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MAPPING OF CORTICAL SPEECH ZONES AND ARCUATE TRACT IN PATIENTS WITH GLIOMAS OF TEMPORAL LOBE OF LEFT HEMISPHERE (ANALYSIS OF A SERIES OF 27 OBSERVATIONS))

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Introduction. Craniotomy in conscious patients is a possible tool for optimizing of tumor resection degree (Extent of Resection) while maintaining the quality of life. Traditionally, the main focus during these operations is on the cortical speech areas. At the same time, there is a shortage of studies on mapping of long associative tracts during the removal of gliomas of dominant speech hemisphere.
Aim. To analyze the data of intraoperative mapping and the postoperative state of speech function in patients with temporal lobe gliomas of left hemisphere (including those involving arcuate bundle) operated by the use of method of craniotomy in consciousness.
Materials and methods. Gliomas of temporal lobe of left hemisphere were removed in 27 patients aged 14 to 67 years (median age 43 years). In 10 patients, the tumor was localized in middle parts of temporal lobe (at the level of middle and upper temporal gyri), in 9 patients – in posterior parts of temporal lobe and exited into the supramarginal zone, in 8 it spread partially from temporal lobe to insular area. Gliomas of high degree of malignancy were detected in 21 patients, 6 had tumors of low degree of malignancy. Surgical intervention was performed with intraoperative "awakening". All patients underwent cortical electrophysiological stimulation in order to control localization of cortical speech zones, subcortical stimulation was performed in 21 cases to identify terminals of arcuate bundle. Speech disorders before and after surgery (on day 4–6) were evaluated by neuropsychologist using the method proposed by A.R. Luria, an automated test with the naming of pictures was additionally used intraoperatively. The average current strength of direct electrical stimulation was 3 (1.9–6.5) mA. In 12 cases, magnetic resonance (MR) tractography with construction of arcuate tract was performed before and after the surgery.
Results. Cortical temporal speech zones during intraoperative electrical stimulation were detected in 20 (74 %) of 27 patients. In 10 patients, the arcuate tract was mapped in form of appearance of mixed speech disorders in the depth of surgical wound. In 23 (85.2 %) of 27 patients in early postoperative period, an increase in speech disorders was noted of which 13 people had disorders of temporal type only and 10 people (surgery on deep posterior parts of temporal lobe) had a combination of temporal and frontal types of speech disorders (conduction aphasia). Postoperative MR-tractography (performed in 12 patients) revealed direct intraoperative tract lesion in 5 cases and ischemia of the tract area passage in 2 cases. These 7 patients had combined speech disorders after surgery. Gross sensory aphasia after surgery was manifested in 4 patients, in 2 of them ischemia was revealed according to postoperative magnetic resonance imaging, and 2 more had hemorrhagic impregnation in the removed tumor bed.
Conclusion. When removing tumors of temporal lobe in "awakening" conditions it is necessary to map speech zones not only in the cortical, but also in the subcortical area with terminals of arcuate bundle. Mapping of speech zones in these different localizations makes it possible to identify fundamentally different speech disorders.

Keywords: surgery with "awakening", gliomas, mapping, arcuate tract

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INTRODUCTION

The incidence of temporal lobe glioma reaches 29 % of all glial tumors, ranking 2nd in frequency after frontal lobe gliomas [1]. Traditionally, both in domestic and foreign literature, the main attention of neurosurgeons is associated with mapping cortical speech zones of the brain [2–6]. The anatomy of arcuate tract was described in detail more than 200 years ago by Karl Friedrich Burdach (1819–1826) and Jules Dejerine (1895). Despite this, Russian sources neither contain descriptions of large series of operations in patients with involvement of this bundle into temporal lobe tumor of left hemisphere in right-handed people with a deep analysis of pre-, intra- and postoperative speech disorders, nor describe cortical and subcortical mapping when performing craniotomy in consciousness in such patients.

In earlier publications, we desired in detail the anatomy of long associative tracts of the brain [7–9] and presented results of arcuate tract mapping in gliomas of dominant hemisphere localized in frontal lobe as well as the features of aphasia when this tract is damaged [10–11]. The present study is a continuation of previous publications by the group of authors (Acad. N. N. Burdenko National Medical Research Center of Neurosurgery, Ministry of Health of Russia), contains both analysis of a series that includes 27 patients with gliomas localized in temporal lobe of left hemisphere who underwent both cortical and subcortical mapping and analysis of intraoperative and early postoperative speech disorders.

