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Review Article

Intraoperative use of low-field magnetic resonance imaging for brain tumors: A systematic review

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ABSTRACT

Background: Low-field magnetic resonance imaging (LF-MRI) has become a valuable tool in the diagnosis of brain tumors due to its high spatial resolution and ability to acquire images in a short amount of time. However, the use of LF-MRI for intraoperative imaging during brain tumor surgeries has not been extensively studied. The aim of this systematic review is to investigate the impact of low-field intraoperative magnetic resonance imaging (LF-IMRI) on the duration of brain tumor surgery and the extent of tumor resection.

Methods: A comprehensive literature search was conducted using PubMed, Scopus, and Google Scholar from February 2000 to December 2022. The studies were selected based on the inclusion criteria and reviewed independently by two reviewers. The gathered information was organized and analyzed using Excel.

Results: Our review of 21 articles found that low-field intraoperative MRI (LF-IMRI) with a field below 0.3T was used in most of the studies, specifically 15 studies used 0.15T LF-IMRI. The T1-weighted sequence was the most frequently reported, and the average scanning time was 24.26 min. The majority of the studies reported a positive impact of LF-IMRI on the extent of tumor resection, with an increase ranging from 11% to 52.5%. Notably, there were no studies describing the use of ultra-low-field (ULF) intraoperative MRI.

Conclusion: The results of this systematic review will aid neurosurgeons and neuroradiologists in making informed decisions about the use of LF-MRI in brain tumor surgeries. Further, research is needed to fully understand the impact of LF-MRI in brain tumor surgeries and to optimize its use in the clinical setting. There is an opportunity to study the utility of ULF-MRI in brain tumor surgeries.

Keywords: Brain tumors, Intraoperative, Low-field magnetic resonance imaging, Neuroimaging

INTRODUCTION

Magnetic resonance imaging (MRI) is a well-established noninvasive imaging technique that offers three-dimensional body images.[17] Its exceptional soft-tissue visualization and ability to distinguish tumors from surrounding normal tissue without radiation exposure have made it a cornerstone in oncology for diagnosis and treatment planning.[34] This reputation

has been earned over years of effective utilization by oncologists.[34]

Technological advancements led to the development of the first MRI machine designed for intraoperative MRI (IMRI) in 1991.[2] In the realm of neuro-oncology, the use of IMRI represents a critical breakthrough. This advanced technology provides an unparalleled level of accuracy in assessing surgical performance and enables real-time monitoring of dynamic intraoperative changes. These include the complex shifts in brain anatomy that can occur during the procedure.[4,13,23] Such phenomena result from a complex interplay of variables, such as changes in intracranial pressure, gravity, head positioning, and brain edema. By capturing the intricate interplay between surgical maneuvers and the brain's responses, IMRI provides the attending surgeon with invaluable insights into the intricate interaction between their actions and the brain's response. Multiple studies in the medical literature have reported a better extent of resection (EOR) in brain tumors due to visualization of residual disease through IMRI, hence, improving survival.[10,11,25] Moreover, the use of IMRI can also reduce surgical complications and postoperative neurological deficits.[23]

Broadly, the MRI can be classified as low-field MRI (LF-MRI) and high-field MRI (HF-MRI). At present, there is no consensus on the cutoff value of field strength to define the two varieties. However, generally, a field strength of 0.5T or less is considered LF-MRI, and a field strength of 1.5T or above is considered. HF-MRI.[24] In addition, ultra-low-field MRI (ULF-MRI) scanners have been defined with a field strength of <1 mT and typically use a standard AC power outlet. Furthermore, these are low-cost to build and operate.[15]

