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Treatment of drug-resistant epilepsy associated with temporal lobe cavernomas

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Pharmacoresistance (drug-resistance) occurs in 40 % of cases of structural epilepsy associated with cavernous malformations. The surgical strategy in the treatment of such patients aims, on one hand, to eliminate the epileptogenic focus and achieve seizure control; on the other hand, to remove the cavernoma and eliminate the risk of recurrent hemorrhage. The following surgical options are identified: 1) removal of only the cavernous malformation; 2) microsurgical removal of the cavernoma with a perifocal area of hemosiderin and a zone of gliosis; 3) stereotactic radiosurgery method. In cases of temporal cavernoma, anterior medial temporal lobectomy is highlighted as an additional method of surgical treatment. This localization requires a special approach to the choice of surgical strategy depending on the location of the cavernoma in relation to the structures of the hippocampal complex, the presence of secondary epileptogenic foci and the duration of epilepsy.

Aim of the work – to analyze the current data on the examined topic, aspects of surgical treatment of patients with structural focal epilepsy associated with cavernomas, using the example of three clinical cases.

Clinical examples are presented based on data from three patients operated on at the Federal Center of Brain Research and Neurotechnologies of the Federal Medical Biological Agency (FMBA) of Russia between 2022 and 2023. A literature review was conducted on treatment options for this category of patients. Articles were searched on the scientific platforms PubMed, Cochrane Library, eLIBRARY. RU, and the Journal of Neurosurgery, using the following search terms: cavernous malformation, structural epilepsy, temporal focal epilepsy.

Keywords: structural focal epilepsy, cavernous malformation, drug-resistant epilepsy, temporal lobe epilepsy, epilepsy surgery

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BACKGROUND

Vascular pathology is the underlying cause of the disease in approximately 6 % of patients with structural focal epilepsy [1]. Cavernoma is a vascular malformation consisting of a collection of vascular cavities separated by thin-walled septa – embryologically reduced capillaries. In 40–70 % of cases, cavernomas manifest with epileptic seizures; in the absence of surgical treatment, 40 % of patients develop drug resistance [2–4].

The key elements of pathogenesis in the formation of an epileptogenic lesion in cavernomas are hemorrhage with hemosiderin deposition and mass effect. The leakiness of the endothelial tissue containing hemoglobin breakdown products, the penetration of iron compounds into surrounding brain tissue, and the generation of free radicals lead to chronic irritation, gliosis of adjacent areas of the cerebral cortex, and ultimately, the initiation of epileptogenesis [5–7].

In the concept of further development of the disease, the main role is given to the structures of the limbic system, the formation of secondary foci in the mesial parts of the temporal lobe, which can be considered as a “double” pathology [8–10].

There are three possible pathogenesis of epilepsy in patients with cavernoma:

- cavernoma-associated epilepsy – with signs of a seizure onset zone in close proximity to the cavernoma;

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- probably cavernoma-associated epilepsy – focal epilepsy arising from the same hemisphere as the cavernoma, but not necessarily in its immediate proximity (given that there is currently no evidence to suggest other causes of epilepsy);
- cavernoma-independent pathology, which is defined as epilepsy in a patient with at least one cavernoma and a proven absence of a causal relationship between them [5].

The aim of this study is to analyze the current data of the examined topic as well as the aspects of surgical treatment for patients with structural focal epilepsy associated with cavernomas, using the example of 3 clinical cases.

We present the clinical cases of three patients operated on at the Federal Center of Brain Research and Neurotechnologies of the FMBA of Russia between 2022 and 2023, as well literature review focused on treatment options for this patient population. Articles were searched on the scientific platforms PubMed, Cochrane Library, eLIBRARY. RU, and the Journal of Neurosurgery using the following terms: cavernous malformation, structural epilepsy, and temporal focal epilepsy.

CLINICAL CASE 1

Female patient Kh., *69 years old, contacted to the Federal Center of Brain Research and Neurotechnologies of the FMBA of Russia with complaints on paroxysmal episodes, accompanied by numbness, disorientation, and loss of consciousness, lasting up to 10 seconds. These episodes typically occur during the daytime, with a frequency ranging from twice a day to twice a week. They began to bother her about a year ago. She was prescribed a regimen consisting of two anticonvulsant drugs.*

While examination in the neurology department during a period of overnight video-electroencephalographic (video-EEG) monitoring, a paroxysmal episode was recorded. Based on clinical and electroencephalographic correlations, this episode was interpreted as a focal motor epileptic seizure with typical automatisms and an onset zone in the left temporal leads (Fig. 1).

Based on the data of brain magnetic resonance imaging (MRI), according to the epilepsy protocol, magnetic resonance (MR) signs of a cavernous malformation in the anterior pole of the left temporal lobe (type II according to the Zabramski classification) were revealed (Fig. 2, a, b).

Taking into account the localization of the cavernous malformation in the area of the left temporal lobe and the duration of epilepsy less than 1 year, the surgical treatment was performed – Taylor resection of the cavernoma with a perifocal area of hemosiderin (data from postoperative MRI and histological examination are shown in Fig. 2, c, d).

The postoperative neurological status remained unchanged. The patient was discharged seven days after surgery. No seizures were recorded during the two-year follow-up period, despite continued anticonvulsant therapy.

