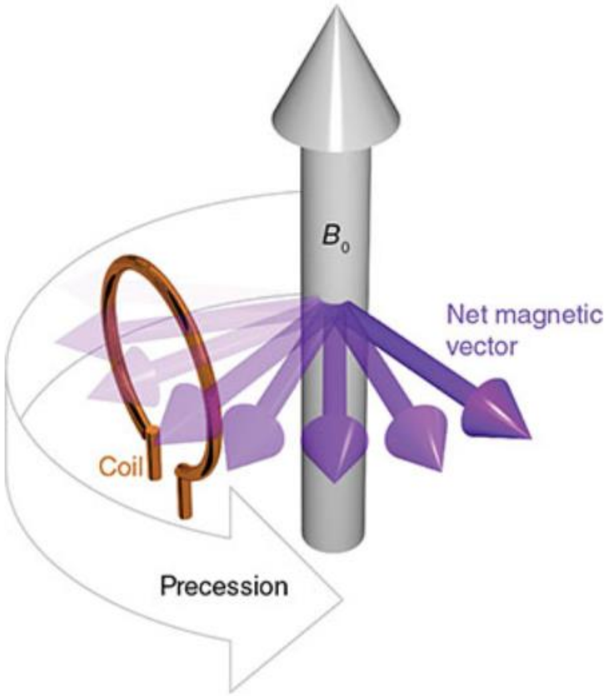
Basic Principles of MRI - Resonance

A resonant radio-frequency (RF) pulse can topple the net magnetization vector (NMV) over

- The NMV will precess in the B_0 field, inducing a signal in the same coil





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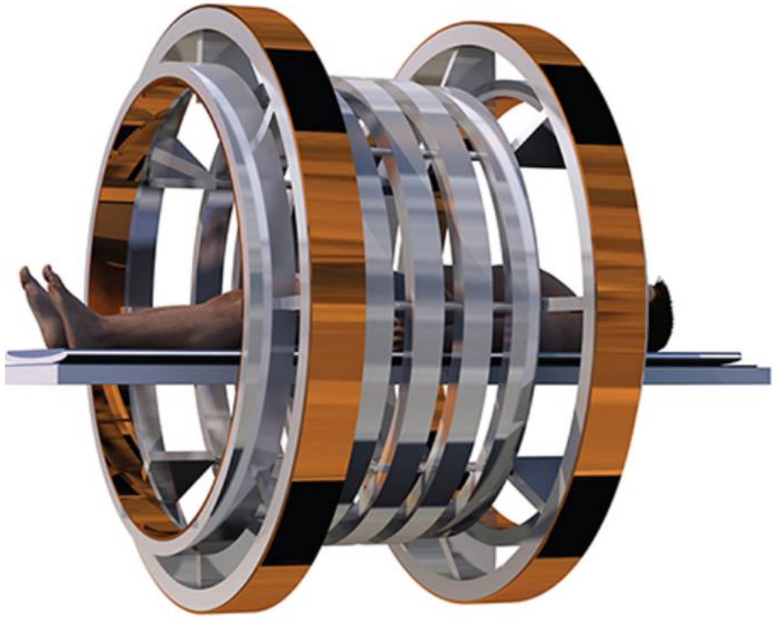
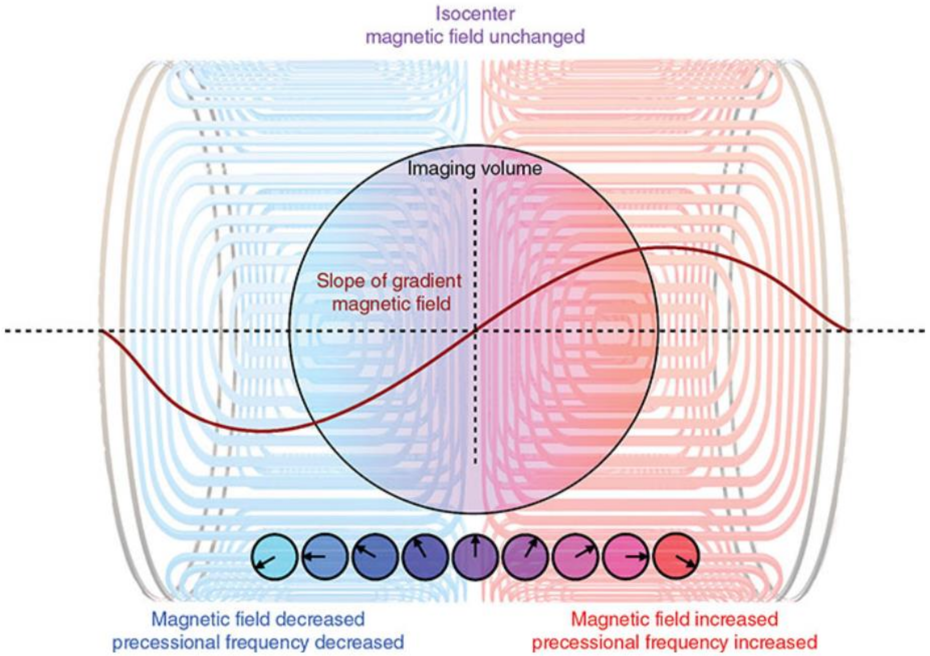
MRI Hardware

The MRI has 3 main components

1. Static B_0 field
2. Gradient magnetic fields
3. RF transmission/receive



Siemens



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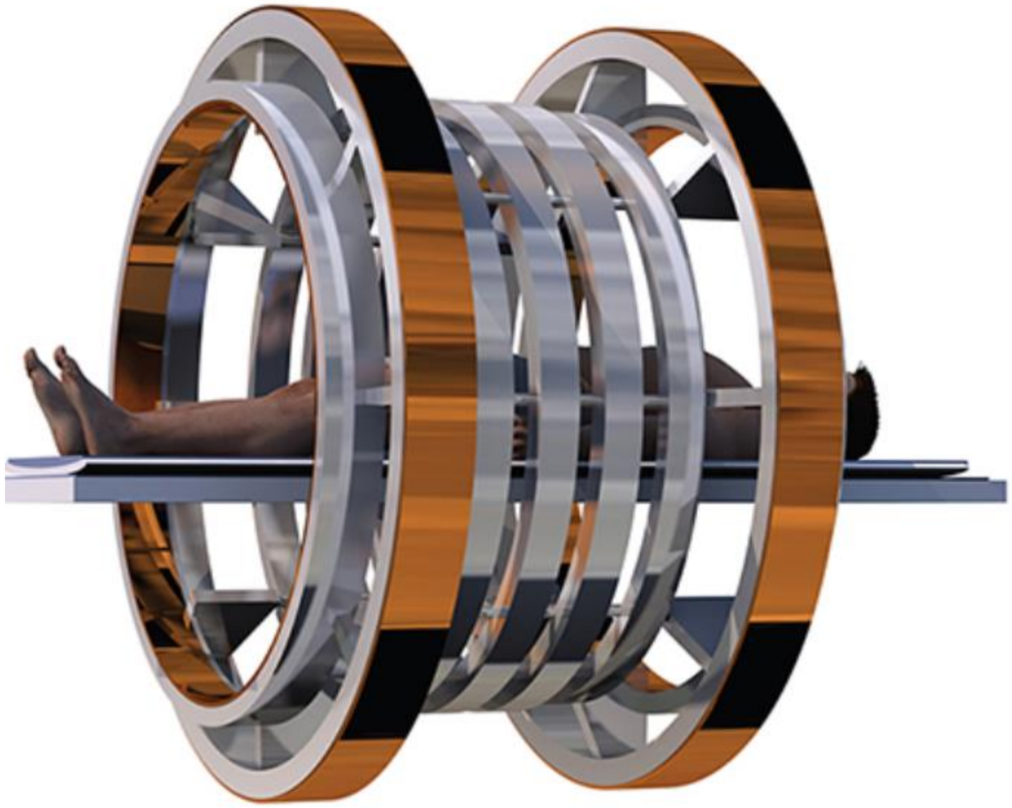
MRI Hardware – B_0 field

