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Review Article

Brain Mapping in Neurosurgery

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ABSTRACT

Background and Aim: Brain mapping is the study of the anatomy and function of the Central Nervous System (CNS). Brain mapping has many techniques and these techniques are permanently changing and updating. From the beginning, brain mapping was invasive and for brain mapping, electrical stimulation of the exposed brain was needed. However, nowadays brain mapping does not require electrical stimulation and often does not require any complex involvement of patients. To perform brain mapping, functional and structural neuroimaging has an essential role. The techniques for brain mapping include noninvasive techniques (structural and functional magnetic resonance imaging [fMRI], diffusion MRI [dMRI], magnetoencephalography [MEG], electroencephalography [EEG], positron emission tomography [PET], near-infrared spectroscopy [NIRS] and other non-invasive scanning techniques) and invasive techniques (direct cortical stimulation [DCS] and intracarotid amytal test [IAT] or wada test).

Methods and Materials/Patients: This is a narrative study on brain mapping in neurosurgery. To provide up-to-date information on brain mapping in neurosurgery, we precisely reviewed brain mapping and neurosurgery articles. Using the keywords "brain mapping", "neurosurgery", "brain mapping techniques", and "benefits of brain mapping", all of the related articles were obtained from Google Scholar, PubMed, and Medline and were precisely studied.

Results: To perform an effective and safe neurosurgical intervention, precise information about the structural and functional anatomy of the brain is obligatory. Based on the information on brain mapping, the selection of suitable patients for the operation, the plan of appropriate operative approach, and good surgical results can be acquired. To provide this information, we can use brain mapping techniques that were formerly applied in neuroscientific brain mapping efforts with noninvasive techniques, such as fMRI, MEG, dMRI, PET, etc and invasive techniques, such as DCS, IAT, etc.

Conclusion: Functional brain mapping is a constantly evolving fact in neurosurgery. All stages in obtaining a functional image are complex and need knowledge of the basic physiologic and imaging features.

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Highlights

• Brain mapping is the study of the anatomy and function of the Central Nervous System (CNS).

• The techniques for brain mapping include noninvasive techniques and invasive techniques, the latter techniques are gold standard techniques for functional mapping and language lateralization.

• Based on the information on brain mapping, the selection of suitable patients for operation, the plan of appropriate operative approach, and good surgical results can be acquired.

Plain Language Summary

Brain mapping is a fundamental part of modern neurosurgery. Brain mapping has undergone much radical and intense modernization and reforms in association with the introduction of new modern techniques since its inception in the 19th century. With brain mapping, you can map the eloquent areas of the cortex and this is essential for the safe and optimal removal of brain lesions. Brain mapping techniques are noninvasive versus invasive techniques and most of them are non-invasive. Direct cortical stimulation (DCS) and intracarotid amytal test (IAT) are invasive techniques and DCS remains the technique of choice. Magnetoencephalography (MEG) and functional magnetic resonance imaging (fMRI) are non-invasive techniques. These noninvasive techniques are minimally uncomfortable for patients, are quick, easy to do, and allow for a complete study. Currently, by combining different methods of brain mapping, we have better results in brain mapping. In this narrative article, we review the advantages, disadvantages, characteristics, indications, contraindications, and mechanisms of brain mapping methods.

1. Introduction

Since about a century ago, neurosurgeons have been involved with brain mapping efforts. Functional brain mapping has a central role in some neurosurgical operations and during functional neurosurgical procedures. The followings are some tips and pearls about brain mapping in neurosurgery to extend our current understanding of brain mapping.

2. Methods and Materials/Patients

We concisely reviewed brain mapping in neurosurgery to provide up-to-date information. Using the keywords of “brain mapping”, “neurosurgery”, “brain mapping techniques”, and “benefits of brain mapping”, all of the related articles were retrieved from Google Scholar, Medline, PubMed, etc. and were precisely studied.

