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Preoperative FMRI associated with decreased mortality and morbidity in brain tumor patients

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ABSTRACT

Background: Functional Magnetic Resonance Imaging (fMRI) is a presurgical planning technique used to localize functional cortex so as to maximize resection of diseased tissue and avoid viable tissue. In this retrospective study, we examined differences in morbidity and mortality of brain tumor patients who received preoperative fMRI in comparison to those who did not.

Methods: Brain tumor patients (n = 206) were selected from a retrospective review of neurosurgical case logs from 2001 to 2009 at the University of Wisconsin-Madison.

Results: Univariate analysis showed improved mortality in the fMRI group and the fMRI + Electrical Cortical Stimulation Mapping (ECM) group compared to the No-fMRI group. Multivariate analyses showed improved mortality of the fMRI group and the fMRI + ECM group compared to the No-fMRI group, with age and tumor grade being the most significant influencers. Overall, the fMRI group showed survival benefits at 3 years; twice that of the No-fMRI group. Furthermore, patients with high-grade tumors showed significant survival benefits in the fMRI group, while patients with low-grade tumors did not (controlling for age and ECM). There was also a significant difference in the two groups with respect to morbidity, with patients receiving fMRI showing improved outcomes in the motor and language domains.

Conclusions: This study analyzing a large retrospective series of brain tumor patients with and without the use of fMRI in the preoperative planning has resulted in improved mortality and morbidity outcomes with the use of

Abbreviations: FMRI, Functional Magnetic Resonance Imaging; ECM, Electrical Cortical Stimulation Mapping; SSDI, Social Security Death Index; IRB, Institutional Review Board; TR, repetition time; FOV, field-of-view; TE, echo time; FA, flip angle; PACS, Picture Archiving System; CI, confidence interval; SEER, Surveillance, Epidemiology and End Results

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fMRI. These results point to the importance of incorporating fMRI in presurgical planning in the clinical management of patients with brain tumors.

1. Introduction

The long-term morbidity and mortality of brain tumor patients undergoing surgical resection is dependent on the extent of tumor resection [1–3] and the identification and avoidance of nearby critical functional brain regions such as motor and language networks [4,5]. Although anatomical landmarks are frequently used to localize functional brain regions, the mass effect and growth of tumors frequently distort normal anatomy and may cause considerable reorganization of nearby functional cortex [6]. Therefore, determining the relative locations of tumor and functional brain parenchyma is hypothesized to minimize intraoperative risks of causing functional deterioration while achieving maximal tumor resection.

Intraoperative Electrical Cortical Stimulation Mapping (ECM) is the current gold standard for functional brain mapping and was shown to increase the quality and extent of tumor resection and decrease morbidity and mortality [7]. Functional Magnetic Resonance Imaging (fMRI) is a newer preoperative imaging modality that provides mapping of functional brain regions with high spatial resolution, and has been corroborated by ECM [8,9]. A few studies have suggested that increased proximity of lesion to functional brain regions identified by fMRI leads to increased morbidity [10]. This is consistent with ECM studies suggesting increased morbidity with increased proximity of lesion to functional areas. However, to our knowledge, there is no study to date comparing the morbidity and mortality of surgical patients that undergo preop fMRI with those that do not undergo preop fMRI. In this retrospective study, we report improvement in morbidity and mortality of brain tumor patients who underwent preoperative functional imaging than those who did not.

2. Methods

2.1. Study subjects

1727 patients undergoing resection of an intracranial mass were selected from retrospective review of neurosurgical cases from 2001 to 2009 at the University of Wisconsin-Madison. Of the 1727 patients reviewed, 206 met the inclusion criteria. 79 of these patients received a preoperative fMRI (fMRI group), while 127 did not (No-fMRI group). Inclusion criteria were initial pathological diagnosis of a primary glial or metastatic tumor, supratentorial cortical location, and initial tumor resection. Patient data, tumor data, and operative data were collected retrospectively from medical records. Mortality information was collected for all patients by using medical records that were cross referenced with the Social Security Death Index (SSDI). Further demographics and clinical information of patients can be found in Table 1. The study was conducted and written informed consent was obtained from all patients in accordance with a protocol approved by the University of Wisconsin-Madison Institutional Review Board (IRB).