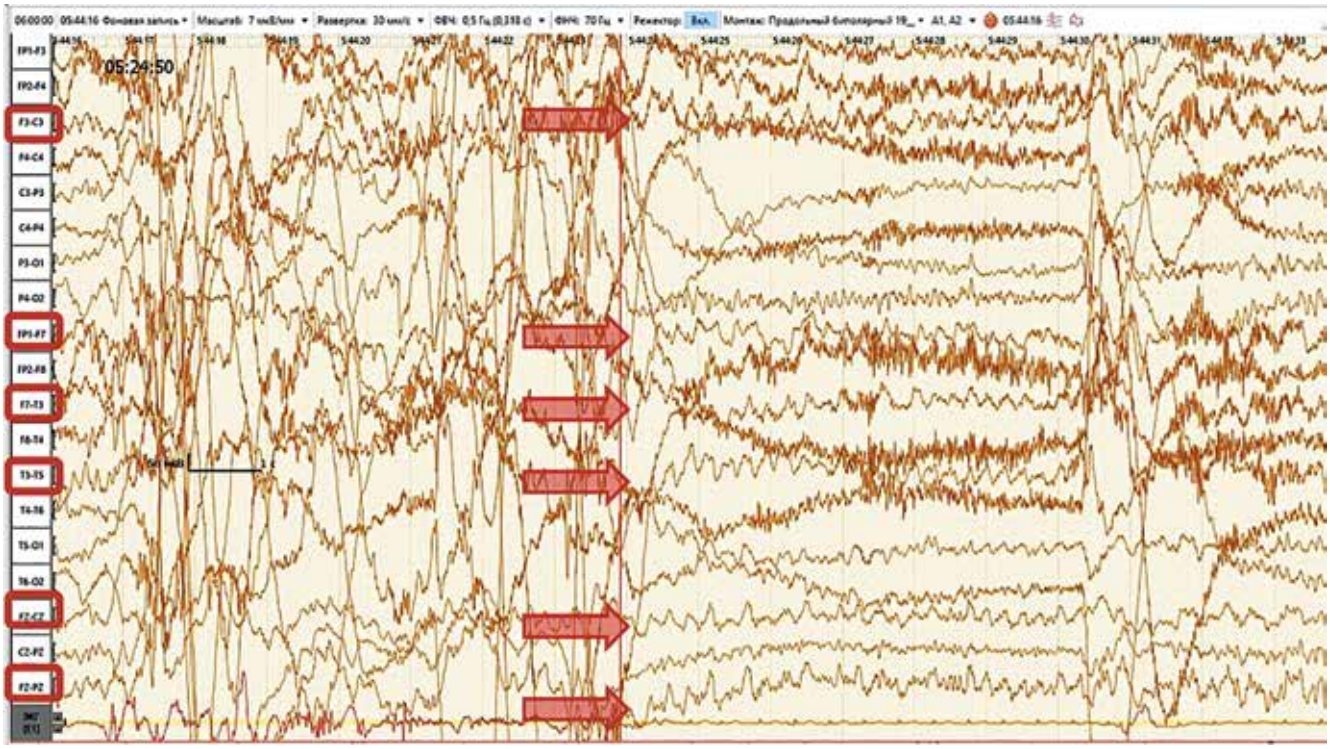

Fig. 1. *Scalp encephalographic monitoring of female patient Kh. Focal motor epileptic seizure was detected beginning with diffuse suppression of the rhythmic activity (with interposition of myographic artefacts complicating interpretation of the data) with subsequent registration of rhythmic low-amplitude slowing in the left temporal area with advancement into the left frontocentral area*

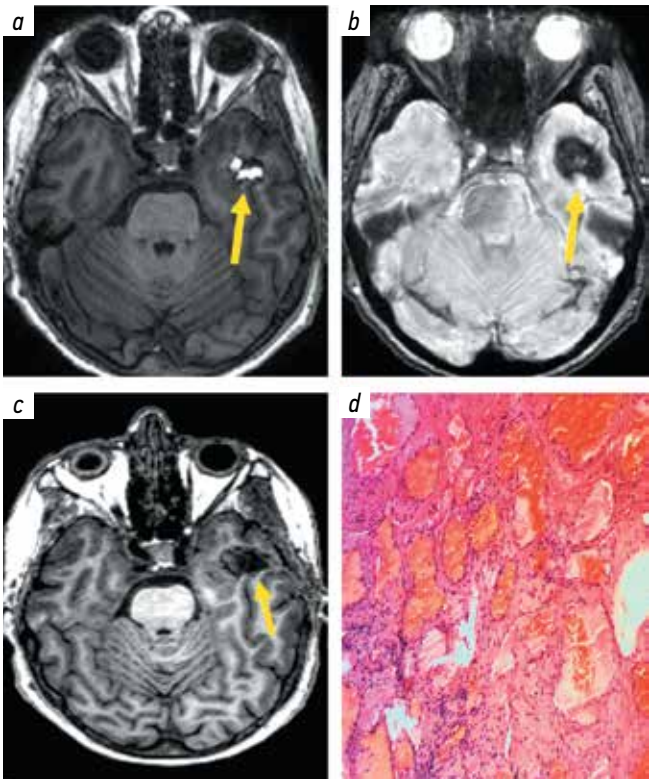

Fig. 2. *Examination of female patient Kh.: a, b – contrast-enhanced brain magnetic resonance imaging (MRI) according to the epilepsy protocol before surgery, T1-weighted (a) and SWAN (b). Cavernoma of the anterior basal parts of the left temporal lobe is observed (yellow arrows); c – brain MRI according to the epilepsy protocol after surgery. In the area of the anterior pole of the left temporal lobe (yellow arrow) in place of cavernous malformation postoperative cavity is observed; d – histological examination (hematoxylin and eosin staining, ×100): cavernoma – fragment of pathologically altered vessels per the cavernous type, venous-type wall with formation of connected cavities (caverns)*

Follow-up examinations at 6 and 12 months postoperatively revealed no epileptiform activity.

