Cerebra

Positively Different

Brain scanning techniques (CT, MRI, fMRI, PET, SPECT, DTI, DOT)

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Background

Brain imaging has greatly advanced in the last 20 years, due to better understanding of the electromagnetic spectrum and radiofrequency waves, in relation to protons in individual molecules within the cells of the brain. New technologies allow non-invasive spatial mapping, (morphology), and observations of processes within the brain during set tasks. By sequencing scanned sections of the brain, activity between neurons in different parts of the brain can be observed and monitored. More recent technologies using a higher frequency resolution can identify the distribution of individual metabolites (large complex molecules), and pharmaceutical drugs. There are a range of scanning techniques, their purpose and limitations are described below[1,2]:

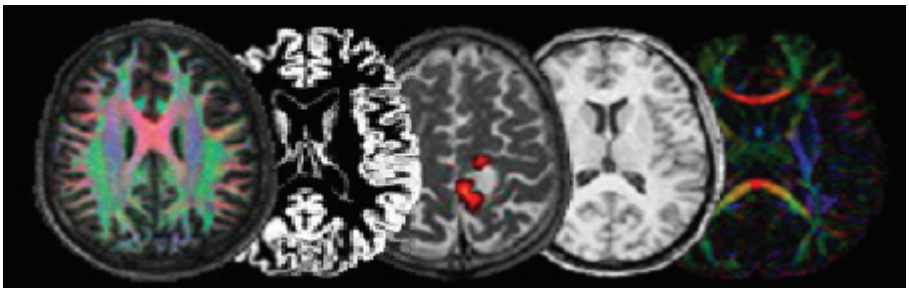

Figure 1: from left to right: DTI MRI fMRI T_1MRI DTI.

Computerised tomography (CT)

Computerised tomography scans use X-rays to show the structure of the brain, with details such as blood perfusion, (plates a and b), the resultant images are two dimensional and of comparatively low resolution, however, the quality has been much improved since 1998. With improved technology, the single section has now become a multisection and the speed has increased eight times, giving well-defined 3-D pictures. A CT scan may reveal underdeveloped parts of the brain or sites of injury from impact, tumours, lesions or infection.[6]

Before a CT scan, the patient may drink but is asked not to eat for four hours beforehand, and not to take strenuous exercise. A CT brain scan will take about 30 minutes and the patient must lie still for the duration.

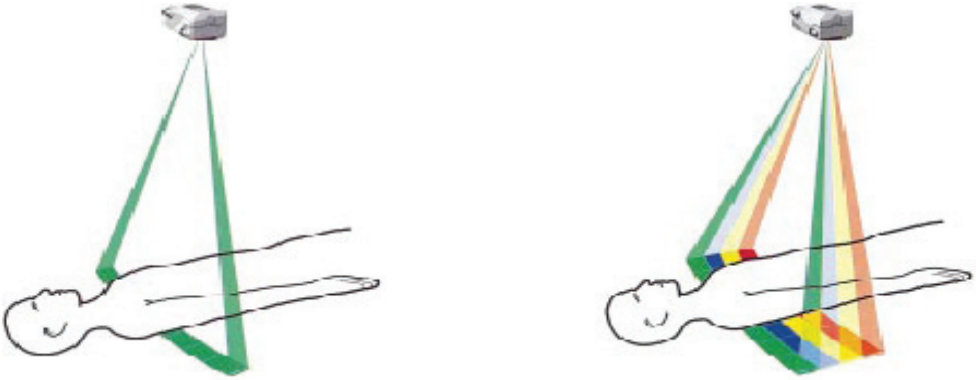

Figure 2: Oblique view of a CT gantry with an X-ray tube, an X-ray fan, and detectors for a single-section scanner and a multisection scanner (foursection system shown).

