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EVOLUTION OF ROLE OF PRE-OPERATIVE MAGNETIC RESONANCE IMAGING IN PLANNING BRAIN TUMOUR SURGERIES: A SYSTEMATIC REVIEW

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Abstract:
Background: "The pre-operative MRI serves as a valuable diagnostic tool in surgical planning, helping to pinpoint and gain a precise understanding of the extent of lesions, especially in brain tumor surgeries. Inadequate tumor removal increases the likelihood of incomplete detection and recurrence. Therefore, we focus on the utility of "pre-operative MRI" for assessing the status of the posterior surface margin due to its visibility and flexibility in guiding surgical resection.
Methodology: This systematic review adheres to the PRISMA guidelines and includes a comprehensive search across prominent electronic databases. The current review included various types of studies, such as Analytical studies, and full-text literature. In our study, we included the studies provide information about the preoperative MRI for planning of brain tumor surgeries. In the current study, the assessment of bias risk was carried out using the recommended method.
Result: In this review, we incorporated a total of 12 studies on MRI findings. The total number of cases included in 12 studies was 3544, with an average age of 48.46 years. Out of the total studies, the majority show that the preoperative MRI helped to improve the accuracy of brain tumor diagnosis and guided surgical procedures to enhance patient outcomes.
Conclusion: We describe the MRI role in pre-surgical brain tumor; the data showed that it reduced the postsurgical morbidity, especially when combined with other advanced imaging methods like diffusion-tensor imaging, intra-operative MRI, or cortical stimulation.

Keywords: *Pre-operative MRI, functional MRI, Glioma, Menigioma.*

INTRODUCTION:

Magnetic resonance imaging (MRI) provides intricate and high-quality brain images without the need for invasive procedures, allowing for precise localization, characterization, and assessment of the tumor and its surrounding structures. The information obtained through pre-operative MRI is essential for the development of a comprehensive surgical strategy, facilitating improved patient outcomes and minimizing potential risks. [1] In recent times, there has been noteworthy discourse about the segmentation of brain tissues, which highlights its critical role in tumor classification, the monitoring of diverse tumor characteristics, and evaluating the effectiveness of treatment interventions. [2]

Magnetic field strength is sufficient to provide detailed images of the brain and its structures, aiding in the precise targeting and planning of brain tumor surgeries. [3] A brain tumor is the result of abnormal cell growth within the brain, which can disrupt brain function and damage healthy cells due to uncontrolled division. [4] The Indian Council of Medical Research (ICMR) recently published a report on brain tumors. This report sheds light on the number of new cases of brain tumors diagnosed in India, which are approximately 30,000 each year. [5]

Brain tumors are typically categorized as either benign (non-cancerous) or malignant (cancerous). Precisely determining the boundaries and types of brain tumors is crucial for treatment planning. [6, 7, 8] Meningioma, glioma, and pituitary cancer are common brain tumor types. [9] Meningioma arises from the brain and spinal cord membranes. Glioma originates in glial cells that support nerve cells. Aggressive glioma has a limited two-year inpatient survival rate when it infiltrates normal nerve cells. [10] Pituitary tumors belong to a category of growths that form within the pituitary gland, a small gland located at the base of the brain. This gland has a crucial function in regulating the endocrine system and controlling the secretion of a range of hormones throughout the body. [11, 12] The primary challenge is forecasting brain tumor lifespan using imaging data. Datasets employ segmentation, classification, and feature extraction. Notably, brain tumor biopsies are deferred until after surgery. [13, 14] Precise brain tumor mapping is vital for treatment decisions and assessing outcomes. Recent research focuses on automating this process, reducing the time and complexity of manual segmentation. [15] Contrast-enhanced MRI is the gold standard for brain tumor biopsy guidance, but it can yield ambiguous results. Distinguishing progressive tumors from radiation-induced injuries remains challenging. [16] Also, noninvasive brain mapping tools like preoperative functional MRI (fMRI) have become standard practice, assisting in treatment decisions for patients with brain tumors. [17, 18]

Pre-operative MRI is an indispensable component of the modern neurosurgical approach to brain tumor management. Its ability to offer detailed diagnostic information, guide surgical planning, preserve neurological function, and minimize surgical risks makes it an essential tool in the quest for successful outcomes in brain tumor surgeries. Some of the previous studies showed the contradictory results. Therefore, this systematic review aims to investigate the role of pre-operative MRI in planning brain tumor surgeries.