The objective is to study the data of intraoperative mapping and postoperative state of speech function in patients with gliomas of temporal lobe of left hemisphere (including those involving arcuate bundle) operated using awake craniotomy technique.

MATERIALS AND METHODS

Removal of a temporal lobe tumor during patient's "awakening" was performed at the Acad. N. N. Burdenko National Medical Research Center of Neurosurgery of Ministry of Health, Russia, in 27 patients aged 14 to 67 years, median age was 43 years, patients" detailed data are given in Table 1.

Table 1. *Characteristics of patients in the study group, N = 27*

Variable		Number of patients, abs	Total
Sex: men women		 8 19	27
Tumor localization			
Isolated in temporal lobe (T1, T2)		10	27
Posterior zones T1 + supramarginal gyrus		9	
Temporal + insular lobes		8	
Histology			
LGG	Dysembrioplastic neuroepithelial tumor	1	6
	Diffuse astrocytomas	3	
	Oligodendrogliomas	2	
HGG	Anaplastic astrocytomas	9	21
	Anaplastic oligodendrogliomas	4	
	Glioblastomas	8	

Note. *LGG – low-grade malignancy gliomas, HGG – high-grade malignancy gliomas.*

Before as well as on the 4th–6th day after the surgery all patients underwent Luria's neuropsychological testing [12]. to a greater extent, the examination represented qualitative side of cognitive impairments and their main mechanism which made it possible to construct an individual rehabilitation plan in the future and first of all it concerned the nature of speech disorders. The detailed set of techniques for neuropsychological research was identical to the one we described earlier [11].

It should be emphasized that when testing patients with temporal lobe tumors, presenting of an enumeration of automated rows (counting from 1 to 10, months and days of the week) is not valid as a speech load because the patient, even with gross damage to temporal lobe, as a rule, does not lose the ability to automated speech. On this basis, as the main speech load we used the naming test ("a golden standard") of 50 simple black-and-white pictures of objects, less often 50 pictures of actions [13], because with temporal lesions objects naming is primarily disordered [12]. The naming of actions as a facilitated test was presented to some patients who already had partially impaired speech before the operation. The image display program was automated. When showing each picture, the patient said, for example: "It is an aquarium." The presence of "it" pronoun made it possible to distinguish whether the patient had forgotten the word or could not speak at all (speech stopping). In addition to naming pictures, when the tumor spread to the posterior parts of temporal lobe, the patient was presented with words and syllables with oppositional phonemes for repetition, for example, "daughter – dot" (in *Russ.* "dochka – tochka"), 20 pairs in total, to test phonemic hearing. Also, during tumor removal, a free dialogue with the patient was continuously conducted.

All patients underwent magnetic resonance imaging (MRI) with contrast before surgery, computed tomography – in the early postoperative period, review MRI – according to indications. MR tractography with construction of arcuate tract was performed in 12 cases before and after surgery. The relationship between the arcuate tract and glioma (intact, infiltration or dislocation of fibers) was evaluated, after surgery we evaluated tract rupture and ischemia in the perifocal zone.

Surgical intervention was performed with intraoperative patients' "awakening" according to the protocol of anesthesia asleep–awake–asleep. All 27 patients underwent cortical electrophysiological stimulation and 21 patients underwent the subcortical one in order to control the localization of functionally significant structures and clarify the permissible volume of resection. to control the appearance or increase of epileptiform activity due to electrical stimulation after opening the dura mater, an 8-pin electrode was installed on cerebral cortex to register an electrocorticogram in such a way that it did not interfere with surgical manipulations, usually subdural, outside the trepanation window, on temporal lobe cortex.

Electrical stimulation was carried out by single rectangular pulses of 1 ms duration with stimulus frequency of 50 Hz (according to Penfield). The stimulus amplitude was 4 mA in most cases. If the patient had typical epileptiform components in the initial electrocorticogram (before the start of stimulation), the stimulus strength was decreased to 2 mA. When a negative effect was obtained at the standard level of stimulation, then the repeated testing was carried out on the cortical area where speech zone was presumably localized according to functional MRI. At the same time, the stimulus strength was increased to 5 or 6 mA. A standard bipolar 2-pin electrode was used as a stimulating probe.