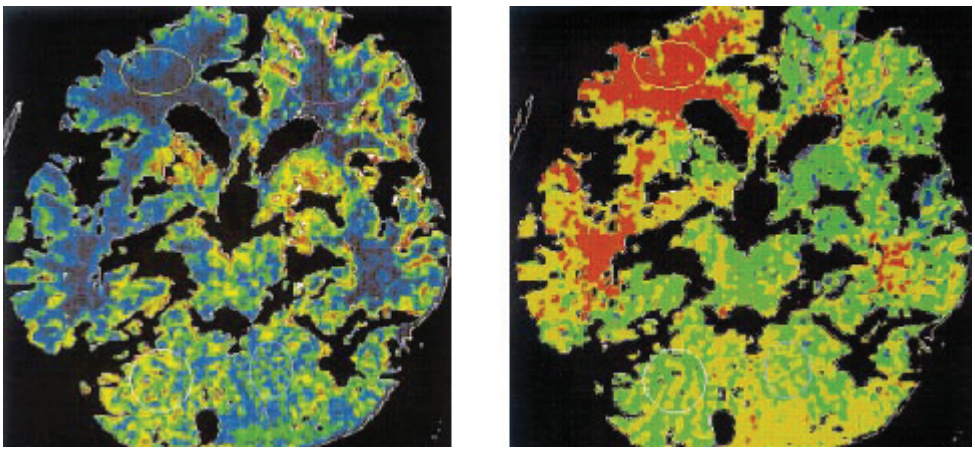

Figure 3:

i) The blue colour shows total blood perfusion throughout the brain.
ii) The red colour shows blood perfusion to the left side of the brain only.

Before a CT scan, the patient may drink but is asked not to eat for four hours beforehand, and not to take strenuous exercise. A CT brain scan will take about 30 minutes and the patient must lie still for the duration. An EEG may be attached to monitor heart rate, and for some investigations, a

tracer injection (iodinated contrast fluid), may be required to highlight blood vessels, sometimes leaving a 'taste' at the back of the throat for a short time afterwards. The radiologist needs to know if the patient is diabetic, pregnant or on medication. The procedure is painless, but does involve exposure to radiation at a very low level.[7]

Magnetic resonance imaging (MRI)

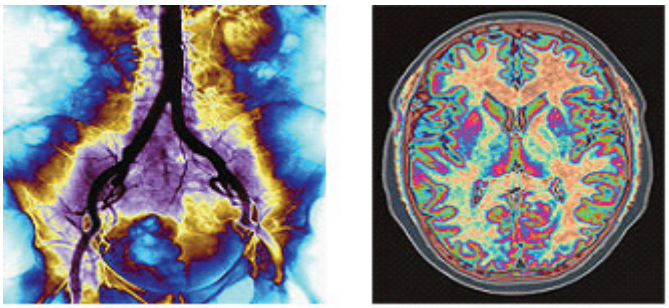

Figure 4: Digitally enhanced MRI images of the brain.

An MRI scanner uses a strong magnetic field and radio waves to create pictures of the tissues and other structures inside the brain, on a computer. The magnetic field aligns the protons (positively charged particles) in hydrogen atoms, like tiny magnets. Short bursts of radio waves are then sent to knock the protons out of position, and as they realign, (relaxation time), they emit radio signals which are detected by a receiving device in the scanner. The signals emitted from different tissues vary, and can, therefore, be distinguished in the computer picture.[1]

An MRI scanner can create clear detailed pictures of the structure of the brain and detect any abnormalities or tumours. Sometimes a dye, or tracer, such as gadolinium may be introduced via a vein in the arm, to improve contrast in the image. Images can be enhanced by differences in the strength of the nuclear magnetic resonance signal recovered from different locations in the brain. The relaxation times, T_1, T_2, and T_{2^*} are measured after the scanner's pulse sequence, and can be chosen to look at specific tissue within the brain.[9,10] For example, at a T_2 setting, water and fluid containing tissue appears bright, whilst fat containing tissue is dark, and this can be used to distinguish damaged tissue from normal tissue. A T_1 setting gives a clear image for the contrast between

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white and grey matter in the brain. T_{2*} imaging uses a marker, eg. gadolinium, to measure cerebral blood volume and flow. It may be seen that by selecting different relaxation times and manipulating radio frequencies, specific brain tissue can be highlighted for examination by the physician.