CLINICAL CASE 2

Male patient A., *33 years old, contacted to the Federal Center of Brain Research and Neurotechnologies of the FMBA of Russia complaining of "freezing" seizures accompanied by tonic-clonic convulsions in the right upper limb, most often occurring while wakefulness. At the time of admission, the patient had been ill for nine years.*

The patient was preliminarily examined in the neurological department: according to scalp video-EEG monitoring (48 hours), epileptic seizures were recorded with the seizure onset zone in the left temporal region (Fig. 3).

During brain MRI according to the epilepsy protocol (3 Tesla tomograph), a round focal formation of a non-homogeneous hypointense structure in all MRI sequences was determined in the structure of the uncus of the left hippocampus, with a cloud-like deposition of hemosiderin along the contour, measuring 6 × 4 × 5 mm, which presumably corresponded to a cavernoma with a rupture (type II according to the Zabramski classification) (Fig. 4).

Taking into account the long-term course of epilepsy, the localization of the cavernoma in the area of the anteromedial structures of the temporal lobe with a high probability of secondary damage to the structures of the hippocampal complex, the decision was made for surgical treatment including anterior medial temporal lobectomy with amygdalohippocampectomy on the left.

The neurological status after surgery was unchanged. Histological findings revealed dual pathology: a cavernoma with concomitant sclerotic changes in the hippocampus (Fig. 5).

According to electroencephalography data there was no epileptiform activity after 6 months (with continued video-EEG monitoring); there were no seizures in the postoperative period. However, after 7 months, a relapse occurred in the form of one bilateral tonic-clonic seizure following abrupt discontinuation of antiepileptic medications. Upon returning to therapy, the patient has not had any further seizures over a 3-year follow-up period. Follow-up EEG monitoring revealed no epileptiform activity.

CLINICAL CASE 3

Male patient K., *30 years old, contacted to the Federal Center of Brain Research and Neurotechnologies of the FMBA of Russia with complaints of bilateral tonic-clonic seizures, beginning with disorientation, followed by loss of consciousness, falling, turning the head to the left and upward, with tongue biting and urination, occurring daily with a frequency of up to twice a day. Episodes began at age 7, and treatment was initiated at age 11. Until age 20, the seizures were uniform; at age 20, a bilateral tonic-clonic component developed, and the frequency of seizures increased. The disease duration at presentation was 23 years.*

Based on the results of scalp video-EEG monitoring in the wakefulness state, multiregional epileptiform activity was recorded: in the right and left temporal regions as well as right posterior frontal-central-vertex leads

Based on the brain MRI data according to the epilepsy protocol, the small foci of structural changes with the presence of gliosis and hemosiderin deposits along the periphery were determined in the basal regions of the right temporal lobe (lateral occipitotemporal gyrus), measuring 8 × 12 × 9 and 4 × 3 × 5 mm, respectively, which was assessed as a cavernoma with signs of previous hemorrhage (Fig. 6).

Due to the lack of clear seizure lateralization, invasive video-EEG monitoring with the placement of depth electrodes was performed, taking into account positron emission tomography (PET) data combined with MRI. During the monitoring period (4 days), 5 focal motor epileptic seizures with or without transition to bilateral tonic-clonic seizures with initiation from the right hippocampus and 12 clinical focal motor epileptic seizures with initiation from the left hippocampus and left amygdala were recorded (Fig. 7).

Therefore, given the bilateral localization of two independent epileptogenic foci in the right and left temporal regions, the surgery would not have resulted in sustained remission

