Role of (fMRI) in Clinical Applications in the Field of Neurosurgery

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Abstract: ***Functional magnetic resonance imaging (fMRI) includes many different techniques and body areas, but the examination that is most commonly associated with the term is brain imaging using blood oxygenation level-dependent (BOLD) contrast. fMRI is being used increasingly for functional brain mapping. It is useful for research of disease processes and to better understand the way the brain works. It is also very useful in a clinical setting, especially for surgical planning. If neurosurgery is needed for a tumor in the brain or to remove a portion of the brain responsible for initiating epileptic seizures, fMRI can identify nearby areas that could be at risk, including areas responsible for motor, sensory, or cognitive functions that may be damaged. This allows the neurosurgeon to plan an approach that will spare as much of these areas as possible. Since its description in the early 1990's, functional magnetic resonance imaging (fMRI) has been used first for research purposes, and after in clinical applications in the field of neurosurgery. The present contribution discusses the clinical use of functional MRI (fMRI) and its role in the most common neurological diseases. The purpose of this paper is to critically review the literature on fMRI to achieve a better understanding of the usefulness of fMRI in brain surgery and to describe the newly-established technique in the field of neurological surgery for fusion imaging.***

Keywords: fMRI; BOLD contrast; Brain mapping; structural MRI; neurosurgery; Epilepsy ; Alzheimer's disease

1. Introduction

The technique of functional magnetic resonance imaging is rapidly moving from one of technical interest to wide clinical application. It measures brain activity via changes in blood circulation. This is therefore an indirect measure and one needs to assume a 'direct' relationship between neural activity and local blood changes .Functional magnetic resonance imaging (fMRI) is a relatively new procedure that uses MR imaging to measure the tiny metabolic changes that take place in an active part of the brain. It becoming the diagnostic method of choice for learning how a normal, diseased or injured brain is working, as well as for assessing the potential risks of surgery or other invasive treatments of the brain. Physicians perform fMRI to: examine the anatomy of the brain. Determine precisely which part of the brain is handling critical functions such as thought, speech, movement and sensation, which is called brain mapping. Help assess the effects of stroke, trauma or degenerative disease (such as Alzheimer's) on brain function. Monitor the growth and function of brain tumors. (1)

There are several other techniques that are used for brain mapping, including positron emission tomography, electroencephalography, and magnetoencephalography, each with its own advantages and disadvantages. Advantages of fMRI over other brain mapping techniques include good spatial resolution, non-invasiveness, and no radiation exposure with radionuclides or ionizing radiation.

With the development of fMRI came the opportunity to not only look noninvasively at the anatomy of organs within the living human but also to evaluate their function With these new imaging techniques, researchers interested in the function of the human brain were presented with an unprecedented opportunity to examine the neurobiological correlates of human behaviors.(2)

2. fMRI &Brain Mapping

Functional MRI brain mapping has been used in research as well as clinical situations for many purposes. It can help provide basic information about brain disease, help determine and guide treatment, and monitor treatment outcomes. Researchers use fMRI to study a wide variety of phenomenon. In a clinical setting, brain perfusion and diffusion examinations for the evaluation of stroke are commonly performed fMRI techniques. Diffusion-weighted examinations also can be done on tumors or organs other than the brain to evaluate blood delivery and distribution. Most cardiac imaging is functional, using real-time imaging to study blood volume and exchange during the cardiac cycle. Cardiac examinations help evaluate the blood supply to the cardiac muscle itself, as well as evaluate for turbulent blood flow in the heart. Another use of fMRI is the functional pancreatic/biliary (cholangiopancreatography) examination, which uses secretion to evaluate the function of the pancreas. Examples of fMRI also include enterography, which provides cine images of bowel motion, and dynamic imaging of the pelvis to evaluate the function of muscles of the lower abdomen and pelvic floor. (3)

However, what is most commonly referred to as fMRI today, and what this paper will focus on, is brain mapping and the evaluation of brain function using blood oxygenation level-dependent (BOLD) imaging. Functional MRI brain mapping has been used in research as well as clinical situations for many purposes. It can help provide basic information about brain disease, help determine and guide treatment, and monitor treatment outcomes.