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The scanner is a large tunnel surrounded by a circular magnet; the patient lies on a couch which slides into the tunnel. It is quite noisy so the patient is given headphones with music of their choice, and has to keep still for 15 to 40 minutes as the tiny radio wave signals are picked up by the computer. It is entirely painless, but children may require a general anaesthetic to keep them still for long enough. The radiographer will need to know if the patient has any metal in their body such as a metal skull plate, inner ear implants, pacemaker, artificial joints, or screws or pins holding bone fracture repairs. The patient may resume normal activities immediately after the scan, and the radiologist studies the pictures and sends a report to the doctor.[3]

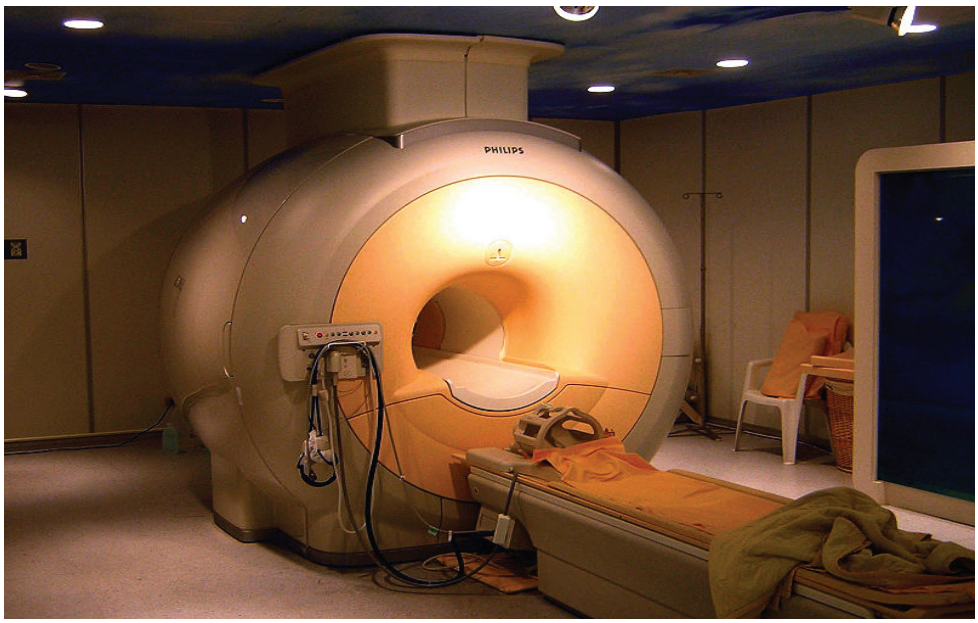

Figure 5: A 3 tesla clinical MRI scanner.

Functional magnetic resonance imaging (fMRI)

Functional magnetic resonance imaging can show which part of the brain is active, or functioning, in response to the patient performing a given task, by recording the movement of blood flow. All atoms and molecules have magnetic resonance, emitting tiny radio wave signals with movement, because they contain protons. Different molecules have different magnetic resonance and two components of blood are tracked to observe brain activity.

Haemoglobin in the blood carries oxygen; oxyhaemoglobin, around the brain and when it is used up, it becomes desoxyhaemoglobin. Where the oxygen is being 'used up' shows the site of activity in the brain. The picture is made by monitoring the ratio of the tiny wave frequencies between these two states whilst the patient carries out a task, eg. tapping a finger, which highlights the area of the brain functioning to carry out this task.[4]

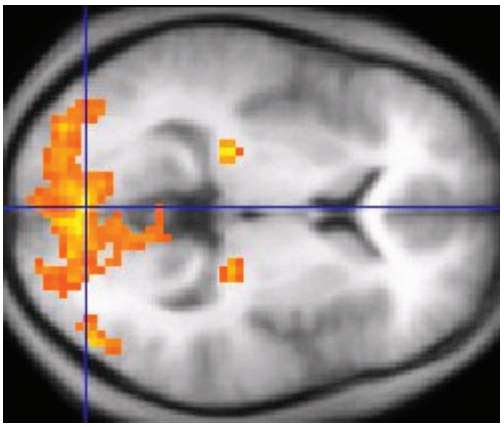

Figure 6: An fMRI scan showing regions of activation, including the primary visual cortex.