HF-MRI offers increased image resolution, field of view, and contrast visibility compared to low-field magnetic resonance imaging (LF-MRI). In addition, HF-MRI takes less time to produce the scans.[1] Nevertheless, LF-MRI offers less risk of device interactions, heating, and risk of metallic projectiles and noise, all at a lower cost and power consumption than HF-MRI.[1] These benefits are, further, enhanced with the use of ULF-MRI. LF-MRI and ULF-MRI having a lower cost of production, installation, and maintenance, in addition to lesser power need than HF-MRI, makes them a far more feasible option for low- and middle-income countries (LMICs) with an additional benefit of ultimately resulting in a smaller carbon footprint.[1]

Numerous studies have consistently demonstrated that incorporating LF-IMRI technology into surgeries for cerebral neoplasms yields remarkable benefits. LF-IMRI's capacity to provide enhanced visualization of residual disease, guide more extensive resections, and ultimately lead to improved patient survival has been well-documented. By offering real-time insights into tumor extent and enabling surgeons to make informed decisions during surgery, LF-IMRI optimizes the precision and completeness of resection. This dynamic approach has been shown to directly correlate with improved long-term outcomes, as the technology empowers surgeons to address residual disease promptly. Consequently, LF-IMRI emerges as a transformative tool with the potential to reshape the landscape of cerebral neoplastic surgeries, offering enhanced patient care, and potentially changing the course of treatment and prognosis.[26]

Despite such compelling results for the use of LF-IMRI in cerebral tumors, there is little information on whether the use of LF-IMRI helps to increase EOR and achievement of gross total resection (GTR); in addition to the effect of LF-IMRI on surgical time. Hence, this systematic review was conducted to evaluate and analyze the outcomes mentioned above for using LF-IMRI for brain tumors.

MATERIALS AND METHODS

This systematic review was conducted according to the guidelines in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement.[19,20] The study's protocol was uploaded on the PROSPERO International Prospective Register of Systematic Reviews (registration number—CRD42023391879)

Search strategy

The medical literature was thoroughly searched from February 2000 to December 2022 by exploring the following electronic databases: PubMed, Scopus, and Google Scholar. The search strategy for all databases was developed using the keywords "magnetic resonance imaging" OR "MRI" OR "Low-field MRI," AND "brain tumor," OR "brain malignancy." To guarantee that all pertinent research was included, reference lists of screened articles were also carefully examined. The complete search strategy utilized can be found in the supporting document.

Study selection

The study design selection process was comprehensive, involving the evaluation of various study designs for potential inclusion in the analysis. The literature search included studies that presented: (1) human subjects of all ages, (2) neurosurgical procedures for intracranial brain tumors, (3) the use of intraoperative LF-MRI, and (4) studies reporting outcomes regarding tumor assessment, the EOR, or survival of the patient in regard to the use of LF-IMRI. Studies were only included if the inclusion mentioned above criteria were met. Review articles, case reports, case series (n < 11), book chapters, guidelines, commentary, letters to the editors, and studies on animals were excluded from the study.

Data extraction

During the extraction process, the author's names, date of publication, country of origin, sample size, histopathological diagnosis, radiological diagnosis, mean follow-up, additional imaging modalities, MRI field strength (Tesla), sequences utilized, scan frequency, Karnofsky performance status score, the EOR, that is GTR or subtotal resection (STR), operation time, and length of stay. A risk-of-bias assessment was performed using the Newcastle-Ottawa Scale to determine the bias associated with observational studies[29] and a Cochrane risk-of-bias tool for randomized trials (RoB 2.0) for randomized clinical trials.[30]

Data analysis

The data were extracted and organized in a tabular format on Microsoft Excel to facilitate clear representation and comprehension.

RESULTS

Our systematic review process screened 525 articles and, after evaluating the titles, abstracts, and full text, 21 of them were selected for inclusion in the final analysis.[3,6,7,12-14,16,18,21-23,25-28,32,33,35,36,38,39] The articles were screened and quality assessed independently by JM and AB, and any discrepancies were resolved by AA. The screening process and quality assessment procedure are thoroughly delineated in Figure 1 of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flowchart, and Tables 1a and b, respectively.