3. Results

To perform effective and safe neurosurgical interventions, precise information about the structural and functional anatomy of the brain is required. Based on the information on brain mapping, the selection of suitable patients for operation, the plan of appropriate operative approach, and good surgical results can be obtained. To provide this information, we can use brain mapping techniques that were formerly applied in neuroscientific brain mapping efforts with noninvasive techniques, such as functional magnetic resonance imaging (fMRI), magnetoencephalography (MEG), diffusion MRI (dMRI), positron emission tomography (PET), etc. and invasive techniques, such as direct cortical stimulation (DCS), intracarotid amytal test (IAT), etc [1].

4. Discussion

Brain mapping is the study of the anatomy and function of the central nervous system (CNS). Brain mapping has many techniques and these techniques are permanently changing and updating. Two types of techniques for brain mapping are noninvasive techniques (fMRI, dMRI, MEG, electroencephalography (EEG), PET, near-infrared spectroscopy (NIRS), and others) and invasive techniques (DCS and IAT or wada test). The DCS and IAT are often the gold standard techniques for doing functional brain mapping and language lateralization [2]. These two techniques become gold standard techniques due to prolonged experience to perform these procedures and the way to localize eloquent brain areas. DCS and IAT are blocking or inhibition techniques. In inhibition or blocking techniques a specific brain area is temporarily disrupted from normal function and then the patient is tested for an inducible neurological deficit. Based on this, we can detect what deficit is expected to occur after surgical resection. The shortcomings of these techniques include highly invasive mapping techniques, both techniques need active patient cooperation during testing, therefore they do not apply to patients with impaired function or altered level of consciousness, limited accessibility of the grey matter within the depth of the sulcus in DCS, and limited time for effective operative planning or regarding other therapeutic strategies in DCS because it is done either during the operation or a short time before it [3]. For this reason, less invasive mapping techniques have been developed. In the majority of these techniques, following the patient's behavioral task (paradigm), the consequent brain changes in the functionality of a particular brain area are measured, for example, in fMRI or MEG after performing a task by the patient, its effects are assessed in the blood flow, metabolism, or electric activity in activated brain areas. The major shortcoming of these techniques is the inability to differentiate between essential brain regions and supportive brain regions in performing the task. In MEG, brain activity is noninvasively mapped by measuring changes in local magnetic fields associated with neural activity. MEG is mostly used in preoperative assessment of epileptic cases that are candid for epilepsy surgery. MEG temporal resolution is excellent but poor for PET and Diffusion Tensor Imaging (DTI). MEG spatial resolution is variable. MEG is the only noninvasive technique that can block neural activity, which is why it can provide a significant advantage to the neurosurgeon. Transcranial Magnetic Stimulation (TMS) is another method for brain mapping. TMS delivers magnetic fields at the scalp that pass through the scalp and skull and induces neuronal changes and stimulate the cortex like DCS. It is an emerging mapping technique. In TMS, a given brain region is directly stimulated and then shows the relationship of the brain tissue with the performance of the task. TMS can be used as an activation or inhibition method. In neurosurgical mapping, for example, it is used as an activation method for motor mapping and as an inhibition method for language mapping. Disadvantages of TMS include: it needs dedicated equipment and personnel, it is not a reliable method for mapping language function, it may be contraindicated in patients with seizures, and TMS may not clarify all of the regions involved in motor performance even with direct mapping of the primary motor cortex. Diffusion Tensor Imaging (DTI) is an advanced structural mapping and not a functional mapping method. DTI demonstrates the location and trajectory of white matter tracts. The basis for this demonstration is to quantify the magnitude and direction of water diffusion in brain tissue. The shortcomings of DTI include: DTI is sensitive to signal loss artifacts from air spaces, yields a small amount of information about the functional status of tracts, poor resolution of crossing white bundles, and poor demonstration of tracts with high curvature. In DTI, if physical continuity exists between tracts and cortical areas of interest, these tracts consider important tracts. To demonstrate and preserve these tracts, we can combine DTI with fMRI. PET is another mapping technique. In PET after using a radiotracer as inhalational, orally, or intravenously, the relative position of the radiotracer is detected in the patient's body. Based on this, we can obtain many functional and physiological data. Because of this property, PET is effective in following conditions to guide the appropriate site of biopsy to prevent sampling error with under grading of tumors with heterogeneous histologic characteristics or to demonstrate regions of interictal hypometabolism associated with epileptogenic foci. PET may one day guide functional neurosurgery with areas under development including the development of specific receptors targeted radiotracers. However, the shortcomings of PET are poor signal-to-noise ratio (SNR), poor temporal resolution, and moderate spatial resolution [2-4].