An fMRI scan is painless and harmless and can, therefore, be carried out at regular intervals to monitor the progress of a patient under treatment.

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Positron emission tomography (PET)

Positron emission tomography scanning produces a three-dimensional image of functional processes in the brain, (not just the structure). PET is a nuclear medicine imaging technique which requires the patient to receive a small injection of radio-active material (a sugar tracer; fluorodeoxyglucose), into the bloodstream. The radio-active material causes the production of gamma-rays, these are a form of electromagnetic radiation like X-rays, but of higher energy. The radio-active material is transported around the body and into the brain. A ring of detectors outside the head is used to detect pairs of gamma rays emitted indirectly by the positron-emitting radionuclide (tracer), in each part of the brain under examination. [8]

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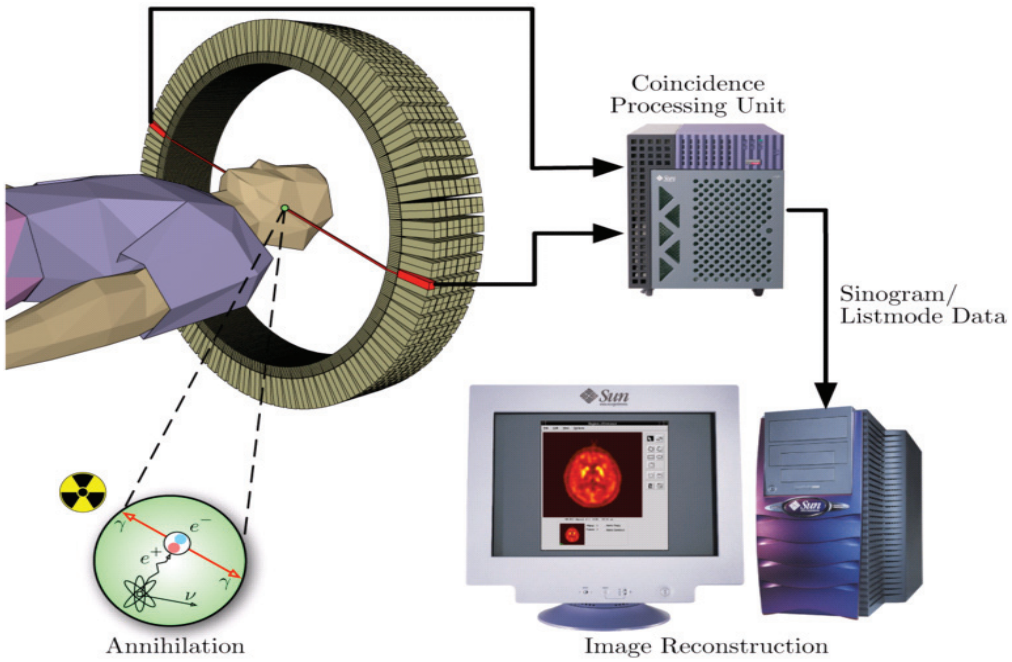

Figure 7: Schematic view of the PET process.

A patient may only have one PET scan, due to radiation dosage regulations. PET has proved to be particularly useful in monitoring visual problems, tumours and metabolic processes.[5]

Single photon emission computed tomography (SPECT)

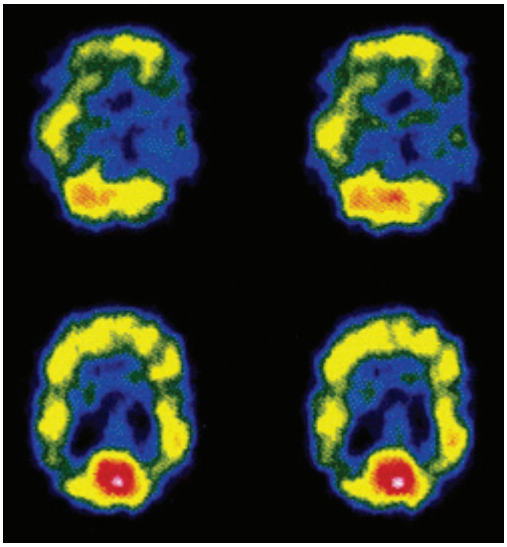

Figure 8: SPECT scan showing blood perfusion.