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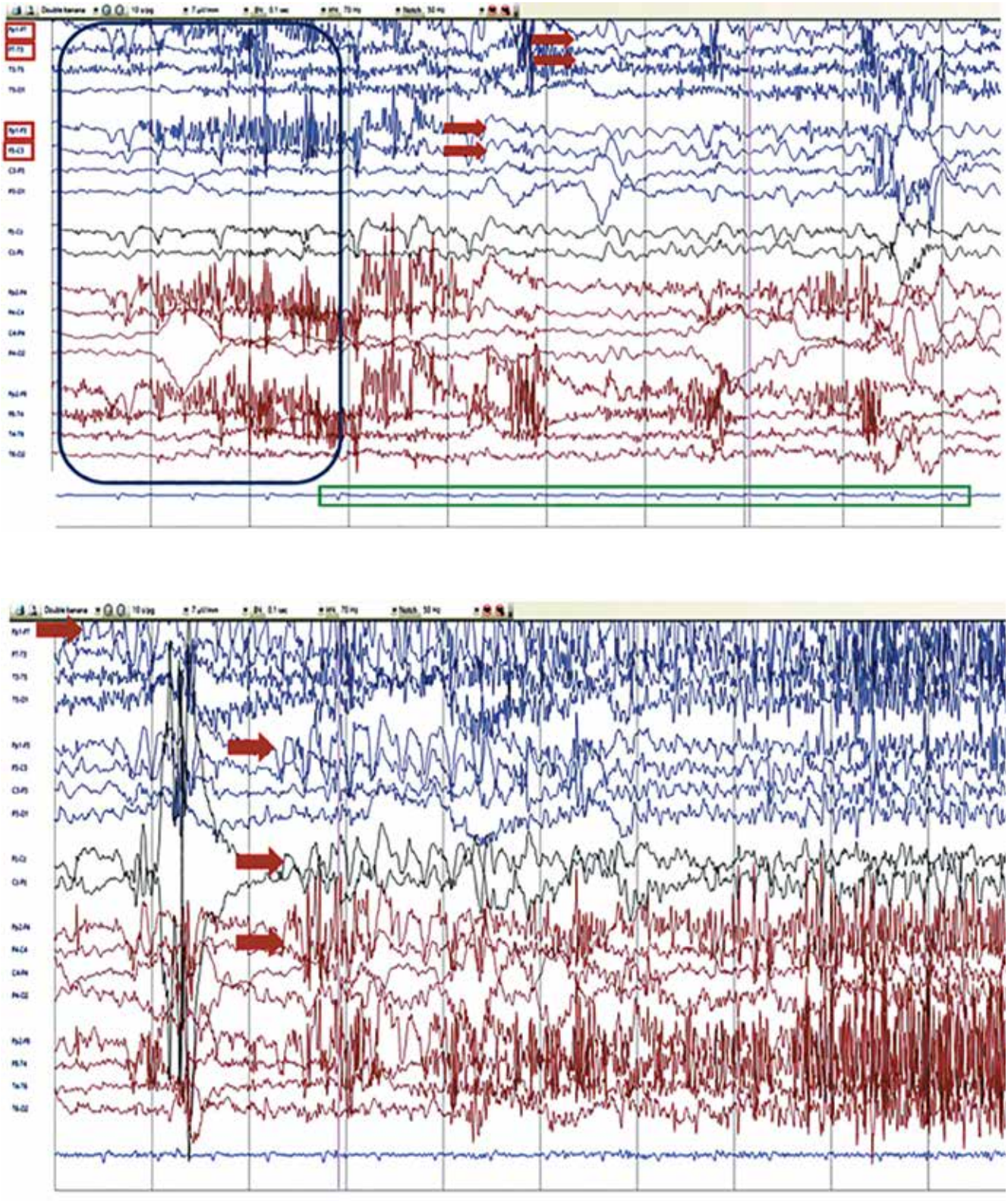

Fig. 3. *Scalp encephalographic monitoring of patient A. At the beginning of seizure, diffuse suppression of the rhythm with interposition of myographic artefacts (blue frame). In the electrocardiography channel, increased heart rate to 90 BPM (green frame). Appearance of regional rhythmic slowing in the left frontotemporal area (red arrows). Transformation of regional slowing to rhythmic sharp-wave activity in the left frontal and temporal areas with subsequent evolution in frequency and amplitude, advancement into the central area and right frontotemporal area (red arrows)*

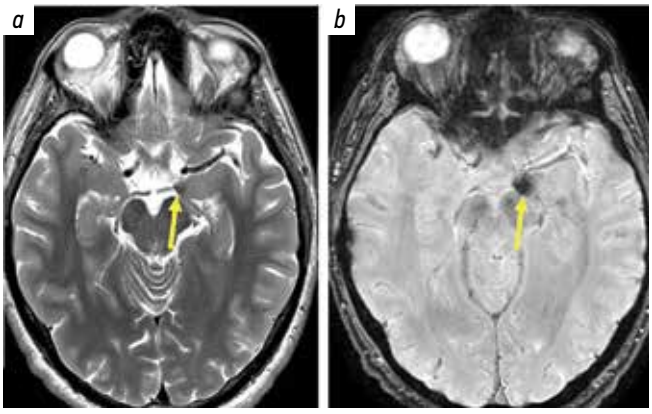

Fig. 4. *Contrast-enhanced magnetic resonance imaging of the brain of patient A. according to the epilepsy protocol, T2-weighted (a) and SWAN (b). Cavernoma of the left temporal lobe uncus with non-homogenous hypointense structure in all MRI sequences, with cloud-like accumulation of hemosiderin on the margins, size 6 × 4 × 5 mm (yellow arrows)*

in this patient. To reduce the frequency of seizures, a vagus nerve stimulator was implanted to this patient.

LITERATURE REVIEW AND DISCUSSION

The following surgical treatment options are available for structural epilepsy associated with a cavernous malformation located in the temporal lobe:

- removal of the cavernous malformation alone;
- microsurgical removal of the cavernoma with a perifocal hemosiderosis and gliosis zone;
- anterior medial temporal lobectomy with amygdalohippocampectomy;
- stereotactic radiosurgery.

In patients with a non-ruptured brain cavernous malformation, the 5-year risk of developing a first seizure is 4 %, after rupture – 6 % [7]. The five-year risk of developing epilepsy after a first epileptic seizure is 94 % [11]. In the study of D.N. Okishev et al., the data from 302 patients with supratentorial cavernomas, 79.6 % of whom had generalized tonic-clonic seizures, were analyzed.

In 49 % of cases, hemorrhage from a cavernous malformation has been established [12]. The type of surgical treatment may be chosen depending on the frequency of seizures, the location of the cavernoma, and the duration of epilepsy. Assessing the expected risk of hemorrhage is also an important factor in decision of cavernomas surgical treatment.

