Department of Medical Physics & Biomedical Engineering

MPHY0001: Introduction to Medical Imaging
Magnetic Resonance Imaging

# 4. Applications of MRI

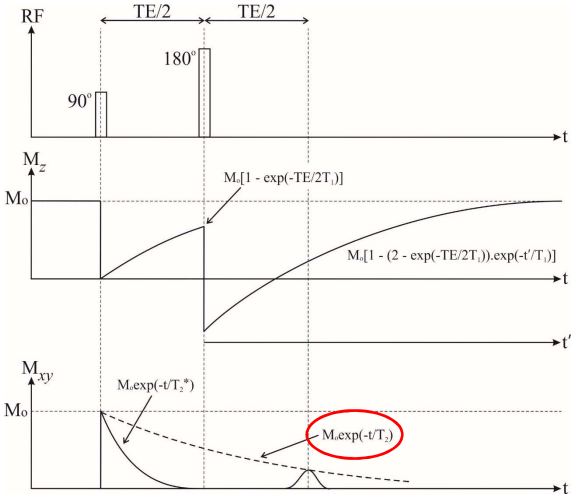
## 4.1 Anatomical imaging

Different tissues have different $T_1$ and $T_2$. Typical values for 3T magnet:

| | | |
|---|---|---|
| Brain (white matter) | $T_1$ = 1100 ms | $T_2$ = 60 ms |
| Brain (grey matter) | $T_1$ = 1600 ms | $T_2$ = 80 ms |
| Muscle | $T_1$ = 1420 ms | $T_2$ = 30 ms |
| Fat tissue | $T_1$ = 360 ms | $T_2$ = 130 ms |

T values are related to tissue physical/chemical properties. Thus MRI is powerful technique for observing contrast between different types of tissue (e.g. white and grey matter in brain).

**Spin-echo sequence**

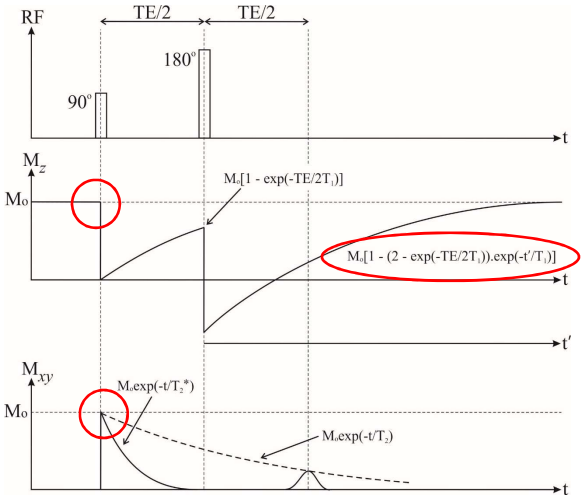



<u>$T_2$-weighted image</u>

Short $T_2$ – low signal (tissue is dark).

Long $T_2$ – high signal (tissue is bright), because echo amplitude will be larger.

**Spin-echo sequence**



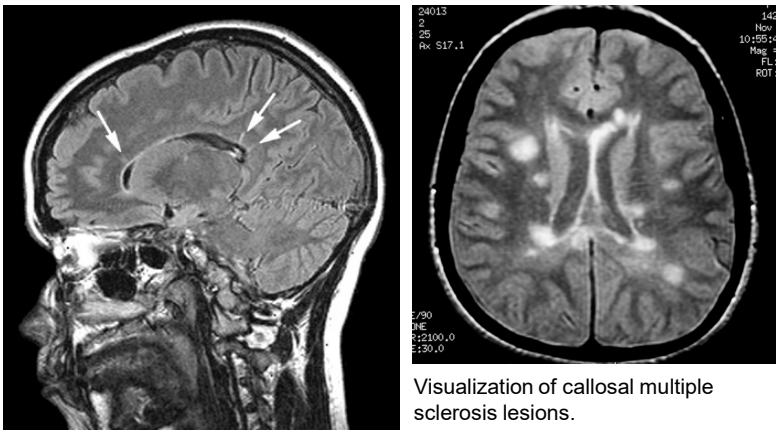

<u>$T_1$-weighted image</u>

Long $T_1$ – low signal (tissue is dark), because $M_z$ will not have recovered prior to next 90º pulse.

Short $T_1$ – high signal (tissue is bright).

MRI is applied to almost all parts of the body.