A superconducting coil of wire creates the B_0 field

- Clinical field strengths range from 0.5T to 3T
- The magnet is <u>always on</u>
- Additional conducting coils help shield and shim the magnet



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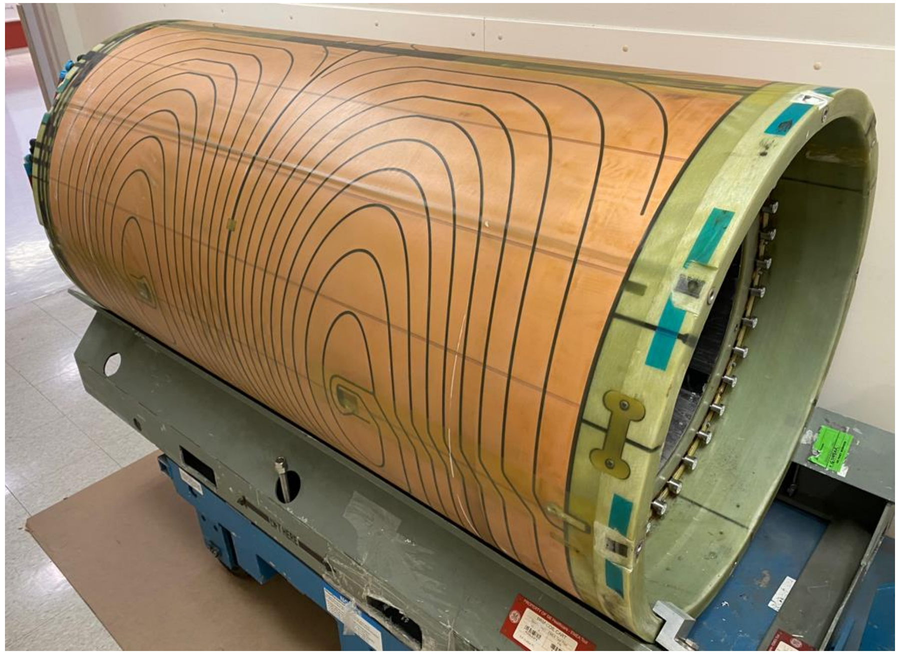
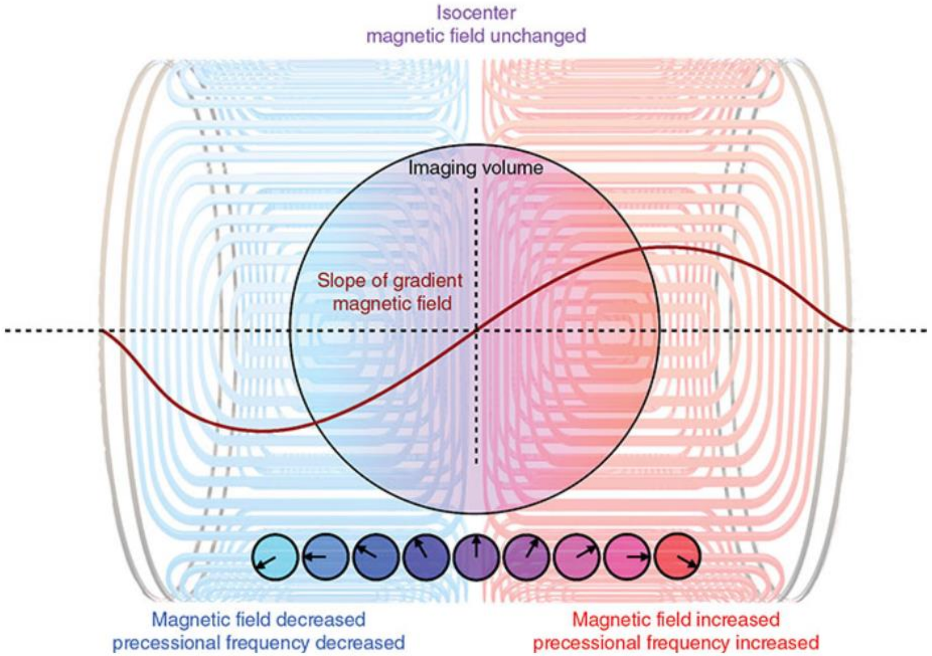
MRI Hardware – Gradients

The gradient coils encode spatial information in the MR signal

- Variation in field strength in all three axis
- Culprit for the loud noise in MRI





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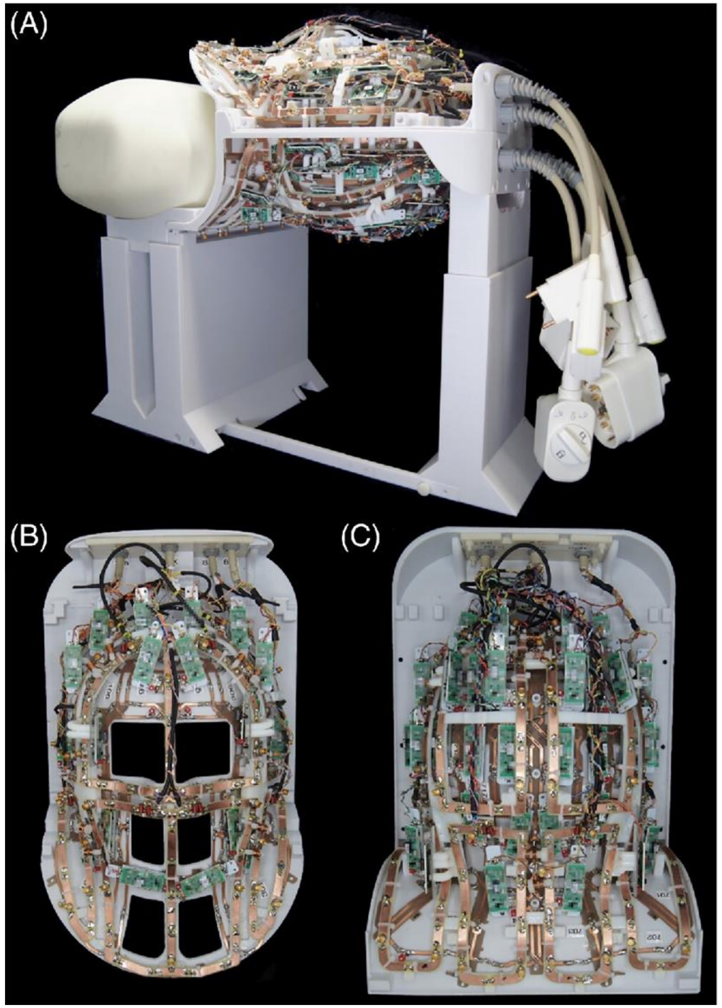
MRI Hardware – RF transmission/receive