Brain mapping helps determine the way that a specific patient's brain is structurally and functionally arranged. Although gross anatomical structure and function of the brain are quite similar in all humans, the detailed organization can vary amongst individuals. For example, portions of the language areas are quite variable between individuals, while motor areas are very similar. If brain injury occurs early in life, fMRI has shown that the brain can reorganize and recruit undamaged areas to carry out the functions of the lost tissue. Adults affected by trauma or stroke may experience some recovery of function in corresponding areas in the unaffected hemisphere. fMRI can be used to predict the functional outcome of patients suffering from trauma, stroke, schizophrenia, and Alzheimer disease.5

Conventional, or structural, MRI is extremely important in the diagnosis of primary and metastatic tumors, and other intracranial masses. Gadolinium contrast agents are used with T1-weighted imaging to assess the integrity of the blood-brain barrier. This helps identify masses that may not be seen on pre-contrast images.(4)

Conventional, or structural, MRI is extremely important in the diagnosis of primary and metastatic tumors, and other intracranial masses because the of excellent soft tissue contrast that provided by it, and the range of sequences that can explore differences in the biophysical properties of the brain and tumours, has made MRI the imaging mode of choice for the assessment of brain tumours. Although MRI has improved our visualization of these tumours, there are a number of areas where it fails to provide us with sufficient information. Gadolinium contrast agents are used with T1-weighted imaging to assess the integrity of the blood-brain barrier. This helps identify masses that may not be seen on pre-contrast images. Preoperatively, 3-dimensional (3D) imaging is often performed for use in stereotactic surgery. This conventional MRI imaging can be used for planning the best way to surgically remove or destroy intracranial masses. Lesions smaller than 30 mm (3 cm) maximum diameter may be treated with stereotactic radiosurgery using gamma radiation.14 Larger lesions can be treated by neurosurgical resection. fMRI can provide the functional information about nearby tissue that may be affected by neurosurgery or stereotactic radiosurgery. It also helps predict the clinical outcome if nearby tissue is inadvertently damaged. The surgical approach to a lesion can be better planned because the surgeon is aware of the location of important functional areas, such as a motor or language center.6 However, fMRI may not be completely dependable in some patients with brain tumors because the vascular response to neural activation may be absent or less than expected, because of changes the tumor makes to the local environment.(5)

Intraoperative brain mapping with fMRI or conventional MRI also can be very useful because the surgeon is actually changing the anatomy during surgery. Images should be reacquired, either as updates or using real-time monitoring. This type of scanning is called interventional MRI (Figure 1). It requires extensive training of personnel, as well as MRI-compatible surgical instruments, monitors, lights, and other equipment required for the surgical suite. (6)Types of surgical procedures done with interventional MRI include stereotactic biopsy, thermal ablation techniques such as hyperthermia (radiofrequency, interstitial laser, and focused ultrasound ablation) and hypothermia (cryoablation), drainage of cysts, and craniotomy.(7)

Figure1: MRI Scanner

3. fMRI and BOLD Imaging

Functional MRI makes use of a special signal called blood oxygen level dependent (BOLD) contrast. It was first found by Dr. Ogawa in 1990, followed by Dr. Kwong in 1992. Neurons do not have internal reserves of energy in the form of glucose and oxygen, so their firing causes a need for more energy to be brought in quickly. This energy supply comes from blood cells, through a process called the haemodynamic response. Blood cells contain molecules of haemoglobin which are bound to oxygen. Because more oxygen is supplied than consumed there is a difference in the concentration of oxyhaemoglobin and deoxyhaemoglobin (oxygen is bound or not to blood haemoglobin) before/after a local neural firing/oxygen consumption. Similarly, because the haemoglobin is diamagnetic when oxygenated but paramagnetic when deoxygenated, the magnetic resonance (MR) signals of blood is slightly different before/after local neural firing/oxygen consumption. This is this difference in magnetic susceptibility that can be detected using an MRI scanner. (8)

Blood flowing through the brain carries oxygen on molecules called hemoglobin. Hemoglobin molecules also carry iron, and so have a magnetic signal. It turns out that hemoglobin molecules have different magnetic properties when they are attached to oxygen than when they are not carrying oxygen, and this small difference can be detected with an MRI machine.(9)

