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EXPERIENCE OF USING INTRAOPERATIVE MAGNETIC RESONANCE IMAGING IN THE SURGICAL TREATMENT OF BRAIN GLIOMAS

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Introduction. Volume of glioma resection positively correlates with treatment results. Advance in extent of resection due to various additive methods leads to prolonged overall survival and delays progression. Our aim was to evaluate the value of intraoperative magnetic resonance imaging.
Objective – to present the first experience of using intraoperative magnetic resonance imaging and evaluate the effectiveness and safeness of this technique in surgery of glial brain tumors.
Material and methods. Prospective analysis of surgical interventions performed using the intraoperative magnetic resonance imaging and the results of neuroimaging in 9 patients with different grade brain gliomas treated in Federal Brain and Neurotechnology Center was carried out.
Results. In all patients we detect variable residual tumor volume after first resection. Additional resection was performed in all cases after the intraoperative magnetic resonance imaging. Mean scan time were 45 minutes overall time for scan were decreasing as we gain experience in using intraoperative magnetic resonance imaging.
Conclusion. Intraoperative high-field intraoperative magnetic resonance imaging can be successfully used in the surgery of brain gliomas. the technique allows increasing the radicality of tumor removal without increasing the risk of complications.

Key words: glioma, brain tumor, MRI, iMRI, intraoperative MRI, intraoperative monitoring

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INTRODUCTION

Gliomas are the most common primary tumors of the central nervous system (CNS) comprising 80 % of malignant tumors, and in the recent years the rate of their diagnosis has been increasing [1–3]. Increased frequency of CNS tumor diagnosis is associated with improvements in diagnostic techniques, higher cancer alertness in local practitioners, and widespread use of tomographs. Despite improvements in surgical techniques, chemotherapy, and radiation protocols, in the last 30 years no significant increase in the life span of these patients was achieved. a direct dependence of survival, time of malignant transformation, and recurrence-free survival on radicality of glioma resection was demonstrated, and completeness of tumor resection is the main predictor of survival. Currently, the gold standard of glioma therapies is maximally radical tumor resection using neuronavigation under light microscopy control. It includes complete resection of hyperintense (FLAIR mode of magnetic resonance imaging (MRI) area in tumors not accumulating contrast agent, as well as full resection of accumulation area in T1-weighted imaging in tumors which retain contrast agent [1, 3, 4]. However, surgeon's first impression on completeness of tumor resection can be erroneous which frequently leads to partial resection of tumor tissue and negatively affects outcomes of surgical treatment [4]. Use of intraoperative control of completeness of tumor resection allows to increase radicality of the intervention; one of these techniques is intraoperative MRI (iMRI) which allows to achieve optimal resection radicality of tumors of varying differentiation grade [4–6].

MATERIALS AND METHODS

The trial had the following inclusion criteria: glial nature of the tumor, tumor location in the cerebral hemispheres or basal ganglia, iMRI examination. The trial was performed between 4/12/2021 and 11/11/2021. Unselected patients were included in the trial. Patients with intracerebral tumors of non-glial nature with contraindications for MRI were excluded. Using these criteria, 9 patients were selected: 6 (67 %) males, 3 (33 %) females. Mean age was 45 (between 23 and 65) years. All patients were lucid, had focal neurological deficit (67 %) and cerebral symptoms (33 %) of varying severity. Mean functional score per the Karnofsky index was 90 (between 70 to 100). Standard preoperative examination was performed including examinations by specialists (neurologist, ophthalmologist, general practitioner), lab and instrumental tests of hospital profile. All patients underwent MRI before, after and during operation in the same device.

In all patients, osteoplastic trepanation was performed, tumor was resected using microsurgical techniques under magnification of the Zeiss OPMI Pentero 900 surgical microscope (Carl Zeiss, Germany); Medtronic Navigation StealthStation S7 (Medtronic, USA) was used for intraoperative navigation; Neuro-IOM 32/B station (Neurosoft, Russia) was used for neurophysiological monitoring.