RF antennas are used to topple the NMV, but also used to receive the induced MR signal

- The closer the coil to the subject, the higher the SNR



May MW, et al. A patient-friendly 16-channel transmit/64-channel receive coil array for combined head–neck MRI at 7 Tesla. *Magn Reson Med*. 2022; 88(3): 1419-1433. doi:10.1002/mrm.29288

Safety Considerations

BBC

Man wearing heavy metallic necklace dies after being sucked into MRI machine

21 July 2025

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Madeline Halpert
BBC News, New York

Forbes

INNOVATION > HEALTHCARE

Lawyer Dies After Shot By His Own Concealed Gun Triggered By MRI Scanner

By Bruce Y. Lee, Senior Contributor. ⓘ Bruce Y. Lee, M.D., MBA, covers health...

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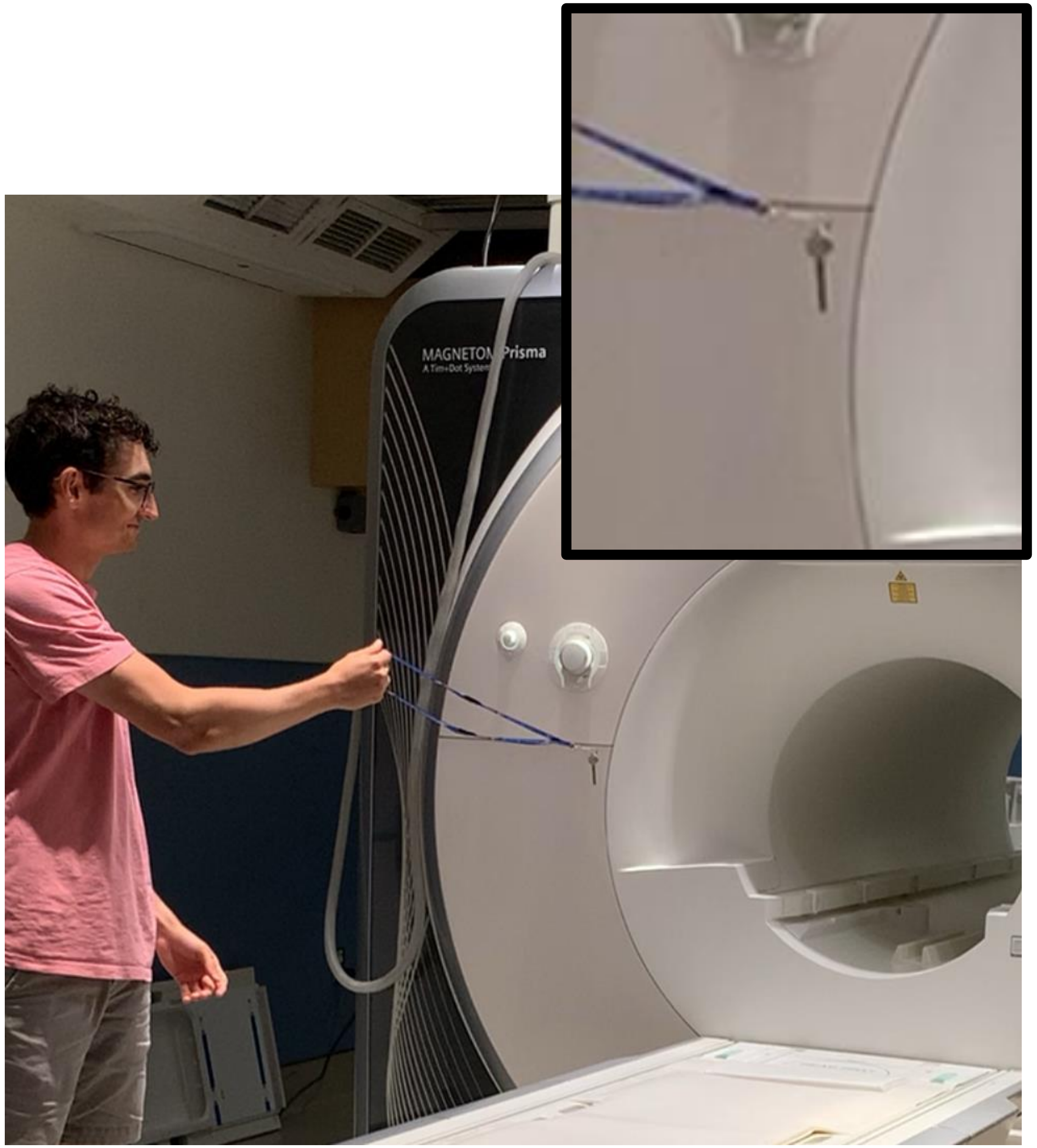
Published Feb 12, 2023 at 09:02am EST, Updated Feb 12, 2023 at 02:07pm EST

Safety Considerations

The MRI is a strong magnet

- We always say “absolute no metals inside an MRI”
- However, some metals are unaffected by magnetic fields



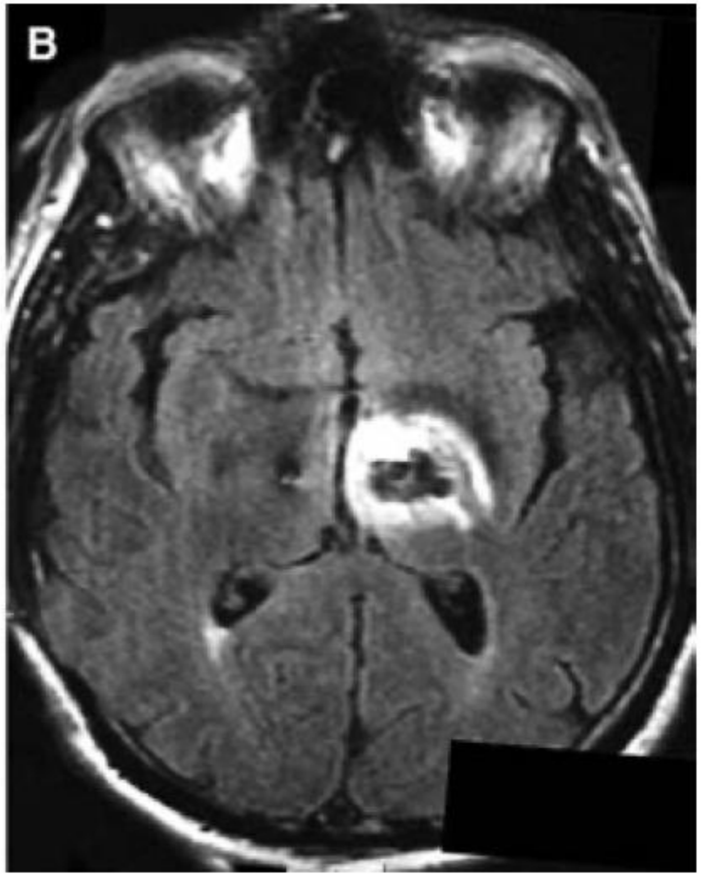
Ferromagnetic Metal	**Non-ferromagnetic Metal**
A metal that strongly attracts a magnetic field	A metal that does not exhibit strong magnetic properties
• Iron	• Copper
• Nickel	• Aluminum
• Cobalt	• Gold
• Steel	• Titanium