The single photon emission computed tomography records the signals from gamma rays, (singly, rather than when the emissions are opposite at 180º), using two or more synchronised gamma cameras, and the multiple 2-D images are computed, tomographically reconstructed, to 3-D. A section may be examined from several angles, but is slightly less clear than a PET image. A SPECT scanner is less expensive than a PET scanner and uses longer-lived, more easily obtained radioisotopes. Tracing blood flow within the brain identifies where metabolic activity is occurring, enabling assessment of brain functions.[11]

The patient will not have to fast before the procedure, but will have to remain absolutely still for 15 to 20 minutes in a scanner, similar to the MRI example in Figure (5). A radiopharmaceutical (tracer) will be injected via a catheter in the arm. The amount of radiation the patient will be exposed to is very small, about 1 to 3 times normal human annual exposure to background radiation. The procedure is painless and the patient may

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resume normal activities immediately afterwards.[12]

Diffusion tensor imaging (DTI)

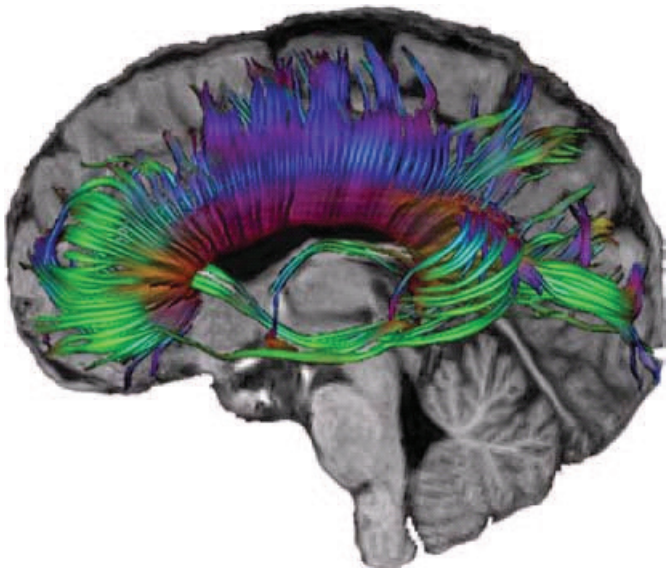

Figure 9: DTI image of neuronal tracts.

Diffusion tensor imaging is a type of diffusion MRI used so that functions in the brain may be observed as they occur, (in vivo). The restricted diffusion of water through the brain tissue under examination is measured; it is often used to image white matter. The direction in which the neuronal axon bundles are oriented determines how water flows, for example, parallel bundles of nerve axons and their associated myelin sheaths, (the insulating layer of cells around each nerve), facilitate diffusion of water molecules along their main direction. The magnetic field variations of the MRI magnet are applied in at least six different directions, which makes it possible to calculate for each pixel, (a tensor that describes this diffusion anisotropy {direction of movement}). [13]

The image can be colour-coded at different wavelengths to illustrate tract position, direction and movement in 3-D.

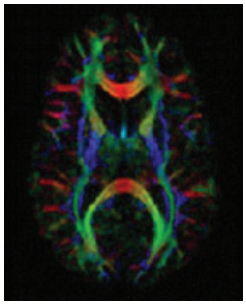

Figure 10: Colour-coded diffusion tensor image.

The DTI can track the neural impulses along the pathways as information travels through the brain, and down the spinal cord to peripheral nerves. A DTI scanner can image white matter lesions, which would not show up on any other MRI techniques. Not only can DTI be used to identify tumours but also to study the way information is processed to control muscles and development during childhood. Areas of abnormality in the brain can be identified in relation to epilepsy, where surgery is considered.[14,15]

Undertaking this procedure is painless and harmless, but the patient will have to remain still for about half an hour, whilst the images are processed. Diffusion tensor imaging is a relatively new technique and consequently, there are very few scanners in the UK at this time.

