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Dear readers!

Our next issue is devoted to various aspects of diagnosis and treatment of vascular diseases of the central nervous system.
Postoperative Applications of the Fast Track Technology in Patients with Herniated Intervertebral Discs of the Lumbosacral Spine

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The fast track technology means a complex of targeted measures involving rational preoperative preparation, minimally invasive surgery, regional anesthesia and short-acting anesthetics, and early postoperative rehabilitation. Elucidating the possibility of applying the fast track technology in neurosurgery, in particular in spinal surgery, is extremely important. This is associated with the epidemiological data and the fact that minimally invasive techniques used in neurosurgery are highly expensive.

Material and methods. The fast track technology following spinal surgery was implemented at the Clinical Hospital of the Presidential Administration of the Russian Federation and the Neurosurgical Department of the Clinical Hospital No. 1 of the Presidential Administration of the Russian Federation using an algorithm of technology application. The study included 48 patients who underwent surgical treatment for herniated intervertebral discs of the lumbosacral spine between January and July 2015.

Results. An analysis of pain severity using the Visual Analog Scale demonstrated a slight decrease (10%) in a group of patients who were subjected to the fast track technology, at discharge and at 1 month after surgery; there was no difference in longer follow-up. An analysis of the functional status using the Oswestry index and Roland-Morris scale demonstrated that patients of the study group had faster and more efficient recovery and an improvement of the functional activity by 20% (p<0.05) compared to those in the control group. An analysis of patient-reported assessment of treatment quality revealed that indicators, such as awareness and pain control, in the study group were highest and amounted to 95% and higher. An analysis of the hospital stay duration showed a decrease in the number of bed-days in an integrated group by 39%, which saved 34 bed-days.

Conclusions. The fast track technology reduces the degree of surgical aggression, increases surgery safety, and decreases the number of intraoperative complications and hospital stay duration.

Keywords: fast track surgery, fast track technology, patient’s school, rehabilitation, spinal neurosurgery, herniated intervertebral disc of lumbosacral spine.

The fast track technology has been developing rapidly over the last decade in the European Union and the United States. It involves implementation of high-technology minimally invasive techniques in daily surgical practice. In a variety of cases this technology made it possible to reduce the degree of surgical aggression, increase surgery safety, decrease the number of intraoperative complications, and shorten the length of hospital stay. Therefore, there is a need to revise the requirements existing to date for outpatient stage, preoperative preparation, management of early and late postoperative periods, and the patient’s recovery period in the hospital and after discharge [1]. The results of studies by foreign authors suggest that the combination of all the above mentioned components in the treatment of patients can be cost-effective [2].

Thus, the current global trend is to treat patients using new surgical techniques based on modern principles and approaches to arrangement of diagnostic and treatment process. These principles have been developed and are being actively implemented in certain areas of surgery in Europe and the United States. It should be noted that elucidating the possibility of applying the fast track strategy in neurosurgery, in particular, in spinal surgery, is extremely important [3]. This is associated with the epidemiological data and the fact that minimally invasive techniques used in neurosurgery are highly expensive. Arrangement of quality and safe care to patients and minimization of the costs represent a significant medical and economic concern [4].

Currently, the fast-track technology has found widespread application in such areas of surgery as coloproctology, orthopedics, gynecology, and urology. We have searched the Internet for scientific publications devoted to the study of the fast-track technology after surgery. Medline and Pubmed databases were searched from 1997 to 2015 using the key words “fast track” and “Enhanced Recovery after Surgery” (ERAS). A total of 4924 publications were found. The results of the analyzed publications are shown in Fig. 1. The increasing number of publications shows the growing interest to the fast-track technology and early rehabilitation. An additional
search criterion to publications (using the key words “spine surgery”) resulted in the full match of only 3 papers of 4924 publications.

Surgical treatment of diseases of the spine is a rapidly developing area. The annual increase in the number of publications confirms the growing interest to this issue. According to experts, this is caused by a variety of clinical, demographic, socio-cultural and economic factors. The number of spinal operations has been growing rapidly in the past decade. At present, surgical treatment gives the patients an opportunity of a faster return to their usual life. Thus, spinal neurosurgery today is also one of the most successful for-profit areas of medicine.

The above mentioned factors underlie the relevance of the fast track technology implementation after surgery on the spine to enable early recovery of body functions on the basis of a multimodal approach to achieve the best outcomes after the operation.

The purpose of the study is to implement and evaluate the application of the fast track technology after surgery in patients with herniated intervertebral discs of the lumbosacral spine.

**Material and Methods**

An algorithm of the fast track technology was developed at the Clinical Hospital of the Presidential Administration of the Russian Federation (http://www.presidentclinic.ru/) and the Neurosurgical Department of the Clinical Hospital No. 1 of the Presidential Administration of the Russian Federation (http://www.volynka.ru/) for further implementation of the technology after surgery on the spine (Fig. 2).

The first stage of the algorithm is to form a working group, which consists of a neurosurgeon, neurologist, anesthesiologist, recreation therapist, physiotherapist and nurses. The present study included 48 patients who underwent surgical treatment for herniated intervertebral discs of the lumbosacral spine from January to July 2015 at the Neurosurgical Department of the Clinical Hospital No. 1 of the Presidential Administration of the Russian Federation. This study was prospective and included a control group. All patients were divided into two groups.

The first group (a control group) included patients who underwent microdiscectomy according to a standard perioperative algorithm. This group consisted of 25 patients (11 women and 14 men) aged 28 to 71 years (the mean age was 42.2 years).

The second group (the study group, or integrated group) included patients who underwent microdiscectomy followed by the fast track technology. This group consisted of 23 patients (9 women and 14 men) aged 29 to 72 years (the mean age was 44.3 years).

Indications for surgical treatment were based on standard criteria: duration of symptoms before surgery and absence of an effect after conservative treatment (6—8 weeks). Before surgery, all patients had an examination that included neurological examination, functional spondylography and MRI of the lumbosacral spine. An operation of microsurgical discectomy was

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*Fig. 1. An analysis of publications using the key words: “fast track” and “Enhanced Recovery after Surgery” (ERAS) from 1997 to 2015 based on Medline and Pubmed databases.*

*Fig. 2. An algorithm of the fast track technology implementation after surgery on the spine developed by the Clinical Hospital and Clinical Hospital No. 1 of the President Administration of the Russian Federation.*
performed in both groups of the patients according to a standard protocol. Tables 1 and 2 present the information on distribution of the patients according to the level of surgical intervention and channels of funding. Traditionally, LIV—LV and LV—SI levels were mostly operated. Duration of the operation and blood loss did not differ significantly between the two groups. It should be noted that the second group was dominated by fee-for-service patients by the hospitalization channels.

Severity of pain syndrome was graded based on the Visual Analog Scale (VAS). The Oswestry index and Roland-Morris scale were used to assess the functional status. Patient satisfaction was evaluated using a special patient-reported assessment questionnaire of treatment quality developed in the Clinical Hospital and the Clinical Hospital No. 1 of the Presidential Administration of the Russian Federation on an order of Ministry of Health of Russia No. 412 of 2011 and a form of the Johns Hopkins Hospital. This questionnaire consists of 8 parts. The questionnaire included patient-reported assessment of medical care provided to the patients by doctors, middle and junior medical staff, including awareness about all stages of treatment (admission, peculiarities of the operation, postoperative activation, discharge, and post-operative regime with a recreation therapist), pain control, diet and conditions of stay in the hospital.

The next step in implementation of the fast track algorithm after surgical interventions on the spine is the development of a guidance manual and a patient’s school. As part of the spine school creation program, together with all healthcare professionals a navigator for patients was developed which serves as a reminder to them (Fig. 3 and 4).