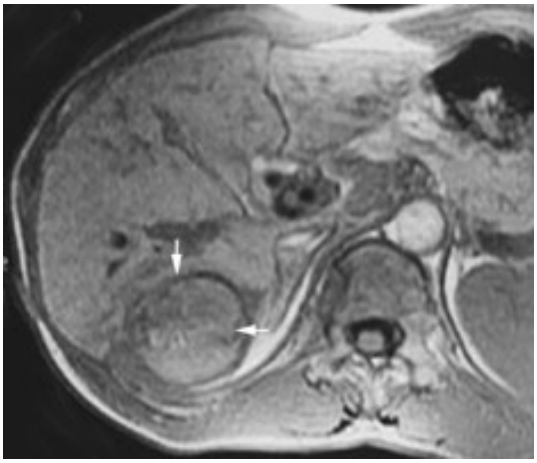
- Brain: diagnosis of acute and chronic neurological diseases; tumours, oedema, stroke, white matter lesions associated with multiple sclerosis, and certain characteristics of Alzheimer's disease.



Visualization of callosal multiple sclerosis lesions.

MRI is applied to almost all parts of the body.

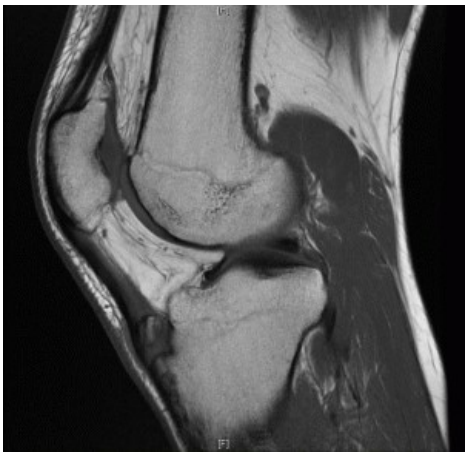
- Liver: tumours, cirrhosis, hemangiomas.



Liver tumour.

MRI is applied to almost all parts of the body.

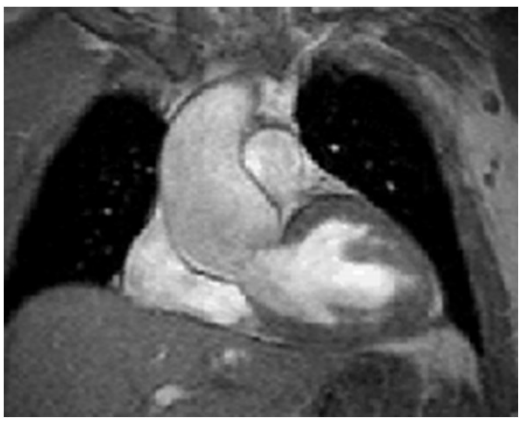
- Musculoskeletal: cartilage degeneration due to rheumatoid- and osteo-arthritis; spinal cord diseases.



Right knee.

MRI is applied to almost all parts of the body.

- Cardiac: myocardial infarcts. (Heart imaging requires scans synchronised with cardiac cycle to eliminate motion artefacts).



Cardiac cycle.

## 4.2 Angiography

Unlike **x-ray angiography**, MRI can visualise flowing blood without a contrast agent.

"Time-of-flight" uses pulse sequences which limit the maximum value of $M_Z$ value within selected slice, so it is much smaller than $M_0$.

However, blood flowing into slice will enter with $M_Z = M_0$.
Thus $T_1$ of in-flowing blood appears shorter.

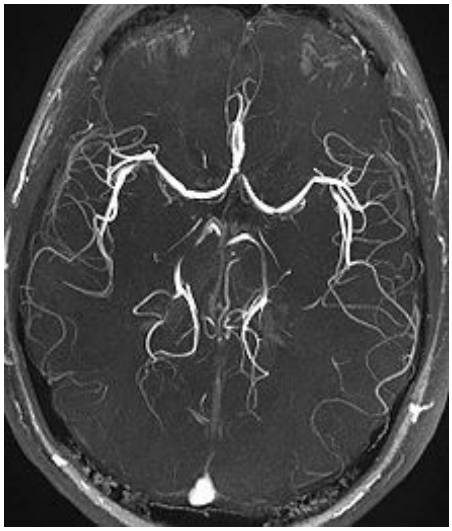
The effective $T_1$ value of the blood is given by:

$$\frac{1}{T_{1(eff)}} = \frac{1}{T_1} + \frac{v}{d}$$

where $v$ = component of blood flow velocity perpendicular to selected slice, and $d$ = slice thickness.

Thus flowing blood can be differentiated from stationary tissue by using $T_1$-weighted pulse sequence.

Multiple slices are added to produce 3D map of blood vessels.



Blood vessels in the brain.

## 4.3 Functional MRI

Deoxyhaemoglobin (Hb) is more “paramagnetic” than surrounding tissues.

Paramagnetic means that Hb molecules set up local field in same direction of the external $\mathbf{B_0}$ field. This produces greater variation in local field, which causes faster dephasing and therefore $T_2$ and $T_2^*$ decrease locally.

This effect is exploited to visualise changes in blood oxygenation resulting from brain activity.