METHODOLOGY:

Protocol:

The protocol of this review was developed in accordance with the guidelines outlined in the Preferred Reporting Items for Systematic Review (PRISMA-P) statement and all changes were properly noted.

Search strategy:

The literature search was conducted through searches in the following database: PubMed, Scopus, Web of Science, Wiley, Google Scholar, Embase, MEDLINE, and Science Direct.

The study encompassed a thorough examination of full-text articles and literature reviews that had been published. We searched for Medical Subject Headings (MeSH) terms and free text terms, full-text articles, case studies, and case series related to preoperative MRI findings of brain tumors, neuroimaging, fMRI, brain oncology, glioblastoma diagnostic imaging, and the use of MRI in planning brain tumor surgeries.

Appropriate Boolean operators were applied, and the materials available in the English language were used. Literature lacking full-text access and studies that could not be located in the specific original datasets was excluded from the current review.

Inclusion criteria:

1. The study in which MRI-based findings of brain tumors were included in this review
2. The complete text of the article was available.
3. Literature in the English language

Exclusion criteria:

1. Abstracts of conferences
2. Copyrights and duplicate articles
3. Articles reporting on brain tumor discoveries that did not include MRI-based findings were not considered.

Table 1: All the studies showing Preoperative MRI findings in brain tumor

Sr. No.	Author Name / Year	Study Design	Sample size	Mean Age of Patients	MRI based findings of brain tumor	Conclusion
01	Trinh VT. et al.(2014)[19]	-	N= 214	±44	fMRI was highly specific in motor areas (100%) but less in Broca's (64%) and Wernicke's (18%) areas. New intraoperative deficits predicted worse outcomes. Using fMRI didn't significantly reduce post-surgery deficits.	FMRI is like Direct cortical stimulation (DCS) for motor area tumors, but less effective for speech areas. Routine fMRI use doesn't significantly prevent new neurological deficits, and further studies will be needed.
02	Nadkarni TN. et al. (2014)[20]	A retrospective study	N=92	±45	-	To improve surgical planning and reduce the risk of post-operative language deficits, the identification of critical functional regions and the calculation of language lateralization indices (LIs) should be customized for each subject by employing a variety of threshold values and diverse tasks.
03	Morrison MA. et al. (2016)[21]	-	N=18	43.2 ± 13.7	FMRI reliability was lower in high-grade tumor patients than in controls or low-grade tumor patients. Motor tasks showed better reliability than language tasks, especially in rhymed vs. phonemic fluency.	Low-grade glioma patients show fMRI data reliability similar to healthy controls. High-grade glioma patients need more study for reliability issues. Careful paradigm selection enhances reliability.
04	Yan PF. et al.(2016)[22]	–	N=762	45.9 ± 14.6	MRI reports for 762 brain tumor patients showed varying diagnostic accuracy by tumor type. Sensitivity and positive predicted value (PPV) ranged from 72.0-90.7% and 91.9-95.4%, respectively.	Conventional MRI is generally sufficient for diagnosing most intracranial tumors; it's advisable not to depend solely on it, especially for specific tumor types. In cases of uncertainty, neurosurgeons should collaborate with neuroradiologists to ensure accurate preoperative diagnoses.
05	Giancarlo D'Andrea et al. (2017)[23]	Prospective study	N=142	59.1	Intraoperative Diffusion tensor imaging (DTI) revealed bundle position shifts of up to +6mm outward and -2mm inward in all patients.	They found strong agreement between fMRI/DTI and intraoperative mapping. Combining them enhances sensitivity, reduces errors, and advances "functional neuronavigation," defining eloquent areas and shortening surgery time.
06	Kosteniuk SE. et al. (2017)[24]	A retrospective study	N=12	38 ± 11	Patients who had fMRI scans tended to exhibit smaller preoperative lesions, measuring 44.4 - 24.5 cm3, as opposed to 72.2 - 37.7 cm3 in the control group. However, this difference did not reach statistical significance (P = 0.1668).	No major differences in outcomes, but trends fMRI patients received more aggressive surgeries and had greater postoperative functional improvement.
07	Yan PF. et	A	N=131	52.89 ± 9.00	Texture and shape analysis	The combination of texture and