The guide provides the information on the most frequently performed operations in degenerative diseases of the spine and postoperative rehabilitation. The main purpose of the guidance manual that we have developed is to raise awareness of the patients and engage the patient as a partner in the treatment process.

The logistics of the fast track technology applications has been formed as follows: during the consultation a neurosurgeon determines the indications for surgical treatment and sends the patient to an anesthesiologist, who at the prehospital stage assesses risks using the American Anesthesiologists Association scale (ASA), describes all the manipulations, their purpose, methods and frequency of anesthesia. After that, a neurosurgeon, using the guide for patients, discusses all the stages of treatment: hospitalization, peculiarities of the operation, postoperative activation, discharge, and a post-operative regime with a recreation therapist. The patient is hospitalized to the hospital in the morning at the day of the operation, and it is important to follow the regime on the eve of the operation, which was recommended by anesthesiologist. Activation of the patient begins 2 hours after surgery in the ward, dressing is performed in the next morning, and discharge on the 2—3 day after the operation. A further post-operative regime is discussed with a recreation therapist.

**Results**

We used standard points to control the state of the patients: before surgery, at discharge, and 1, 3 months and 6 months after surgery. An analysis of pain severity using the Visual Analog Scale demonstrated a slight decrease (10%) in a group of patients who were subjected to the fast track technology, at discharge and at 1 month after surgery; there was no difference in longer follow-up. An analysis of the functional status using the Oswestry index and Roland-Morris scale demonstrated that patients of the study group had faster and more efficient...
recovery and an improvement of the functional activity by 20% \((p<0.05)\) compared to those in the control group. An analysis of patient-reported assessment of treatment is presented in Table 3.

An analysis of patient-reported assessment of treatment quality (the filling of the patient-reported assessment questionnaire is regulated by the order of the Russian Ministry of Health) revealed that indicators,
such as awareness and pain control, in the study group were highest and amounted to 95% and higher (Fig. 5).

In the study, each of the two groups had one case of poor healing of the wound. An analysis of the hospital stay duration showed a reduction in the number of bed-days in an integrated group by 39% (Table 4).

Table 4 shows that 34 bed-days were saved in the 2nd group ($p<0.05$). It should be noted that fee-for-service patients dominated in the 2nd group who were treated by VMI (57%) and self-financing (39%).

**Discussion**

As early as in the mid 90-ies of the XX century, H. Kehlet [5] from Denmark professor, anesthesiologist resuscitationist was professionally interested in the nature of the pathophysiological mechanisms of complications after elective surgery. After systems analysis a multi-component complex of measures to reduce the stress response of the organism to surgical aggression was proposed. Reduction of consequences of stress has become a cornerstone of the concept, known as the fast track surgery (enhanced recovery after surgery). H. Kehlet [5] was one of the first to offer a multimodal approach to influence all stages of the perioperative period, taking the reduction of the number of complications and length of the patients on ward stay as a criterion of effectiveness of medical measures. In addition, in the early stages of formation of the fast-track surgery concept, the focus was on the faster patient’s discharge from the hospital and reduced cost of treatment, and the program itself was somewhat fragmented. The concept turned out to be successful and was not rejected by the participants of perioperative patient follow-up. Moreover, it received further development on a multidisciplinary basis, and terminological additions indirectly indicate its relevance. Thus, at present, alongside with the term “fast track surgery” outside Russia other terminology is used to refer to fast track programs due to the peculiarities of mentality, regulations of surgical associations and the established rights to the name. The Enhanced Recovery after Surgery (ERAS) term has become widely used, which stands for fast recovery after surgery.

The main statements of the multimodal concept of the fast track recovery of surgical patients after elective operations in its present form were formulated at the beginning of the XXI century [6, 7] (Fig. 6).

The fast track technology involves the use of a complex of measures at all perioperative stages: before surgery, during surgery and in the postoperative period in order to minimize the impact of stress on the patient’s body after surgical treatment. The complex of measures, in very general description, includes rational preoperative preparation, minimally invasive surgery, regional anesthesia, the use of short-acting anesthetics, and early rehabilitation in the postoperative period [8]. This results in improvement of surgical treatment outcomes, reduced occurrence of complications and cost of the treatment. The increase in quality of the patient’s hospital stay is noticeable and the response to the treatment improves [9, 10].

It is known that some experience has already been accumulated worldwide concerning the implementation of the fast track technology after surgery in coloproctology, endoprosthetics, gynecology and urology, which we can and should add it to our armoury. To date, the associations that replicate protocols for different clinical disciplines have been created. In this situation, trajectory of extrapolations of the fast track technology in spinal surgery follows the one in orthopedics. An increased demand for spinal surgery makes the use of the fast track technology in spinal neurosurgery extremely relevant [11].

During the first studies performed in this area (Denmark), the results of surgical treatment of 60 patients with stenosis of the lumbosacral spinal canal were analyzed. The integrated group with the fast track recovery and early rehabilitation included 28 patients while 32 were subjected to standard program of perioperative period. After the comparative analysis, P. Nielsen et al. [2] have published evidence that the

<table>
<thead>
<tr>
<th>Scale</th>
<th>Before operation</th>
<th>At discharge</th>
<th>After 1 month</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>The 1st group</td>
<td>The 2nd group</td>
<td>The 1st group</td>
</tr>
<tr>
<td>VAS</td>
<td>8.7 (6—10)</td>
<td>8.9 (6—10)</td>
<td>3.8* (5—1)</td>
</tr>
<tr>
<td>Oswestry index</td>
<td>43 (32—47)</td>
<td>42 (30—47)</td>
<td>19* (13—29)</td>
</tr>
<tr>
<td>Roland-Morris scale</td>
<td>18 (12—22)</td>
<td>19 (14—22)</td>
<td>13* (7—18)</td>
</tr>
</tbody>
</table>

Footnote. * — here and in Table 4: the difference compared to indicators of the control group is significant ($p<0.05$).
concept of the fast track technology and early rehabilitation in spinal surgery is cost-effective as compared with standard treatment programs.

T. Wainwright et al. [12] in their work consider the relevance of application of the fast track technology after spinal surgery. The authors show that in light of rising costs of operation and level of patient dissatisfaction, implementation of the ERAS concept in spinal neurosurgery, including the awareness of patients, minimizing surgical aggression, adequate anesthesia, minimally invasive surgery, early activation and rehabilitation in the postoperative period, enables a much faster patient recovery after surgery on the spine and improve long-term outcomes of treatment.

Conclusions

We suppose that implementation of the fast track technology should be considered as a medical technological process, i.e., a complex of actions of medical, technical, and administrative personnel of medical institutions and the patient, which are necessary for the implementation of diagnostic and treatment as well as arrangement and management measures performed in a certain sequence, association and time regimes aimed at effective health care [GOST 27878-88].

Our experience shows that the fast track technology does not increase the number of negative events, reduces pain intensity in the short-term period by 10% and improves the functional activity by 20%, which greatly accelerates the patient rehabilitation, recovery of the patients working activity, and, hence, return to normal life.

The use of the guide for patients and the creation of the spine patient’s school increase patient awareness of the upcoming treatment and rehabilitation and an engagement of the patient as a partner leads to better patient-assessed quality of treatment.

The concept of enhanced recovery is a successful means to achieve a high level of patient satisfaction and reduce treatment costs. Reduction of the hospital stay by 39% resulted in saved 34 bed-days in the study group compared to the control group. It should be noted that the 2nd group was dominated by fee-for-service patients treated by VMI (57%) and self-financing (39%).

Authors declare no conflict of interest.