Safety Considerations

However, even non-ferromagnetic metals can be dangerous

- The RF transmission can couple with metals causing immense heating
- Wires and metallic leads are most susceptible to heating

Fork in microwave

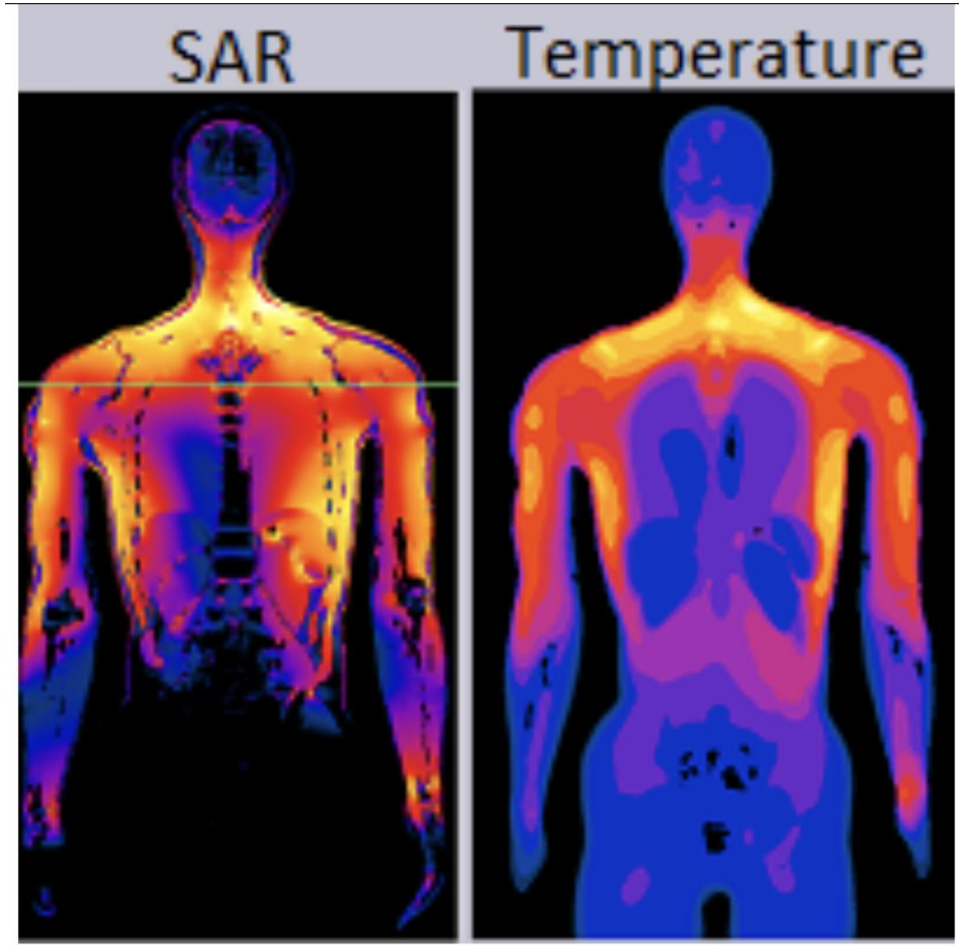


Henderson, 2005. Permanent neurological deficit related to magnetic resonance imaging in a patient with implanted deep brain stimulation electrodes for Parkinson's disease: Case report

Safety Considerations

However, even *normal* tissue can heat up

- The Specific Absorption Rate (SAR) is a measure of RF energy absorption
- Calculated by scanner, given sequence parameters, patient body mass & height