Examinations were performed using high filed (3.0 T) MRI device Discovery MR750w (General Electric Healthcare, USA), 16-channel GEM Flex Medium coil (General Electric Healthcare, USA) was used for scanning. Algorithm of pre- and postoperative MRI did not differ from the standard contrast-enhanced MRI program for brain tumors. Tumor volume before, during and after surgery was assessed by contrasted part for contrast-positive tumors and by hyperintense signal on T2-weighted and FLAIR images for tumors not accumulating contrast agent. Prior to surgery, tumor volume was measured in mL, and after primary resection it was assessed using iMRI measuring total volume of pathological tissue (in mL), and its change was compared to the preoperative volume (in %). Postoperative MRI was also used to measure residual tumor volume (in mL) and to calculate its change compared to tumor volume on iMRI (in %).

The following main parameters were evaluated: presence of residual tumor after primary resection and after surgery, volume of residual tumor and its change compared to preoperative volume; scan time; presence of complications associated with iMRI.

Intraoperative scan procedure

Hybrid operating room in the Federal Center of Brain and Neurotechnologies of the Federal Medical-Biological Agency of Russia is equipped with an MRI device installed as a "side room" with automatic sliding doors isolating the Faraday cage from the operating space. Control room is connected to the MRI examination room and allows to break the seal of the isolating cage without scan disruption during opening of the doors (in case of emergency need to access the patient or equipment). Relative disadvantage of this organization is the necessity to bring patient to the MRI machine, however this is achieved using rotating operating table and mobile MRI table with common rail system for moving patient carriage between them. Benefits of this type of organization are absence of the necessity for additional magnetic field shimming and shielding of other rooms, use of any MRI-incompatible equipment in the operating room (which is economically expedient due to lower expenses), absence of the necessity to conform with safety rules, unlimited access to the patient, ability to install other equipment in the operating room.

When, in surgeon's opinion, radical resection is achieved or another necessity appears (severe brain dislocation, complex anatomical location, suspicion of complications, questionable neurophysiological monitoring data), the patient is prepared for examination: hemostasis of the intraoperative wound is performed, it is abundantly irrigated from hemorrhagic substrate, the cavity is filled with physiological solution (to leave the postresection cavity expanded) and/or markers are attached to the areas of interest (small fragments of patient's adipose tissue/bone wax), the wound is covered with a bone flap (the margins should be cleaned of metallic particles left from craniotomy) with partial juxtaposition of the dura mater and skin, all MRI-incompatible objects are removed from the area of interest. Then the patient's head is wrapped in a sterile single-use plastic bag, patient is disconnected from the ventilator and connected to the mechanical manual device for temporary pulmonary ventilation. Neurosurgical table is attached to the MRI table where the patient is transferred. Above the area of interest, a radiofrequency coil is installed locked in place by belts or bandages. Patient on the MRI table is transferred to the procedure room where the table is attached to the MRI machine, patient is connected to the MRI-compatible ventilator and vitals monitor, as well as contrast agent injector. Scan is then started.

Full examination protocol including transfer takes 30–40 minutes on average, patient transfer with their settling and connection to MRI-compatible equipment takes 5–10 minutes (after wrapping of the patient's head in a sterile bag), necessary preparation for resection continuation takes 15–20 minutes.

Every patient undergoes at least 3 MRI scans: preoperative (at least a day prior for elimination of the contrast agent from the brain matter prior to surgical intervention), intraoperative (one or more if necessary), postoperative (control).

It should be noted that preoperative and control MRI are multiparameter routine examinations: DWI (diffusion-weighted MRI), T1 FSE (fast spin echo) before and after contrast enhancement, T2 FSE, T2 FLAIR, SWAN, DSC-PWI, tractography, and single voxel spectroscopy. the volume of intraoperative examination depends on the context, obtained information, as well as surgeon's and neuroradiologists's decisions.