	al.(2017)[25]	prospective study			identified six significant features, and the SVM classifier achieved the best performance, with an AUC of 0.87.	shape analysis, particularly when integrated with an SVM classifier, demonstrates promising performance in predicting the grade of meningiomas before surgery. This approach holds potential for practical clinical applications.
08	Gunal V. et al.(2018)[26]	A prospective study	N=23	38.9 ±11.9	All patients had routine brain CT and MRI scans. Most had intra-axial tumors; one had an extra-axial tumor. Intra-axial tumors were in the insula or around the inferior frontal gyrus IFG.	Preoperative fMRI is valuable for surgery near language areas, revealing potential functional reorganization due to brain lesions. Plasticity likely starts early, persists through treatment. Postoperative fMRI studies are needed for a full understanding.
09	Vysotski S. et al.(2018)[27]	-	N=206 No-FMRI (n = 127) FMRI (n = 79)	No-FMRI 57.7 FMRI 45.8	The fMRI group had a 3-year survival rate twice that of the group without fMRI, and high-grade tumor patients, in particular, showed significant improvements, especially in their motor and language outcomes.	This study found that using fMRI in preoperative planning for brain tumor patients led to better outcomes, reducing mortality and morbidity. It emphasizes the importance of including fMRI in clinical management.
10	Arita K. et al. (2020)[28]	-	N=1061	55.8 ± 18.7	Initial diagnosis had 75.8% sensitivity, varying by tumor type. Multiple opinions improved it to 86.3%. Overall, PPV was 76.9%, but in 3.4% of cases, all three diagnoses were incorrect.	In this study the sensitivity is 75% and PPV for preoperative brain tumor diagnosis, increasing to 85% with multiple opinions. This is the improved value and should consider for the surgical planning.
11	Rijnen S. et al.(2020)[29]	-	N=208	+18	In this study, they found lower cognitive performance before and after surgery compared to healthy controls.	This study identifies pre-surgery risk factors for cognitive issues, enabling early awareness and management for GBM patients, emphasizing cognitive care in clinical practice.
12	Jiang J et al (2023)[30]	A retrospective Study	N= 675	Brain invasion 49.9 ± 14.4 Brain invasion 51.2 ± 13.0	Univariate and multivariable analyses revealed significant factors for diagnosing meningioma WHO grades and predicting brain invasion. The tumor-brain interface is particularly effective, with high AUCs (0.779 and 0.860) for assessing WHO grade and brain invasion. When combined, these factors improve diagnostic accuracy (AUCs of 0.834 and 0.935) for both.	Preoperative MRI is highly effective in determining the WHO grade and brain invasion of meningiomas, with the tumor-brain interface being a critical factor. These MRI features can aid in predicting WHO grade and brain invasion, leading to better outcomes for patients by enabling complete tumor removal.

RESULTS:

In this systematic review, the initial search resulted in 1,125 articles. 10 extra records were obtained through the cross referencing. 669 copies were excluded because of duplication. After analyzing all available databases 158 articles were excluded because of some missing parameters in articles. The articles which are incomplete and irrelevant with present study are also excluded. 56 full articles were assessed for the study. After performing complete screening, Non-published works have also been excluded from the present review. After a thorough analysis of all available data, a total of 12 studies adhered to the inclusion criteria and were chosen. Our analysis includes 12 studies, 3 retrospective studies and, and 3 prospective study.