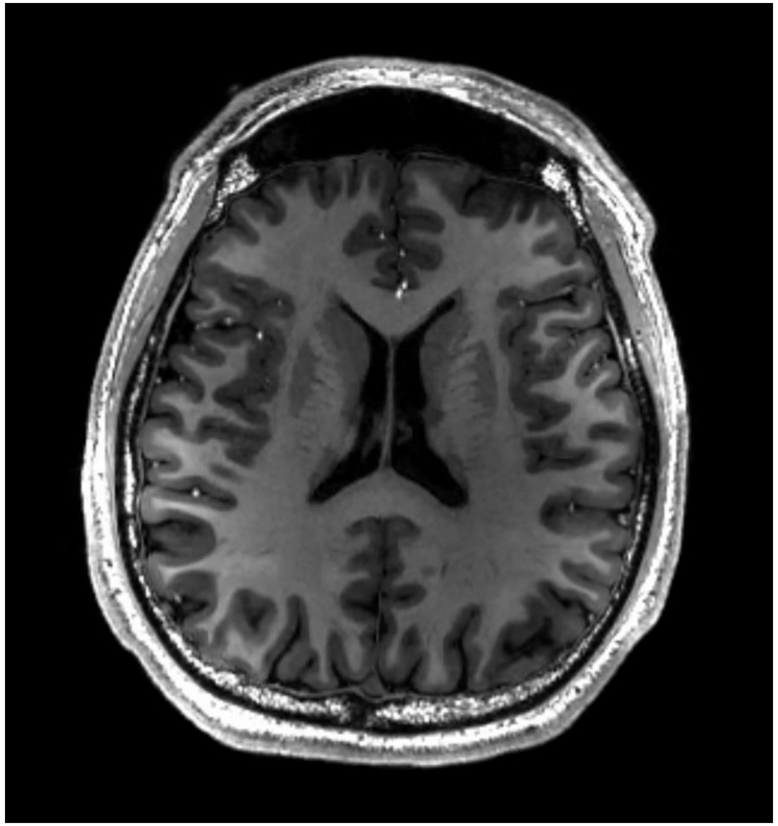


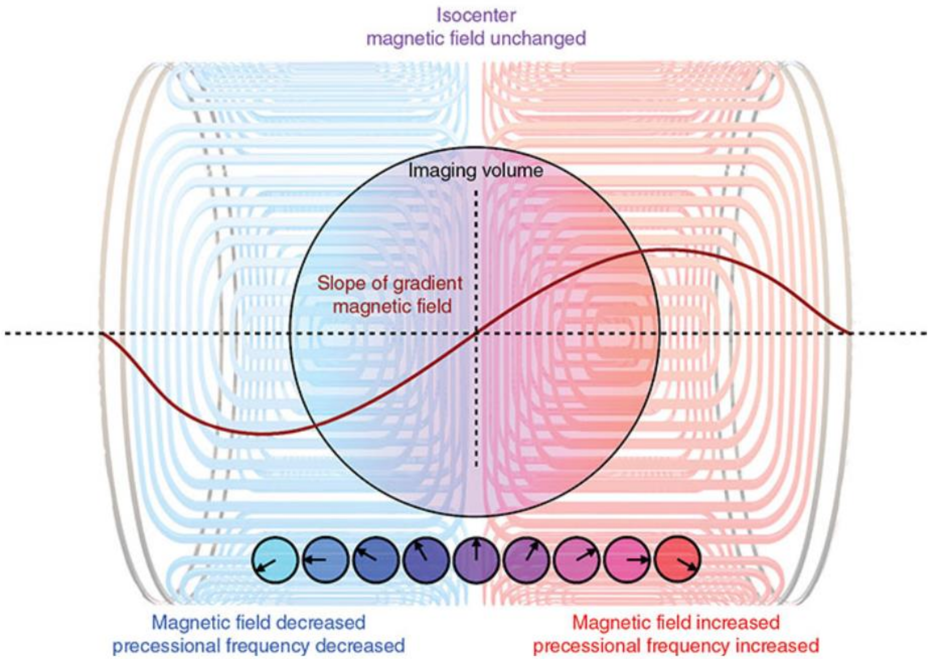
https://itis.swiss/customized-research/mri-safety-evaluation/

Making an Image

The gradients add spatial localization to the MR signal

- Each tissue has a unique MR signal





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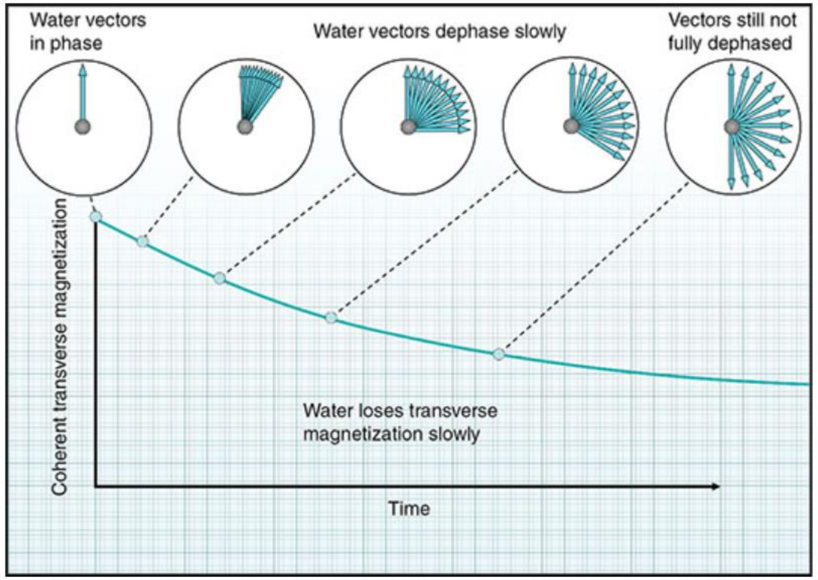
Making an Image

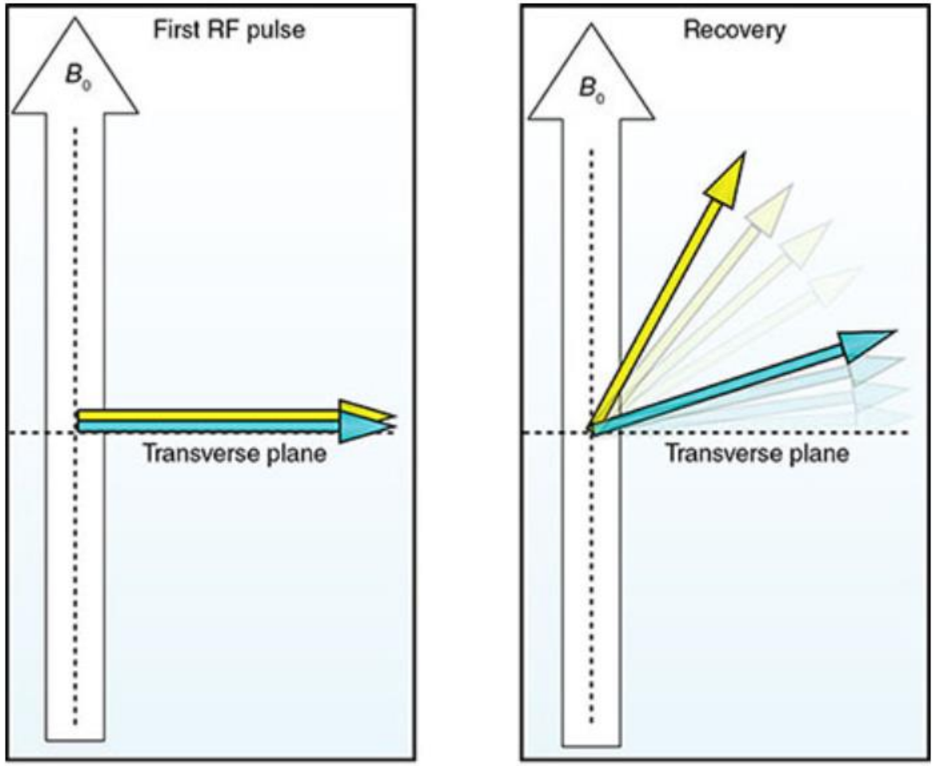
The MR signal will decay due to

- Longitudinal magnetization recovery (**T1**)
- Loss of transverse magnetization coherence (**T2**)

T2 relaxation



T1 relaxation



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Making an Image

Each tissue has a unique T1 and T2 relaxation constant

Tumor Detection by Nuclear Magnetic Resonance

Raymond Damadian

Table 1. Spin-lattice (T_1) and spin-spin (T_2) relaxation times (in seconds) of normal tissues.

Rat No.	Weight (g)	Rectus muscle T_1	Rectus muscle T_2	Liver T_1	Liver T_2	Stomach T_1	Small intestine T_1	Kidney T_1	Brain T_1
1	156	0.493	0.050	0.286	0.050	0.272	0.280	0.444	0.573
2	150	.548	.050	.322	.060	.214	.225	.503	.573
3	495	.541	.050	.241	.050	.260	.316	.423	.596
4	233	.576 (0.600)*	.070	.306 (0.287)*	.048	.247 (0.159)*	.316 (0.280)*	.541 (0.530)*	.620 (0.614)*
5	255	.531		.300		.360	.150	.489	.612
Mean and standard error									
		0.538 ± 0.015	0.055 ± 0.005	0.293 ± 0.010	0.052 ± 0.003	0.270 ± 0.016	0.257 ± 0.030	0.480 ± 0.026	0.595 ± 0.007

* Spin-lattice relaxation time after the specimen stood overnight at room temperature.