Brain mapping modalities, such as observational mapping (PET, MEG, or fMRI), inhibition mapping (TMS), or advanced structural mapping (DTI) are rapidly evolving and have an extensive clinical role in the neurosurgical planning phase. With the combination of different functional mapping methods, we can achieve optimal results. To detect and not miss an eloquent brain area every time, we use these methods for surgical planning, it is essential to consider sensitivity and specificity [2-4].

To prevent postoperative neurosurgical deficits in operations adjacent to or within the eloquent brain regions, presurgical functional neuroimaging of the brain is necessary. For this purpose, different techniques include fMRI, PET, and diffusion-weighted imaging (DWI) [5, 6]. These techniques are useful to clarify the risk and plan of operation [7-9]. The disadvantages of these techniques are as follows. The first disadvantage is the use of neuronavigation systems to match preoperative functional imaging data to the intraoperative site but the degree of precise image fusion after craniotomy is unclear due to brain shifting. With this brain shift, target registration errors up to 5 mm may occur [10, 11]. Another disadvantage of these techniques is limited spatial resolution. To overcome these shortcomings, we can use a functional imaging technique called

Intraoperative Optical Imaging (IOI). In IOI, by obtaining and evaluating camera images from the bare brain surface, the neurosurgeon can detect changes in the cortical optical characteristics. IOI has a high temporal and spatial resolution. Based on the data of IOI, we can show metabolic changes, followed by cortical organization [12-14] and neuronal interconnectivity [15-17]. In brain mapping, IOI has been broadly used to observe, recognize, and map somatosensory areas and the visual cortex [18-23], and to clarify seizure focus [24, 25] and brain tumors [26, 27]. The use of IOI to decide for tumor removal based on language-related observations is still not conclusively clarified [28-34].

Brain mapping techniques

There are different techniques for brain mapping and we will describe some of these techniques.

Functional MRI (fMRI)

fMRI is the most commonly employed functional mapping technique for operative planning. It works based on the measurement of changes in oxygenated and deoxygenated hemoglobin and thus blood flow as a surrogate for neural activity. It is a non-invasive mapping technique and is deployable on many clinical MRI scanners. fMRI physiologic data can be taken with and co-registered to corresponding structural images. Because of the safety and relative ease of fMRI, we can use it to plan optimal surgical strategy, guide the decision for surgery, and consider the risk of operation [35-39]. The shortcomings of fMRI are as follows:

Technical difficulties

• fMRI works based on the changes in cerebral blood flow using Blood Oxygen Level-Dependent (BOLD) contrast on T2* weighted images and does not directly assess neuronal activation. For this reason, an intact auto-regulatory response is required to correct signal interpretation. Any disruption in neural hemodynamic coupling by any pathologic processes can change the concordance between neuronal activity and cerebral blood flow and can distort the BOLD signal interpretation, such as the signal disruption by the mass effect of a lesion.

• No accepted standard procedure exists to acquire and analyze fMRI and behavioral paradigms.

• To interpret data, different statistical approaches and diverse statistical analyses of the data are available.

• fMRI shows the topography of the functional cortical areas without any data about the white matter connections [40].

• Vein effect-larger draining cerebral veins-induced susceptibilities can distort the BOLD signal interpretation. This phenomenon can significantly decrease the precision of spatial localization [41]. To cancel this phenomenon, the spin echo (SE) sequence is recommended [42]. However, the SE sequence has some limitations, as it first requires prolonged scanning acquisition times due to the less sensitivity to magnetic susceptibility effects (the basis of the BOLD signal), and the second, covers smaller areas.

