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MRI

Quest takes a closer look at magnetic resonance imaging

Magnetic resonance imaging (MRI) machines play an important part in the diagnosis and monitoring of diseases, abnormalities and injuries affecting the soft tissues of the body. As the name implies, they use magnetism to make images, but how do they do this?

An adult human body is typically 50–70% water, with soft tissues having a much higher water content than bone. The hydrogen atoms in water molecules (H_2O) have a positively charged proton making up the nucleus, and each proton spins on its own axis, generating a tiny magnetic field with a north and south pole. Usually, the axes of the protons are oriented in different directions, but when a person is placed inside an MRI machine and exposed to its strong magnetic field, all the axes line up with that field. Next, a pulse of radiofrequency (RF) energy is applied, exciting the protons enough to make them temporarily tip out of alignment. As the protons return to the resting, aligned state they emit energy, which is recorded as an RF signal. Different tissues yield different signal intensities, which are processed by software in the MRI machine and displayed as shades of grey. The slice-by-slice scans are used to build a 2D or 3D image of the body part.

Various MRI 'sequences' are used to obtain images showing specific structures or problems. These sequences are particular settings of RF pulses and gradients, such as changing the repetition time (TR) between successive pulses or the echo time (TE) between a pulse and receipt of the signal. The most common MRI sequences produce T1-weighted or T2-weighted images. T1-weighted images use short TR and TE times, which results in protons from some tissues not having relaxed back into the aligned state before the next measurement is made, nor having returned to spinning out of phase with one another. This yields a high signal for fat but a low signal for water, whereas the converse applies for T2-weighted images, which use longer TR and TE times. The different intensity and contrast levels mean that cerebrospinal fluid, for example, appears black on T1-weighted images but white on T2-weighted images.

Patients undergoing a T1-weighted scan are often injected with a contrast agent containing the rare earth metal gadolinium, which increases the speed at which protons realign with the magnetic field. By highlighting areas with increased blood flow, gadolinium-enhanced images make identification of tumours, abscesses, and sites of inflammation and infection easier.

A variation of a T2-weighted sequence known as diffusion-weighted imaging (DWI) uses differences in the random motion – or Brownian motion – of water molecules in tissues to generate contrast. Since diffusion is restricted both by cell death, as occurs in a stroke, and by rapid proliferation of cells, typical of a malignant tumour, DWI is an important tool for rapid diagnosis of brain-related emergencies as well as long-term management of cancer cases. Some MRI sequences are optimised to image bones

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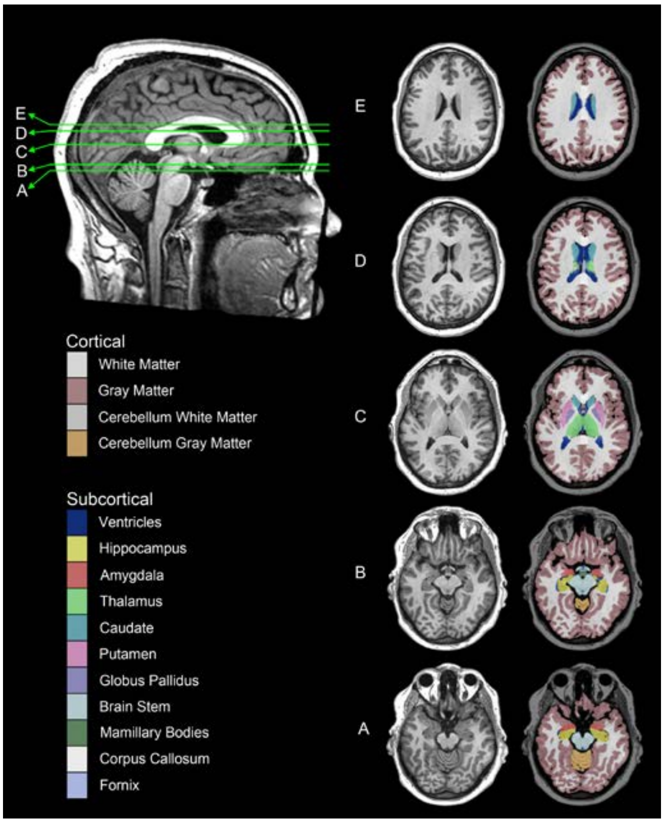
Advanced software allows greyscale MRI data to be visualised as colour 3D imagery.



Axial T1-weighted MRI slices of the brain, showing greyscale and colorised versions.

University of Pretoria

The Onderstepoort Veterinary Academic Hospital of the University of Pretoria's Faculty of Veterinary Science recently acquired its own 1.5 T MRI scanner. Here, Sister Sinazo Nikelo prepares a sedated patient for a scan.

and joints, and are often used to assess sports injuries such as shin splints, stress fractures, torn ligaments and meniscal tears in the knee.

Rather than imaging body structures, or anatomy, functional MRI (fMRI) measures and maps brain activity by detecting changes in blood flow. It uses the MRI sequence known as BOLD – for blood oxygenation level dependent – which relies on the fact that areas with active neurons require more oxygen, causing a shift in the ratio of oxyhaemoglobin and deoxyhaemoglobin in red blood cells. Haemoglobin contains iron, giving it magnetic properties, but the oxygenated form is diamagnetic, meaning it is repelled by a magnetic field, while the deoxygenated form is paramagnetic, being attracted to a magnetic field. These differences are reflected in the MRI signal.

Patients might be given an fMRI prior to surgery to remove a brain tumour or repair an aneurysm, for example. By asking them to move their hands, speak or solve a simple problem while undergoing the fMRI, areas of the brain involved in these functions can be pinpointed so that the surgeon can try to avoid damaging them. The method is also widely used in research, with the aim of allowing accurate early detection of neurodegenerative disorders such as Alzheimer's disease, or diagnosing developmental disorders like autism. In the United States, the Adolescent Brain Cognitive Development (ABCD) study, launched in 2016, has enrolled nearly 12 000 youth aged 9 to 10 countrywide, and will track their development through repeated MRI scans over a decade. The data has already revealed which brain regions are involved in a range of psychological processes, including cognitive control, reward processing, working memory and social/emotional function.

MRIs are painless procedures and, unlike X-rays and computed tomography (CT) scans, they involve no ionising radiation. Some people may feel claustrophobic and anxious inside the MRI, and the 'stronger' machines can cause vertigo – the dizzying sensation of falling or being in moving surroundings – apparently due to the magnetic field pushing on the current of charged particles in the inner ear fluid. Most MRIs are either 1.5 T or 3 T (tesla; a fridge magnet is about 0.01 T), but in the past few years some 7 T machines have been approved for clinical use. These provide a higher signal-to-noise ratio and increased resolution, allowing structures less than a millimetre to be visualised. Stronger machines are used for research on human volunteers, cadavers and animals. The world's most powerful is a 21.1 T MRI at the US MagLab headquarters in Tallahassee, Florida, but since the interior space is a mere 10.5 cm, it can only be used to study small animals like lab rats, mice and birds.

These machines are tremendously heavy – the largest that can accommodate an entire human body is the 11.7 T one at NeuroSpin in France, and the magnet alone weighs about 120 tonnes. In common with most MRI machines, it is a superconducting magnet, in this case made from 182 km of niobium-titanium alloy wire wound in coils. To maintain its superconducting state, it must be kept in 7 000 litres of helium to ensure the temperature does not rise above −271°C, but it allows exploration of the human body at a resolution of one-tenth of a millimetre!

Written by Quest Editor, Sue Matthews