The majority of the studies were retrospective cohort studies (50%), followed by prospective cohort studies (33.3%) and one randomized controlled trial. The average number of participants in all of the studies was 54, with sample sizes ranging from 11 to 229. In addition, the mean age of the participants was 46.7 years, with a range between 29 and 59 years. A significant proportion of the included studies

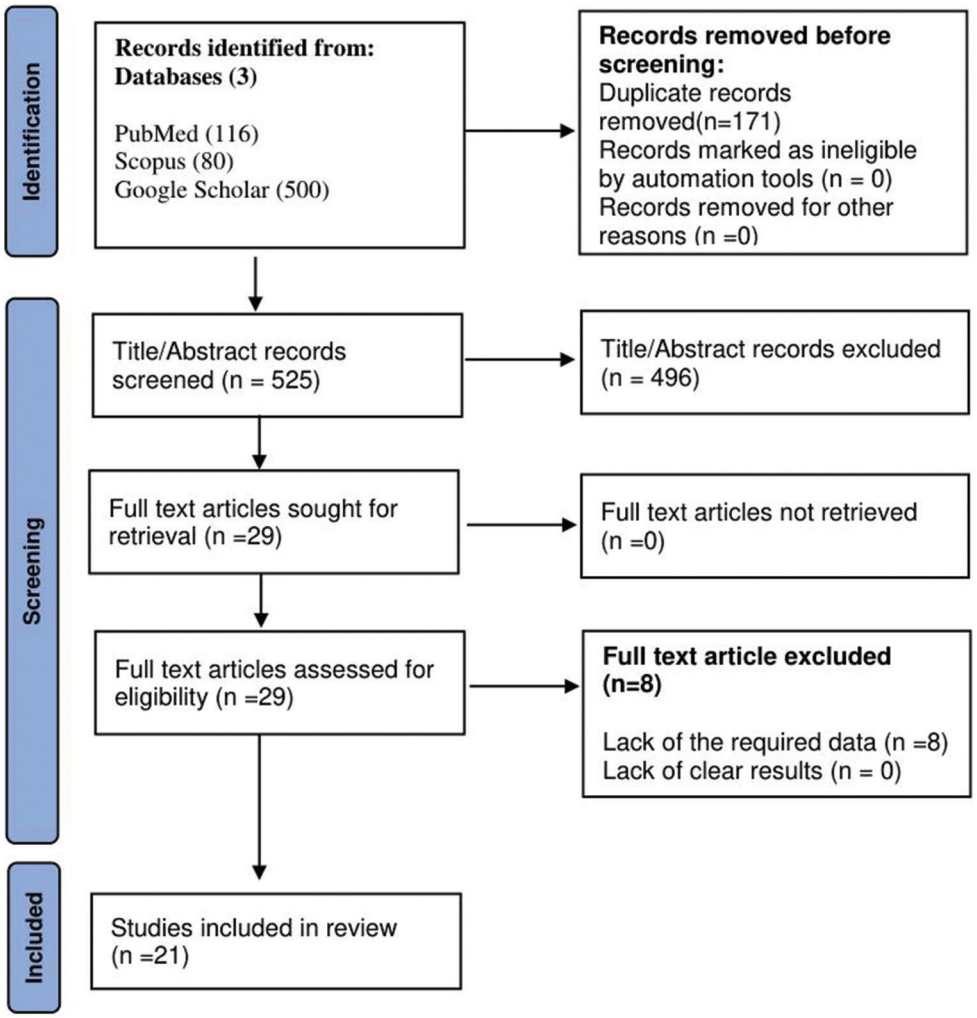

Figure 1: Preferred reporting items for systematic reviews and meta-analyses flow diagram. Number (n).

Table 1a: Newcastle-Ottawa scale quality assessment.