During the tumor removal, continuous dynamic electrical stimulation was performed using a special ring electrode connected to a vacuum aspirator. Monopolar cathode stimulation was carried out with the same technical parameters as during cortical stimulation. The reference electrode (anode) was located at the point Fz. The stimulus strength during subcortical stimulation ranged from 2 to 4 mA (initially a current of 4 mA was supplied, with the appearance of speech disorders, the current strength was reduced to 2 mA). After appearance of speech disorders during dynamic monopolar stimulation, more selective bipolar stimulation was used to clarify localization of the white matter pathways (bipolar probe, current from 4 to 8 mA).

RESULTS

Before surgery. The nature of complaints and cognitive status before surgery directly depended on the detected tumor malignancy degree. In patients with glioblastomas, acoustic-mnestic aphasia was mainly detected; in anaplastic gliomas – a combination of epileptic seizures and speech disorders (by the type of acoustic-mnestic aphasia), and in gliomas of low malignancy an epileptic syndrome prevailed. Also in all patients, without exception, the auditory-speech memory displayed deterioration of various degrees. All patients were right-handed according to self-assessment.

The ratio of arcuate bundle and the tumor evaluated according to MR-tractography, is given in Table 2. The term of "infiltrated" means that the tract does not stretch before surgery, it is located in the tumor zone but there are no or almost no speech disorders; the term "dislocated" means that it is located on the tumor periphery and is deformed due to its growth; the term "damaged" means that it is not stretched after surgery, it was in the tumor zone and speech disorders have appeared. It should be noted that anisotropy degree of MR-tractography before and after surgery was the same.

Table 2. *Magnetic resonance tractography with reconstruction of left arcuate tract before and after surgery*

The state of the tract	Before surgery	After surgery
Intact	5	3
Infiltrated	3	0
Infiltrated + dislocated	3	1
Dislocated	1	1
Damaged	0	7
Total:	*12*	*12*

It can be seen from Table 2 that MR-tractography before surgery revealed 5 cases with an intact tract and less often – infiltrated and dislocated arcuate bundles. At the same time, according to postoperative MR-tractography, out of 7 identified cases of the tract damage 5 were direct rupture (by microsurgical instruments) and 2 were indirect (ischemic).

The MR-tractography performed before surgery made it possible to plan the volume of the upcoming tumor resection. So, for example, when according to MR-tractography tumor infiltrated the arcuate tract then before the surgery it was assumed that it would not be possible to completely remove the tumor since this part of the tract can retain its functions. When according to MR-tractography the tract was intact (it was not a part of the tumor) then the tumor was planned to be completely removed.

When analyzing the size of the tumor on the basis of preoperative MRI, medium and large tumors (from 3.0 to 7.5 cm) were noted in 22 cases.

Research during surgery. During surgery of 27 patients, electrostimulation revealed speech zones in 20 patients, not revealed in 7. of these, 1 patient with glioblastoma was taken for an operation with "awakening" with already pre-existing clear acoustic-mnestic aphasia which made the test data unreliable. In another 4 patients, upon awakening (in the presence of preoperative non-rough speech disorders), only automated rows and free dialogue were used as speech load without valid naming tests. In 1 patient with tumor of frontotemporal localization (grade III) without speech disorders before surgery, the speech zones may not have entered the trepanation window. Another 1 patient with an extensive tumor of the temporo-insular region with long-term general convulsive attack had no speech disorders during stimulation of temporal lobe cortex, but during stimulation of zone of insular lobe base this patient's consciousness became confused and he was given general anesthesia.

In the remaining 20 patients, temporal speech zones were detected, and, that is very important, different speech effects were observed depending on temporal lobe zone stimulation.

During electrostimulation of patients with tumors in *middle parts of temporal lobe* (upper and middle temporal gyrus) the typical pattern of speech disorders by the type of acoustic-mnestic aphasia was observed [12]. When naming pictures (more often objects) during electrical stimulation of both the cortical and deep parts of temporal lobe, the patients forgot words, they had literal paraphasia, sometimes there were rough difficulties with understanding instructions (patients asked them again). Word searches were also noted with free dialogue, but the patients repeated the automated rows well. During testing, 1 patient of this group had frequent focal epileptic seizures during electrical stimulation confirmed by EEG data, that is why testing had to be stopped.