REFERENCES


Fig. 6. Multimodal concept of early rehabilitation (Kehlet and Dahl, 2003).
The article is devoted to a new and extremely important issue: the implementation of the fast track recovery technology in spinal neurosurgery. A variety of factors determine the relevance of this study. First of all, data of epidemiological studies and the use of minimally invasive techniques in neurosurgical operations show the rapidly increasing number of spinal operations. Currently, the use of modern surgical techniques gives the patients an opportunity of fast return to work and normal life.

The fast track technology is based on a multimodal approach of task-oriented integrated interaction of surgical specialists: anesthesiologists-resuscitationists, neurologists, and recreation therapists so that to influence all stages of the perioperative period. In addition, the patient’s awareness of all stages of the treatment process is important, which reduced the level of anxiety and worry, the risk of depression — the conditions that worsen treatment outcomes, especially in people with high levels of anxiety. This promotes early activation in the postoperative period. According to foreign literature, it was found that the interaction between a physician and a patient, patient education before surgery, and clarifying the role of active engagement of the patients in the treatment process reduce length of hospital stay.

The authors of the article developed an algorithm of the fast track technology after surgery in patients with herniated intervertebral discs of the lumbosacral spine and introduced the algorithm into practice. The paper analyzes the group of patients who underwent surgical treatment for hernias of intervertebral discs of the lumbosacral spine. The fast track technology was found to be a successful means to achieve better and faster recovery, a high level of patient satisfaction, reduce treatment costs, and shorten length of hospital stay.

Thus, the presented article is a pioneering work on the implementation of the fast track strategy used in neurosurgery, in particular, in spinal surgery. It is highly important to continue to study the possibilities of the fast track technology and early rehabilitation in spinal neurosurgery, which will improve the existing approaches of the treatment process, reduce surgical aggression, enhance patient safety, decrease the number of intraoperative complications, and shorten length of hospital stay.

The article is devoted to an urgent issue, includes novel points, has practical value and deserves publication in the journal.

A.A. Kuleshov (Moscow, Russia)
Displacement of the cerebellar tonsils below the foramen magnum is known as Chiari 1 malformation (CM1). Clinical manifestations of CM1 include cephalgia and pain in the cervical and occipital region, symptoms of compression of the posterior fossa structures. CM1 is often accompanied by syringomyelia and related myelopathy symptoms. Posterior decompression of the craniovertebral junction is the most common method of surgical treatment for CM1 [1].

In this paper, we present an approach to the choice of the extent of the posterior decompression in children with CM1 based on our own experience of these operations.

**Materials and methods**
We analyzed the results of 76 surgeries for the posterior decompression of the craniovertebral junction for CM1 carried out in our department from 2001 to 2015. Data on the patients are summarized in Table 1. We considered only those cases when posterior decompression was the first method of treatment. Obstructive hydrocephalus and mass lesions were considered as contra-indication to posterior decompression. We excluded patients with signs of spinal dysraphism or anamnestic signs of purulent meningitis. The average age of patients was 11 years (1 to 18 years). Most often, the disease manifested in the form of cephalgia, balance and/or coordination disorders, spinal sensory or motor loss, progressive scoliosis, stem and/or cranial nerve dysfunction (diplopia, disturbance of swallowing, stridor, sleep apnea). No patients had signs of intracranial hypertension in the fundus; dilation of the brain ventricles without obstruction of cerebrospinal fluid pathways was observed in 13 (17%) patients. Syringomyelia was diagnosed in 52 (68%) patients.

The operation was aimed at restoring smooth CSF circulation at the craniovertebral junction. Patients we operated on in sitting position, and only in 5 cases in prone position. The extent of the surgery was determined depending on the presence and extent of syringomyelia, neurological symptoms, intraoperative findings, and personal preferences of the surgeon. There was no unified operation protocol.

Four different surgical techniques were used:
- The first option, extradural decompression (EDD, 14 cases). The operation included wide resection of the margin of the foramen magnum, economic resection of the occipital bone, resection of C1 posterior vertebral arch, and excision of the outer layer of the dura mater (DM). EDD was never planned in advance, and surgeons confined to this option, when intact DM was not tense after bone decompression. Tense DM was always dissected.
- The second option, extra-arachnoid duroplasty (EAD, 21 cases). In this surgical option, attention was paid to preserve the integrity of the arachnoid. DM incision extended downwards until the inferior margin of the cerebellum tonsil was visible and large occipital cistern was filled with the cerebrospinal fluid. Subsequently, DM was not sutured, and a patch was tightly sewn into the incision to increase the dural sac volume at the craniovertebral junction; soft tissues were tightly sutured.
Table 1. Data on patients

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Number of patients (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, years:</td>
<td></td>
</tr>
<tr>
<td>0—4</td>
<td>8 (10)</td>
</tr>
<tr>
<td>5—9</td>
<td>24 (32)</td>
</tr>
<tr>
<td>10—14</td>
<td>26 (34)</td>
</tr>
<tr>
<td>15—18</td>
<td>18 (24)</td>
</tr>
<tr>
<td>Clinical presentation of the disease:</td>
<td></td>
</tr>
<tr>
<td>Pain in the neck and occipital region and/or headache</td>
<td>51 (67)</td>
</tr>
<tr>
<td>Balance and/or coordination disorders</td>
<td>40 (53)</td>
</tr>
<tr>
<td>Motor loss</td>
<td>33 (43)</td>
</tr>
<tr>
<td>Sensory loss</td>
<td>27 (36)</td>
</tr>
<tr>
<td>Cranial nerve (VI-XII) dysfunction</td>
<td>21 (28)</td>
</tr>
<tr>
<td>Spine deformity</td>
<td>21 (28)</td>
</tr>
<tr>
<td>Nausea, vomiting</td>
<td>12 (16)</td>
</tr>
<tr>
<td>Nystagmus</td>
<td>11 (14)</td>
</tr>
<tr>
<td>Dizziness</td>
<td>4 (5)</td>
</tr>
<tr>
<td>Pelvic disorders</td>
<td>4 (5)</td>
</tr>
<tr>
<td>Endocrine disorders</td>
<td>4 (5)</td>
</tr>
<tr>
<td>Various nonspecific symptoms and complaints</td>
<td>13 (17)</td>
</tr>
</tbody>
</table>

Preoperative Chiari Severity Index [2]:

Clinical Grade I:
- Pain in the neck and occipital region during straining 20 (26)
- Hard-to-localize headache 11 (15)

Clinical Grade II:
- Pain in fronto-temporal region
- No headaches

Clinical Grade III:
- Myelopathy symptoms 45 (59)

MRI data:
- Ventriculomegaly:
  - Cerebral ventricles are not dilated 63 (83)
  - Cerebral ventricles are dilated 13 (17)
- Syringomyelia:
  - No 24 (32)
  - Yes 52 (68)

The third option, intra-arachnoid dissection and duroplasty (IAD, 21 cases). In 16 cases, cerebrospinal fluid did not flow from the fourth ventricle after opening of the DM. In connection with this, we explored foramen of Magendie. In 4 patients, subpial resection of cerebellar tonsils was additionally done in order to reduce the mass effect. In 5 cases, arachnoid was opened unintentionally and massive outflow of the CSF from the large occipital cistern was observed. Expansive duroplasty and wound closure were the same as in the case of EAD.

The fourth option, in 20 cases, after revision of the foramen of Magendie aimed at preventing its re-obliteration, ventriculoperitoneal subarachnoid stents were implanted followed by duroplasty (StD). The decision to stent the foramen of Magendie was made individually at surgeon’s discretion. Stents were not used in the absence of syringomyelia. In some patients with extended syringomyelia (holocord), we originally planned revision of the foramen of Magendie and/or stent implantation, regardless of the intraoperative findings. We used approximately 15-mm-long silicone stent made of a standard ventricular catheter. One end was placed into the fourth ventricle through the foramen of Magendie, and the other end was dipped into the spinal subarachnoid space. The stent’s cuff was fixed to the arachnoid or the inner layer of the dura mater using a non-absorbable monofilament suture 5-0 or 6-0 on anatraumatic stitching needle followed by duroplasty, similarly to EAD.