Study	Selection (4)	Comparability (2)	Outcome (3)	Overall star rating (9)
Wu *et al.* 2009[36]	☆☆☆☆	☆☆	☆☆	8
Kim *et al.* 2013[13]	☆☆☆	☆☆	☆☆	7
Makary *et al.* 2011[18]	☆☆☆☆	☆	☆	6
White *et al.* 2018[35]	☆☆☆☆	☆	☆	6
García *et al.* 2017[8]	☆☆☆	☆☆	☆☆	7
Bohinski *et al.* 2001[3]	☆☆☆	☆	☆☆	6
Nimsky *et al.* 2003[21]	☆☆☆☆	☆☆	☆	7
Kırış and Arıca 2011[14]	☆☆☆	☆	☆☆☆	7
Hlavica *et al.* 2013[12]	☆☆☆	☆☆	☆☆☆	8
Thiabpha and Hansasuta 2016[32]	☆☆☆	☆	☆	5
Livne *et al.* 2014[16]	☆☆☆☆	☆☆	☆☆	8
Senft *et al.* 2010[26]	☆☆☆	☆☆	☆☆	7
Nimsky *et al.* 2003[22]	☆☆☆	☆	☆☆☆	7
Senft *et al.* 2008[27]	☆☆☆	☆☆	☆☆☆	8
Zimmermann *et al.* 2001[39]	☆☆☆	☆	☆☆	6
Zimmermann *et al.* 2000[38]	☆☆☆	☆	☆☆	6
Czyż *et al.* 2011[7]	☆☆☆	☆☆	☆☆	7
Buchfelder *et al.* 2002[6]	☆☆☆	☆☆	☆☆☆	8
Senft *et al.* 2010[28]	☆☆☆	☆☆	☆☆	7
Ungar *et al.* 2021[33]	☆☆☆	☆☆	☆☆	7

☆: 1 point, ☆☆: 2 points, ☆☆☆: 3 points, ☆☆☆☆: 4 points

Table 1b: Cochrane risk-of-bias tool for randomized trials (RoB 2.0).

Study	Outcome	D1	D2	D3	D4	D5	Overall
Senft *et al.* 2011[25]	EOR	+	+	+	+	+	+

+: Low risk. D1: Randomization process, D2: Deviations from the intended interventions, D3: Missing outcome data, D4: Measurement of the outcome, D5: Selection of the reported result, EOR: Extent of resection

used the Polestar N20 with 0.15 tesla, while two of the studies utilized the superconducting MR system SIGNA SP 0.5T IMRI, as shown in Table 2.

Gadolinium-based contrast was used in 12 of the studies to enhance image quality, while one study used a ferromagnetic contrast agent, and the others did not specify any contrast agent used. Neuronavigation was used as an adjunct imaging technology in 13 of the studies to assist the procedure in which LF-IMRI was used, while awake mapping was used in one study, and motor and sensory-evoked potential was used in two of the studies as adjunct technologies. In 20 studies that provided information on the sequences used in the analysis, T1-weighted sequences were commonly utilized. In addition, T2 and fluid-attenuated inversion recovery sequences were used in eight and five studies, respectively, alongside the T1 sequence. Thirteen studies mentioned the average scanning time for the LF-IMRI in the operating room. The average time for all the studies was 24.26 ± 18.6 standard deviation (SD) min, as shown in Table 3.

In our review, it was observed that 17 of the studies investigated the effect of LF-IMRI on tumor resection. All of these 17 studies reported a favorable impact, with the percentage increase in tumor resection ranging from 11% to 52.5%. Table 4 shows, LF-IMRI resulted in increased resection in all of the studies that assessed this outcome.

DISCUSSION

This systematic review was conducted to enhance the understanding of the role and extent of aid LF-IMRI can offer neurosurgeons operating on brain tumors. The prevalent pattern noted in the studies under our review indicates that patients who underwent brain tumor surgery with the support of a low-field IMRI device, which is an economical imaging technology, exhibited increased rates of complete tumor resection, reduced complications, and improved progression-free survival. However, it is important to note that this came at the expense of a longer surgical duration.

Table 2: General characteristics of the included studies.