The most interesting test results were obtained in patients with tumor localization *in posterior temporal lobe* with its spread to *supramarginal gyrus*. When electrostimulation of cortex in the patients, as in those of the previous group (with tumors of middle parts of temporal lobe), naming disorders were noted in the form of forgetting words and literal paraphasia's. However, with electrical stimulation of subcortical area (at depth of about 2.5 cm) during the tumor removal, the pattern changed fundamentally: motor speech disorders were additionally observed. The patients experienced difficulties with the beginning of pronouncing a word up to speech stopping (as with stimulation of the Broca's zone), in mild cases "stumbles" were detected when naming and perseverating words and syllables, some patients began to "stretch" words and speak them by syllables. That is, when deep posterior parts of temporal lobe were stimulated, there were revealed speech effects that were very similar to those when the Broca's area of frontal lobe was stimulated (the so-called conductor aphasia). The topography of the electrode location corresponded to projection of arcuate tract that was confirmed by the data of postoperative MR-tractography in some patients.

During intraoperative electrical stimulation of patients with tumors of *temporal lobe that partially extended to insular lobe*, word forgetting and literal paraphasia also occurred. When the stimulation zone is shifted closer to insular lobe then there were individual effects of tongue "numbness" with impossibility of its voluntary movement or, conversely, clonic twitching of the tongue.

Research after surgery. Speech disorders after surgery were not detected in 2 patients only: in a patient with an anaplastic astrocytoma of temporomandibular region and in 14-year-old boy with a dysembrioplastic neuroepithelial tumor (grade I). In them, the speech zones were not revealed by electrostimulation during surgery. Another 2 patients with glioblastomas of middle parts of temporal lobe did not show any increase in speech disorders that existed those before surgery in the form of acoustic-mnestic aphasia.

When tumor was located in *middle parts of temporal lobe* as well as in case of tumor spread to *insular lobe*, an increase in acoustic-mnestic aphasia with forgetting words and describing objects on functional basis was revealed in 9 patients, as expected. In 4 patients, the speech disorders after surgery were gross and characterized as acoustic-gnostic (sensory) aphasia – the patients' speech resembled verbal hodgepodge, was replete with literal paraphasia and speech comprehension and phonemic hearing were disordered. Tumors in this group of patients were extensive and occupied large volume of temporal lobe; in 2 patients of them the focal ischemia was confirmed and 2 more had hemorrhages in the removed tumor bed.

After surgery, in10 patients the speech disorders had a complex nature, namely: there were signs of damage to the temporal and frontal lobes, i. e., acoustic-mnestic aphasia was combined with distinct motor component of speech impairment. In 7 of them, the tumor was located in the *posterolumbinal parts* of left temporal lobe with partial transition to *supramarginal gyrus*, and, in the rest of them, the tumor captured large volume of left temporal lobe. Upon awakening, motor effects were also observed in these patients.

Out of 10 patients with conductor aphasia, MR-tractography was performed in 7 cases after surgery: 5 patients revealed direct damage of arcuate tract (torn), in 2 more cases there was marginal ischemia in the removed tumor bed with absence of fibers in the tract passage area (see Table 2).