• Head movements-data quality is severely degraded with any head movement during fMRI. These head movements during fMRI have two effects, one is to add “false” activation and second is to decrease or obscure “real” activation. Signal artifacts of motion are higher in paretic patients than in nonparetic patients. If the displacement is more than 2 mm, repeating fMRI is indicated to better capture the motion of parameters. Otherwise, then the data is not interpretable [43, 44].

• Susceptibility artifacts-susceptibility artifacts can occur at the border of air and tissue interfaces, such as in the middle fossa (in the proximity of mastoid air cells) and in the orbitofrontal cortex (in the proximity to nose and air sinuses) [45] and then in post-operative cases due to the presence of surgical clips, titanium plates, metal dust from a skull drill, or prior blood products. These susceptibility artifacts cause geometric distortions and signal intensity reduction. Thus it should be cautious in interpreting fMRI data in postsurgical patients. The habitual way of overlaying functional brain maps on T1W images causes the artifacts to no longer be discernible [45].

• Higher incidence of neurological deficits- If surgical resection of a brain lesion is performed in 0.5 to 2 cm of the eloquent cortex and fMRI alone is used as a mapping technique, the likelihood of neurological deficit is higher in contrast to the usage of DCS. Therefore, if there is a spatial distance of 2 cm or less between the lesion and the functional cortex, the intraoperative DCS is preferred for mapping of the functional cortex [46-49].

Magnetoencephalography (MEG)

Neuronal activities have been associated with local magnetic fields. The basis of MEG is to measure changes in these local magnetic fields and based on these measurements, noninvasive mapping of brain activity is performed. MEG is mostly applied for preoperative evaluation of epileptic patients. The disadvantages of MEG are [50]:

• Very expensive technique- MEG scanners and the shielded room are very expensive and need dedicated personnel

• High sensitivity to the surrounding magnetic fields, even the magnetic field of the earth itself

• Low spatial resolution and signal source localization [50]

• Difficult interpretation [51]

Positron emission tomography (PET)

PET provides functional and physiological information based on the detection of the position of radiotracer compounds in the patient's body. Because of this property, PET is effective in the following conditions: To guide the biopsies from suitable locations or to demonstrate areas of inter-ictal hypo-metabolism associated with epileptogenic foci. PET has the followings shortcomings:

• Low spatial and temporal resolution

• Relatively invasive technique-To perform PET, we have to use radioactively labeled tracers and for this reason, it is prohibited in some cases, such as children.

• Very expensive-PET imaging needs very expensive equipment of PET scanners and requires dedicated personnel and a cyclotron to generate radioactively labeled tracers.

• Susceptibility to signal distortion-PET is a hemodynamically based imaging study like fMRI and thus is susceptible to signal contortions from uncoupling issues.

• Low differentiation ability-PET cannot differentiate functionally essential areas from functionally supportive areas for task performance [40].

Diffusion tensor imaging (DTI)

• DTI is an advanced structural mapping technique and not a functional study. DTI data can clarify the location and trajectory of white matter tracts, and based on these data may help interpret functional brain areas. DTI is the only method that can show white matter tracts. DTI has the following technical limitations:

• Obscure visualization-Because of the 3D tractography implantation over all brain, a large mass of fibers is created which makes a faint visualization. Seeding from specific anatomical or functional landmarks aids in the selective visualization of tracts. One shortcoming of DTI is for tracts that are in proximity to a brain lesion. For these tracts, DTI has difficulty in differentiation between tracts that are inside the lesion and those that are beyond the lesion [52]. Fractional anisotropy of white matter is important in DTI and any factor which decreases the anisotropy, such as tumor infiltration or edema, distorts the presence of preserved tracts.

• DTI does not provide any information about the interactions between white bundle tracts and functional cortical regions.

• DTI does not recognize eloquent structures in the mapped white bundle tracts and cannot detect tracts that are obligatory for task execution.

