🧠 Functional Brain Mapping

🧠 Functional Brain Mapping Modalities

Functional brain mapping can be categorized into **non-invasive** and **invasive** modalities. Each technique varies in spatial and temporal resolution, risk profile, and clinical utility.

🧠 Non-Invasive Mapping Techniques

Modality	Principle	Use Case	Resolution
fMRI (functional MRI)	Measures BOLD signal during cognitive or motor tasks	Language, motor mapping pre-surgery	High spatial, low temporal
MEG (Magnetoencephalography)	Detects magnetic fields from neuronal activity	Epilepsy focus, motor/language mapping	High temporal, moderate spatial
TMS (Transcranial Magnetic Stimulation)	Magnetic pulses induce neuronal activity; responses are mapped	Motor and speech localization, outpatient mapping	Moderate spatial, moderate temporal
PET (Positron Emission Tomography)	Measures regional metabolism via radiotracer uptake	Tumor metabolism, epilepsy foci	Low spatial, poor temporal

🧠 Invasive Mapping Techniques

Modality	Principle	Use Case	Resolution
ECoG (Electrocorticography)	Records electrical activity directly from cortex	Real-time seizure detection, functional mapping	Very high temporal and spatial
CSM (Cortical Stimulation Mapping)	Electrical stimulation of cortex during awake surgery	Functional validation of eloquent cortex (speech, motor)	Gold standard for eloquence
SEEG (Stereo-electroencephalography)	Intracerebral depth electrodes monitor deep cortical and subcortical areas	Refractory epilepsy, functional connectivity	High depth resolution

🧠 Choosing the Right Modality

The choice of modality depends on:

- **Clinical scenario**: tumor, epilepsy, DBS
- **Location of interest**: cortical vs subcortical
- **Patient status**: awake-capable vs not
- **Urgency and risk tolerance**

For example:

- **fMRI** is preferred for **non-invasive preoperative planning**.
- **CSM/ECoG** are used in **awake craniotomy**.
- **SEEG** is standard in **deep epileptogenic zone localization**.
- **MEG** is useful when **EEG or MRI are inconclusive**.

Tags: `functional_mapping` `modalities` `noninvasive` `invasive` `epilepsy_surgery` `fMRI` `CSM` `ECoG` `MEG` `TMS`

Types

Awake brain mapping.

Brain Mapping.

Intraoperative stimulation mapping.

Language mapping.

Motor mapping.

Preoperative mapping.

see Functional Mapping.

see Process Mapping.

Functional brain mapping refers to the identification and localization of specific brain areas responsible for motor, sensory, language, memory, and higher cognitive functions. It is a cornerstone in modern neurosurgery, particularly in the treatment of lesions near or within eloquent cortex.

🧠 Clinical Applications

Functional mapping is essential for:

- Tumor resection near eloquent cortex (gliomas, metastases)
- Epilepsy surgery (focal cortical dysplasia, mesial temporal sclerosis)
- Deep brain stimulation (DBS) targeting
- Vascular malformations and arteriovenous malformation (AVM) planning
- Awake craniotomies

🧪 Mapping Techniques

Non-Invasive Methods

- **fMRI (functional MRI)**
  - Measures BOLD (blood-oxygen-level dependent) signal changes during tasks.
  - Localizes language, motor, and visual areas.

- **MEG (Magnetoencephalography)**
- High temporal resolution, useful for epilepsy focus localization.

- **PET (Positron Emission Tomography)**
- Identifies metabolic activity, especially in tumor and epilepsy cases.

- **TMS (Transcranial Magnetic Stimulation)**
  - Used for preoperative motor and language mapping in outpatient setting.

Invasive Methods

- **ECoG (Electrocorticography)**
  - Intraoperative or extraoperative electrode recording.
  - High spatial and temporal resolution.

- **Cortical Stimulation Mapping (CSM)**
  - Performed during awake surgery to identify and preserve essential functions (speech arrest, motor inhibition, etc.).

- **Stereo-EEG (SEEG)**
  - Used in refractory epilepsy; allows deep functional exploration with depth electrodes.

Key Functional Areas

- **Primary Motor Cortex (M1)** – Precentral gyrus
- **Primary Sensory Cortex (S1)** – Postcentral gyrus
- **Broca's Area** – Inferior frontal gyrus (language production)
- **Wernicke's Area** – Posterior superior temporal gyrus (language comprehension)
- **Supplementary Motor Area (SMA)** – Medial frontal cortex
- **Visual Cortex (V1)** – Calcarine sulcus, occipital lobe

Software Tools and Platforms

- **SPM (Statistical Parametric Mapping)** – Widely used in fMRI analysis.
- **FSL (FMRIB Software Library)** – Analysis of structural, diffusion, and functional data.
- **FreeSurfer** – Cortical surface-based analysis and parcellation.
- **Brainstorm**, **MNE**, **FieldTrip** – For MEG and EEG source localization.
- **Lead-DBS** – Used in DBS targeting and connectivity-based mapping.

