The ABC’s of functional MRI in the pre-surgical evaluation of patients

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Learning objectives

To understand the science and capabilities behind functional magnetic resonance imaging (fMRI) for the pre-surgical evaluation of patients.
Background

fMRI exhibits regional, time-varying changes in brain metabolism. It uses include the pre-surgical assessment of patients suffering from intracranial tumours or from epilepsy [1]. fMRI helps demonstrate the spatial relationship between eloquent areas of the brain and surgical lesion. Blood Oxygen Level Dependent (BOLD) fMRI is a proven and valuable tool illustrating changes in the concentration of deoxyhaemoglobin following task-induced alterations in neural metabolism. fMRI offers the ability to localise and lateralise function using a collection of tasks [2].

The utilisation of fMRI has become widespread due to increasing availability, resolution, relatively low cost and noninvasiveness. Its basis relies on the changes in ratio of oxyhaemoglobin (oxyHb) and deoxyHb seen when neural upregulation takes place following a visual or auditory stimulus or task [3]. When a region of the brain is "activated" performing a function, increased neural firing occurs resulting in the upregulation of the cerebral metabolic rate of oxygen (CMRO$_2$). A buildup of waste products leads to the release of chemical mediators that increase cerebral blood flow (CBF) to restore oxygen concentration and in turn reduce deoxyhaemoglobin levels [3]. Increased CBF and alterations in oxygenation concentration are the two factors that give fMRI its unique ability to illustrate changes in brain metabolism. BOLD contrast results from changes in the magnetic field around red cells and the oxygen state of haemoglobin. Fully deoxygenated haemoglobin is highly paramagnetic creating local gradients resulting in increased T2* signal as seen in task activation studies [4].
Presurgical planning fMRI is becoming routine practise in tertiary institutions. Motor and language assessment is crucial to avoid inadvertent injuries to the eloquent regions of the brain. Primary motor and somatosensory cortices are located in the precentral and postcentral gyri correspondingly (Fig 1). The primary motor cortex is functionally organised, and specific tasks can elicit a BOLD response. For example, tongue movement, finger-tapping and toe-tapping will selectively activate the anatomical region along the precentral gyrus from lateral to medial.

The supplementary motor area is located in the dorsomedial aspect of the superior frontal gyrus and contributes to the control of movement. Anteriorly to posteriorly the SMA denotes the head to the lower extremities from a somatotopic viewpoint [5]. Working memory tasks and word generation triggers a BOLD response in the SMA rostrally with dominance to the left side. The contralateral SMA is activated by multifaceted motor tasks [6]. Lesions within the SMA (Fig 2,3) result in transient weakness, gait apraxia and aboulia. Unilateral resection of the SMA can lead to SMA syndrome and is characterised by akinesia contralaterally; however, the strength of the muscle in extremities is preserved [7].

The neuroanatomical theory of dual streams originally postulated by Ungerleider and Mishkin for vision was later expanded upon by Hickok and Poeppel to incorporate language. The theory hypothesises a dorsal stream involved with production and articulation of language originating in the superior temporal gyrus and extending through the supramarginal gyrus to the frontal lobe with expansions to the premotor cortex [7]. Example tasks for this pathway involve the repetition of speech [8]. The ventral route involved with the understanding of language and semantic access extends from the superior temporal gyrus to the left inferior frontal gyrus [7]. Example tasks for the ventral pathway include listening to and attaining meaning from dialogue [8].