In 45 cases, autofascia was used for duroplasty; in recent years (16 cases), collagen matrix Durepair (Medtronic) was used instead. Currently (25 cases), DM suture is routinely sealed with Tissucol (Baxter) or Evigel (Ethicon) adhesive, containing fibrin and thrombin.

Control MRI study and examination were advised 4 and 24 months after surgery and then as needed. Catamnesis has been studied in 48 (63%) patients (2—85 months, on the average 17 months).

We analyzed the relationship between the incidence of complications and reoperations and the extent of the operation and preoperative parameters, including sex, age, clinical manifestations, the presence of ventriculomegaly, the presence and extent of syringomyelia; we used Fisher’s exact test (for qualitative parameters) or Student’s test (for quantitative parameters).

**Results**

The relationship between the extent of the surgery and preoperative parameters is shown in Table 2. Duroplasty is often used in patients with syringomyelia and, more rarely, in Grade 2 patients according to the Chiari Severity Index scale [2]. Intra-arachnoid manipulations were more common in patients with syringomyelia and myelopathy symptoms. Stents were implanted only in patients with syringomyelia. The duration of the surgery was on the average 90 minutes (30—160 minutes), and was significantly shorter in the case of EDD (Table 3).

The postoperative period. Pain in the surgical area required medical treatment for an average of 2.5 days after surgery (less after EDD ). Vomiting continued on the average 0.8 days after surgery (it was longer after StD, 1.6 days); no vomiting was observed after EDD. On the average, fever above 38°C was observed less then 24 h after surgery (it was less after EAD). Maximum body temperature during the first 7 days after the surgery averaged 37.6°C (it was lower after EDD and EAD and higher after IAD). Lumbar puncture for CSF sampling or unloading were carried out on the average 0.8 days after surgery (it was longer after EAD). Duration of postoperative hospital stay averaged 9 bed days (it was longer in the IAD group).

Options of surgical technique and characteristics of postoperative period are shown in Table 3.

Complications occurred in 15 (20%) patients. Complications resulted in death of 1 (1.3%) patient. Compli-
cations were more common after intra-arachnoid dissection (34% vs. 3%; \(p=0.0009\)) and after stenting (40% vs. 20% of the total number of complications; \(p=0.02\)). Data on the incidence and types of complications are shown in Table 4. Other preoperative and intraoperative parameters did not correlate with the incidence of complications (12%).

Wound liquorrhea (12%) was the most common complication; in 4 (5%) cases it was treated using the external lumbar drainage (it was more often after IAD, 14%). Seven (9%) patients had meningitis, pathogens were isolated from the CSF in 5 cases. Four patients developed meningitis as a result of wound liquorrhea; 2 patients — after stent implantation (stent removal was required); in one case, infection occurred during long-term external drainage of the CSF. In 2 patients with holocord syringomyelia and myelopathy symptoms, there was a transient sciatic nerve dysfunction after operations in the sitting position. In 2 patients with holocord syringomyelia and myelopathy symptoms, respiratory depression of central origin occurred after extubation; in one case, it was reversible and resulted in no consequences. In another patient, who underwent surgery with revision of the foramen Magendie in the prone position, breathing disorders were followed by catastrophic increase in the brainstem symptoms in the form of depression of consciousness up to coma followed by oculomotor disorders. The patient died without regaining consciousness on the 57th day after the surgery due to infectious complications. Two (3%) patients without ventriculomegaly before treatment required shunt surgery in connection with the development of hydrocephalus.

Reoperations (see Table 3) at the craniovertebral junction were performed in 8 (11%) cases. Six of them were required due to the ineffectiveness of the first intervention, 2 — in order to remove infected stents. Reoperation rate was significantly lower in patients aged 10 to 14 years (0% vs. 19% of the total; \(p=0.045\)). Five (7%) patients required implantation of the ventriculo-peritoneal shunt within the period from 15 to 2392 days (median 22 days) after posterior decompression; of these, 3 patients had dilated ventricles before the surgery, while 2 patients developed hydrocephalus de novo.

**Discussion**

It is believed, that surgical treatment of CM1 and syringomyelia was started in 1950, when W. Gardner [3] published surgical series consisting of 17 observations, although scattered cases were published earlier. Until 1970s, mortality after surgery for CM1 and syringomyelia was more than 10% [4, 5]. Later on, implementation of CT and MRI resulted in refinement of indications for the use of the posterior decompression and surgical technique has evolved towards reduced invasiveness, which led to improved outcomes.

The results of the posterior decompression for CM1 and syringomyelia. In the current series and population studies, the incidence of complications after posterior decompression of the craniovertebral junction is 2—22% [1, 6—10]. The most common complications include pseudomeningocele (15%), meningitis (8%), wound liquorrhea (4%), wound infection (3%), and neurological deficit (2%) [1]. In the pediatric population, complications occur more frequently in patients younger than 5 years [7], in the case of hydrocephalus, or concomitant genetic pathology with significant changes in the arachnoid membrane [9]. The incidence of complications varies depending on the surgical technique: it is the highest in the case of revision of the foramen of Magendie [9] and minimal in the case of EDD [8]. Postoperative mortality is 0—3% [1, 6—12]. The following death reasons were reported: infectious complications, respiratory distress/apnea, postoperative bleeding [1, 4]. 74—95% of patients [9—12] said that they feel better after the posterior decompression. In children, neurological disorders regressed in 84% of cases, and worsened in 9% of cases [1]. Regression of the motor disorders caused by myelopathy [2, 12] is the least likely to occur. Headache regresses in 74—95% of children [1, 11]. According to MRI data, re-

<table>
<thead>
<tr>
<th>The extent of the surgery</th>
<th>Syringomyelia</th>
<th>CSI Grade*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td><strong>Duroplasty:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Performed</td>
<td>46</td>
<td>16</td>
</tr>
<tr>
<td>Not performed</td>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td>Application frequency, %</td>
<td>88</td>
<td>67</td>
</tr>
<tr>
<td><strong>Intra-arachnoid dissection:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Performed</td>
<td>37</td>
<td>4</td>
</tr>
<tr>
<td>Not performed</td>
<td>15</td>
<td>20</td>
</tr>
<tr>
<td>Application frequency, %</td>
<td>71</td>
<td>17</td>
</tr>
<tr>
<td><strong>Stenting:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Performed</td>
<td>20</td>
<td>0</td>
</tr>
<tr>
<td>Not performed</td>
<td>32</td>
<td>24</td>
</tr>
<tr>
<td>Application frequency, %</td>
<td>38</td>
<td>0</td>
</tr>
</tbody>
</table>

Footnote. * — Chiari Severity Index Grade [2]; ** — Fisher’s exact test; nr — no significant relationship (\(p>0.05\)).
Table 3. Options of the surgical technique and postoperative characteristics