The preferred treatment option for patients with drug-resistant cavernoma-associated epilepsy is microsurgical resection of the cavernoma with a perifocal hemosiderosis, which allows complete elimination of the epileptogenic potential and prevents the recurrent hemorrhage. Cavernomas themselves are believed to contain no neuronal structures and are not intrinsically epileptogenic.

Therefore, hemosiderin plays a key role in cellular hyperexcitability and seizure onset [13]. Extended resection of the perifocal hemosiderosis and gliosis zone has been shown to result in better seizure control than excision of the cavernoma alone. Accordingly, depending on the location and morphology of the malformation, as well as the anatomical proximity to functionally significant zones, a maximally radical resection of the lesion should be performed [3, 5, 8, 12–16].

In meta-analysis by D. Ruan et al., which included data from 594 patients, class I outcome according to the Engel scale was observed in 74 % of cases in patients with cavernoma resection with perifocal hemosiderin versus 68 % in patients without additional hemosiderin resection ($p = 0.01$) [17]. In study by L. Shoubash et al., the frequency

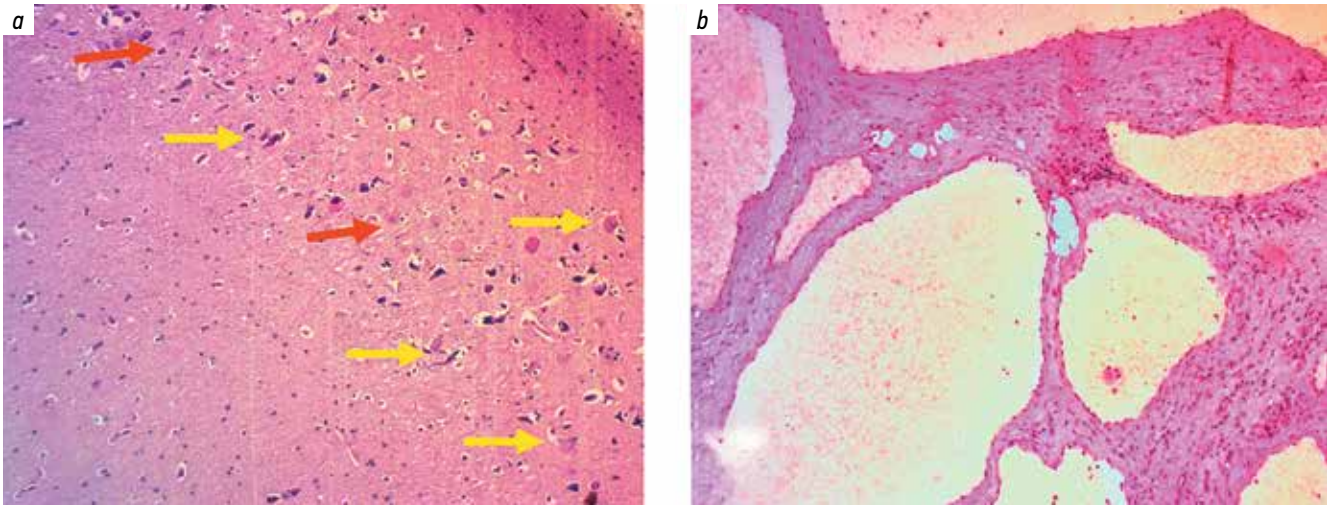

Fig. 5. *Histological examination of postoperative material from patient A. (hematoxylin and eosin staining, ×100): a – hippocampal sclerosis. Fragment of the cortex in the CA1 zone: yellow arrows – ischemic and necrobiotic changes in the neurons (nuclear condensation, karyolysis, cytoplasm thickening, smaller size of the cells); red arrows – marked dystrophic changes in the neurons (pale cytoplasm, increased size of the nucleus with chromatin clearing (increased cell synthetic activity)); b – cavernoma. Fragment of pathologically altered vessels per the cavernous type, venous-type wall with formation of connected cavities (caverns)*