When an area of the brain is active there is a corresponding increase in blood flow. This coupling of blood flow and brain metabolism was first described in 1890 by Sherrington and is the principle behind fMRI. The increased blood flow is not matched by an increase in oxygen extraction, so the concentration of deoxyhaemaglobin is reduced. Since deoxyhaemaglobin is paramagnetic there is a change in the T2* signal. This change, referred to as blood-oxygen level dependent contrast (BOLD), (10) is detected by the MR sequence. To produce reproducible results, activation paradigms are devised to allow specific functions to be assessed. It is possible to assess any brain activation, but in practice only assessment of motor function and language are considered clinically. Motor activation is stimulated by movement of the relevant part of the body, interspersed with rest. Studies comparing motor fMRI to direct cortical stimulation in awake patients have found excellent correlation. (11, 12) Language activation is more problematic as this is a more complicated series of processes that involve many brain regions. The accuracy of fMRI in mapping language tasks is poorer than motor studies and usually will require the assessment of multiple language tasks.(13) For bilingual patients there is evidence that there are different areas responsible for each language function, and this needs to be accounted when language is being assessed. (14)

When we start thinking, neurons in our brain use more oxygen and demand more blood. Functional MRI can detect the difference in signal caused by the increase in blood flow to specific areas of the brain. The MRI scanner measures this signal difference and displays the activity as a colored area (Figure 2).So functional MRI studies are not actually looking at neuronal activity directly, but are looking at how blood oxygen levels change, and assuming that this is connected to nerves firing. Diseases like vascular malformations, tumors, and even normal aging can change the relationship between neural activity and the local blood flow that results in BOLD signal.

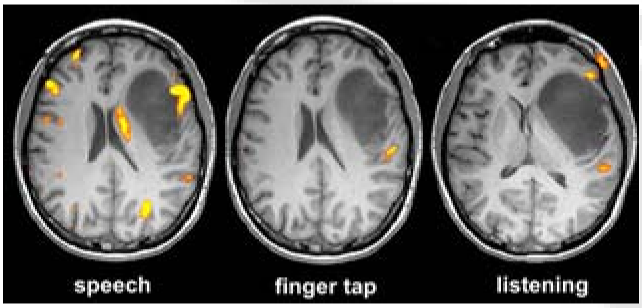

Figure 2: In functional MRI, brain areas "light-up" when performing certain tasks

4. Epilepsy and Alzheimer's Disease

FMRI was found a reliable and reproducible examination tool resulting in a wide distribution of fMRI methods in presurgical evaluation of epilepsy in determining the relationship of eloquent areas and the epileptic focus. Preliminary data suggest that fMRI using memory paradigms can predict the postoperative memory decline in epilepsy surgery by determining whether a reorganization of memory functions took place. Speech-activated fMRI became the most used tool in determining hemispheric dominance. Visual and sensory-motor cortex can also be routinely investigated by fMRI which helps in decision on epilepsy surgery. FMRI combined with EEG is a new diagnostic tool in epilepsy and sleep disorders (15). FMRI can identify the penumbra after stroke and can provide additional information on metabolic state of the threatened brain tissue. FMRI has a predictive role in post-stroke recovery. In relapsing-remitting MS an adaptive reorganization can be demonstrated by fMRI affecting the visual, motor, and memory systems, despite preserved functional performance. Much more extensive reorganization can be demonstrated in secondary progressive MS. These findings suggest that the different stages of MS are related to different stages of the reorganization and MS becomes progressive when there is no more reserve capacity in the brain for reorganization. Functional MRI has been used to explore memory impairment resulting from diseases such as schizophrenia, Alzheimer disease and dementia.6 Researchers using fMRI are able to detect changes in neural function in individuals with a genetic risk of Alzheimer disease long before they are clinically affected.16,17 Because treatment is not very effective after clinical onset, it is hoped that early detection may lead to prevention or improved treatment of the disease. These efforts are hindered by the high degree of individual variation in normal brain anatomy and function, and by the difficulty in distinguishing early changes of Alzheimer disease from mild cognitive impairment and normal aging.(16)

5. Conclusion

As fMRI has matured as an imaging technology and the body of existing research has grown, it has become increasingly possible to use fMRI data to 'read' mental states from brain activity, first informally and increasingly using formal methods from machine learning. I believe that these methods will provide the basis for the next generation of neuroimaging in combination with more detailed models of neural connectivity and computational. In addition to the structural information from conventional MR sequences, advanced fMRI provides important information on tumour pathology and biology. It is likely that these techniques will become an essential tool in the assessment of brain tumours. These techniques can be used to improve identification of the tumour margin, tumour grading, reducing surgical risk and assessing the response to therapy. It is important for the neurosurgeon to understand what information can be obtained from these sequences, and that they ensure they are used to further develop the assessment and management of brain tumour.

6. Acknowledgement

The researcher gratefully acknowledges the Dean Ship and staff of the College of Medical Radiological Sciences, Najran University. Firstly and finally, my thanks to my Allah, the most gracious and most merciful

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