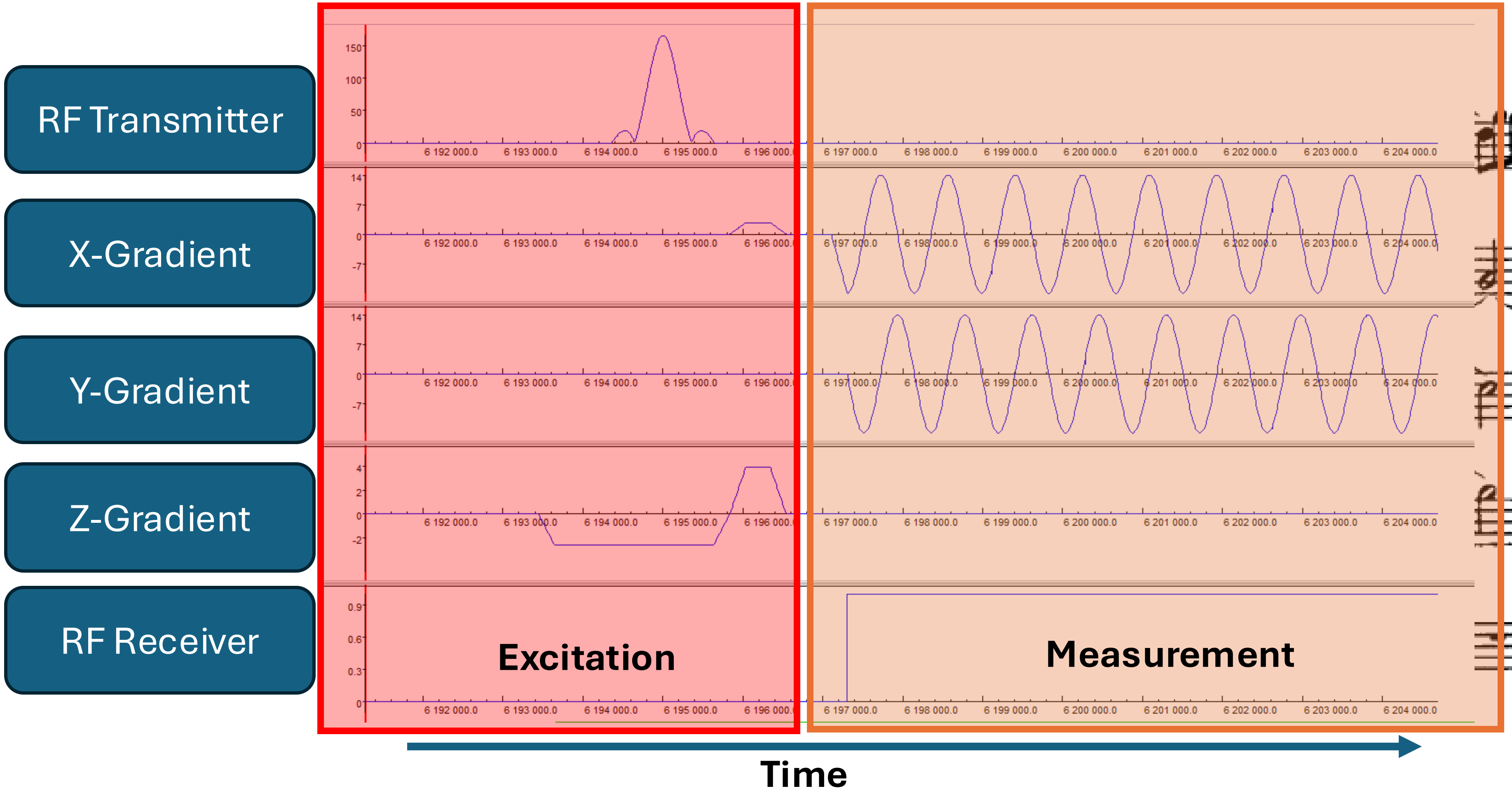
Table 2. Spin-lattice (T_1) and spin-spin (T_2) relaxation times (in seconds) in tumors.

Rat No.	Weight (g)	T_1	T_2
Walker sarcoma			
6	156	0.700	0.100
7	150	.750	.100
8	495	.794 (0.794)*	.100
9	233	.688	
10	255	.750	
Mean and S.E.		0.736 ± 0.022	.100
P		< .01†	
Novikoff hepatoma			
11	155	0.798	0.120
12	160	.852	.120
13	231	.827	.115
Mean and S.E.		0.826 ± 0.013	0.118 ± 0.002
P		< .01†	
Fibroadenoma (benign)			
14		0.448	
15		.537	
Mean		.492	

(measured in 1971)

Making an Image – Pulse Sequence

An MR image is created through the precise **orchestration** of the gradients and RF transmitter in the pulse sequence



What’s the deal with 7 Tesla?

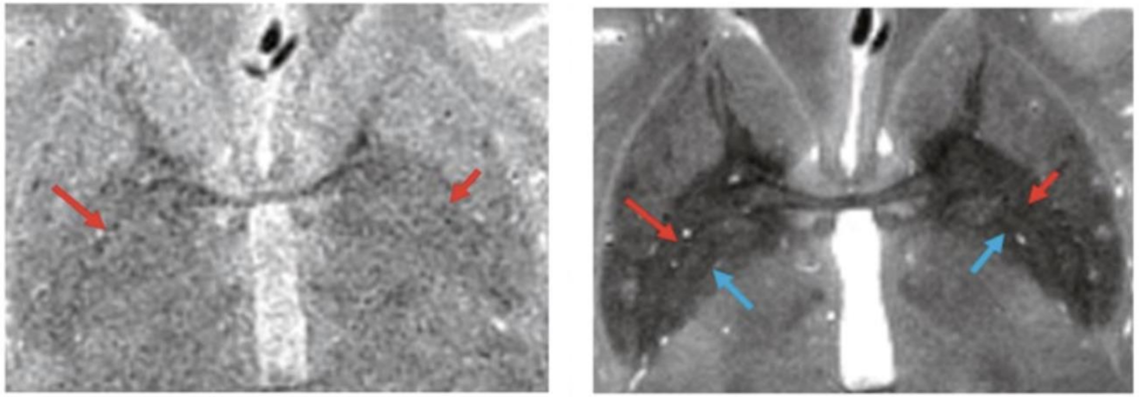
Higher magnetic field strength allows for

- Higher SNR, CNR, changes in T1 and T2 relaxation constants

7 Tesla MRI allows us to unlock

- The tiniest structures and vessels in the brain
- Subtle tissue differences

3 Tesla 7 Tesla



globus pallidus sub-segments

Maruyama, S., Fukunaga, M., Fautz, HP. *et al.* Comparison of 3T and 7T MRI for the visualization of globus pallidus sub-segments. *Sci Rep* **9**, 18357 (2019). https://doi.org/10.1038/s41598-019-54880-x