Brain shifting

The most critical limitation of the use of preoperative brain mapping techniques is brain shifting. Brain shifting occurs following the dural opening, surgical manipulation, CSF drainage, edema, and effects of gravity and positioning. Brain shifting causes an anatomical disparity between the preoperative and the operative field images. With the progression of the surgery, this displacement increases, and after an hour of dural opening, an anatomical displacement greater than 10 mm can occur [53-58]. The solution for these shortcoming effects of brain shifting is intra-operative imaging and comparing them to the pre-operative functional images [40]. If available, intra-operative MRI will provide a significant advantage. However, fMRI is unlikely to be possible due to the degree of time and patient cooperation needed for fMRI [59, 60]. Intraoperative DTI can acquire and show displacements of about 1-1.5 cm [61].

Intra-operative mapping and imaging

To prevent postoperative neurological deficits in patients undergoing neurosurgical operations in the vicinity of or within the eloquent brain regions, preoperative functional neuroimaging of the brain is required [7-9]. Two major drawbacks of these methods are first, as mentioned above, brain shifting occurrence following craniotomy and dural opening with target registration errors up to 5 mm [10, 11], and secondly, most of the mentioned techniques have limited spatial resolution. To remove these drawbacks, we need intraoperative mapping and imaging. Intraoperative Optical Imaging (IOI) is a functional imaging technique and can overcome these drawbacks. By acquiring and evaluating camera images (with high temporal and spatial resolution) from the bare brain surface, the surgeon can observe changes in cortical optical properties. In IOI based on the inspection of metabolic changes, we can investigate cortical organization [21, 31, 41] and neuronal connectivity [41, 51, 59]. IOI is broadly used in the followings:

• For the visualization, recognition, and mapping of somatosensory areas [12, 20, 22, 42, 62] and visual cortex [32]

• To identify seizure focus [42, 50] and brain tumors [51, 60].

The use of IOI for decision-making during tumor removal is still not conclusively clarified, especially compared to fMRI and DCS [30, 52, 63]. In contrast to the electrode strips, IOI functional maps have high spatial resolution and can be easily semi-transparently visualized over the actual intra-operative field. In contrast to preoperative fMRI which needs registration accuracy, it is negligible for IOI shifting of the brain and the resultant loss of registration accuracy of the neuro-navigation system.

Appropriate pre-surgical mapping with suitable paradigm

For appropriate preoperative brain mapping, an appropriate paradigm must be selected and the followings are important for this selection:

• Clinical status of the patient [64]

• Position of the lesion

• Designed trajectory

• Functional structure of the cortex that participates in voluntary motor movements includes the primary motor cortex, the supplementary motor area, the primary somatosensory cortex, and the premotor area. In the primary motor and primary somatosensory cortex, a topographic map of each body region exists, such as the hand at the upper portion, the leg at the medial portion, and the tongue at the lateral portion. Therefore, by tapping the finger, the upper portion of the motor cortex is activated, and by wiggling the toe, the medial portion is activated and by moving the tongue, the lateral portion is activated, respectively and these are appropriate paradigm for preoperative motor mapping [65, 68].

• Reciprocal neural interconnectivity between the precentral and postcentral gyri due to this sensory paradigm that are more likely to favor the postcentral gyri can also activate the motor cortex [69-71].

Appropriate preoperative motor mapping techniques

• fMRI: As described above

• Functional connectivity Magnetic Resonance Imaging (fcMRI): fcMRI is a task-free technique that recognizes spontaneous synchronized changes in brain activation [72-74]. The advantages of this technique are first that in a short time (single 20 minute scanning session), we can evaluate multiple brain functions, and the second, the patients' compliance is not important (fcMRI is doable in cases under general anesthesia and even in human infants) [75].

• TMS: Disadvantages of TMS include low spatial resolution and can increase seizure risk in epileptic cases. TMS is the only non-invasive mapping technique that works based on direct brain stimulation or inhibition. With the incorporation of TMS into a frameless stereotactic navigational system, a correlation within 5 mm is observed between TMS and DCS [76] and in another study, a correlation within 1 cm is observed between TMS and DCS technique [77].