2.2. Language paradigms

The language paradigms used to assess patients are described in detail by Moritz and Haughton [11]. The current study used 2 types of word-generation tasks for identifying Broca's area: 1) alternating 20-second blocks of antonym-word-generation versus rest, and 2) alternating 20-second blocks of letter-word-generation tasks versus rest. Wernicke's area was identified with alternating 20-second blocks of text-reading versus a 20-second block of random symbols. Each paradigm was about 4 min in length. Multiple tasks were used because not all patients showed language related activation with any single task. We selected the task that resulted in most robust activation for each subject because not all patients performed all tasks.

2.3. Motor paradigms

Motor tasks were chosen based on the location of tumor relative to the motor cortex. The motor paradigms were selected from a subset of the following movements: right and/or left ankle rotation, right and/or left thumb to ipsilateral finger tapping, lip pursing, and tongue movement across the hard palate. Each individual motion was done as a repetitive block paradigm of 20-seconds of motion followed by 20-seconds of rest; each paradigm was 3 min in length.

2.4. FMRI acquisition

Imaging was done with either a 1.5 T or 3 T commercial MR imaging scanner (GE Healthcare, Milwaukee Wisconsin) equipped with high speed gradients. BOLD-weighted single-shot EPIs were obtained repeatedly at intervals defined by the repetition time (TR) for each patient during task performance. Technical parameters were the following: field-of-view (FOV): 24 cm; matrix: 64 × 64; TR: 2000 ms; echo time (TE): 40 ms (for 1.5 T) or 27 ms (for 3 T); flip angle (FA): 85° (for 1.5 T) or 75° (for 3 T); 6-mm coronal plane sections (for 1.5 T) or 5-mm axial plane sections (for 3 T). Spatial coverage was sufficient to provide mapping of the entire cortex. The number of images and the length of imaging varied with the paradigm, ranging from 3 to 5 min. Additional high-resolution anatomic scans, including 3D volumetric T1- and T2-weighted sequences were acquired in the preoperative assessment.

2.5. FMRI processing

All processing was performed with AFNI [12] and Prism Clinical Imaging software [13]. Activation was determined by cross correlation of the time-course of the EPI signal intensity at each voxel to a smoothed and temporally delayed boxcar reference function, modeling the presumed hemodynamic response. This comparison provided a voxel wise *t*-statistic, with which images were thresholded individually to optimize visualization of language and/or motor areas. These were overlaid on co-registered anatomic brain volume maps. Thresholding was subjectively applied with the intent of optimizing specificity and

Table 1
Patient and tumor characteristics.

	No-FMRI (n = 127)	FMRI (n = 79)	p-Value
Mean age (range)	57.7 (20–84)	45.8 (20–73)	< 0.001
Sex (M/F)	72/55	54/25	0.128
Handedness (R/L/B/U)	45/2/0/80	58/12/2/7	0.055
Hemisphere (R/L)	75/52	20/59	< 0.001
Lobe (F/P/O/T)	52/17/9/49	35/13/0/31	0.109
Tumor volume (cm^3)	32.3 (0.31–140.99)	32.4 (0.16–211.38)	0.980
Mean distance (mm) to Broca's, Wernike's, and motor area (range)	36.2 (0–113.3), 36.7 (0–95.6), 31.6 (0–84.7)	29.2 (0–96), 36.1 (0–107.7), 29.0 (0–76)	0.034, 0.855, 0.350
Tumor grade (1/2/3/4/M/Mode)	2/14/14/70/27/4	9/29/9/24/8/2	< 0.001

Handedness (R = right, L = left, B = bilateral, U = unknown); Lobe (F = frontal, P = parietal, O = occipital, T = temporal).

sensitivity to expected regions of task response, and minimizing spurious voxels that were considered artifacts (e.g., due to head motion). Thresholding was also adjusted to highlight the expected responses (e.g., Broca area or primary sensory motor) at a level that displayed a typical suprathreshold extent. This was subjectively adjusted to localize a particular gyrus or region, which represented a statistical probability of greatest confidence as indicated by the *t*-statistical overlay. An optimal threshold was applied to balance the need to highlight an expected response with the concern of minimizing artifacts.