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Total</th>
<th>EDD</th>
<th>EAD</th>
<th>IAD</th>
<th>Std</th>
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<tbody>
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<td>14</td>
<td>21</td>
<td>21</td>
<td>20</td>
</tr>
<tr>
<td>Duration of the surgery, min:</td>
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<td></td>
<td></td>
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<tr>
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<td>68</td>
<td>100</td>
<td>92</td>
<td>92</td>
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<tr>
<td>(Range)</td>
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<td>(30—100)</td>
<td>(45—160)</td>
<td>(50—150)</td>
<td>(70—130)</td>
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<tr>
<td>(p^*)</td>
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<td>0.053</td>
<td>0.5</td>
<td>0.5</td>
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</tr>
<tr>
<td>Need for analgesia, days after surgery(***):</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>2.5</td>
<td>1.1</td>
<td>2.9</td>
<td>2.8</td>
<td>2.9</td>
</tr>
<tr>
<td>(Range)</td>
<td>(0—7)</td>
<td>(0—3)</td>
<td>(1—6)</td>
<td>(0—7)</td>
<td>(1—7)</td>
</tr>
<tr>
<td>(p^*)</td>
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<td>0.3</td>
<td>0.5</td>
<td>0.3</td>
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<tr>
<td>Vomiting, days after surgery(***):</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>0.8</td>
<td>0</td>
<td>0.7</td>
<td>0.9</td>
<td>1.6</td>
</tr>
<tr>
<td>(Range)</td>
<td>(0—7)</td>
<td>(0—0)</td>
<td>(0—5)</td>
<td>(0—5)</td>
<td>(0—7)</td>
</tr>
<tr>
<td>(p^*)</td>
<td>0.02</td>
<td>0.6</td>
<td>0.9</td>
<td>0.01</td>
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<tr>
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<td></td>
<td></td>
<td></td>
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<tr>
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<td>0.2</td>
<td>0.1</td>
<td>1.3</td>
<td>0.9</td>
</tr>
<tr>
<td>(Range)</td>
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<td>(0—2)</td>
<td>(0—1)</td>
<td>(0—6)</td>
<td>(0—7)</td>
</tr>
<tr>
<td>(p^*)</td>
<td>0.2</td>
<td>0.04</td>
<td>0.01</td>
<td>0.4</td>
<td></td>
</tr>
<tr>
<td>Maximum body temperature, °C(***):</td>
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<tr>
<td>Average</td>
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<td>37.1</td>
<td>37.4</td>
<td>38</td>
<td>37.8</td>
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<tr>
<td>(Range)</td>
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<td>(36.6—38.5)</td>
<td>(36.8—39.5)</td>
<td>(36.7—39.2)</td>
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<td>0.04</td>
<td>0.03</td>
<td>0.09</td>
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<tr>
<td>Average</td>
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<td>0</td>
<td>0.6</td>
<td>1.1</td>
<td>1</td>
</tr>
<tr>
<td>(Range)</td>
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<td>(0—3)</td>
<td>(0—3)</td>
<td>(0—3)</td>
</tr>
<tr>
<td>(p^*)</td>
<td>0.0003</td>
<td>0.5</td>
<td>0.01</td>
<td>0.2</td>
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<tr>
<td>Postoperative bed-days, days:</td>
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<tr>
<td>Average</td>
<td>9</td>
<td>6</td>
<td>6</td>
<td>13</td>
<td>10</td>
</tr>
<tr>
<td>(Range)</td>
<td>(2—57)</td>
<td>(2—19)</td>
<td>(3—15)</td>
<td>(4—57)</td>
<td>(3—33)</td>
</tr>
<tr>
<td>(p^*)</td>
<td>0.2</td>
<td>0.1</td>
<td>0.02</td>
<td>0.8</td>
<td></td>
</tr>
<tr>
<td>Complications, number of patients:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(n)</td>
<td>15</td>
<td>0</td>
<td>1</td>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td>(%)</td>
<td>20</td>
<td>0</td>
<td>5</td>
<td>29</td>
<td>40</td>
</tr>
<tr>
<td>(p^{**})</td>
<td>0.06</td>
<td>0.05</td>
<td>0.3</td>
<td>0.02</td>
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<td>Reoperations at the craniocervical junction:</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of patients</td>
<td>8</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>(%)</td>
<td>11</td>
<td>21</td>
<td>5</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>(p^{**})</td>
<td>0.2</td>
<td>0.4</td>
<td>1.0</td>
<td>0.7</td>
<td></td>
</tr>
<tr>
<td>Poor outcome (complications of reoperation):</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of patients</td>
<td>19</td>
<td>3</td>
<td>2</td>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td>(%)</td>
<td>25</td>
<td>21</td>
<td>10</td>
<td>29</td>
<td>40</td>
</tr>
<tr>
<td>(p^{**})</td>
<td>1.0</td>
<td>0.07</td>
<td>0.8</td>
<td>0.1</td>
<td></td>
</tr>
</tbody>
</table>

Footnote. * — Student’s t-test, the significance of differences between the parameter value in the study group and that in other groups (values<0.05 are shown in bold); ** — Fisher’s exact test (two-sided variant), the significance of the differences between the parameter value in the study group and that in other groups (values<0.05 are shown in bold); *** — Within 1 week after surgery.

Reduced syringomyelia is observed in 65—82% of cases [1, 8, 9, 11—14]. Reoperations due to the lack of improvement or recurrence of symptoms are required in 7—10% of cases [8—10].

In our series, complications occurred in 20% of patients, postoperative mortality was 1.3%, and reoperations were required in 11% of patients. These figures correspond to the published data, but they do not satisfy us; we suggest that the approach to the extent of the surgery should be changed.

Extra-arachnoid decompression. In 1981, Logue suggested to preserve the arachnoid during the posterior decompression in order to avoid bleeding into the subarachnoid space. In this case, duroplasty was not performed; incidence of complication reached 17% [15, 16]. Duroplasty reduces the incidence of complications to 0—5% [17—19]. The best results of treatment of syringomyelia are achieved using this technique [20]. In our series, the results of treatment were the most favorable after EAD: complications or the need for reoperation occurred only in 10% of cases. We consider the EAD as a method of choice in primary surgery in children with CM1.

Extradural decompression was suggested in 1993 by T. Isu [21]. This operation is attractive, because there
is no risk of complications. Higher incidence of reoperations due to the ineffectiveness of the first intervention (on the average 13%) is a cost for safety [22]. In the case of EDD, regression of syringomyelia is more rare [20]; even adherents if this operation recommend selective use of this technique [8]. Intraoperative criteria do not provide reliable prediction of the effectiveness of EDD [23].

In our series, there were no complications after EDD, operations were shorter, the need for analgesia was reduced, and there was usually no fever and vomiting after surgery. In 21% of patients, the first intervention was ineffective and reoperation was required. We consider EDD as a safe option for children with moderate dislocation of the cerebellar tonsils and slowly progressing complaints, but only in the absence of myelopathy symptoms caused by syringomyelia.

**Revision of the foramen of Magendie** followed by duroplasty is still a de facto standard of the posterior decompression for the CM1 [1]. Reliability of the method is among its advantages, while high rate of complications is its shortcoming [9, 22]. However, the series with low rate of complications have been also reported in the literature [10, 12]. The risk of complications is probably associated with personal experience of the surgeon. [9] Proponents of this technique suggest that frequent detection of arachnoid adhesions at the foramen of Magendie during surgery is the ground for routine revision of the fourth ventricle [9, 24]. There are the following counterarguments: first, the effectiveness of the extra-arachnoid decompression is at least not inferior to the revision of the fourth ventricle [20]; second, post-operative adhesion itself is an important cause of ineffective decompression and recurrences [25, 26]. Our experience in the revision of the fourth ventricle is negative: the postoperative period was the least favorable, with high rate of complications. At present, we see no reasons to inspect the foramen of Magendie during primary surgery; it is inevitable only during reoperations after previous explorations of the subarachnoid space.