• DTI: DTI can be used as a preoperative mapping technique for the patient's motor system. Based on the DTI information, corticospinal tracts can be demonstrated, enabling the neurosurgeon to preserve displaced white bundle tracts. Based on the DTI information in low-grade gliomas, the neurosurgeon can detect and preserve functional white bundle tracts within the tumor lesion during tumor operation [78]. To illustrate motor cortical regions with associated descending tracts, we can combine DTI with fMRI [79-82].

Mapping of language

Localization of language regions and clarification of the dominant hemisphere or bilateral support for the language is called language mapping. For language mapping, we can use the following techniques:

• IAT: This technique is the gold standard to determine language and memory dominance. IAT has some significant complications [83]. In some patients due to crossflow of amobarbital in IAT to another hemisphere, it is difficult to definitively determine language dominance due to altered cerebrovascular flow [84].

• fMRI: Functional MRI has a concordance rate of about 90%-100% with IAT [85-91]. The reliability of fMRI for lateralization of language is similar to that of the IAT [92-94].

• DTI: To further clarify the anatomic and physiologic causes of asymmetrical language lateralization, we can combine fMRI with DTI. Based on this combination that is done in some studies, the structural asymmetry of white matter tracts in arcuate fasciculus can cause language lateralization. This asymmetry can be measured by DTI [95, 96].

• MEG: To map and lateralize the functional cortex for language reception, we can use MEG. MEG enables the neurosurgeon to tract the temporal course of language activation. The concordance rate between MEG and IAT is about 88%-93% [97, 98]. We can replace IAT with MEG because MEG has enough reliability to replace IAT [99, 100].

Localization of language

So far, there is no single standardized robust clinical fMRI language battery and no universal paradigm for planning the surgical removal of brain lesions near Broca's or Wernicke's areas. There are different paradigms for language mapping and localization, such as picture naming, etc. [100-105]. Following difficulties are present for language localization:

• Functional heterogeneity of peri-Sylvian language regions

• Brain lesions adjacent to the language cortex can cause possible lesion-induced plasticity, false negatives associated with edema or mass effect, or low performance due to language impairments.

• In fMRI, a relationship exists between the language-associated region of activation and the selected statistical threshold, as the statistical threshold decreases, the area of activation increases, and vice-versa.

• A relation is observed between the degree of activation and the baseline task. With a resting baseline task, more extensive activations will be seen whereas, with an increased level baseline task, a lower level of activation pattern is likely to be seen. For this purpose, an appropriate selection of active and control tasks in using fMRI as a language mapping technique is essential and needs great care and attention. Therefore, the validation of fMRI against DCS for language mapping has a lower sensitivity and specificity than motor-sensory brain mapping [100-105].

Considering brain mapping in specific diseases:

Gliomas

Gliomas warp normal brain anatomy and make pathological changes in brain vasculature. High-grade gliomas (HGG) distort the biochemical environment in the brain and induce neovascularization [106, 107]. Due to the reduction of perivascular cells, these newly formed vasculatures are not normal; they are weak, disorganized, and immature. Hence, this immature vasculature cause focal hemorrhage and fluid transudation leak and increase the oxygen availability to activated neural cells [108-111] thereby decreasing normal oxygen extraction levels of activated neural regions. Therefore, due to the two following changes, the formation of the blood-oxygen-level-dependent (BOLD) signal is decreased and BOLD signal distortion occurs; first, due to decreased normal oxygen extraction level of activated neural regions, a lower concentration of deoxyhemoglobin with resultant uncoupling effect exists and second, the mass effect of the rapidly growing tumor exists with the compression of surrounding vasculature. Due to this uncoupling phenomenon, the reliability of fMRI in High-Grade Gliomas (HGG) is prominently decreased and can be incorrectly interpreted as brain plasticity [112].

Brain mapping is particularly helpful for Low-Grade Gliomas (LGG). Due to the functional adaptation and cortical topographic reorganization that occurs in LGG with slow-growing character of this tumor, interpretation of unusual activation configurations is complex [113]. Two mapping techniques may be particularly helpful in LGG, including MEG in patients with LGG and refractory seizures by allowing both brain mapping and a seizure onset localization and DTI in patients with LGG with preserved tracts within the lesion. DTI can differentiate infiltration from displacement or destruction of tracts by the tumor. The lack of tract visualization can occur with tumor infiltration or edema [113].