2.6. Image analysis and interpretation

Images used in the analysis were compiled at the time of surgery by a trained MR imaging technologist and were used by the neurosurgical team for presurgical planning. Tumor edge was defined as the enhancing margin for tumors that intensify with contrast on T1-weighted images or the peripheral margin of the solid portion of the tumor as noted in T2-weighted images. Distances from the tumor edge to activation centers were measured at the subjective thresholds defined above. The volume of tumors was measured from the structural scans, consistent with Newman 2007 [14]. Measurements were taken in the transverse (x), anterior/posterior (y), and superior/inferior (z) axes using Picture Archiving System (PACS) software. Tumor volume was calculated using the equation: $^{(x\times y\times z)\pi}/_{6}$.

2.7. Statistical analysis

The Pearson's chi-squared test (or Fisher's exact test) and independent samples *t*-test were used to compare the baseline characteristics in both groups, including age, gender, handedness, hemisphere, tumor location, tumor volume, distances from Broca's and Wernicke's areas, and tumor grade. We evaluated the association between the predictor variables (i.e., the presence of fMRI and cortical mapping, age, gender, handedness, hemisphere, location, tumor volume, tumor grade, and distances from Broca's and Wernicke's areas) and the response variable (i.e., survival time) by using separate univariate Cox proportional hazards models and a multivariate Cox proportional hazards model. Cumulative survival functions for the treatment groups over the entire study period were estimated by the Kaplan-Meier method. The log-rank test was used to compare Kaplan-Meier curves among the groups. The Pearson's chi-squared test was used to compare perioperative motor and language deficits in the fMRI and no fMRI groups and the change in deficits at 6 months. All statistical analyses were performed by using R statistical software [15].

3. Results

3.1. Patient and tumor characteristics

Median follow-up in the fMRI cohort was 1967 days (CI: 1538–2533) and 1057 days (CI: 925–1960) in the No-fMRI cohort. Statistically significant differences between the two cohorts were found in patients age ($p < 0.001$), tumor grade ($p < 0.001$), hemisphere ($p < 0.001$), and proximity to Broca's area ($p = 0.034$). Overall, patients who underwent a preoperative fMRI were younger, more likely to have presented with a lower tumor grade (likely non-enhancing) in the dominant left hemisphere, and the tumor was closer to Broca's area. Other patient demographics and tumor characteristics are detailed in Table 1.

3.2. Univariate and multivariate analysis

The data were analyzed for influence on mortality in both univariate and multivariate model. Univariate analysis of brain tumor patients showed improved mortality of the fMRI group ($p < 0.0001$) and the fMRI + ECM group ($p < 0.0001$) compared to the No-fMRI group. The univariate model further identified the presence of age, location, tumor grade, and distance from Broca's and Wernicke's areas as statistically significant factors influencing mortality, with hemisphere and tumor volume as trending significant factors (Table 2). Even after controlling for these multiple other factors that were different between the two groups which influenced mortality, multivariate analysis showed improved mortality of the fMRI group ($p = 0.0136$) and the fMRI + ECM group ($p = 0.0195$) compared to the No-fMRI group. The multivariate Cox proportional hazards model corroborates the effects of fMRI, cortical mapping, age, and tumor grade on mortality. From the multivariate proportional hazards model, tumor grade was found to be the best predictor of postoperative mortality ($p < 0.0001$, CI: 4.5028–48.982), followed by age ($p = 0.0037$, CI: 1.0080–1.0419), fMRI + ECM ($p = 0.0195$, CI: 0.1192–0.8298), and fMRI-alone ($p = 0.0136$, CI: 0.2159–0.8387). Hemisphere location and proximity to Broca's area were other factors identified to be statistically significant when comparing the two groups, and were found to not significantly influence mortality ([$p = 0.2985$, CI: 0.8142–1.9539], [$p = 0.9789$, CI: 0.9872–1.0133], respectively). Handedness was excluded from analysis due to the high amount of data not recorded in the patient chart.

3.3. Survival analysis

Fig. 1 represents the Kaplan-Meier curves for those who received a preoperative fMRI (± ECM) versus those who did not. Of note, the

Table 2
Univariate and multivariate analysis of factors influencing mortality.