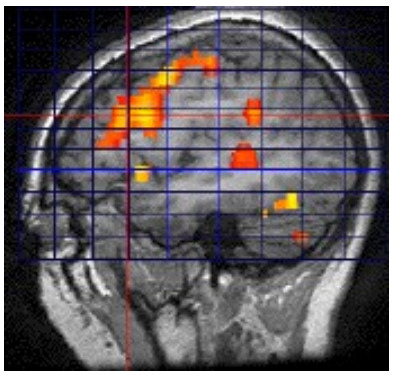
Neural activity causes localised changes in blood flow, causing concentrations of oxyhaemoglobin ($HbO_2$) to increase and of Hb to fall.

Pulse sequences are designed to reveal the local changes in $T_2$ and $T_2$*, a phenomenon known as the blood oxygen level dependent (BOLD) effect.

Functional MRI (fMRI) is used to study brain response to cognitive tasks, and functions such as speech, language, and the senses.

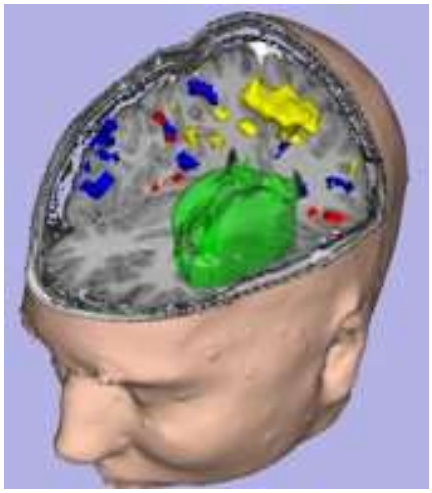
fMRI signals are weak and require significant averaging to provide a sufficient SNR. Functional information is displayed in colour on top of MRI image.

**Example**: Use of fMRI to identify regions associated with verbal skills.



This shows cortical areas activated when an individual performed a verbal fluency task. This involved sub-vocalising words beginning with a given letter.

**Example**: Use of fMRI to identify critical regions of brain prior to surgery.



An MRI scan is used to form 3D surface models of head and brain tumour (green).

fMRI data identifies regions associated with motor skills (yellow), auditory verb generation (red), and visual verb generation (blue).

## 4.4 Contrast agents

To improve visualisation of certain tissues, contrast agents can be applied.

Paramagnetic contrast agents shorten local value of $T_1$.

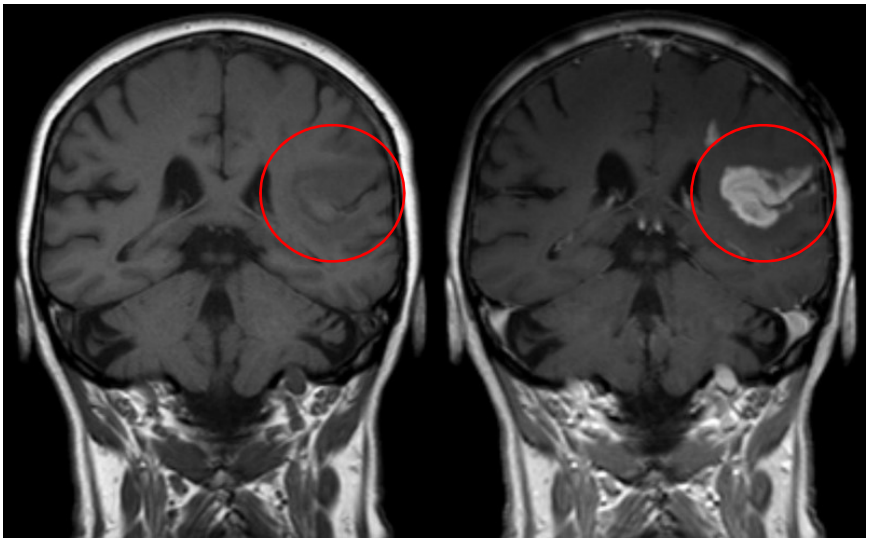
Clinically approved paramagnetic agents are based on gadolinium ion Gd 3+ surrounded by a chemical chelate.

Agents are injected intravenously shortly before scan, and tend to distribute within tumours. They remain visible for ~few hours before being removed by the kidneys. Agents are also used to study blood vessels.

The effect on $T_1$ is described by:

$$\frac{1}{T_{1(CA)}} = \frac{1}{T_1} + \alpha_1 C$$

where C = concentration (mmol/kg) and $\alpha_1$ is the "$T_1$-relaxivity" of agent.



$T_1$-weighted images, before (left) and after (right) contrast medium administration.

Contrast agents based on superparamagnetic substances (iron oxides), produce very strong inhomogeneities in local magnetic field, causing very fast T2 and T2* relaxation. They are primarily used to diagnose liver disease.