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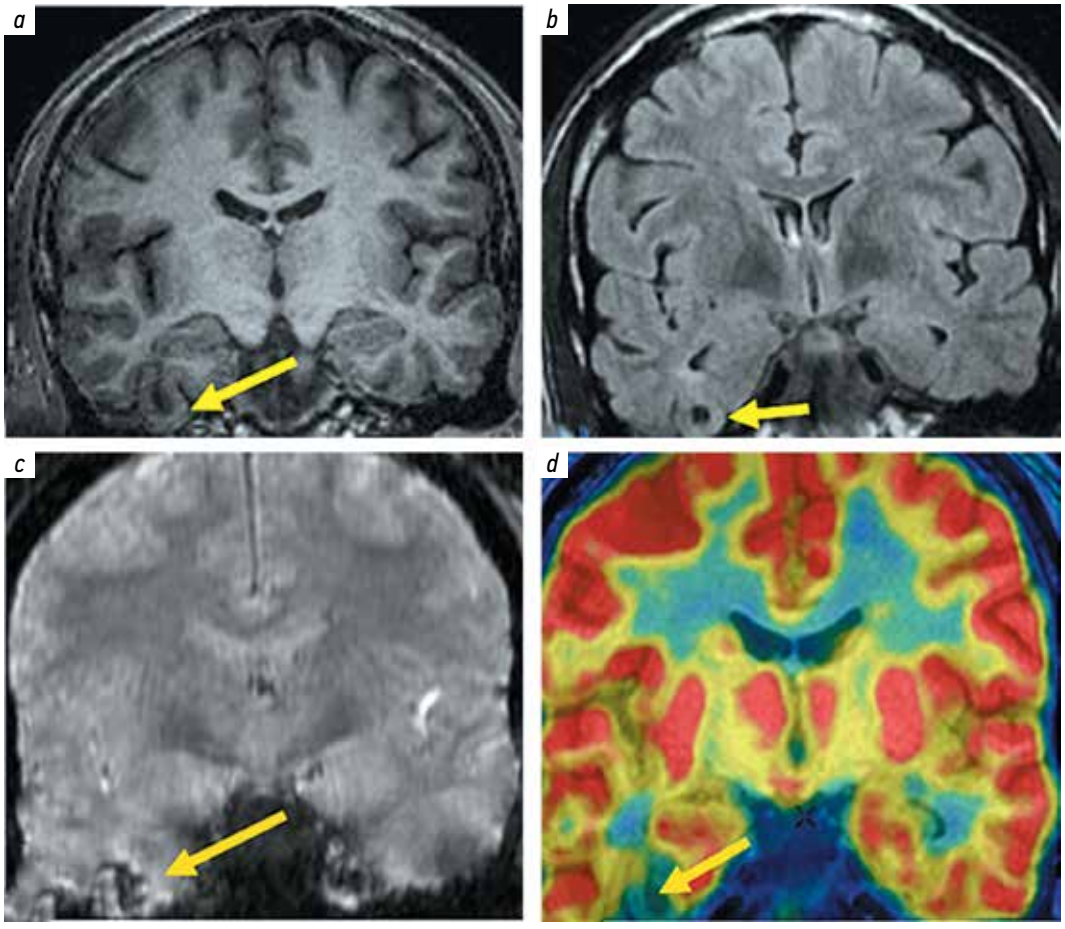

Fig. 6. *Examination of patient K.: a–c – contrast-enhanced brain magnetic resonance imaging of patient A. according to the epilepsy protocol, T1-weighted (a), T2-weighted (b) and SWAN (c). Cavernoma of the right lateral fusiform gyrus with gliosis and accumulation of hemosiderin on the periphery (yellow arrows); d – positron emission tomography/ magnetic resonance imaging of the brain. An area of decreased (up to 40 %) accumulation of radiopharmaceutical drug by the brain matter neighboring the above-described lesions (right temporal lobe) (yellow arrow)*

of postoperative hemosiderin detection was higher in the group with class II–IV outcome according to the Engel scale – 80 %, than in the group with class I outcome – 43.8 % [3]. At the same time, in a number of studies there was no statistically significant relationship between cavernoma resection and additional hemosiderin resection [18–21].

In addition to the resection radicality, the timing of microsurgical resection influences the persistence of seizures after surgery. It is believed that performing surgical treatment within 2 years from the onset of seizure syndrome is a factor in achieving seizure control. Thus, in the study of D.J. Englot et al., seizure control (Engel class I) was achieved in 75 % of patients (915/1226) after surgical interventions performed within 2 years from the onset of the disease [21]. M. Kapadia et al. report the long-term seizure freedom in 95 % of patients operated on after 1–2 epileptic seizures [16].

The prolonged course of the disease, with the formation of persistent epileptogenic connections and, subsequently, secondary foci against the background of ongoing seizures, reduces the likelihood of a favorable outcome over time [10]. In the case of temporal lobe cavernomas, this issue is most pressing and determines the extent of surgical treatment. For patients with temporal lobe cavernomas, the following options are available: Taylor resection of the cavernoma, resection of the cavernoma with a perifocal hemosiderosis, or anterior medial temporal lobectomy with amygdalohippocampectomy.

While cavernomas are localized in the structures of the hippocampal complex (hippocampus, parahippocampal gyrus, amygdala, uncus, and entorhinal cortex), as well as secondary epileptogenic foci in this region, the resection of the medial temporal lobe structures is essential to achieve seizure control. The resection of temporal lobe cavernomas with perifocal lesions within one year of disease onset results in remission in over 90 % of cases.

While performing the anterior medial temporal lobectomy within 1 to 5 years from the onset of the disease in such patients results in complete long-term remission in 76 % of cases, contrary to resection of the cavernoma with perifocal hemosiderin alone results in complete long-term remission only in 29 % of cases. Recurrence of seizures was observed in 24 and 71 % of cases, respectively [8].