Study name	Study design	Cohort size	Age in years (mean)	Gender (M/F)	LF-IMRI machine	Tesla (T)
Wu *et al*. 2009[36]	Prospective cohort	55	46	36/19	Polestar N20	0.15-T
Kim *et al*. 2013[13]	Retrospective cohort	229	46	121/108	Polestar N20	0.15-T
Makary *et al*. 2011[18]	Retrospective nonrandomized, controlled, cohort study	65	49	39/26	Polestar N20	0.15-T
White *et al*. 2018[35]	Prospective cohort	36	46	20/16	Polestar N10	0.12-T and 0.15-T
García *et al*. 2017[8]	Prospective cohort	30	55	17/13	Polestar N30	0.15-T
Bohinski *et al*. 2001[3]	Retrospective cohort	40	44	25/15	Hitachi AIRIS II	0.3-T
Nimsky *et al*. 2003[21]	Retrospective cohort	106	40	63/43	*MO-MR Scanner	0.2-T
Kırış and Arıca 2011[14]	Retrospective cohort	11	53	6/5	NR	NR
Hlavica *et al*. 2013[12]	Retrospective cohort	104	59	57/47	Polestar N20	0.15-T
Thiabpha and Hansasuta 2016[32]	Prospective cohort	11	41	5/6	Polestar N30	0.15-T
Livne *et al*. 2014[16]	Retrospective cohort	163	43	83/80	Polestar N-10, 20, and 30	0.15T-0.12T
Senft *et al*. 2010[26]	Prospective cohort	204	59	115/89	Polestar N20	0.15-T
Senft *et al*. 2011[25]	Randomized controlled trial	24	55	16/8	Polestar N20	0.15-T
Nimsky *et al*. 2003[22]	Case–control	20	29	10/10	*MO-MR scanner	0.2-T
Senft *et al*. 2008[27]	Retrospective cohort	103	48	NR	Polestar N20	0.15-T
Zimmermann *et al*. 2001[39]	Retrospective cohort	32	47	15/17	S-MR-SSSP*	0.5-T
Zimmermann *et al*. 2000[38]	Retrospective cohort	44	44	24/20	S-MR-SSSP*	0.5-T
Czyż *et al*. 2011[7]	Prospective cohort	58	54	24/34	Polestar N20	0.15-T
Buchfelder *et al*. 2002[6]	Prospective cohort	29	33	18/11	*MO-MR Scanner	0.2-T
Senft *et al*. 2010[28]	Prospective observational	63	46	36/27	Polestar N20	0.15-T
Ungar *et al*. 2021[33]	Retrospective cohort	73	37	60/13	Polestar N30	0.15-T

NR: Not Reported, M/F: Male/Female, *MO-MR Scanner: Magnetom Open MR Scanner, S-MR-SSSP*: Superconducting MR system SIGNA SP, LF-IMRI: Low-field intraoperative MRI

Our review revealed that the use of low-field IMRI has been associated with a significant increase in the number of patients who achieved GTR of brain tumors. Attaining GTR is of paramount importance, as it has been shown to be associated with prolonged survival in various brain tumor types. A meta-analysis conducted by Brown *et al*. reported that patients who underwent GTR had better 1-year and 2-year survival rates compared to those who had STR. In addition, patients who achieved GTR had a lower likelihood of disease progression within 6 months.[5] Another meta-analysis by Xia *et al*. demonstrated that patients who underwent GTR had better 5-year and 10-year survival rates compared to those who had STR.[37]

While aiming for GTR, preservation of neurological function postsurgery is crucial. Maximal preservation of neurological function is not only essential to preserve a good quality of life but is also associated with better survival.[9] There were multiple patients in our patient pool where GTR was planned, and the LF-IMRI showed residual tumors; however, the surgeons did not choose to resect further due to the tumor being in very close proximity to the brain's eloquent areas to avoid neurological deficit postsurgery. Nevertheless, multiple studies that employed the use of IMRI and resected additional tissue with the help of IMRI did not report a higher percentage of neurological deficit compared to patients in which IMRI was not utilized.[25,31]