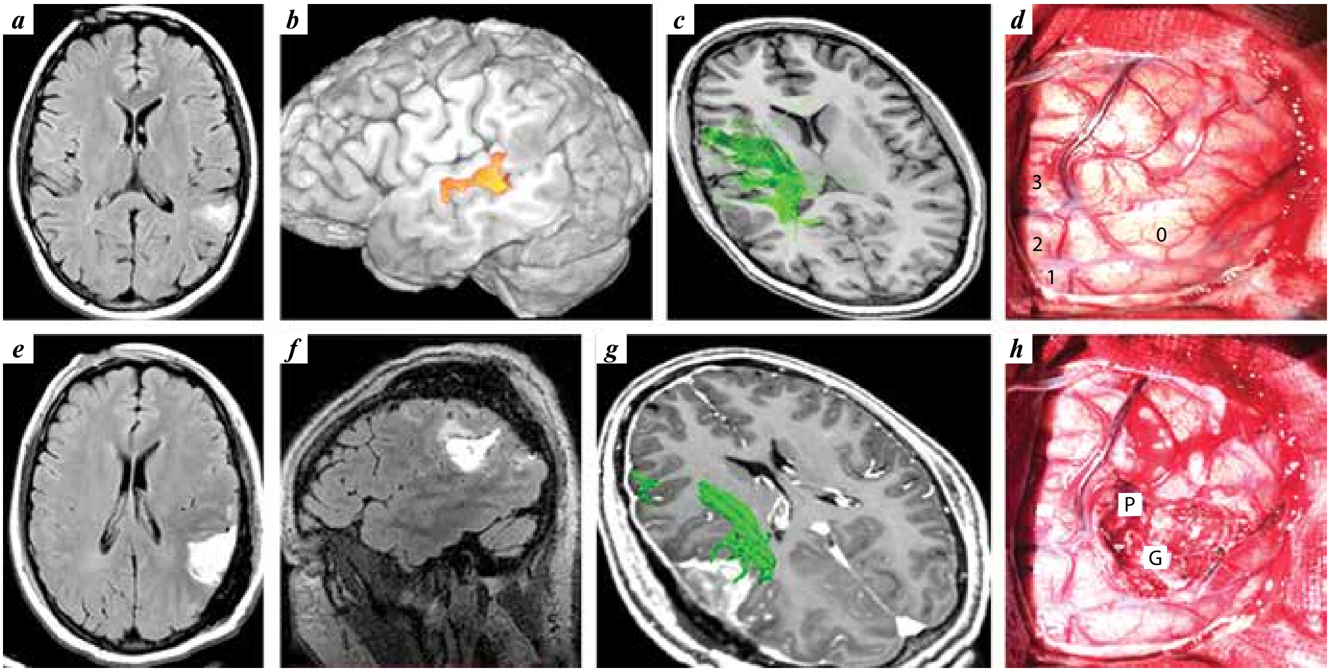
CLINICAL EXAMPLE

Patient R., 32 years old, oligodendroglioma (grade II) in left temporal lobe and supramarginal gyrus of parietal lobe. From anamnesis: I began to note that lately, at the slightest distraction, I immediately forgot what I had read.

Neuropsychological examination before surgery. *Speech and writing are preserved. There is a distinct decrease in auditory-speech memory in the delayed link.*

Intraoperative monitoring (awake craniotomy). *With electrical stimulation of the cortex (current strength 4 mA) anteriorly from the tumor in the posterior parts of superior temporal gyrus (see zone 2 in Figure, d) literal paraphasia have been identified. At the end of the tumor resection in combination of continuous subcortical electrical stimulation (current strength 4 mA) with free dialogue in the posterior parts of temporal lobe at a depth of about 3 cm a clear motor component of speech disorders was revealed – perseveration of words and syllables until complete impossibility to start pronouncing the word – speech stops (zones G and P in Figure, h). At this point, the tumor removal was stopped.*

Neuropsychological examination after surgery. *In the patient we revealed sings of temporal acoustic-mnestic aphasia (she forgot the name, but described the subject) in combination with frontal motor aphasia (an abundance of perseverations,*



Magnetic resonance imaging (MRI) performed ***before surgery:*** *a) FLAIR, axial sections, b) Wernicke's functional MRI zone (anterior to the tumor) (given in orange), c) MR tractography: an arc – shaped bundle (intact) located along the posterior border of the tumor and closely it is attached to it (given in green);* ***during the intraoperative period:*** *d) 0 – projection of the tumor, 1 – middle temporal gyrus, 2 – Wernicke zone, 3 – lower parietal lobule; h) G, P – arcuate tract;* ***after surgery:*** *e, f) FLAIR, axial and sagittal sections, g) MR-tractography: arc-shaped bundle (given in green)*

including when writing – an agraphia, because of the perseverations she could not even write her last name), conductor aphasia that coincided with lesion of arcuate tract (see in Figure, g).

DISCUSSION

The history of "awake" neurosurgical operations originates in the works of W. Penfield, G. Jasper, O. Foerster, etc. In later years, these studies were continued in Europe and USA by such outstanding neurosurgeons as Hugues Duffau (Salle-Petrier Clinic in Paris, since 2006 – University of Montpellier) and Mitchell S. Berger (University of San Francisco). In our country, the first awake craniotomy was performed by neurosurgeon Prof. V. A. Loshakov and anesthesiologist Prof. A. Y. Lubnin in 1996. At a later date, these operations began to be performed more frequently at the Neurosurgery Center, and the complications of these interventions were analyzed [4]. Later, works on the use of craniotomy when patient's consciousness were also published by authors from other clinics [6].