🧾 Summary Table

Method	Invasiveness	Resolution	Use Case
fMRI	Non-invasive	High spatial, low temporal	Pre-op planning
MEG	Non-invasive	High temporal	Epilepsy, language
ECoG	Invasive	Very high	Real-time mapping
CSM	Invasive	Functional confirmation	Awake surgery
TMS	Non-invasive	Good spatial	Language/motor screening

Tags: `functional_mapping` `brain_mapping` `fMRI` `ECoG` `CSM` `MEG` `TMS` `epilepsy` `glioma` `dbs` `language` `motor` `awake_surgery`

Functional brain mapping (FBM) is an integral part of contemporary neurosurgery. It is crucial for safe and optimal resection of brain lesions like gliomas. The eloquent regions of the like motor cortex, somatosensory, Wernicke's area, and Broca's area are usually mapped, either preoperatively or intraoperatively. Since its birth in the nineteenth century, FBM has witnessed immense modernization, radical refinements, and the introduction of novel techniques, most of which are non-invasive. Direct electrical stimulation of the cortex, despite its high invasiveness, remains the technique of choice. Non-invasive techniques like fMRI and magnetoencephalography allow us the convenience of multiple mappings with minimal discomfort to the patients. They are quick, easy to do, and allow thorough study. Different modalities are now being combined to yield better delineations like fMRI and diffusion tensor imaging.

Sagar et al., reviews the physical principles, applications, merits, shortcomings, and latest developments of nine FBM techniques. Other than neurosurgical operations, these techniques have also been applied to studies of stroke, Alzheimer's, and cognition. There are strong indications that the future of brain mapping shall see the non-invasive techniques playing a more dominant role as they become more sensitive and accurate due to advances in physics, refined algorithms, and subsequent validation against invasive techniques [1].

Types

Resting state fMRI.

Awake brain mapping.

Language mapping.

Preoperative mapping.

Intraoperative stimulation mapping.

The vast majority of centers use electrophysiological mapping techniques to finalize target selection during the implantation of deep brain stimulation (DBS) leads for the treatment of Parkinson's disease and tremor. This review discusses the techniques used for physiological mapping and addresses the questions of how various mapping strategies modify target selection and outcome following subthalamic nucleus (STN), globus pallidus internus (GPi), and ventralis intermedius (Vim) deep brain stimulation. Mapping strategies vary greatly across centers, but can be broadly categorized into those that use microelectrode or semimicroelectrode techniques to optimize position prior to implantation and macrostimulation through a macroelectrode or the DBS lead, and those that rely solely on macrostimulation and its threshold for clinical effects (benefits and side effects). Microelectrode criteria for implantation into the STN or GPi include length of the nucleus recorded, presence of movement-responsive neurons, and/or distance from the borders with adjacent structures. However, the threshold for the production of clinical benefits relative to side effects is, in most centers, the final, and sometimes only, determinant of DBS electrode position. Macrostimulation techniques for mapping, the utility of microelectrode mapping is reflected in its modification of electrode position in 17% to 87% of patients undergoing STN DBS, with average target adjustments of 1 to 4 mm. Nevertheless, with the absence of class I data, and in consideration of the large number of variables that impact clinical outcome, it is not possible to conclude that one technique is superior to the other in so far as motor Unified Parkinson's Disease Rating Scale outcome is concerned. Moreover, mapping technique is only one out of many variables that determine the outcome. The increase in surgical risk of intracranial hemorrhage correlated to the number of microelectrode trajectories must be considered against the risk of suboptimal benefits related to omission of this technique [2].

[1]
Sagar S, Rick J, Chandra A, Yagnik G, Aghi MK. Functional brain mapping: overview of techniques and their application to neurosurgery. Neurosurg Rev. 2018 Jul 13. doi: 10.1007/s10143-018-1007-4. [Epub ahead of print] Review. PubMed PMID: 30006663.
[2]
Gross RE, Krack P, Rodriguez-Oroz MC, Rezai AR, Benabid AL. Electrophysiological mapping for the implantation of deep brain stimulators for Parkinson's disease and tremor. Mov Disord. 2006 Jun;21 Suppl 14:S259-83. Review. PubMed PMID: 16810720.