Quality evaluation of the included studies: In this present review, using the RevMan software, we evaluated the risk of bias for randomized control trials using the Cochrane associated tool. The domains for risk assessment were categorized with either a high, indeterminate, or low risk based on criteria such as selection bias (random sequence generation), performance bias (blinding of patients and personnel), attrition bias (incomplete outcome data), selective reporting (reporting bias), and other potential biases. Individual studies were then categorized as having low, unclear, or high risk according to these domains and criteria. In Fig.2, we show the risk of bias assessment for the 12 studies included. Blinding of outcome assessors was low 53.33% of the trials and there was an unclear risk in 46.67%, % of trials. (Fig 3)

MRI based findings of included study:

The studies incorporated into this review demonstrated the reliability of various preoperative MRI features in the diagnosis of brain tumors. Additionally, these features aided in lesion removal, guided specimen sampling, enhanced the precision of diagnosing brain invasion, and ultimately improved patient prognosis. [21-27]

According to the study conducted by the **Trinth et al. [19]** showed the some varied results as in 40% of cases, fMRI aided eloquent cortex localization. In the other 129 cases, fMRI wasn't helpful due to noise. fMRI had varying success rates compared to DCS. A new deficit during dissection predicted worse outcomes ($p < 0.001$). The utilization of fMRI during surgery did not lead to a significant prevention of worsened neurological deficits immediately after the operation ($p = 1.00$) or at the 3-month follow-up ($p = 0.42$).

Nadkarni TN. et al. [20] found that, Patients with brain tumors showed left-lateralization in antonym-word generation and text-reading tasks at increased thresholds, while they displayed bilateral activation during letter-word generation. Patients with vascular lesions similarly demonstrated left-lateralization, particularly during antonym and letter-word generation, especially at higher thresholds. This data provided the most precise insights for surgical planning aimed at reducing post-operative language deficits. The study done by **D'Andrea G. et al. [23]** in every instance reported that, the incorporation of tractographic information into the volumetric dataset for neuronavigation proved to be technically feasible. During surgery in every patients, intraoperative DTI revealed a displacement of the bundle's location due to the surgical procedure, with shifts occurring in both outward and inward directions within the range of +6 mm and -2 mm. DTI and fMRI shows high concordance and increasing the definition of eloquent areas and also reducing the time of surgery.

In addition, other study done by **Vysotski S.et al. [27]** in their study, they compared the no-fMRI group with the fMRI and the combination of fMRI and Electrical Cortical Stimulation Mapping (ECM) group, and had better outcomes and survival rates. In the multivariate analysis, age and tumor grade were identified as key factors. The fMRI group had a 3-year survival advantage, especially for high-grade tumors. Low-grade tumors in the fMRI group didn't show the same benefit when considering age and ECM. There were also major differences in morbidity, with the fMRI group showing better outcomes in motor and language domains. These findings underscore the significance of integrating fMRI into preoperative planning for the clinical care of individuals with brain tumors.

Arita k. et al. [28] the results they found that, the initial diagnosis had an overall sensitivity of 75.8%. Sensitivity was highest for hypothalamic-pituitary and extra-axial tumors (84-94%), moderate for intra-axial tumors (67-75%), and lower for intraventricular and pineal region tumors (29-42%). It was high for brain metastasis, lymphoma, and glioblastoma (83.8%, 81.4%, and 73.1%), but lower for other gliomas. When including additional diagnoses, sensitivity increased to 86.3% with a 76.9% positive predictive value. In 3.4% of instances, all three preoperative diagnoses proved to be inaccurate, even with broader tumor classifications. **Rijnen** S**. et al.[29]** was identified preoperative cognitive risk factors for post-surgery cognitive impairment in GBM patients, enabling early intervention and emphasizing the importance of addressing cognitive function in clinical management. **Jiang J. et al. [30]** Univariate and multivariable analyses identified distinct Characteristics used in the diagnosis of WHO grades and predicting brain invasion in meningiomasCritical factors used for diagnosing WHO grades included the presence of the lobulated sign, characteristics of the tumor-brain interface, the appearance of finger-like protrusions, the presence of a mushroom sign, and the occurrence of bone invasion. Additionally, the prediction of brain invasion depended on factors such as tumor size and ADC value. The tumor-brain interface was the most notable feature, with AUCs of 0.779 in WHO grade diagnosis and 0.860 in predicting brain invasion. When these variables were combined, they collectively yielded AUCs of 0.834 for WHO grade and 0.935 for brain invasion.