Category	Deceased	Alive	Univariate			Multivariate		
			HR	Cl	*p*-Value	HR	Cl	*p*-Value
fMRI	24	55	0.3143	(0.1851, 0.5337)	< 0.0001	0.4255	(0.2159, 0.8387)	0.0136
ECM	3	0	1.0343	(0.3256, 3.2854)	0.9540	1.5787	(0.4202, 5.9303)	0.4990
fMRI + ECM	7	22	0.1732	(0.0791, 0.3796)	< 0.0001	0.3145	(0.1192, 0.8298)	0.0195
Age (mean)	57.7	48.3	1.0478	(1.0330, 1.0630)	< 0.0001	1.0248	(1.0080, 1.0419)	0.0037
Gender (M vs F)	64.2%	58.0%	1.1370	(0.7643, 1.6910)	0.5260	1.3888	(0.8875, 2.1732)	0.1505
Hemiphere (R vs L)	50.9%	41.0%	1.4343	(0.9793, 2.1010)	0.0640	1.2613	(0.8142, 1.9539)	0.2985
Lobe (P vs F)	17.0%	12.0%	1.7974	(1.025, 3.151)	0.0406	1.2048	(0.5621, 2.5823)	0.6320
Lobe (O vs F)	5.7%	3.0%	2.5320	(1.067, 6.008)	0.0351	1.5671	(0.4675, 5.2525)	0.4667
Lobe (T vs F)	40.6%	37.0%	1.2486	(0.809, 1927)	0.3160	0.9086	(0.4739, 1.7419)	0.7728
Volume	31.68	33.05	1.0051	(0.9997, 1.011)	0.0618	1.0034	(0.9968, 1.0101)	0.3103
Grade (HGG vs else)	82.1%	49.0%	26.529	(8.348, 84.30)	< 0.0001	14.8512	(4.5028, 48.982)	< 0.0001
Broca's area	35.59	31.32	1.0100	(1.002, 1.018)	0.0145	1.0002	(0.9872, 1.0133)	0.9789
Wernicke's area	31.86	41.51	0.9898	(0.9813, 0.9984)	0.0205	0.9892	(0.9752, 1.0035)	0.1370
Motor	30.09	31.67	0.9927	(0.9816, 1.004)	0.1990	1.0011	(0.9834, 1.0035)	0.9027

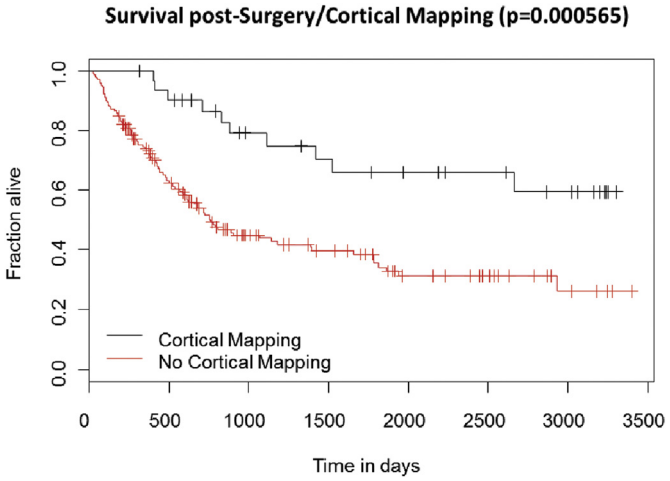

Fig. 1. FMRI vs No-fMRI groups. Survival of those receiving preoperative fMRIs vs those without preoperative fMRIs.

cohort receiving a preoperative fMRI maintained a survival rate > 50% at the study's endpoint, therefore median survival for the fMRI cohort could not be calculated. We therefore compared the two groups on the percent survival at 3-years after the date of resection. Overall, the fMRI cohort had 74.6% survival at 3 years, twice that of the No-fMRI group (37.3%) (Table 3).