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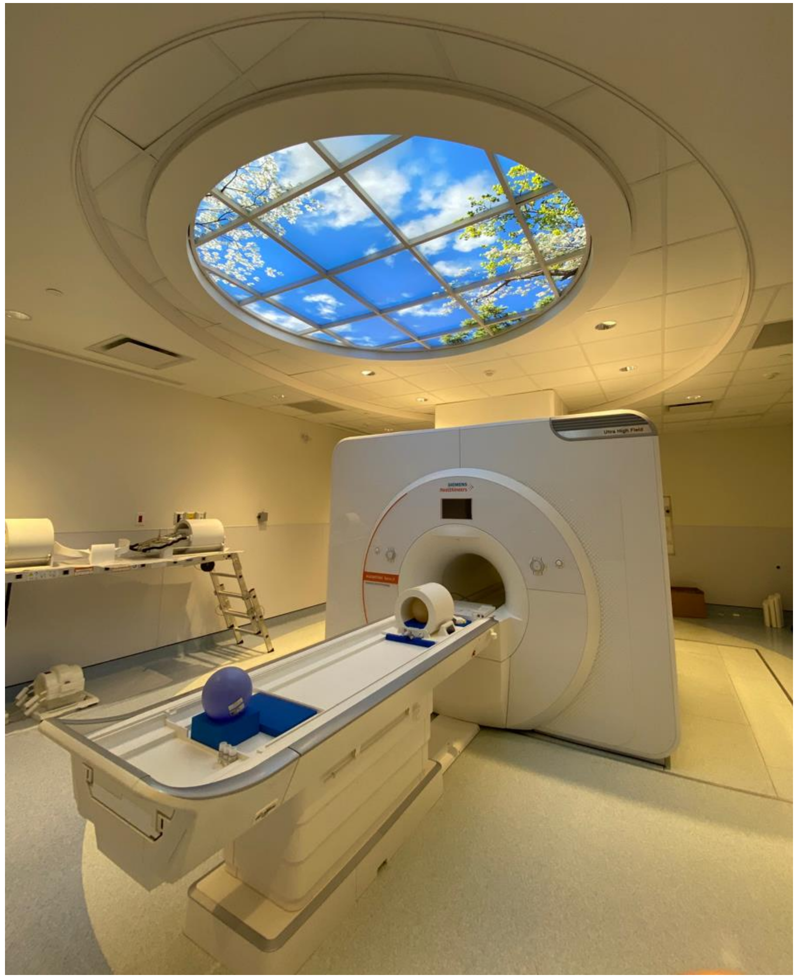

What's the deal with 7 Tesla?

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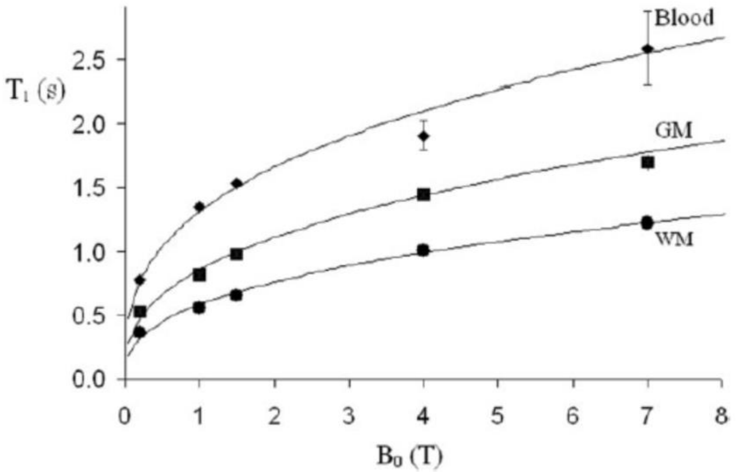
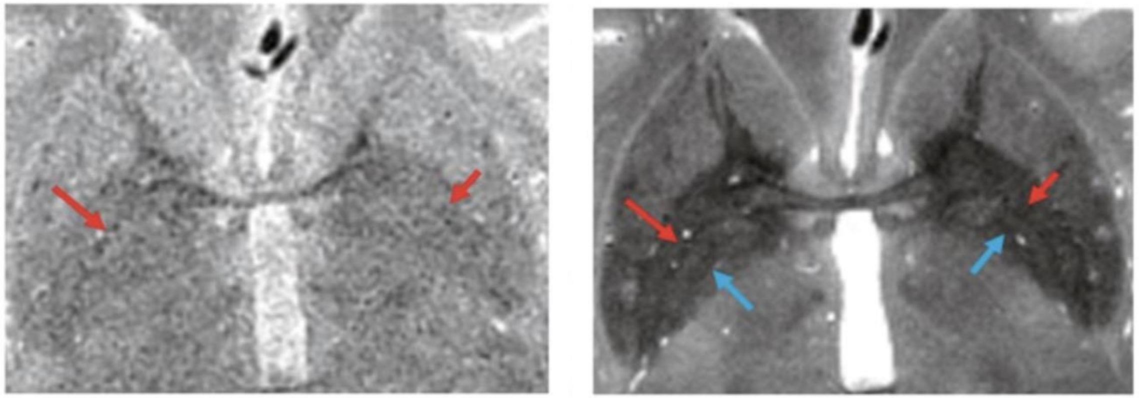


Rooney WD et al. Magnetic field and tissue dependencies of human brain longitudinal 1H2O relaxation in vivo. Magn Reson Med. 2007 Feb;57(2):308-18.



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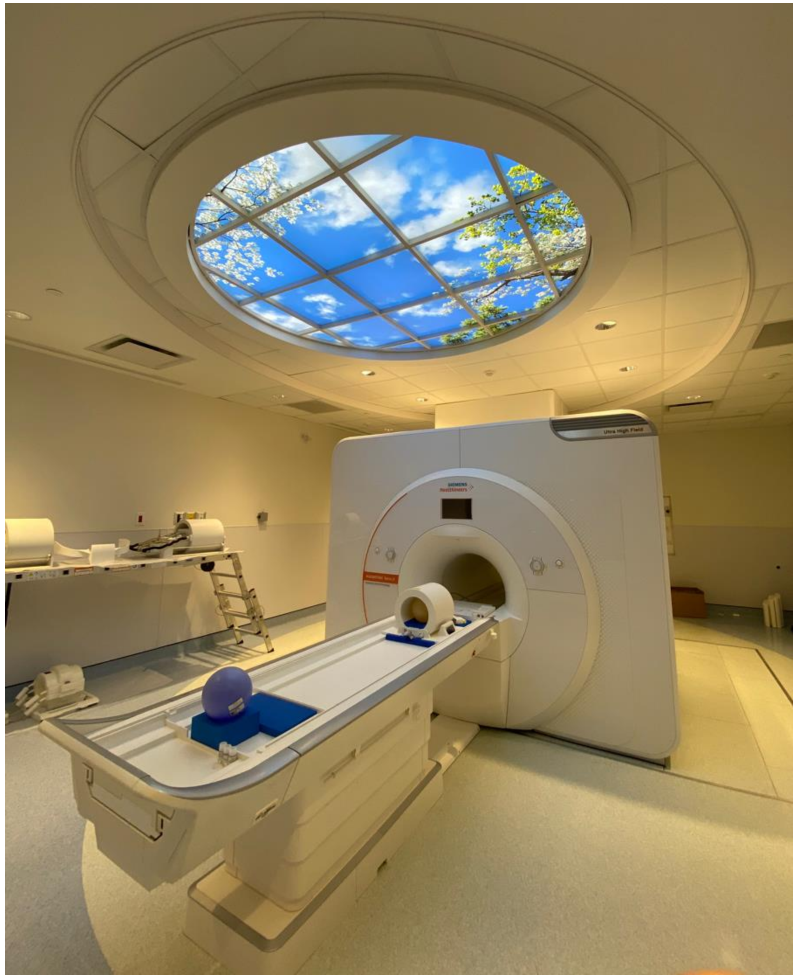