However, the main attention of the authors regarding functional mapping of speech during these operations, according to their domestic publications, was given to search for cortical speech zones (Broca and Wernicke area). At the same time, much less attention during operations with "awakening" was paid to the most important of the long associative tracts – the arcuate bundle connecting these areas with each other. In 2018, we have analyzed the mapping of this bundle in gliomas of frontal lobe of left hemisphere [10].

Numerous cases of transient postoperative aphasia during surgical resection of gliomas located in speech-dominant hemisphere with "awakening" have been described in the literature [14–16].

The posterior temporal-parietal region of dominant in speech left hemisphere is a complex anatomical and functional brain area which includes intersection of various long associative tracts. In this regard, according to the literature, this area is designated by term "hot spot" [17–18].

According to data by A.S. Kulikov et al. (2015), in 16 % of cases during craniotomy in consciousness, a deterioration in the neurological status was noted, most often associated with anatomical damage to the pathways or ischemic damage to the fibers of the inner capsule. This may be due to an underestimation of neurosurgical risk and especially due to risk of ischemic injury as well as insufficient use of subcortical electrical stimulation of the pathways [4]. In our series, 6 patients with direct damage to the arcuate tract during surgery had no or insufficiently thorough subcortical electrical stimulation.

Significantly fewer publications concern analysis of complex speech syndrome seen in postoperative period after craniotomy in consciousness. The speech syndrome in case of injury of arcuate tract displaying a combination of features of temporal and frontal lesions was described by us earlier in a smaller group of patients and was interpreted as conductive aphasia due to arcuate tract injury [10–11].

The present work is a continuation of accumulation and analysis of observations from patients with brain gliomas who underwent craniotomy in consciousness. The peculiarity of our series is localization of the tumor in temporal lobe of dominant in speech left hemisphere, as well as the use of subcortical mono- and bipolar electrical stimulation for mapping of posterior portion of arcuate tract and thorough analysis of pre-, intra- and postoperative speech disorders. As a result of the present work, it was found that the nature of speech disorders depended on the tumor localization within temporal lobe. When the tumor was located in the posterior temporal region, especially when it spreads to the subcortical area, there was a possibility of damage to the arcuate tract during the surgery. Therefore, speech disorders in some patients were limited by exclusively temporal symptoms (forgetting words), while others had speech symptoms "at a distance" – frontal symptoms (perseverations) caused by damage to the posterior part of arcuate tract passing in temporal lobe; i. e., the so-called conductor aphasia was detected.

Previously, J.M. Anderson et al. [19] and J.P. Zöllner et al. [20] also found symptoms typical for conductor aphasia in case of subcortical electrical stimulation in the posterior parts of left temporal lobe and the angular gyrus in patients with epilepsy. It is important that speech disorders having different mechanism required development of different rehabilitation programs.

Gross sensory aphasia after surgery was noted in 4 patients. of these, in 2 patients, according to postoperative MRI, was revealed ischemia, and 2 more had hemorrhagic impregnation in the removed tumor bed. According to our data, the occurrence of ischemia, hemorrhagic impregnation and edema in the surgery area led to a worsening of speech disorders after surgery. However, this issue needs further study.

CONCLUSIONS

1. When intracerebral tumors are localized in the middle and posterior parts of temporal lobe of left hemisphere, it is advisable to perform MR-tractography with construction of arcuate bundle to assess its relationship with the tumor.
2. When removing glial tumors of temporal lobe of left hemisphere, it is necessary not only to employ electrostimulation mapping of cortical speech zones, but also to apply subcortical stimulation of arcuate bundle and its terminals located in the middle and posterior parts of this lobe.
3. Stimulation at the subcortical level can be carried out simultaneously with tumor removal by the use of monopolar electrode attached to the body of the surgical aspirator. At the same time, intraoperative speech effects may be diverse and may include both isolated temporal components and combination of temporal and frontal speech disorders due to stimulation of the arcuate tract terminals.
4. The postoperative pattern of speech disorders, their severity and nature depend on the tumor localization in temporal lobe (in the middle or posterior parts), involvement of the arcuate tract and its anatomical and functional state after the tumor resection.

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S.B. Buklina: data collection and analysis, writing an article;
R. Afandiev: data collection and analysis;
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