When analyzed by grade, the difference between the fMRI and No-fMRI groups in low-grade tumors was negligible. The differences become notable in the high-grade tumors (50.8% survival with fMRI and 27.8% survival with No-fMRI). After controlling for factors found in the multivariate analysis to influence mortality (age and ECM) a sub-analysis was performed on the high-grade tumors. Age < 65 years, in comparison to those older, was correlated with increased survival in both the fMRI group (78.1% vs 42.9%) and the No-fMRI group (47.1% vs 20.4%). However, across all ages those with a preoperative fMRI had significantly increased survival overall in comparison to those without fMRI ($^{<}$65: 78.1% vs 47.1%; ≥65: 42.9% vs 20.4%). Age cutoff was placed at 65 years based on the 1973–1991 Surveillance, Epidemiology and End Results (SEER) data, finding that the age of $^{>}$65 years conveys a poor prognosis [16]. ECM was shown to increase survival at 3-years post-resection for both cohorts (fMRI: 81.2% vs 70.7%, No-fMRI: 66.7% vs 36.5%). The Kaplan-Meier survival curve for those with ECM + fMRI vs fMRI-alone vs no mapping is shown in Fig. 2. The group with ECM + fMRI conferred slightly improved survival compared to the fMRI-alone group which showed a significant survival benefit in comparison to No-fMRI ($p = 6.86 \times 10^{-9}$).

The incidences of preoperative and postoperative language and motor deficits are presented in Table 4, which were collected from neurosurgery and neurology clinical notes. All cohorts showed gross improvement in postoperative deficits when compared to preoperative deficits, however the difference in postoperative motor and language deficits were not significant ($p = 0.7523$ and $p = 0{\cdot}3478$, respectively) between the fMRI and No-fMRI cohorts. While some patients with preoperative deficits improved postoperatively, not all postoperative deficits/mortality were present preoperatively. Therefore, a better metric is to analyze whether patients' preoperative deficits improved, worsened/deceased, or did not change postoperatively; this is shown in Table 5. When compared to the fMRI cohort, the patients without preoperative fMRIs were more likely to have worsened/deceased motor (21.2% vs 3.95%) and language (24.2% vs 5.26%) deficits post-operatively. Conversely, the fMRI cohort showed more improved postoperative changes in both motor (27.6% vs 14.1%) and language (11.8% vs 9.09%) deficits. The improvement in motor deficits was greater than language in both the fMRI (27.6% vs 11.8%) and the No-fMRI (14.1% vs 9.09%) cohorts. The difference in outcomes for both motor and language were found to be statistically significant ($p = 0.001$ and $p = 0.003$, respectively).

4. Discussion

The long-term prognosis in patients with intracranial tumor has been associated with patient age, functional status, tumor size, completeness of resection, and tumor grade. The mortality varies widely depending on the grade of the tumor: low-grade gliomas confer a median survival of 3.67–7.80 years [2,17], while grade 4 gliomas with modern therapy carry a median survival of 14.6 months [18]. Long-term mortality is secondary to tumor recurrence or complications in low [7] and high [17] grade gliomas. As such, studies have demonstrated that gross total resection of both low-grade and high-grade supratentorial tumors are associated with an improvement in mortality [2,19–21]. Recent work by Chang et al. demonstrated that patients with low-grade gliomas near functional cortex recur earlier than tumors resected from further locations [22]. Tumor location in functional areas may increase mortality by precluding complete debulking of tumor, leading to recurrence and malignant transformation. Chang et al. demonstrated that intraoperative ECM likely improves long-term survival by increasing extent of resection while avoiding presumed functional brain regions by delineating diseased tissue from healthy parenchyma [22]. Similar work by Duffau et al. corroborate that there is increased total resection when ECM is utilized in patients with low-grade gliomas, reporting complete resection in 93.5% in those with ECM utilization versus 74.6% in those without [7].

The results of functional MRI have been compared to ECM, finding high correlation between the two. Specifically in tumor patients, Bizzi et al. showed that fMRI had high overall sensitivity (83%) and specificity (82%) for detecting functional cortex adjacent to a focal mass lesion, finding lower sensitivity for high-grade compared to low-grade gliomas [23]. These spatial associations of activated cortex on fMRI with tumors have been validated by ECM [23,24]. However, to our knowledge, there have been no studies that attempted to demonstrate long-term mortality in patients undergoing tumor resection with fMRI cortical mapping alone.