One setback of performing surgeries with LF-IMRI is the additional surgical time taken. The time taken for the scan ranged from 7 min to 72 min, with a mean and standard deviation of 24.26 ± 18.6 SD min. Furthermore, the additional time taken to complete the surgery ranged from 30 min to 250 min in our study. This leads to prolonged surgeries and additional time in surgical suits, leading to a higher operative cost.[31] Better EOR coming at a higher cost puts emphasis on the need for further prospective research with long-term follow-ups, which can help clarify if the increased EOR, specifically through the use of LF-IMRI, improves survival and other outcomes including but not limited to disease progression and *de novo* postsurgical neurological deficits. This can significantly help us understand how cost-effective mass installation of LF-MRIs will be.

Limitations

There are some limitations to this review, which should be considered when interpreting the results. The included studies

Table 3: Impact of LF-IoMRI on surgery duration.

Study name	LF-IMR (Tesla)	Contrast agent (dose)	Use of adjunct imaging technology	MRI sequences	Scanning time (min)	Extra OR time (hr/s)
Wu *et al.* 2009[36]	0.15T	Gd-DPTA	NNG	T1	7	1.8
Kim *et al.* 2013[13]	0.15T	Gd-DPTA (4 mL/kg)	NNG	T1-axial and coronal	7	NR
Makary *et al.* 2011[18]	0.15T	Gd-DPT	NR	*T1-axial or T2/FLAIR	13	0.5–2
White *et al.* 2018[35]	0.13T and 0.15T	NS	Awake mapping	NR	NR	NR
García *et al.* 2017[8]	0.15T	Ferromagnetic (Gadobutrol 1 mmol/m)	NR	T1	NR	NR
Bohinski *et al.* 2001[3]	0.3T	Omniscan (gadodiamide, nycomed)	NNG	T1-saggital, axial and coronal and fast spin T2 for low grade	16	NR
Nimsky *et al.* 2003[21]	0.2T	Gd-DPT	NNG	T1 and 3D FLASH	NR	NR
Kırış and Arıca 2011[14]	0.15T	NR	NR	NR	72	NR
Hlavica *et al.* 2013[12]	0.15T	Gd-DPT	NR	T1	30	1.53
Thiabpha and Hansasuta 2016[32]	0.15T	Gd-DPT	NR	T1	12	NR
Livne *et al.* 2014[16]	0.15T-0.13T	NR	NR	T1W1, T2W1, FLAIR	27.4	0.7
Senft *et al.* 2010[26]	0.15T	NR	NNG	T1	20–40	NR
Senft *et al.* 2011[25]	0.15T	NR	NNG	T1	12	1
Nimsky *et al.* 2003[22]	0.2T	Gd-DPT	NR	T1 and T2	NR	NR
Senft *et al.* 2010[28]	0.15T	NR	NNG+MSEP	T1	NR	NR
Zimmermann *et al.* 2001[39]	0.5T	Gd-DPT	NNG	T2w spin echo and T1w spin echo	NR	1
Zimmermann *et al.* 2000[38]	0.5T	Gd-DPT	NNG	NR	NR	NR
Czyż *et al.* 2011[7]	0.15T	Gd-DPT	NNG+Neuro electrophysiological monitoring	T1, T2 and FLAIR	NR	3.6
Buchfelder *et al.* 2002[6]	0.2T	NR	NNG	T1	15	NR
Senft *et al.* 2008[27]	0.15T	Gd-DPT	NNG	T1, T2 and FLAIR	NR	NR
Ungar *et al.* 2021[33]	0.15T	Gd-DPT	MSEP	T1, T2 and FLAIR	49	NR

Gd-DPT: Gadolinium-diethylenetriamine penta-acetic acid, NR: Not reported, NS: Not specified, *T1-axial with gadolinium for enhancing non-pituitary tumors or T2/FLAIR for nonenhancing non-pituitary tumors. NNG: Neuronavigation, MSEP: Motor or sensory-evoked potentials, OR: Operating room, hr/s: Hour/s, MRI: Magnetic resonance imaging, FLAIR: Fluid-attenuated inversion recovery, LF-IMRI: Low-field intraoperative magnetic resonance imaging, FLASH: Fast low angle shot

Table 4: Impact of LF-IMRI on EOR.