Fig1: A flowchart illustrates a systematic review that involved databases and registered searches. (PRISMA)

Registering studies to identify them Registers and databases

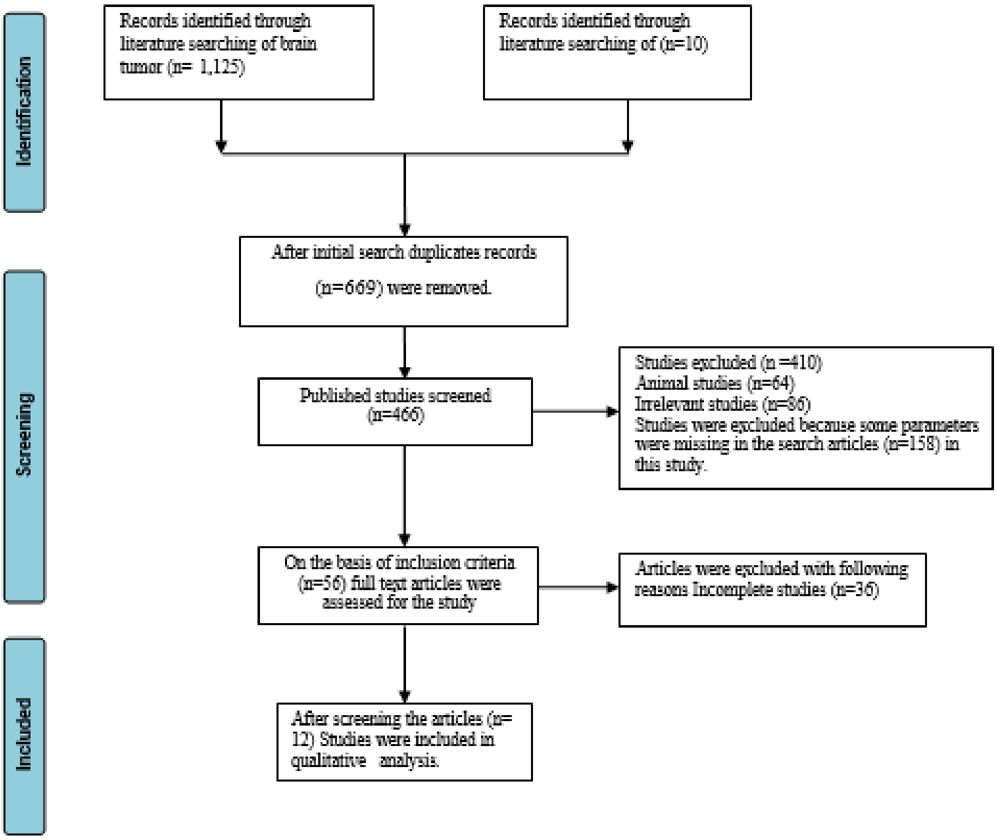

Fig 2: Risk of bias graph: Percentages demonstrating review authors' evaluation of each risk of bias item across all collected literatures.