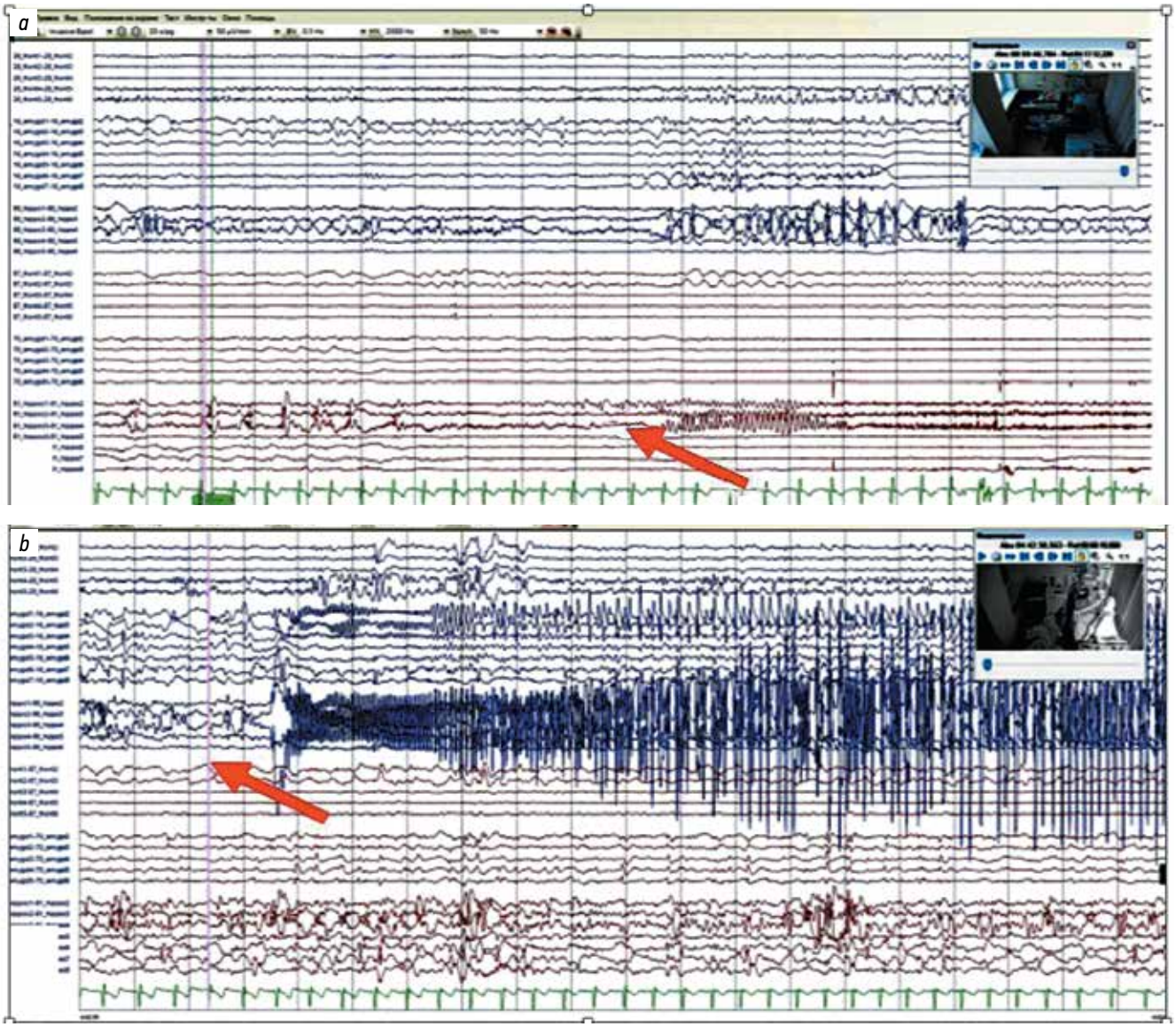

Fig. 7. *Invasive video-electrographic monitoring of patient K.: a – focal motor epileptic seizure beginning at the 1–2nd contacts of electrode from the right hippocampus; b – focal motor seizure transforming into bilateral tonic-clonic seizure beginning at the 1–2nd contacts of electrode from the left hippocampus and left amygdala*

In the case of MR-positive damage to the hippocampal structures, i. e., the formation of dual pathology, the choice of surgical tactics is not particularly difficult [9, 10]. However, with an MR-normal hippocampus, the determining factor in the choice of surgical tactics is the duration of epilepsy.

In patients with epilepsy duration more than 5 years, the first-line surgical treatment is anterior medial temporal lobectomy with amygdalohippocampectomy [8]. A longer course of the disease and persistent seizures may ultimately lead to damage of the structures of both temporal lobes as well as to development of bitemporal epilepsy, and resection of the lesion on one side will not lead to seizure remission.

Stereotactic radiosurgery (SRS) is another treatment option for cavernoma-associated epilepsy. The mechanism of radiosurgical action involves the destruction of epileptogenic hyperexcitable parenchyma, including perifocal hemosiderin, with the formation of the necrosis foci. An advantage of SRS over microsurgery is the ability to use the method in cases of multiple cavernomas, as well as in cases of their localization in functionally significant areas [2, 21]. For patients with epilepsy duration more than 2 years or with 2 and more epileptic seizures, SRS may be a treatment option [22].

However, according to various studies, the frequency of seizure remission after SRS is generally lower comparing to surgical resection. Thus, in a meta-analysis by X. Gao et al., class I outcome according to the Engel scale was achieved in 79 % of patients in the microsurgery group and in 49 % in the radiosurgery group [2]. In addition, the outcome in the form of seizure improvement has a long latent period – from 10 to 12 months after SRS. Thus, the late period of cavernoma obliteration and

the non-radical elimination of the risk of hemorrhage after irradiation are limitations of SRS [3, 4, 22].

CONCLUSION

Thus, in patients with brain cavernomas and epilepsy, the seizure freedom is an important goal of surgical treatment. To achieve this, it is necessary to determine the extent to which seizures are associated with vascular pathology (this requires scalp video-EEG monitoring with seizure recording). The volume of surgical intervention in this case is determined by the location of the cavernoma and the duration of the disease. In cases of temporal lesion location, depending on the duration of the disease, it may be limited to removal of the cavernoma with hemosiderin debris or extended to an anteromedial temporal lobectomy.