Study name	LF-IMRI (Tesla)	Tumor pathology	GTR (*n*)	*GTR (No residual tumor spotted with IMRI)	#GTR (Residual tumor spotted IMRI)	Partial resection (n)	+EOR (%)
Wu *et al.* 2009[36]	0.15T	Pituitary macroadenomas	46	32	15	8	33.3
Kim *et al.* 2013[13]	0.15T	Pituitary adenomas	182	154	30	2	17.5–83.3
Makary *et al.* 2011[18]	0.15T	Oligodendroglioma, anaplastic astrocytoma, caraniopharyngioma	NR	NR	28	NR	43
White *et al.* 2018[35]	0.13T and 0.15T	Glioblastoma, astrocytoma, oligodendroglioma	21/36	12/36	9/36	15	28

(Contd...)

Table 4: *(Continued)*.

Study name	LF-IMRI (Tesla)	Tumor pathology	GTR (*n*)	*GTR (No residual tumor spotted with IMRI)	#GTR (Residual tumor spotted IMRI)	Partial resection (n)	+EOR (%)
García *et al*. 2017[8]	0.15T	Nonfunctioning adenomas, functioning adenomas	25	19	7	5	20
Bohinski *et al*. 2001[3]	0.3T	Gliomas	30	NR	NR	10	52.5
Nimsky *et al*. 2003[16]	0.2T	Gliomas	54	38	16	52	26
Kırış and Arıca 2011[14]	0.15T	Glioblastoma, oligoastrocytoma, oligodendroglioma, epindymoma	NR	NR	NR	NR	NR
Hlavica *et al*. 2013[12]	0.15T	Nonfunctioning pituitary adenomas	70	NR	NR	34	41.3
Thiabpha and Hansasuta 2016[32]	0.15T	Pituitary adenoma	9	NR	NR	2	NR
Livne *et al*. 2014[16]	0.15T-0.13T	Gliomas, metastases	94	NR	NR	69	42.3
Senft *et al*. 2010[26]	0.15T	Gliomas	109	NR	NR	NR	21
Senft *et al*. 2011[25]	0.15T	Gliomas	23	NR	8	1	33
Nimsky *et al*. 2003[21]	0.2T	Gliomas	16	14	2	4	10
Senft *et al*. 2010[28]	0.15T	Glioblastoma, pituitary adenoma/ Craniopharyngioma, metastases	69	NR	NR	34	30
Zimmermann *et al*. 2001[39]	0.5T	Meningioma, Astrocytoma, Glioblastoma, Oligodendroglioma, metastases, cavernoma	28	NR	NR	4	NR
Zimmermann *et al*. 2000[38]	0.5T	Meningioma, Oligodendroglioma, Astrocytoma, Glioblastoma, metastases, cavernoma	36	NR	36	8	NR
Czyż *et al*. 2011[7]	0.15T	Meningioma Glioma, Pituitary adenoma, metastatic tumor	NR	NR	NR	NR	NR
Buchfelder *et al*. 2002[6]	0.2T	Low-grade gliomas, cavernomas	21	23	NR	8	11
Senft *et al*. 2008[27]	0.15T	Gliomas	38	39	10	23	22
Ungar *et al*. 2021[33]	0.15T	Gliomas, cavernous angiomas, primitive neuroectodermal tumor, pilocytic astrocytomas, ependymoma, demyelinative tumor, ganglioglioma, glioneuronal tumor, pleomorphic xanthoastrocytomas, central neurocytoma, subependymoma, metastasis, and enhancing glial tumors	60	42	18	13	32.8