Intraoperative data are analyzed by a surgeon and a neuroradiologist, and if necessary they are integrated into the neuronavigation system for further additional tumor resection.

Examination of the area of postoperative intervention

In the early postoperative period, edema of the soft tissues of the scalp with varying volumes of fluid (serous fluid, blood, cerebrospinal fluid (CSF) can give a complex MRI signal) and air in different proportions is a typical observation.

Frequently, extra- and intracranial air (hypointense in all modes), most commonly in the subdural space above the frontal cortex (examination is performed when patient is lying on their back), as well as in the postoperative defect area, CSF space, soft tissues is observed during postoperative examination. Dynamic monitoring shows relatively fast elimination of even large volumes of air.

Detection of small quantity of blood in the soft tissues of the sculp, epidural clusters, and postresection cavity is typical during surgery. Some blood can be observed in the subarachnoid spaces of the sulci and ventricular system of the brain (due to regurgitation).

It should be noted that differentiation of hemostatic agents soaked in blood from true hemorrhages is a complex problem, though the latter are characterized by a more complex signal which changes on images from different impulse sequences, and cooperative interpretation with a neurosurgeon simplifies this task.

Soft tissues of the sculp (injured muscles), dura mater, as well as cerebral parenchyma at resection margins, can demonstrate early thin reactive accumulation of the contrast agent if intraoperative scan with intravenous contrast was performed.

The result of the operation is a cavity with varying volumes of CSF, blood, and hemostatic material. These cavities can change in size with time (for example, if they are connected to the ventricular system).

During evaluation of the postresection cavity, small local areas of ischemia are commonly detected. Usually, they are adjacent and appear due to use of bipolar coagulation. For detection of this phenomenon, combined analysis of DWI and ADC maps is usually sufficient, but MRI perfusion can help if difficulties are encountered.

Ischemic areas can lead to overevaluation of the volume of residual tumor tissue if during combined analysis MRI perfusion and DW data are not considered, as a small mass effect and elevated signal on T2-wheighted images can imitate tumor tissue. Attentive analysis of all obtained data also allows to differentiate ischemic area from vasogenic edema.

Cerebral edema is an inevitable postoperative phenomenon (irrespective of the type of intervention) but in most cases this edema is not clinically relevant and is resolved with time.

The main cause of iMRI artifacts, in our experience, is disruption of magnetic field heterogeneity due to paramagnetic (even in extremely small concentrations) presence in the body (metallic particles, some plastics and more standard – titanium implants/craniofixes/instruments), enhancement of natural interfaces due to surgical intervention (postresection cavity with air, hemorrhagic component or extensive connection with cranial air cells etc.).

RESULTS

Mean iMRI examination time was 45 minutes and varied between 36 and 55 minutes. With experience of performing intraoperative scans, total time of iMRI decreased.

Preoperative tumor volume varied between 3.8 and 135 mL with mean value of 51.4 mL. According to iMRI data after primary resection, residual tumors tissue was detected in all 9 (100 %) patients. Residual tumor volume was between 0.05 (0.2 %) and 40 (44 %) mL (mean value was 7.2 mL) and did not depend on histological subtype of the tumor. Therefore, radicality of primary resection varied between 56 and 99.8 % with mean value of 84.2 %. In 3 (33.3 %) of 9 patients, volume of residual tumor was significantly higher: more than 12 % from the baseline. Analysis of these cases showed that in 1 male patient glioblastoma resection was a repeat operation and was performed after radiation therapy; 1 female patient had deep cystic-solid tumor located in the subcortical nuclei and brain stem; 1 patient had highly differentiated tumor of low volume. These characteristics could complicate orientation in the white matter causing higher volume of residual tumor.