Vascular malformations

fMRI is a reliable brain mapping tool in brain vascular malformations. The results of fMRI resemble intraoperative brain mapping techniques [114, 115]. For preoperative planning of surgical resection of cavernous hemangiomas, functional mapping is effective [79, 116]. In arteriovenous malformation (AVM), searching for the functional integrity of surrounding brain territories of AVM with fMRI has some limitations. The blood pressure in the arterial portion of the AVM is low and in the venous portion is high, therefore the feeding pressure of the artery is relatively lower than normal and the draining pressure of the draining vein is higher. Hence, brain territories surrounding AVMs have low cerebral perfusion pressure and disruption of the BOLD signal, resulting in the obscuration of activation in functionally active brain areas. Therefore, fMRI may incorrectly show functionally active brain areas as inactive. To minimize the risk of AVM operation and resection based on the fMRI, AVM is subcategorized, based on the distance between the AVM and the functional cortex as defined by fMRI [29]:

1. Low-risk group: functionally active brain regions are separated by at least one complete gyrus from AVM.

2. High-risk group: functionally active brain regions are profoundly associated with AVM.

3. Indeterminate risk group: functionally active brain regions and AVM are bordering each other.

4. In planning the resection of AVM in the low-risk group, the fMRI may be used alone. The second group is generally considered inoperable and is usually referred for radiotherapy. For the third group, direct electrocortical stimulation is performed (spatial distance of less than 1 cm between AVM and eloquent cortex) [29].

Epilepsy

The target of operation in epilepsy surgery is usually a region of brain tissue rather than a tumor or others, for this reason, preoperative functional brain mapping is essential. In epilepsy surgery, brain mapping can be used to select pre-surgical cases and procedure planning. To assess memory dominance and risk of postsurgical memory loss in temporal lobectomy and amygdalohippocampectomy, IAT and fMRI, including fcMRI can be used [117, 118]. We can use the IAT, fMRI, and MEG to lateralize and localize language. In cases with temporal lobe epilepsies compared to healthy subjects, more bilateral language activation exist in association with a higher incidence of activation in the homologous language areas of the contralateral hemisphere [119]. In the evaluation of epilepsy cases, it is essential to localize the seizure focus. For this localization, the following techniques can be used:

• MEG: MEG can help us to localize seizure focus by localizing interictal discharges. Although the correlation is still not perfect [120].

• Fluorodeoxyglucose (FDG): PET and Single-Photon Emission Computerized Tomography (SPECT)- FDG-PET can localize seizure focus by analyzing interictal metabolism and FDG-SPECT by analyzing ictal-interictal metabolism differences [121, 122].

• fMRI: fMRI can help us localize seizure focus. In cases with frequent interictal discharges, the combination of fMRI with EEG can localize the seizure focus. To lateralize medial temporal lobe epilepsies, we can do spike-triggered fMRI and by adding the spatial resolution of the MRI to the temporal resolution of EEG, we can localize seizure focus [123, 124].

5. Conclusion

Nowadays, numerous brain mapping techniques are available for neurosurgeons. With the combination of functional and anatomical results of these techniques, we can select appropriate patient and surgical planning. Currently, brain mapping techniques are more accessible and still evolving. All stages in obtaining a functional image are difficult and need knowledge of the underlying physiologic and imaging characteristics, and what is particularly important is the experience and knowledge of neurosurgeons to interpret these highly processed data of functional imaging techniques.

Ethical Considerations

Compliance with ethical guidelines

No human or animal subjects participated in this study.

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Authors' contributions

Conception and design: Guive Sharifi, Ali Kazeminezhad; Data analysis and interpretation: Guive Sharifi, Ali Kazeminezhad, Navid Kalani; Drafting the article: All authors;Critically revising the article: All authors; Reviewing submitted version of manuscript: Guive Sharifi, Ali Kazeminezhad and Navid Kalani; Approving the final version of the manuscript: All authors.

Conflict of interest

The authors declared no conflict of interest.

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