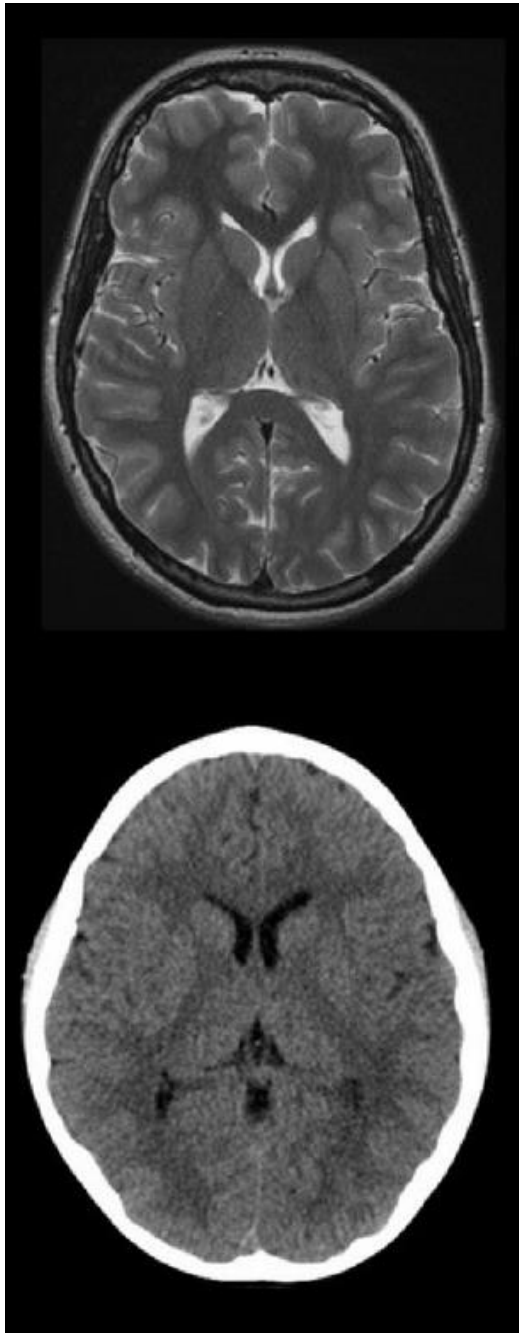
Why Choose MRI?

MR imaging has exquisite soft tissue contrast

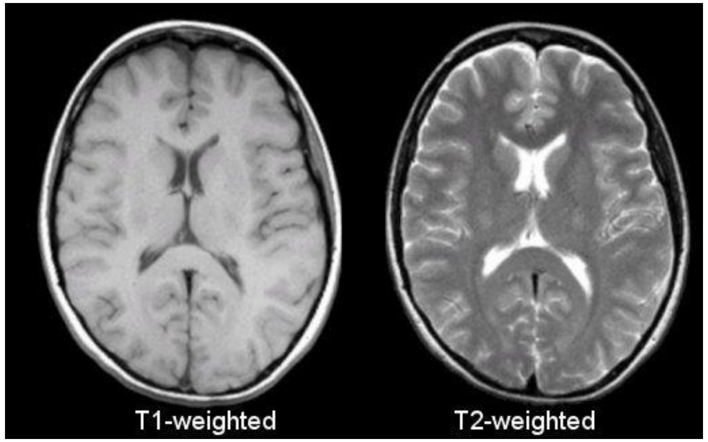
- Gray and white matter have nearly the same density
- CT image results in poor contrast

No ionizing radiation

- Unlimited number of scanning opportunities

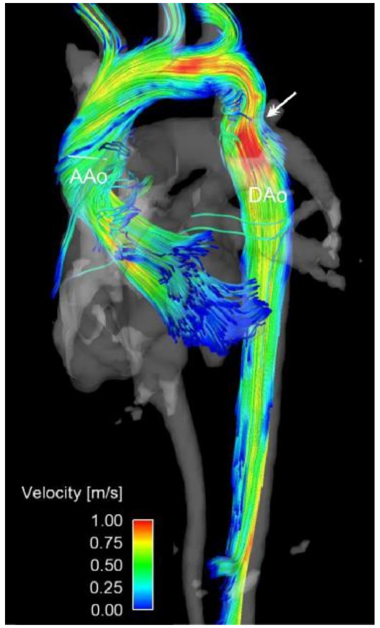


Why Choose MRI?

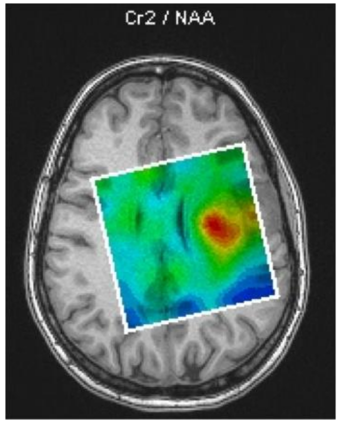


Conventional Imaging
(1972)

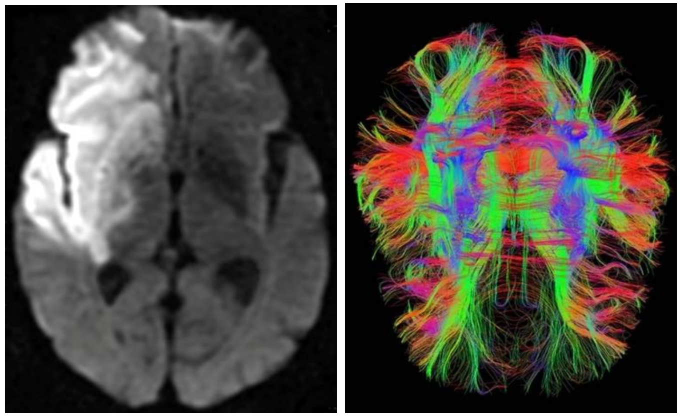
Angiogram
(Dumoulin and Hart 1986)



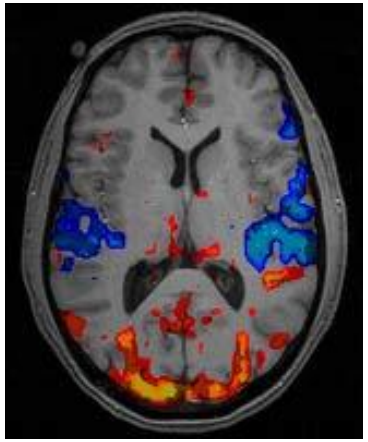
Phase contrast
(~1980s?)



Spectroscopy (Carr 1952)



Diffusion Image
(Bihan 1986)



fMRI
(Seiji Ogawa 1990)