According to postoperative MRI data, final resection radicality was 99.8 %, residual tumor tissue of minimal volume was observed in 1 patient with glioma of the thalamus and mesencephalon. No complications associated with iMRI procedures were observed. None of the patients had suppurative and inflammatory complications in the postoperative period. Summary data are presented in the Table.

CLINICAL EXAMPLES

Male patient no. 6*: 33 years. Diagnosis: intracerebral tumor of the right frontal lobe. Operation was performed: craniotomy of the frontal area, microsurgical removal of the tumor. iMRI showed residual tumor fragment on the posterior wall of the resected tumor cavity (Fig. 1). After examination, additional resection of the residual tumor tissue was performed. Histological conclusion: astrocytoma, WHO grade 2. Control MRI showed no residual tumor. Total scan time was 51 minutes.*

Male patient no. 3*: 61 years. Diagnosis: intracerebral tumor of the left frontal lobe. Intraoperative iMRI (Fig. 2) showed residual tumor fragments in the anterior and posterior parts of the resection zone. Consequently, resection of the residual fragment of the tumor was performed. Control MRI after surgery showed total resection of the tumor. Histological conclusion: glioblastoma, WHO grade 4. Scan time was 46 minutes.*

Female patient no. 7*: 27 years. Diagnosis: intracerebral tumor of the left frontal lobe. After primary tumor resection, iMRI (Fig. 3) was performed: residual fragments of the tumor*

Characteristics of patients who have undergone intraoperative MRI

Patient no.	Age, years	Gender, m/f	Tumor localization (lobe)	Tumor WHO Grade	Scanning time, min	Preoperative tumor volume, ml	Residual tumor volume, ml (%)	Residual tumor volum, ml (%)
1	64	m	Frontal	4	55	81	0.2 (0.25)	0
2	55	m	Temporal	4	48	90.2	40 (44)	0
3	61	m	Frontal	4	46	42.4	4.9 (11.5)	0
4	65	m	Insular	4	45	34.7	2.2 (6.4)	0
5	32	f	Thalamus	2	36	27	10 (37)	0.3 (1.1)
6	33	m	Frontal	2	51	18	0.05 (0.2)	0
7	27	f	The same	3	38	30.6	2.45 (8)	0
8	48	m	– « –	4	44	135	4.1 (3)	0
9	23	f	– « –	2	42	3.8	1.2 (31.5)	0

Note. *M – male, f – female.*

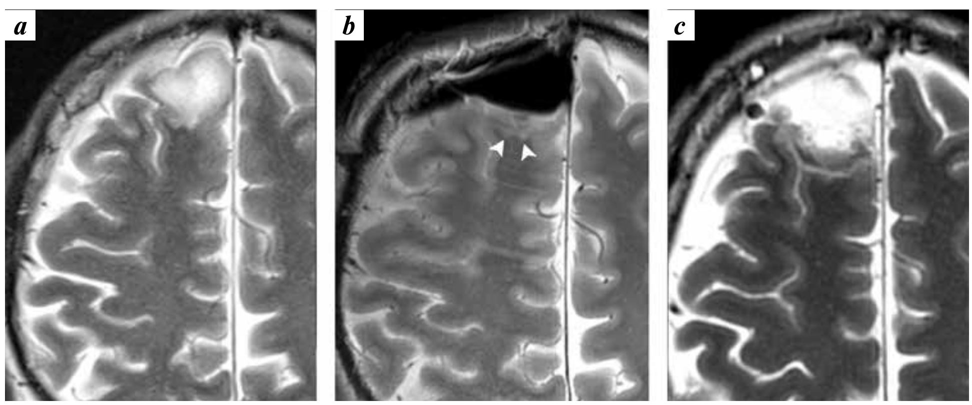

Fig. 1. *Brain MRI (Patient no. 6). Axial T2 non-contrast images: a – preoperative MRI with diffuse intrinsic frontal lobe tumor; b – intraoperative images with residual tumor (arrowheads); c – postoperative MRI, no signs of residual tumor mass after additional resection*

on the walls of the resection cavity are visible. Additional resection of pathological tissue detected during intraoperative scan was performed. Control postoperative MRI should no residual tumor tissue. Histological conclusion: astrocytoma, IDH-mutant, WHO grade 3. Intraoperative scan time was 38 minutes.