**Stenting in patients** with CM1 was describes by Rhoton in 1976 [27]. Some surgeons routinely used stents in primary operations; properly placed stent ensures the absence of recurrences. Later on, the widespread use of the method was abandoned, which was motivated by the cases of irritation of the bottom of the fourth ventricle, including the need for reoperation [10, 26]. In our series, the immediate postoperative period after StD was more favorable than after the IAD, but later on, 2 stent had to be removed due to infection. Now we believe that stenting in an option during the revision of the foramen of Magendie, while the use of catheters impregnated with antibiotics can be reasonable.

**Conclusion**

EAD is the most safe and effective method of the posterior decompression for CM1. This operation is attractive as a primary intervention regardless of the presence of syringomyelia. EDD is a safe option of primary operations in children, which is acceptable in the absence of myelopathy signs, rapid progression of the posterior cranial fossa compression symptoms, and severe dislocation of tonsils. Intra-arachnoid dissection, including that with stenting, is hardly reasonable during primary operation, but it may be inevitable in the case of revision.

**Authors declare no conflict of interest.**

### Table 4. Postoperative complications

<table>
<thead>
<tr>
<th>Complications</th>
<th>Number of patients (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wound liquorrhoea</td>
<td>9 (12)</td>
</tr>
<tr>
<td>Meningitis:</td>
<td>7 (9)</td>
</tr>
<tr>
<td>CSF inoculation test is negative</td>
<td>2 (3)</td>
</tr>
<tr>
<td>Pathogen:</td>
<td></td>
</tr>
<tr>
<td>Staphylococcus epidermidis</td>
<td>2 (3)</td>
</tr>
<tr>
<td>Staphylococcus aureus</td>
<td>1 (1)</td>
</tr>
<tr>
<td>Enterococcus faecalis</td>
<td>1 (1)</td>
</tr>
<tr>
<td>Acinetobacter baumannii</td>
<td>1 (1)</td>
</tr>
<tr>
<td>Neurological deficit:</td>
<td>4 (5)</td>
</tr>
<tr>
<td>Positional neuropathy of the sciatic nerve</td>
<td>3 (4)</td>
</tr>
<tr>
<td>Central respiratory disorders*</td>
<td>2 (3)</td>
</tr>
<tr>
<td>Hydrocephalus**</td>
<td>2 (3)</td>
</tr>
<tr>
<td>Sepsis, multiorgan failure</td>
<td>1 (1)</td>
</tr>
<tr>
<td>Total number of patients with complications</td>
<td>15 (20)</td>
</tr>
</tbody>
</table>

**Footnote:** * — only situations, where long-term artificial ventilation was required; ** — patients without ventriculomegaly required shunt operation prior to the posterior decompression.

### References


7. Greenberg JK, Olsen MA, Yarbrough ChK, Ladner TR, Shannon ChN, Piccirillo JF, Anderson RCE, Wellons JC, Smyth MD, Park TS, Limbrick DD. Some surgeons routinely used stents in primary operations; properly placed stent ensures the absence of recurrences. Later on, the widespread use of the method was abandoned, which was motivated by the cases of irritation of the bottom of the fourth ventricle, including the need for reoperation [10, 26]. In our series, the immediate postoperative period after StD was more favorable than after the IAD, but later on, 2 stent had to be removed due to infection. Now we believe that stenting in an option during the revision of the foramen of Magendie, while the use of catheters impregnated with antibiotics can be reasonable.
Commentary

The article presents clinical analysis of the results of 76 operations for posterior decompression in children with Chiari I malformation performed between 2011 and 2015. The study was aimed at comparing the results of surgical interventions and clinical outcomes based on surgical selection criteria for patients with Chiari I malformations. J of Clinical Neurosurgery. 2014;21(12):2201-2206.

The relevance of the work is determined by the lack of a unified approach to the diagnosis algorithm, selection of indications, methods, and extent of surgical treatment of patients with Chiari I malformation. Most neurosurgeons “adapt surgical approach for patients” based on conflicting literature data and their own experience [1]. In recent years, there is a tendency to use more sparing surgical treatments, although some surgeons still advocate “radical” methods [2]. On the basis of this work confirmed by parametric and nonparametric statistical methods, the authors concluded that the method of extra-arachnoidal decompression is the method of choice for patients with Chiari I malformation.
choice during primary surgery for Chiari 1 malformation in children. The incidence and nature of the complications, depending on the technique used, are consistent with the literature [3]. Stenting operations are recognized as a possible option during reoperations for revision of the foramen of Magendie.

Initially, surgeons decided whether to perform the revision of the foramen of Magendie based on the lack of SCF flow from the fourth ventricle after the opening of the dura mater. In the literature, there are articles discussing the relationship between the arachnopathy (according to J. Klekamp) and the need for subarachnoid manipulations [4]. In this regard, it would be interesting to know the authors’ personal opinions on the feasibility and practical benefits of such a grading. Furthermore, correlation between the clinical results of treatment and postoperative MRI data, if it was studies, is of interest as a possible subject for discussion. This aspect is of interest in connection with available publications, reporting that increase in the size of the large occipital cistern is not always indicative of the presence of the normal sine-wave CSF flow in the latter [5], and the length and diameter of syringomyelia may not reflect the degree of neurological deficit. The number of patients (5%) with endocrine disorders as clinical manifestations of the disease is also noticeable. It was interesting to get information on atypical, in my view, forms of Chiari 1 malformation.

Thus, the results correspond to the current knowledge that decompression of the craniovertebral junction with plastic repair of the dura mater without subarachnoid manipulations is an effective and pathogenetically valid method of surgical treatment of patients with Chiari 1 malformation, aimed at correcting SCF circulation disorders and eliminating compression effects on the neural structures of the posterior fossa [6].

The study in undoubtedly of great scientific and practical interest. The need to change the approach to the choice of the extent of the surgery, as well as its standardization, which is emphasized by the authors, once again confirms the relevance of the opinion of J. Ball and K. Crone [7] that, despite more than a century of studying and discussing Chiari malformation in the medical literature, “there are still more questions than answers on this topic”.

A. Reutov (Moscow, Russia)

REFERENCES


Keywords: trigeminal neuralgia, microvascular decompression, venous compression, neurovascular conflict.

Abbreviations

TN — trigeminal neuralgia
MVD — microvascular decompression
TrN — trigeminal nerve
MHRV — monitoring of heart rate variability
MRI — magnetic resonance imaging
BNI scale — Barrow Neurological Institute scale

Objective. The study objective was to verify venous compression as a cause of trigeminal neuralgia (TN) and to define the optimal surgical tactics for TN patients.

Material and methods. Four hundred twenty one patients were operated on for TN at the Neurosurgical Department of the City Hospital №2 from 1998 to 2015. Veins in the trigeminal nerve root entry zone, as a significant compression factor, were identified in 40 patients (9.5%). Intraoperative data, questionnaires, and self-assessment inventories were analyzed. Treatment outcomes were assessed using the Barrow Neurological Institute (BNI) scale.

Results. Patients with venous compression were divided into two groups. Eleven (27.5%) patients in the first group had isolated venous compression. The feature of microvascular decompression (MVD) in these patients was identification of all veins, vein mobilization, and, if possible, vein coagulation and resection. Resection of the vein along its course is a basic procedure to avoid recurrent neuralgia. The second group included 29 (72.5%) patients with a combination of venous and arterial compression. In these patients, a vein acted as an “assisting” compression factor: the vein changed the course of a compressing artery or nerve and exerted an additional compression effect on the nerve. The surgical tactics involved exploration of the trigeminal nerve root entry zone, arterial loop mobilization, and placement of a Teflon protector; venous vessels were coagulated and resected. The MVD efficacy was as follows: in group 1, 10 patients had a BNI score I—III, and 1 patient had a BNI score IV; in group II, 25 patients had a BNI score I—III, and 4 patients had a BNI score IV.