n: Number of cases, MRI: Magnetic resonance imaging, LF-IMRI: low-field intraoperative magnetic resonance imaging, NR: Not reported, GTR: Gross total resection. *Number of cases in which GTR was done and no residual tumor spotted with L-MRI, #Number of cases where GTR was done and residual tumor spotted with IMRI, +EOR: Extent of resection increase with use of IMRI

may not have controlled for all variables that could have influenced the results, contributing to confounding factors. The studies varied in design, lacking consistent control groups for direct resection comparison. This heterogeneity might affect conclusion generalization. Surgeons' inconsistent pre-IMRI resection perceptions introduced potential bias, possibly inflating LF-IMRI's attributed resection improvement. Due to the limited amount of literature available on the topic, case series with sample sizes of >10 were included in the study.

Future direction

Going forward, prospective and randomized controlled trials with large sample sizes are necessary to evaluate the utility of LF-MRI in routine neurosurgical care and to determine how LF-MRI can be effectively implemented in areas with limited resources, it is crucial to carry out prospective studies in LMICs. It is also important to study the feasibility and utility of the emerging field of ULF-MRI in the neurosurgery operating room.

CONCLUSION

Our review highlighted that LF-MRI has the potential to be an important tool for intraoperative brain tumor imaging, which is known to increase the EOR and subsequently improve outcomes of brain tumors. To fully realize the potential of LF-MRI in LMICs, where access to high-field MRI is often limited, efforts should be made to increase the accessibility of LF-MRI machines, develop specialized protocols, provide training and education for healthcare professionals, conduct research and evaluations, develop teleradiology linkages with experts in LF-MRI interpretation, and partner with equipment manufacturers to create low-cost and low-maintenance machines. With these efforts, LF-MRI has the potential to improve diagnosis and treatment outcomes of brain tumors in LMICs.

Declaration of patient consent

Patients' consent not required as patients' identities were not disclosed or compromised.

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Conflicts of interest

There are no conflicts of interest.

Use of artificial intelligence (AI)-assisted technology for manuscript preparation

The author(s) confirms that there was no use of artificial intelligence (AI)-assisted technology for assisting in the writing or editing of the manuscript and no images were manipulated using AI.

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SEARCH STRATEGY

PubMed: (No of articles retrieved, 116)

((“magnetic resonance imaging” AND (“low-field” OR “low field” OR “low field”) AND (“Brain Neoplasms”[Mesh] OR “brain tumor” OR “brain tumor” OR “cns tumor” OR “cns tumor” OR “central nervous system tumor” OR “central nervous system tumor” OR “brain malignancy” OR “cns malignancy” OR “central nervous system malignancy” OR “glioma” OR “medulloblastoma” OR “ependymoma” OR “meningioma”) AND (“surgery, computer-assisted” OR “neuronavigation” OR “therapy, computer-assisted”))

Scopus (No of articles retrieved, 80)

(“intraoperative” OR “neuronavigation”) AND (“magnetic resonance imaging”) AND “low-field” AND (“Brain Neoplasm” OR “brain tumor” OR “cns tumor” OR “cns tumor” OR “central nervous system tumor” OR “central nervous system tumor” OR “brain malignancy” OR “cns malignancy” OR “central nervous system malignancy” OR “glioma” OR “medulloblastoma” OR “ependymoma” OR “meningioma”)

Google Scholar: (No of articles retrieved, 500)

((“magnetic resonance imaging”|“Neuroimaging”) (“low-field”|“lowfield”|“low field”) (“Brain Neoplasms”|“brain tumor” |“brain tumor”|“cns tumor”|“cns tumor”| “central nervous system tumor”|“central nervous system tumor” |“brain malignancy”|“cns malignancy”| “central nervous system malignancy”|“glioma” |“medulloblastoma” |“ependymoma”|“meningioma”) (“surgery, computer-assisted ”|“neuronavigation”|“therapy, computer-assisted”))