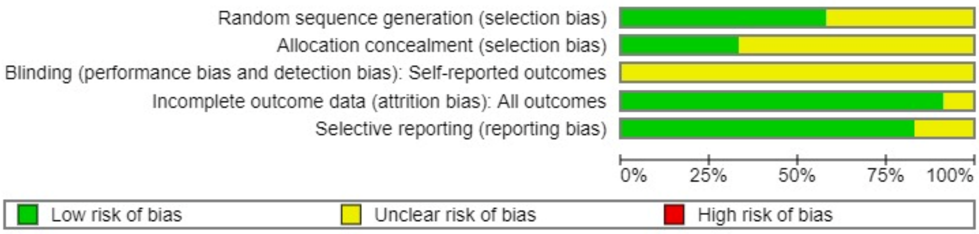

Fig 3: An illustration of the risk of bias graph showing the review authors' assumptions for each risk of bias item for each included study.

DISCUSSION:

Surgical resection of brain tumors located in critical cortical areas associated with important brain functions remains a complex and demanding procedure. [31, 32]

Previous research had documented significant variability in both sensitivity and specificity, as per studies, the divergent findings among different studies restrict the level of confidence in the technique's reliability and clinical applicability.

In most of the studies included in this review, fMRI was used as a diagnostic tool. In high-grade glioma cases with preoperative functional imaging, the survival rate was increased this survival rate matches or surpasses some brain tumor treatments. Current therapy for supratentorial gliomas typically entails surgery, followed by radiotherapy and chemotherapy.

According to the studies included in this review, pre-operative MRI in brain tumor surgeries shows significant results as it lowers the post-operative morbidity and sometimes reduces the surgical timing. It’s not always enough, especially for some specific tumor types.

The study conducted by **Haberg, asta et al**. showed, Most primary brain tumor patients were able to successfully complete fMRI tasks, and the data gathered played a crucial role in preoperative preparations. A distance of 10 mm or greater between the functionally active brain regions identified through fMRI and the tumor substantially lowered the likelihood of postoperative functional impairment. [33]

Precise understanding of how a glioma interacts with nearby essential cortical regions is crucial to enhance tumor removal, reduce the risk of postoperative neurological issues, and ensure patient safety. For over a decade, functional MRI has been used before surgery to locate and map these vital cortical networks in patients with intracranial gliomas. [34] Functional MRI is a highly reliable approach for preoperative sensory-motor mapping. However, when it comes to language mapping, DCS remains essential for precise localization. [35]

Preoperative fMRI before brain tumor surgery is a valid and reasonably sensitive method for accurately identifying distinct body representations in the primary motor and somatosensory cortex. This also holds true for language localization and lateralization. In this context, fMRI has the potential to decrease the requirement for invasive diagnostic procedures and direct their focused utilization.[36] in another study conducted by **Watanabe Y. et al.[37]** they showed; Meningioma ADC values had an inverse relationship with histological grade. Among various factors, only ADCMIN at b = 4000 showed a significant independent correlation with meningioma histological grade, while factors like tumor shape were not significant. In another study conducted by **F. Prada et al**. [**38]** combining intraoperative ultrasound with preoperative MRI for neuro-navigation is a dependable, precise, and user-friendly approach. It aids in correcting brain shift and tissue distortion, providing real-time guidance during surgery, while being cost-effective and efficient compared to alternative intraoperative imaging methods, ensuring high precision and orientation.

Celine amiez et al [39] in their study, author used preoperative fMRI in conjunction with intra-operative assessment of higher-order cognitive functions, which can prove valuable in surgical planning for patients with lesions near the premotor cortex (PMdr). They involved four patients with brain tumors, and the fMRI data provided precise localization and delineation of the functional premotor brain region around the tumors in the four patients, which helped in the planning of surgery.

CONCLUSION:

Various preoperative MRI characteristics provide dependable diagnostic information for determining the type of brain tumor and forecasting brain invasion. A less distinct tumor-brain interface on preoperative MRI is indicative of a higher WHO grade for meningiomas and an increased probability of brain invasion. This, in turn, assists in achieving complete lesion removal, guiding specimen sampling, enhancing the precision of diagnosing brain invasion pathologically, and helpful for improving patients outcomes. These findings emphasize the significance of integrating MRI into preoperative planning in the clinical care of patients with brain tumors.

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