Conclusions. Venous compression can play both independent and assisting roles in the TN genesis. When exploring the trigeminal nerve, examination of the proximal trigeminal nerve is of particular importance, with paying attention to veins that may be a compression factor. In the case of isolated venous compression, the MVD surgical technique has some peculiarities, in particular coagulation and resection of veins compressing the trigeminal nerve root entry zone.

Material and Methods

A total of 421 patients (19 males and 21 females) with the mean age of 60±12 years (range, 28—81 years) underwent surgery for TN at the Department of Neurosurgery of the City Multifield Hospital №2 (Head — Prof. Yu.A. Shulev) in the period from 1998 to 2015. All patients had intractable TN; the mean duration of disease was 8 years (range, 3 months to 30 years). All patients were operated on by the first author according to the classical procedure described by P. Jannetta [11]. In all cases, we used the standard retrosigmoid approach, with the patient lying on the contralateral side.
Intraoperative data, questionnaires, and self-assessment questionnaires were analyzed.

Venous blood vessels in the trigeminal nerve root entry zone, as a significant compression factor, were detected in 40 (9.5%) patients. Of these, 5 (12.5%) patients underwent previous destructive surgery on the trigeminal nerve (TrN) at other clinics. A total of 43 MVD operations were performed; 3 patients were re-operated after 1—2 weeks because of persisting postoperative pain. Arterial compression of the TrN was eliminated by mobilization of an artery, followed by its retraction and placement of a Teflon protector, often together with a gelatin sponge. Venous compression was eliminated through coagulation of a vein, followed by its resection, or through mobilization of the vein with placement of a Teflon pad between the vein, TrN, and pons. Veins are named according to the Matsushima-Rhoton classification [12, 13]. Clinical outcome was evaluated using a Barrow Neurological Institute (BNI) scale (Tables 1 and 2) [14].

Surgeries were carried out using monitoring of the heart rate variability (MHRV) to detect an early manifestation of the trigeminocardiac reflex being a demyelination site marker [15, 16]. MHVR is based on recording standard lead ECG, followed by graphical representation of a calculated heart rate in the form of a R—R interval histogram (Fig. 2b and Fig. 5). Demyelination in the area of TrN root compression, which causes TN, leads to the fact that manipulations in this area induce more intense afferent impulsion and, consequently, the emergence of trigeminocardiac responses. Adequate and sparing manipulations in the TrN root entry zone do not induce the true trigeminocardiac reflex (severe bradycardia, up to asystole; hypotension), and an early manifestation of the trigeminocardiac reflex can be detected through analysis of graphically represented dynamics of successive R—R intervals and analysis of a histogram.

Therefore, monitoring of pathological TrN irritation areas is based on evaluation of early manifestations of the trigeminocardiac reflex, which serve a marker for manipulations in the area of TrN demyelination and, consequently, in the area of true neurovascular conflict.

Results

Patients with venous compression were divided into two groups (Table 3).

The 1st group included 11 (27.5%) patients with isolated venous compression. The peculiarity of MVD in these patients was careful exploration of the root entry zone, identification of all veins, and their coagulation and resection. Extensive resection of a vein is the essential and crucial moment to prevent recurrence associated with potential recanalization of a coagulated vein.

We allocated these patients into three subgroups because each subgroup served the argument to support a hypothesis of potential venous compression in TN (Table 3).

Subgroup 1 (7 patients). A vein is the only vessel contacting the TrN. The TrN was separated from the vein; the contact was eliminated; pain disappeared immediately and completely (Table 4; a clinical case 1).

Clinical case 1

A 66-year-old female patient presented with TN on the right (type I, branch II) and complaints of facial electric shock-like pain attacks. The pain was provoked by washing, brushing the teeth, and talking. The patient suffered for 5 years.

Intraoperatively, we identified a large vein (pontotrigeminal vein) that came along the pons, medial to the TrN (in the axilla of the TrN), and opened into the superior petrosal sinus, stretching the TrN. The vein was coagulated and extensively resected (from the bifurcation on the pons to the opening into the superior petrosal sinus). The superior cerebellar artery was not identified in the operative site (Fig. 1). After surgery, the pain disappeared completely and immediately (BNI I). The patient was discharged on the 5th day.

Subgroup 2 (1 patient). A vein is the only vessel contacting the TrN. The vein was spared because of a high risk of complications, and the pain persisted (Table 3, Fig. 2).

Subgroup 3 (3 patients). A vein remained the only vessel contacting the TrN after failed first MVD surgery that eliminated only contact between an artery and the TrN. In this group, the artery was located in the TrN root entry zone, and artery retraction was initially considered to be sufficient. Contact with a vein was intentionally preserved to avoid excessive manipulations in the brainstem region. However, facial pain persisted after the first surgery. Elimination of the contact between the TrN and the preserved vein during the second MVD

Table 1. The Barrow Neurological Institute scale of trigeminal pain intensity

<table>
<thead>
<tr>
<th>BNI grade</th>
<th>Pain intensity</th>
</tr>
</thead>
<tbody>
<tr>
<td>BNI I</td>
<td>No pain</td>
</tr>
<tr>
<td>BNI II</td>
<td>Occasional pain, no medications required</td>
</tr>
<tr>
<td>BNI III</td>
<td>Tractable pain</td>
</tr>
<tr>
<td>BNI IV</td>
<td>Intractable pain</td>
</tr>
<tr>
<td>BNI V</td>
<td>Severe intractable pain</td>
</tr>
</tbody>
</table>

Table 2. The Barrow Neurological Institute scale of facial numbness

<table>
<thead>
<tr>
<th>BNI grade</th>
<th>Facial numbness intensity</th>
</tr>
</thead>
<tbody>
<tr>
<td>BNI I</td>
<td>No numbness</td>
</tr>
<tr>
<td>BNI II</td>
<td>Minor numbness that does not cause discomfort and anxiety</td>
</tr>
<tr>
<td>BNI III</td>
<td>Numbness that causes discomfort and anxiety</td>
</tr>
<tr>
<td>BNI IV</td>
<td>Severe numbness that very disturbs the patient</td>
</tr>
</tbody>
</table>
Fig. 1. Surgical stages in a female patient N. (Table 1)

a — the pontotrigeminal vein (shown by the dashed line) comes in the “axilla” of the TrN; b — the TrN is retracted with a bellied bougie; c — coagulation of a venous portion rostral to the TrN; d, e — the rostral portion of the vein is coagulated and resected, the caudal vein portion located on the pons is seen; f — the vein is completely resected over a long distance.

led to complete disappearance of the pain. Although an arterial vessel in this subgroup was located in the TrN root entry zone, separation of the artery from the nerve did not lead to regression of pain that disappeared only after resection of the vein, which allowed us to consider a vein in these cases as a significant compression factor.
**Clinical case 2**

A 75-year-old male patient presented with TN on the right (type I, branch II) and complaints of electric shock-like pain attacks arising only upon provocation (touching the face, shaving, eating). The patient suffered for 2 years.

A Y-shaped superior cerebellar artery that rostrally compressed the TrN was identified during the first MVD. The superior cerebellar artery was mobilized, retracted, and isolated from the TrN using Teflon wool and a gelatin sponge. A large vein attached to the pons was visualized intraoperatively. Given the identified and eliminated arterial compression, we decided to refrain from manipulations with the vein. The pain persisted after surgery (Fig. 3).

MVD was repeated after 7 days. In the area of the TrN entrance into the brainstem, the vein of cerebellopontine fissure was the only vessel contacting the TrN. The vein was mobilized and resected over a long distance (Fig. 4). After surgery, the pain disappeared completely and immediately.