DISCUSSION

Surgeons' dissatisfaction with the radicality of performed operations in case of using standard techniques promotes search for new approaches to intraoperative control. One of such promising approaches is intraoperative neurovisualization. The first approach of this type was use of stationary and later mobile computed tomography machines. With technological advances, intraoperative CT ceased to satisfy neurosurgeons' demands due to its poor image quality, and it was replaced by MRI. One of the first reports describes intraoperative use of an open MRI machine with 0.2 T magnetic field in 1998 [7].

M. Lacroix et al. (2001) proposed the concept of maximum extent of resection (EOR). In the study (cohort of 416 patients with histologically confirmed glioblastoma and tumor resection), the authors concluded that removal of 89 % and more of baseline tumor volume is a necessary predictor of increased survival, and resection of 98 % of volume is a significant independent predictor of survival in multidimensional data analysis. A new concept was established: the larger the volume of resected tumor mass, the better prognosis in patients with glioblastoma [8]. This concept promoted intensive studies and lead to publication of data showing similar connection between resection volume, volume of residual tumor tissue, and patient survival [9–12].

Surgeon's opinion on the radicality of tumor resection can be erroneous which negatively affects treatment outcomes in the presence of residual tumor [4]. In our trial, iMRI was performed after the surgeon concluded that the tumor was totally resected. Radicality of primary resection was 84.2 %, and residual tumor tissue of varying volume was detected in all 9 (100 %) patients. All patients of the studied group underwent additional resection of residual tumor fragments which increased final radicality to 99.8 %.

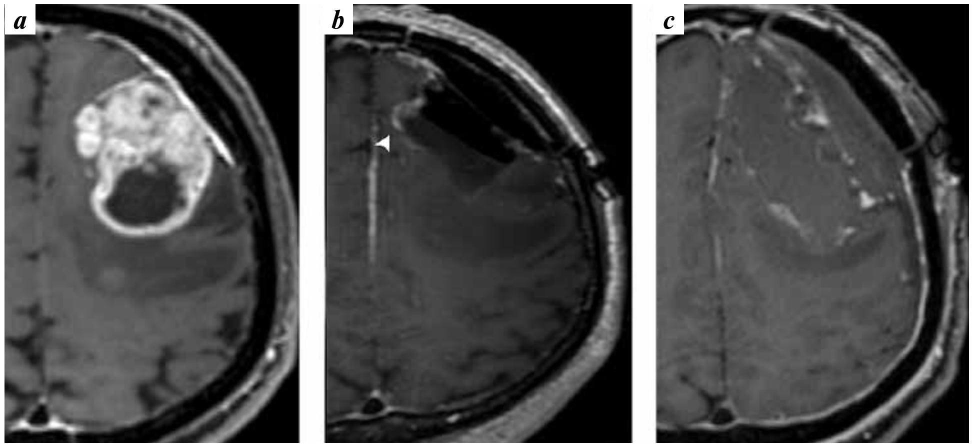

Fig. 2. *Brain MRI (Patient no. 3). Axial T1 contrast-enhanced images: a – preoperative MRI, high-grade frontal lobe tumor; b – intraoperative scan, residual tumor (arrowhead); c – postoperative MRI, no signs of tumor after additional resection*