Diffuse optical tomography (DOT)

Diffuse optical tomography (DOT), is a non-invasive imaging technique in which near-infrared light is used to probe the interior of the brain to record oxygenation and other physiological changes, which may have occurred after a stroke, seizure or haemorrhage. Although the spatial resolution is limited compared to MRI, the advantage of DOT is its simplicity and speed of measurements; the instruments are compact and portable, about the size of a small suitcase and a laptop, and can therefore, easily be taken to the bedside for constant monitoring of brain activity. The DOT analysis involves spectroscopy to monitor haemoglobin involved in oxygenation and therefore, this system also enables the identification of other metabolites such as proteins. Applications include diagnostic imaging of joints and limbs and mammography.

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DOT systems uses frequencies, continuous wave measurements, and time-resolutions such as time-correlated photon counting. Measurements are mostly made at wavelengths between 750 nm and 1000 nm.

A major challenge in optical imaging of biological tissue is the strong scattering of visible and infrared light by tissue. Unlike X-rays, low-energy photons do not travel through the body in a straight line, but instead propagate in a diffuse manner and thus, carry little spatial information about the volume.

DOT systems use detectors to sample as much reflected light as possible over a surface area, processing the information with statistical models of photon transport to generate cross-sectional or 3-D images of the tissue. In addition to structural data, these images provide functional information about the tissue, such as the typical absorption spectra of specific molecular species, such as oxyhaemoglobin and deoxyhaemoglobin.

DOT systems uses frequencies, continuous wave measurements, and time resolutions such as time-correlated photon counting. Measurements are mostly made at wavelengths between 750 nm and 1000 nm. Typically, detectors placed close to the light source will detect light scattered from tissue just below the surface, while detectors placed further away will detect light from deeper tissue, where the signal is very weak. Imaging deeper tissue thus requires detectors with high sensitivity and wide dynamic range. Detectors should also have excellent time or frequency response in order to discriminate between surface scattering and deep-tissue scattering.[16]

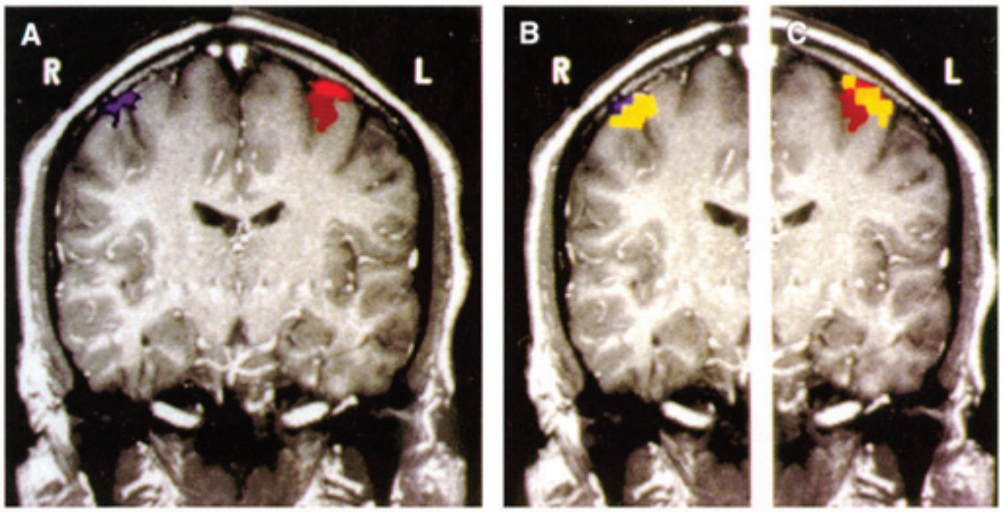

Figure 11: Comparison of optical and functional magnetic resonance images of motor cortex activation.