This study focused on patients undergoing resection of primary or metastatic brain tumors, comparing mortality of those who received preoperative fMRI with those who did not. We found increased 3-year survival in the patients receiving preoperative fMRI (74.6% vs 37.3%). When controlling for tumor grade, the difference in 3-year survival of those with low-grade gliomas between the two cohorts was not significant. The lack of notable difference in low-grade tumors is likely due to the excellent outcomes with decreased recurrence of these tumors. Low-grade gliomas have a median survival up to 7.8 years [7,22,25], therefore any benefit that an fMRI could convey in the immediate postoperative years would, at best, be small.

However, there was a significant increase in 3-year survival of high-grade tumor patients who received a preoperative fMRI compared to the No-fMRI group (50.8% vs 27.8%, respectively). This improved survival within the fMRI group remains after controlling for other factors that influence mortality: age (< 65: 78.1% vs 47.1%, > 65: 42.9% vs 20.4%), and ECM (+ECM: 81.2% vs 66.7%, −ECM: 70.7% vs

Table 3
Percent three-year survival of tumor patients by grade.

Category	No-fMRI	FMRI	FMRI benefit
All tumor	37.3	74.6	38
Grade (1/2/3/4/M)	(100/100/42.9/20.6/43.6)	(100/100/100/32.8/45)	(0/0/57/13/1)
Low-grade	100	100	2
High-grade	27.8	50.8	24
Age (< 65, > 65)	47.1, 20.4	78.1, 42.9	29, 35
ECM (+/−)	66.7/36.5	81.2/70.7	15/35

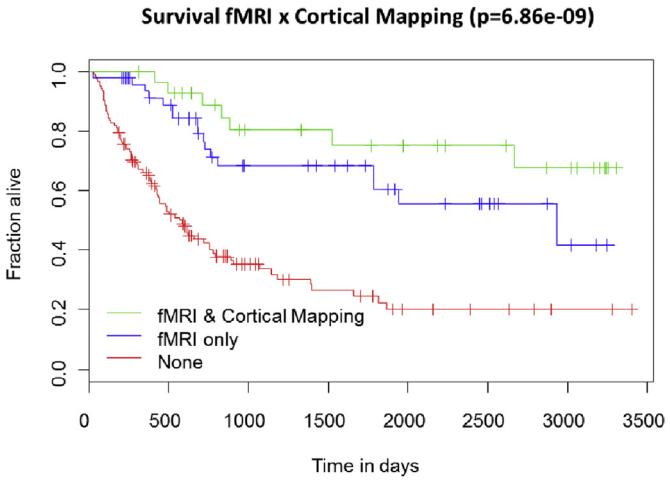

Fig. 2. FMRI + ECM vs fMRI-alone vs no mapping. Survival of those receiving fMRI with ECM vs preoperative fMRIs alone vs without any mapping.

36.5%). A meta-analysis of 12 randomized trials by the Glioma Meta-analysis Trials (GMT) Group found that patients with high-grade gliomas have a 2-year survival dependent on age: 13% survival in patients > 60 years old, 19% in those 41–59, and 55% in those < 40 [18]. More recently, Stupp et al. showed that grade 4 glioma patients treated with modern surgery, radiotherapy and temozolomide exhibited a 2–3 year survival in the low to mid 20% [26]. These studies are concordant with results from the No-fMRI group, yet our fMRI cohort had a significantly better 3-year survival of 52%. To our knowledge, this is the first reported survival improvement in patients undergoing resection of supratentorial primary or metastatic tumors based on fMRI.

We hypothesize that preoperative fMRI improves median survival by several factors. Petrella et al. showed that preoperative fMRIs are correlated with more aggressive surgical approaches, and in certain patients decreased surgical time, increased extent of resection, and decreased craniotomy size [27]. Similarly, Medina et al. corroborates that preoperative imaging increases surgeon confidence in identification of critically functional cortex [28]. With increasing confidence of the boundary between healthy and tumor tissue, the likely mechanism of increased survival is due to improved resection of the tumor. This would be consistent with the reported improvement in 6 month progression free survival for high grade gliomas patients who underwent 5-aminolevulinic acid fluorescence-guided surgery [29], and improved median survival due to ECM and more aggressive tumor resection in low-grade tumors by Chang et al. and Duffau et al. [7,22] To our knowledge, the increase in median survival due to any mode of cortical mapping (fMRI, ECM) has not been demonstrated in high-grade gliomas. However, it has been reported in this cohort that more complete resection is correlated with long-term median survival.