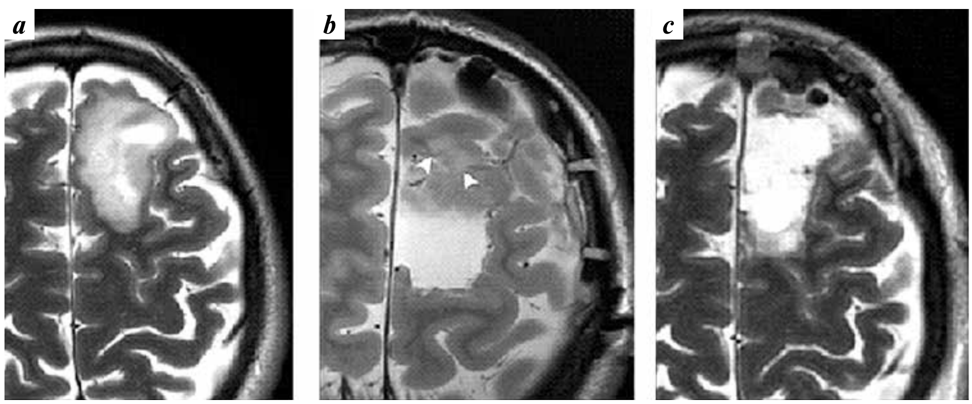

Fig. 1. *Brain MRI (Patient 7). Axial T2 non-contrast images: a – preoperative scan, frontal lobe tumor in premotor area; b – intraoperative MRI, residual tumor in anterior aspect of resection cavity (arrowheads); c – postoperative MRI with no signs of tumor after additional resection*

First quantitative meta-analysis establishing the connection between resection radicality and survival of patients with glioblastoma was published by T.J. Brown et al. (2016) [13]. the analysis included 37 articles published between January of 1996 and December of 2015 and showed that complete resection increases probability of 1-year survival by 61 % compared to subtotal resection, while 2-year survival increases by 19 %, progression-free survival for 12 months by 51 % [13]. The researchers concluded that for gliomas with low malignancy grade, increased resection volume increases survival and significantly decreases probability of recurrence (by 1.5 times) or malignization [14–16]. This is very important because residual tumor matter gradually degenerates into poorly differentiated astrocytoma which significantly decreases patients' expected life span.

Currently, the standard of postoperative control of the radicality of glioma resection is CT or MRI (with or without contrast enhancement) performed 24 to 72 hours after surgery [1, 3, 17]. These timelines result from appearance of reactive lesions of contrast accumulation in the long term after surgery which do not correspond to tumor changes; even with high filed scanners frequency of such changes can reach 30 % [17]. iMRI can minimize the number of such false positive lesions [17]. iMRI methods are superior to postoperative MRI in relation to determination of resection radicality due to lower number of artefacts. the difference can vary between 22.7 % for contrast-accumulating tumors to 37.5 % for tumors without contrast-positive fragments [17].

Intraoperative MRI allows to assess the presence of residual tumor tissue during operation when the surgeon can still change surgical tactics and selectively remove residual tumor fragments [6]. Use of iMRI leads to more frequent additional resection: in up to 70 % of cases [4, 6, 18]. The effectiveness of the approach was confirmed in a randomized study with level of evidence I: patient group with iMRI had higher operation radicality and associated survival time compared to patients who underwent standard resection with neuronavigation [6]. Additional resection was performed in 70 % of cases with iMRI use, mean volume of residual tumor was 3.16 ± 0.38 cm^3. No effect of surgeon's experience on the volume of residual tumor or frequency of repeat resection after iMRI was shown. Residual tumor volume was more common in large tumors, highly differentiated gliomas (grade 1–2), and tumors in the functionally significant areas [4, 5].

In a prospective study of the effectiveness of iMRI in glioma resection, T. Finck et al. (2020) showed that use of intraoperative visualization significantly increases the radicality of tumor resection: from 76 to 96 % [19]; in a study by M.A. Hatiboglu et al. it increased from 83 to 98 % [7]. During evaluation of the effectiveness of iMRI in patients with gliomas of the language zone, J. Zhang et al. noted that increase in resection volume from 89.8 to 95.5 % leads to two-fold increase in recurrence-free period from 6.6 to 12.5 months (the changes are statistically significant) [18]. In the study by T. Finck et al., residual tumor tissue was observed in 34.8 % of cases with iMRI, total resection was achieved in 45.2 % of patients, in 20 % of patients, tumor fragment was left intentionally as it was located in a functional zone [19].