In keeping with this theory, the principle of Broca’s and Wernicke’s area representing the expression of speech and language processing has expanded over time covering a larger area, and studies show connection via the superior longitudinal fasciculus and arcuate fasciculus [9,10]. Broca's area located in the inferior frontal gyrus is further separated into three subdivisions (Fig 4). The posterior parietal cortex is dorsal and caudal to the postcentral sulcus and includes the superior and inferior parietal lobules. The inferior parietal lobule contributes to Wernicke's area and is further subdivided into the supramarginal gyrus that caps the superior temporal gyrus and angular gyrus that caps the middle temporal gyrus (Fig 5) [7]. Lesions closely related to both Broca's and Wernicke's area can affect BOLD activation during word generation and speech comprehension tasks, respectively (Fig 6-9).
Fig. 1: T1 weighted axial-oblique image illustrating the central sulcus (yellow line) separating the primary motor cortex from the primary somatosensory cortex with the precentral gyrus (a), the post central gyrus (b) and the paracentral lobule (c) demonstrated. 

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Fig. 2: 35 year-old male with a recurrent left superior frontal gyrus pilocytic astrocytoma. fMRI motor paradigm right hand task showed BOLD activation in the left precentral gyrus (motor cortex) as well as the dorsomedial superior frontal gyrus (supplementary motor cortex/ SMA). The posterior tumor margin abuts the SMA BOLD activation. Post-operatively the patient experience transient contralateral weakness for several weeks prior to making a full recovery consistent with SMA syndrome.

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Fig. 3: 45 year-old female with an infiltrative high grade glioma in the left posterior frontal lobe occupying the left middle frontal gyrus (pre-motor area). fMRI motor paradigm bilateral hand task showed BOLD activation in the precentral gyrus (motor cortex) as well as the dorsomedial superior frontal gyrus (supplementary motor cortex/ SMA).

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Fig. 4: T1 weighted sagittal image illustrating the inferior frontal gyrus, part of the prefrontal cortex and is the location of Broca's area which is involved in speech production and processing of language. The inferior frontal gyrus is subdivided into three distinct areas as shown. a - Pars orbitalis b - Pars triangularis c - Pars opercularis

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**Fig. 5:** T1 weighted sagittal image illustrating the inferior parietal lobule, one of three divisions of the parietal lobe and is involved in sensorimotor integration, auditory and visuomotor processing. The inferior parietal lobule is subdivided into two distinct areas as shown. a - Angular gyrus b - Supramarginal gyrus

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Fig. 6: 55 year-old female with a cortical low grade glioma in the inferior right frontal lobe. fMRI word generation and speech comprehension tasks were performed. Word generation showed BOLD activation in the left par opercularis and the lateral aspect of the precentral gyrus (Broca's area). Speech comprehension tasks confirmed left hemisphere speech dominance with BOLD activation in the posterior superior temporal lobe (Wernicke's).

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Fig. 7: 38 year-old male presented with expressive dysphasia. MRI revealed an extensive infiltrative glioma in the left frontal temporal lobe. fMRI word generation and speech comprehension tasks were performed. Word generation showed absence of BOLD activation in the left inferior frontal region likely due to loss of neurovascular coupling in the Broca’s area. Speech comprehension tasks confirmed left hemisphere speech dominance with BOLD activation in the supramarginal gyrus (Wernicke’s area).

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**Fig. 8:** 32 year-old male with a large left frontal glioblastoma. fMRI word generation and speech comprehension tasks were performed. Speech lateralization was to the left side as demonstrated with BOLD activation in the left inferior frontal lobe (Broca’s area) and the posterior superior temporal lobe (Wernicke’s). Laterality Index is a useful surrogate to determine speech lateralization by counting the number of active BOLD positive voxel compared to the contralateral hemisphere.

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**Fig. 9:** 65 year-old male with a left anterior temporal glioblastoma. fMRI picture naming, word generation and speech comprehension tasks were performed. Speech was left lateralized. Visual BOLD activation areas involves the cuneus and lingual gyrus of the occipital lobes (primary visual cortices above and below the calcarine fissure) as well as the fusiform gyrus (basal temporal language association area/visual word form area).

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Conclusion

fMRI has become well established in the field of medicine. Given the valuable information it provides clinicians in pre-surgical planning for patients with intracranial tumours and epilepsy, its future utility will help further our understanding of the brain.
References


