Modern neuroimaging: the meaning behind the pictures

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Recent technological advances have expanded the role of magnetic resonance imaging to include mapping the brain's dynamic function.

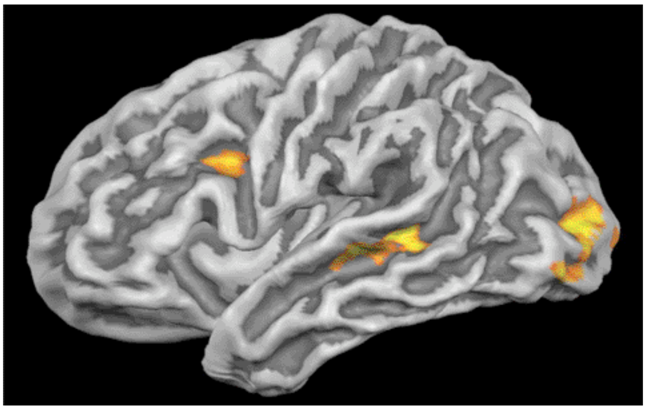

Figure 1. A functional MRI activation map indicating significant BOLD activity in Broca's (front) and Wernicke's (middle) areas during an experimental language task designed to determine hemispheric language dominance prior to epilepsy neurosurgery.

Advances in physics and computing over the last decade have led to the development of astonishing brain imaging techniques that now allow clinicians to examine the complementary aspects of brain structure and function with excellent spatial resolution. The combination of magnetic resonance imaging (MRI) technology, sophisticated signal processing and advanced statistical and visualisation methodologies now make it possible to study aspects of the brain's dynamic function and the interconnections between different brain regions. We describe two examples of these new functional imaging techniques and their use in clinical practice.

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Functional MRI

Although clinicians will be familiar with the use of MRI technology to identify brain structures in order to diagnose abnormalities, not all will be aware of the more recent application of using MRI to assess brain function. In the past, information relating to brain function was gleaned from electrophysiology studies, including evoked potentials and electroencephalography. Crude neuroimaging techniques were also used, including positron emission tomography and single photon emission computed tomography. The difficulty with these forms of imaging was that they offered poor spatial resolution and required a significant 'leap of faith' to extrapolate findings from the images produced to specific brain regions.

In the early 1990s a chance discovery highlighted that it was possible to measure changes in the brain's haemodynamics that correlated with neural activity. Researchers described this new MRI technique as blood oxygenated level-dependant (BOLD) imaging and showed that it was possible to non-invasively obtain information on brain function at a much finer spatial resolution than was previously possible.[1] BOLD imaging is based on changes in cerebral blood flow associated with mental activity within the grey matter, and the BOLD signal indirectly measures neural activity by localising the metabolic activity that follows it.

Imaging revolution

The BOLD-functional MRI (fMRI) technique has revolutionised the way brain function is studied by providing a window into the workings of the brain. The methodology lends itself to many applications, such as psychiatric investigations into aberrant circuitry involved in processing emotion, and can also be coupled with transcranial Doppler to provide greater insights into cerebrovascular autoregulation in health and disease.[2]

fMRI in epilepsy

An important clinical application of fMRI relates to epilepsy. When neurosurgery is being considered for patients with intractable seizures, fMRI can be used to define the eloquent regions of the brain that relate to language, memory and/or the sensory motor strip and where they are positioned in relation to a patient's seizure focus.

There is now great acceptance of the BOLD-fMRI approach for localising receptive (Wernicke's) and expressive (Broca's) regions of language function (Figure 1). It has also been shown that

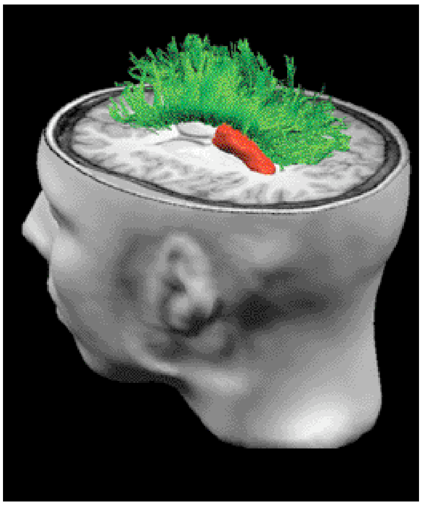

Figure 2. Diffusion tensor imaging tractography illustrating a newly diagnosed neurocytoma (red) in close proximity to the fibres of the corpus callosum (green).

fMRI is better at predicting postoperative language deficits than the traditional intracarotid amobarbital procedure (Wada test). Hundreds of centres around the world are now using the technique for both clinical purposes and research endeavours.

Diffusion tensor imaging

Towards the end of the 1990s several research groups made an equally significant advance when they developed MRI methods designed to analyse the white matter tracts that form the long-range connections of the brain.[3,4,5]

Using conventional diffusion weighted MRI, which measures the rate at which water molecules diffuse in a specific direction, researchers described a method to chart the path followed by water as it diffuses within the white matter. This was a major advance because traditional MRI techniques for determining the functional implications of cerebral disease have largely relied on the analysis of relationships of brain structures to grey matter anatomy. This is because of the grey matter's readily identifiable contrast. White matter, on the other hand, is more opaque to routine imaging as a consequence of its less visible margins and more complex functional associations.

Using diffusion tensor imaging (DTI), as it was named, it is possible to reveal the brain's underlying neuronal microstructures, such as white matter fibres surrounding a tumour, which are normally 'invisible' when using conventional structural imaging techniques (Figure 2). DTI is now being used clinically for presurgical planning but in the research realm, it has future applications in diseases such as multiple sclerosis, schizophrenia and traumatic head injury.

Further resources

CADE Clinic, Royal North Shore Hospital
www.cadeclinic.com

Brain Bytes Series – Acta Neuropsychiatrica 2007, Volume 19, issues 1 and 2
www.actaneuropsych.com

Benefits of functional imaging

Both fMRI and DTI techniques can be combined in a single session and, because MRI is noninvasive, serial and longitudinal measurements can be carried out on the same patient with minimal risk. Serial and longitudinal measurements allow for signal averaging, which improves sensitivity, thereby providing the opportunity to correlate behaviour and disease state to fMRI and DTI.

Measurements of fMRI and DTI can also reveal changes to the brain as it matures, learns a new skill or is exposed to specific treatments such as drug or behavioural therapy.

Limitations of functional imaging

For determining brain function and connectivity, fMRI and DTI are unparalleled by any other imaging modality. Both techniques do have limitations and these need to be carefully considered. In the case of fMRI, results need to be interpreted with caution as the underlying relationship between neural and hemodynamic responses has not yet been fully elucidated. Also, it needs to be borne in mind that the DTI technique only demonstrates gross fibre architecture and does not provide any detail regarding functional or synaptic connections.

Conclusion

The past 15 years have seen unprecedented advances in the methodologies used to measure structure and function in the human brain. It is important that clinicians understand the benefits of new technologies such as fMRI and DTI while also appreciating their limitations. In its early days, brain computer tomography was seen as an expensive nonclinical intervention of doubtful value but that view has changed dramatically. The technologies discussed here will, like computer tomography, become more widely available and eventually provide clinical insights that inform diagnosis and management. MT

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