Currently, surgery of gliomas has 2 main trends developing side by side: pursuit for increased radicality of interventions and preservation of functional status. the gold standard responsible for preservation of neurological status is neuromonitoring in all of its variations; metabolic and frameless neuronavigation is responsible for increased radicality.

Effectiveness of frameless neuronavigation is low in cases of pronounced brain dislocation associated with surgical manipulation, CSF aspiration, or cerebral edema. iMRI does not have this disadvantage as the surgeon sees the image in real time [20].

In the late 1990s, metabolic neuronavigation with 5-aminolevulinic acid (5-ALA) entered neurosurgical practice. Products of 5-ALA metabolism selectively accumulate in tumor cells and fluoresce in blue light (5-ALA FN). In a meta-analysis dedicated to comparative evaluation of the radicality of brain tumor resection, no advantages of metabolic navigation compared to iMRI were demonstrated [2]. Combination of these methods allowed to achieve maximal oncological radicality which significantly surpassed the effectiveness of standard neuronavigation [2]. Strong point of 5-ALA is better sensitivity in the tumor infiltration zone, as well as lower cost. However, 5-ALA does not accumulate in all tumors, so its use is limited (only 20 % of highly differentiated gliomas accumulate 5-ALA) [2].

During resection of highly differentiated tumors (Grade 1, 2), it is difficult to determine the margin of tumor expansion and infiltration zone. Standard control techniques (examination through a light microscope in white light, ultrasound scan, or metabolic navigation in the absence of 5-ALA accumulation) can fail to provide the necessary data. In this case, differential diagnosis can be performed using high filed iMRI machines with additional modes including DWI, PWI (perfusion-weighted MRI), MR spectroscopy [20].

However, iMRI has its weak points: increased operation time, necessity of costly equipment, presence of artifacts which can imitate residual tumor or hide infarction lesions [4, 17, 21].

Complications in evaluation of postcontrast T1-weighted images obtained using iMRI stem from differentiation between changes caused by surgical manipulations and residual tumor tissue [7]. As a result, it is advisable to move from resection to iMRI after careful hemostasis. It is very important not to leave blood clots or hemostatics in the cavity of the removed tumor [7].

Minimal residual zone of contrast accumulation on the walls of the resection cavity does not always correspond to residual tumor. Histological verification showed that such zones can appear after outflow of the contrast agent from small vessels into the cavity of the resected tumor [7].

The most common artefacts during iMRI are new area of contrast agent accumulation not associated with the tumor or areas of new hyperintensity in T2-weighted images. These changes are called reactive: they arise from the brain's reaction to surgical trauma and flow of the contrast agent from the vessels in the resection zone due to disturbed permeability of the blood-brain barrier [4, 5, 17, 22]. Use of dynamic contrast allows to reliably differentiate reactive postoperative changes from residual tumor tissue [22]. However, some researchers show that use of so-called black blood sequences allows to better evaluate such transitional areas due to some unique characteristics of iMRI [19]. Such specific problems are contrast extravasation zones, areas of blood clot formation [19].