References

1. Balestrini S., Arzimanoglou A., Blümcke I. et al. The aetiologies of epilepsy. Epileptic Disord 2021;23(1):1–16. DOI: 10.1684/epd.2021.1255
2. Gao X., Yue K., Sun J. et al. Treatment of cerebral cavernous malformations presenting with seizures: a systematic review and meta-analysis. Front Neurol 2020;11:590589. DOI: 10.3389/fneur.2020.590589
3. Shoubash L., Nowak S., Greisert S. et al. Cavernoma-related epilepsy: postoperative epilepsy outcome and analysis of the predictive factors, case series. World Neurosurg 2023;172:e499–e507. DOI: 10.1016/j.wneu.2023.01.062
4. Willie J.T., Malcolm J.G., Stern M.A. et al. Safety and effectiveness of stereotactic laser ablation for epileptogenic cerebral cavernous malformations. Epilepsia 2019;60(2):220–32. DOI: 10.1111/epi.14634
5. Rosenow F., Alonso-Vanegas M.A., Baumgartner C. et al. Cavernoma-related epilepsy: review and recommendations for management – report of the Surgical Task Force of the ILAE Commission on Therapeutic Strategies. Epilepsia 2013;54(12):2025–35. DOI: 10.1111/epi.12402
6. Josephson C.B., Rosenow F., Salman R.A.S. Intracranial vascular malformations and epilepsy. Semin Neurol 2015;35(3):223–34. DOI: 10.1055/s-0035-1552621
7. Al-Shahi Salman R. The outlook for adults with epileptic seizure(s) associated with cerebral cavernous malformations or arteriovenous malformations. Epilepsia 2012;53(Suppl 4):34–42. DOI: 10.1111/j.1528-1167.2012.03611.x
8. Jehi L.E., Palmini A., Aryal U. et al. Cerebral cavernous malformations in the setting of focal epilepsies: pathological findings, clinical characteristics, and surgical treatment principles. Acta Neuropathol 2014;128(1):55–65. DOI: 10.1007/s00401-014-1294-y
9. Yang P.F., Pei J.S., Jia Y.Z. et al. Surgical management and long-term seizure outcome after surgery for temporal lobe epilepsy associated with cerebral cavernous malformations. World Neurosurg 2018;110:e659–e70. DOI: 10.1016/j.wneu.2017.11.067
10. Vale F.L., Vivas A.C., Manwaring J. et al. Temporal lobe epilepsy and cavernous malformations: surgical strategies and long-term outcomes. Acta Neurochir (Wien) 2015;157(11):1887–95. DOI: 10.1007/s00701-015-2592-4
11. Josephson C., Leach J.-P., Duncan F.R. et al. Seizure risk from cavernous or arteriovenous malformations. Prospective population-based study. Neurology 2011;76(18):1548–54. DOI: 10.1212/WNL.0b013e3182190f37
12. Okishev D.N. Surgical treatment of cavernous hemispheric cysts. Analysis of immediate and long-term treatment results. Abstract of dis. ... cand. med. sci. Moscow, 2012. (In Russ.).
13. Menzler K., Chen X., Thiel P. et al. Epileptogenicity of cavernomas depends on (archi-) cortical localization. Neurosurgery 2010;67(4):918–24. DOI: 10.1227/NEU.0b013e3181eb5032
14. Alonso-Vanegas M.A., Cisneros-Franco J.M., Otsuki T. Surgical management of cavernous malformations presenting with drug-resistant epilepsy. Front Neurol 2012;2:86. DOI: 10.3389/fneur.2011.00086
15. Dammann P., Wrede K., Jabbarli R. et al. Outcome after conservative management or surgical treatment for new-onset epilepsy in cerebral cavernous malformation. J Neurosurg 2017;126(4):1303–11. DOI: 10.3171/2016.4.JNS1661
16. Kapadia M., Walwema M., Smith T.R. et al. Seizure outcome in patients with cavernous malformation after early surgery. Epilepsy Behav 2021;115:107662. DOI: 10.1016/j.yebeh.2020.107662
17. Ruan D., Yu X.B., Shrestha S. et al. The role of hemosiderin excision in seizure outcome in cerebral cavernous malformation surgery: a systematic review and meta-analysis. PLoS One 2015;10(8):e0136619. DOI: 10.1371/journal.pone.0136619
18. Cappabianca P., Alfieri A., Maiuri F. et al. Supratentorial cavernous malformations and epilepsy: seizure outcome after lesionectomy on a series of 35 patients. Clin Neurol Neurosurg 1997;99(3):179–83. DOI: 10.1016/s0303-8467(97)00023-1
19. Shang-Guan H.C., Wu Z.Y., Yao P.S. et al. Is extended lesionectomy needed for patients with cerebral cavernous malformations presenting with epilepsy? A meta-analysis. World Neurosurg 2018;120:e984–e90. DOI: 10.1016/j.wneu.2018.08.208

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V.V. Krylov: development of the research concept and design, scientific editing of the article;
O.O. Kordonskaya: collection and processing of material, article writing, scientific editing of the article;
A.A. Zalogina, N.V. Pantina, E.A. Baranova, O.I. Patsap: collection and processing of material, article writing;
I.V. Senko: scientific editing of the article;
V.M. Dzhafarov: collection and processing of material, scientific editing of the article;
Yu.V. Rubleva, S.G. Burd, Yu.V. Voronkova, I.I. Kovaleva: collection and processing of material.

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