In both the fMRI and No-fMRI cohort, this study found an overall yet insignificant improvement in motor (80.5% and 72.0%, 0.7523) and language (63% and 31.6%, $p = 0.3478$) deficits after surgery (Table 4). In this analysis, the fMRI cohort had less worsening/morbidity of deficits and proportionally had a higher level of deficit improvement, indicating that preoperative fMRIs may be associated with more complete debulking without associated damage to healthy neighboring parenchyma. The analysis also shows increased deficits and morbidity rates for postoperative language deficits when compared to motor, suggesting that the language networks are more delicate and recover less resiliently than motor from the insult of tumor and surgery.

In our study, the 3-year survival in those with preoperative functional imaging in high-grade gliomas was 50.8%, a 183% improvement over the 27.8% in the No-fMRI cohort. This is comparable or better than some of the brain tumor treatments. Current therapy for supratentorial gliomas include surgery followed by radiotherapy and chemotherapy. A recent meta-analysis of the traditional adjuvant chemotherapy regimen used in high-grade gliomas, procarbazine-lomustine-vincristine, suggests a 2-month increase in mean survival time [30]. Stupp et al. demonstrated that this novel agents such as Temozolomide leads to a median increase in survival of 2.5 months in high-grade gliomas. While chemotherapy has serious side effects, limited risks have been identified in humans exposed. Nausea and vomiting are the most common side effects, and neutropenia and thrombocytopenia being the major toxicities. Studies have not identified significant biological or neurocognitive risks in humans exposed to high strength magnetic fields [31,32]. Because of the impact on survival we recommend that preoperative fMRIs should be regularly considered for patients undergoing surgical resection of supratentorial intracranial tumors.

A possible limitation of this study is the inclusion of metastases in our analysis. The natural history of brain metastases confers a poor prognosis of 2–4 months. Surgery is statistically correlated with wide variations in median survival; 6.7 months for melanoma, 11 months for non-small cell lung cancer, 13.8 months for renal cell carcinoma, and 16 months for thyroid carcinoma [33,34]. Patients with metastases were disproportionally present in the No-fMRI group, however tumor grade, age, and ECM were controlled for in our overall analysis.

Another possible limitation of this study is that the data was retrospectively collected from physician notes. This did not allow us to match patients risk profiles and tumor characteristics so we appropriately controlled for these variables in our statistical analysis. The physician notes did not follow a standardized form, and hence the preoperative and postoperative deficits were not reported in a consistent level of detail. Also, individually thresholded fMRI maps were provided to the neurosurgeons so that patient-specific information could be used in surgical planning. There was no standardized information available to describe how the fMRI data altered their surgical approach. It is proposed that future prospective studies standardize patient reporting in the different stages, accounting for deficits, neuropsychological testing, functional status, and volume of tumor resection.

In conclusion, this study is the first to show that the administration of preoperative fMRI conveys improved survival benefit to patients undergoing an initial craniotomy for a high-grade supratentorial tumor. We posit that the survival benefit conferred by fMRI is primarily due to accurate spatial localization of functional brain regions leading to maximal tumor resection while minimizing functional deficits. Because of the advantage of increased survival times without any known side effects, we recommend that the standard of care for selected patients undergoing first-time resection of high-grade tumors should include a preoperative functional MRI.

Table 4
Incidence of preoperative and postoperative deficits.

Category	No fMRI			fMRI			*p*-Value
	Preop	Postop	% improved	Preop	Postop	% improved	
Motor	36	7	80.5	25	7	72.0	0.7523
Language	27	10	63.0	19	13	31.6	0.3478

Table 5
Change in preoperative vs postoperative deficits.

Category	No fMRI			fMRI			*p*-Value
	No change	Decreased	Improved	No change	Decreased	Improved	
Motor	64 (64.6%)	21 (21.2%)	14 (14.1%)	52 (68.4%)	3 (3.95%)	21 (27.6%)	0.001
Language	66 (66.7%)	24 (24.2%)	9 (9.09%)	63 (82.9%)	4 (5.26%)	9 (11.8%)	0.003

Disclosures

The authors declare no conflict of interest.

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