In a study by M. Knauth et al. (1999) [23], 4 types of changes associated with surgical manipulations observed during T1-weighted contrast-enhanced iMRI were described, and these changes can be observed in 100 % of cases. Their main sign is absence of such changes in the postcontrast series obtained prior to surgery which is explained by reaction to the operation. These artifacts of contrast accumulation can be located in the dura, ventricular vascular plexuses, resection margins, parenchyma near the area of tumor resection, and are observed in 100, 13.7, 80.4, 9.8 % of cases, respectively. Leptomeningeal pattern is characterized by linear areas of paramagnetic accumulation and is observed in 100 % of patients at first scan and does not change during iMRI; in the postoperative MRI, it either becomes more intense or does not change. Enhanced contrast of ventricular plexuses at the surgery site is observed in 13.7 % of patients (in all of the patients, ventricle was dissected during surgery); it was shown that intensity of the changes does not change or increases with time. In 80.4 % of patients, linear enhancement of resection margins and increased signal from the fluid in the resection cavity was observed; during postoperative scan, these changes disappeared or became less pronounced. In 9.8 % of cases, parenchymal areas of contrast accumulation near the resection zone were observed; they do not change with time, and in most patients, they were associated with areas of electrocoagulation; in the postoperative series, such changes are not visible or are less pronounced [23].

Gadolinium-based contrast agent used in iMRI can have neurotoxic effect. In a small number of patients, for whom iMRI showed subarachnoid contrast accumulation and contrast accumulation in the resection cavity, increased frequency of focal seizures and epileptic status was observed. In all patients of this group, surgeons noted increased blood flow to the tumor and difficulty achieving hemostasis [24].

The main objective of iMRI is detection of residual tumor tissue. In surgery of contrast-positive tumors, we note the area of disruption of the blood-brain barrier – area of contrast accumulation in standard T1-weighted images. All imaging techniques should be directed towards improved detection of this particular area [19]. Despite advances in MRI, they are still not widespread in the world and in Russia, and one of the reasons is high cost of the equipment.

Compared to low filed iMRI systems, high field devices have several important advantages: better image quality and signal-to-noise ratio lead to better presentation of the perifocal infiltration zone, they allow to perform tractography and functional MRI, have shorter scan times and better spatial resolution [18, 20].

Use of iMRI can help diagnose various complications (hemorrhages, occlusion of CSF pathways) during surgery and help change operative tactics in accordance with the diagnosis [20].

Another research topic is safety during iMRI. Increased resection volume can increase risk of complications. According to data from S. Voglis et al. (2021), additional resection after iMRI leads to statistically significant increase in the volume of ischemic changes (from 0.4 to 3 cm^3 according to DWI data) around the resection area, however no effect on the frequency of neurological deficit was observed [25]. In itself, use of iMRI and subsequent additional resection, according to data gathered by many researchers, are not associated with increased neurological deficit even during interventions in functionally significant zones [4, 6, 7, 18]. One of the potential advantages of iMRI is early detection of complications, for example, ischemia or hemorrhage in the resection zone or at a distance from it [20].

Another problem associated with iMRI is intraoperative neurophysiological monitoring (IOM). IOM is successfully used in resection of various CSN tumors and allows to increase safety of the intervention and its radicality [26]. a well-known effect of metal heating during MR scan is frequently unpredictable for different devices. There are no officially approved subcutaneous electrodes for MRI, and in many clinics the electrodes are removed prior to iMRI and then reimplanted. However, this approach increases operative time and creates danger of contaminating sterile space. a study of safety of use of standard subdermal electrodes for IOM showed minimal tissue heating near the electrodes. Therefore, they can be safely used during iMRI if they are located outside the scanning coil, the patient gave their consent, and it was approved by the local ethics committee. Electrodes made of iridium and platinum cause smaller number of artifacts and lesser heating in the area of their installation [26].

CONCLUSION

Surgeon's impression of the radicality of tumor resection can be erroneous which leads to partial tumor resection and negatively affects treatment outcomes and patients' survival. Scans with intraoperative magnetic resonance imaging during resection of gliomas of the brain can increase oncological radicality without increased surgical risk. It was shown that it does not lead to complications associated with increased operative time and patient transfer from the operating room to the magnetic resonance imaging room and back.

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S.A. Melchenko: data obtaining, collection and analysis;
I.V. Senko: research design of the study, scientific editing of the article;
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