An image tomographically reconstructed from an optical scan shows focal areas of hemoglobin saturation rising more than 2 SD above the mean (yellow), which correspond to motor activation maps generated in the same subject using functional magnetic resonance imaging (fMRI) alone (left-hand activity, blue; right-hand activity, red; T1-weighted image, grey). The fMRI images alone (A); overlay of left-hand optical image (B); overlay of right-hand optical image (C). There is good spatial agreement between the two methods, however, the optical image yields quantitative changes in hemoglobin saturation.[17]

References

[1] Turner R and Jones T, (2003), 'Techniques for imaging neuroscience'. British Medical Bulletin 65: 3-20

[2] Bachert P, Schroder L, (2003), 'Magnetic resonance imaging spectroscopy'. Radiology. 43(12):1113-26

[3] Netdoctor, (2009), MRI Scan Advice, [online] Available from: www.netdoctor.co.uk/health_advice [Accessed 3 June 2009]

[4] Dyson M, Banks D, Stewart M, (2006), 'Exploring the Brain', The Open University, Milton Keynes, 24-27

[5] Singh K, (2002), 'Signals and Perception', The Open University, Milton Keynes, 165

[6] Rydberg J, et al. (2000), 'Multisection CT:Scanning Techniques and Clinical Applications', Radiographics, 1787-1806

[7] BMI Healthcare, (2009), CT Scanning, [online], Available from: http://www.bmihealthcare.co.uk/treatment [Accessed 3 June 2009]

[8] Young H, (1999), 'Measurement of clinical and subclinical tumour response using [18F]-fluorodeoxyglucose and positron emission tomography: review and 1999 EORTC recommendations' European Journal of Cancer, Volume 35, Issue 13, Pages 1773-1782

[9] Rosen Y, (2007), 'The recent advances in magnetic resonance neurospectroscopy', Neurotherapeutics, 27(3):330-45

[10] Chen C, Hoult D, (1998), Biomedical Magnetic Resonance Technology, Taylor and Francis, (Medical Science Publishers), London

[11] Frankle W, et al., (2005), 'Neuroreceptor Imaging in Psychiatry: Theory and Applications', International Review of Neurobiology, 67:385-440

[12] Keyword, (2009), Brain SPECT, [online]. Available from: http://md.gehealthcare.com [Accessed 3 June 2009]

[13] Lazar M, Weinstein DM, Tsuruda JS, et al (2003), 'White matter tractography using diffusion tensor deflection', Human Brain Mapping, 18: 306-321

[14] Minati L, Aquino D, (2006), 'Probing neural connectivity through diffusion tensor imaging', Cybernetics and Systems, 263-68

[15] Le Bihan, et al, (2001), 'Diffusion Tensor Imaging: Concepts and Applications', Journal of Magnetic Resonance Imaging, 13:534-546

[16] Medical diagnostics, (2010), http://hamamatsu.com/en/applications [Accessed 7 July, 2010]

[17] Benaron D A, Hintz S R, Villringer A, Boas D, Kleinschmidt A, Fraham J, Obrig H, Houten J C, Kermit E L, Cheong W-F, and Stevenson D K, (2000), 'Noninvasive Functional Imaging of Human Brain Using Light', Journal of Cerebral Blood Flow and Metabolism, 20:469-477

Figure references

[1] www.sciencelearn.org.nz (Google 'Report Images')

[2] www.medical-dictionary.thefreedictionary.com/CT

[3] www.medical-dictionary.thefreedictionary.com/CT

[4] http://www.fotosearch.com/photos-images/brain-scan.html

[5] http://en.wikipedia.org/wiki/MRI

[6] http://en.wikipedia.org/wiki/FunctionalMRI

[7] http://encarta.msn.com/encyclopedia

[8] www.mayfieldclinic.com

[9] www.capersonalinjurycaselawnotes.com

[10] http://emedicine.medscape.com (media file 6)

[11] http://www.nature.com/jcbfm/journal/v20/n3/fig_tab/9590901f2.html#figure-title

The Cerebra In-house Research Team carries out desk-based research into a number of areas, based upon parent and professional requests, new scientific evidence and issues raised by our staff. We aim to provide information that is relevant to parents and carers of children with disabilities as well as the professionals who come into contact with them. By empowering parents and professionals with knowledge, we can help them to improve the lives of the children they care for and support.

If you require further information or would like to suggest avenues for further research, please get in touch.

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