The latter clinical case clearly demonstrates that several potentially significant sites of TrN compression can simultaneously exist. All of them need to be visualized, and the conflict should be resolved. Application of the MHRV technique for neurophysiological monitoring makes it possible not only to control the safety of manipulations but also to intraoperatively monitor areas of pathological irritation.

The 2nd group consisted of 29 (72.5%) patients with a combination of venous and arterial compression. In these patients, a vein acted as an assisting compression factor: the vein changed the course of a compressing artery or the nerve and exerted an additional compression effect on the nerve. The surgical tactics involved exploration of the trigeminal nerve root entry zone, arterial loop mobilization, and placement of a Teflon protector; venous vessels were coagulated and resected. In this group, it is difficult to reliably prove or disprove the role of an assisting vein. During retraction and coagulation of a vein, we observed pronounced changes in the form of TrN deformation, formation of an excavation in the retracted vein area, and thinning of the arachnoid membranes (Fig. 5).

According to the BNI scale, the efficacy of MVD in our series was as follows: in group 1, 10 patients had a BNI score of I—III, and 1 patient had a BNI score of IV; in group 2, 25 patients had a BNI score of I—III, and 4 patients had a BNI score of IV. Information on the surgical treatment outcomes is summarized in Tables 5 and 6.

Based on our previous experience, we believe that venous vessels located in the TrN root entry zone act as a compression factor. An indirect indicator for this may be changes during MHRV that reflects occurrence of the trigeminocardiac reflex during manipulations on the TrN root. In 16 patients of this group, mobilization of an arterial vessel was not accompanied by changes in the MHRV data recorded on an R-R interval electrocardiogram, while coagulation of a venous vessel was associated with significant signs of TrN irritation.

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**Table 3. Groups and subgroups of patients with venous compression**

<table>
<thead>
<tr>
<th>Group. Subgroup</th>
<th>Group/subgroup characteristics</th>
<th>Number of patients</th>
<th>Commentary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1</td>
<td>Isolated venous compression</td>
<td>n=11</td>
<td></td>
</tr>
<tr>
<td>1st subgroup</td>
<td>A vein was the only vessel contacting TrN</td>
<td>7</td>
<td>Effective primary MVD with vein resection</td>
</tr>
<tr>
<td>2nd subgroup</td>
<td>A vein was spared because of a high risk of complications</td>
<td>1</td>
<td>Facial pain persisted after MVD. A patient was referred to stereotactic gamma-irradiation</td>
</tr>
<tr>
<td>3rd subgroup</td>
<td>A vein remained the only vessel contacting TrN after ineffective first MVD when contact of arteries with TrN was eliminated</td>
<td>3</td>
<td>A patient underwent repeated MVD with dissection and coagulation of the vein, which resulted in the disappearance of facial pain</td>
</tr>
<tr>
<td>Group 2</td>
<td>Venous compression was combined with arterial compression. A vein acted as an assisting compression factor</td>
<td>n=29</td>
<td>MVD involved mobilization of an arterial loop and resection of venous vessels</td>
</tr>
</tbody>
</table>

**Table 4. Clinical characteristics of patients in the 1st subgroup (n=7)**

<table>
<thead>
<tr>
<th>№</th>
<th>Gender</th>
<th>Age, years</th>
<th>Side</th>
<th>Branch</th>
<th>TN type</th>
<th>Vein</th>
<th>Technique</th>
<th>MVD outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>M</td>
<td>59</td>
<td>Right</td>
<td>II</td>
<td>2</td>
<td>Vein of cerebellopontine fissure</td>
<td>Resection</td>
<td>Excellent, BNI I</td>
</tr>
<tr>
<td>2</td>
<td>F</td>
<td>57</td>
<td>Left</td>
<td>III</td>
<td>2</td>
<td>Pontotrigeminal vein</td>
<td>Resection</td>
<td>Excellent, BNI I</td>
</tr>
<tr>
<td>3</td>
<td>M</td>
<td>57</td>
<td>Right</td>
<td>II</td>
<td>2</td>
<td>Pontotrigeminal vein</td>
<td>Resection</td>
<td>Excellent, BNI I</td>
</tr>
<tr>
<td>4</td>
<td>F</td>
<td>66</td>
<td>Right</td>
<td>III</td>
<td>2</td>
<td>Pontotrigeminal vein</td>
<td>Resection</td>
<td>Excellent, BNI I</td>
</tr>
<tr>
<td>5</td>
<td>M</td>
<td>69</td>
<td>Right</td>
<td>II</td>
<td>1</td>
<td>Transverse pontine vein</td>
<td>Resection</td>
<td>Excellent, BNI I</td>
</tr>
<tr>
<td>6</td>
<td>F</td>
<td>58</td>
<td>Right</td>
<td>II</td>
<td>2</td>
<td>Superior petrosal vein</td>
<td>Resection</td>
<td>Excellent, BNI I</td>
</tr>
<tr>
<td>7</td>
<td>F</td>
<td>62</td>
<td>Left</td>
<td>II</td>
<td>2</td>
<td>Vein of cerebellopontine fissure</td>
<td>Resection</td>
<td>Excellent, BNI I</td>
</tr>
</tbody>
</table>
Thus, we may define the criteria of a compressing vein: 1) a venous vessel is located in the TrN root entry zone; 2) the vein deeply invades the entry zone and forms an excavation on the nerve trunk; 3) the appearance of TrN irritation signs, according to the MHRV data, during dissection and coagulation of the vein.

Discussion

Our experience and an analysis of the intraoperative data confirm that veins may cause TN.

Recognition of the venous compression slightly disharmonizes the concept of neurovascular conflict as a cause of TN because veins have no pulsation effect on the TrN. However, it should be noted that veins, as a possible cause of TN, have not been ignored since the emergence of the concept of neurovascular conflict. Walter Dandy wrote: “In another group of cases, a petrosal vein branch runs across a sensitive root or transfixes it. This observation took place in 30 (14%) cases. I am less inclined to consider this relationship as a cause of TN, although it is hard to believe that this is not an actual causative factor” [3]. P. Jannetta [17] considered veins as an isolated compression factor during MVD in 13% of patients (151 out of 1,204 surgeries).

Opponents of the venous compression concept may be divided into two groups. In one case, these are

Fig. 2. A 43-year-old female patient. NT on the right (type I; branches II and III on the left).
A large vein (a) was located in the “axilla” of the TrN. Attempts to mobilize the vein were accompanied by apparent trigeminocardial responses (b), which resulted in termination of surgery. The vein was spared. Pain persisted after surgery (BNI IV). The patient was referred to stereotactic gamma-irradiation.

Fig. 3. A Y-shaped superior cerebellar artery (SCA) rostrally compressing the TrN (a, b) was retracted and isolated from the TrN with a Teflon protector (c).
proponents of the concept of neurovascular conflict, but only with arterial compression [10]. In the second case, these are opponents of the very concept of neurovascular conflict, denying the phenomenon of “vascular compression” and explaining the efficacy of MVD by microtraumas to the TrN during surgery, which is equivalent to rhizotomy [10, 18]. However, the international community has recognized that TN results
USA) detected venous compression in 4 of 6 TN patients aged 3—18 years during MVD. Separation of the nerve and a vein and elimination of contact provided complete pain relief in all cases. According to our data, there was no significant difference in the age of patients with isolated venous compression (62±6 years) and isolated arterial compression (64±9 years), which may be due to an insufficient number of venous compression cases for reliable statistical analysis.

Many authors have not found clinical features of venous compression (side, branches, a type of the clinical course). In a series of 7 patients with isolated venous compression, Matsushima et al. (Fukuoka, Japan) detected paroxysmal TN (Burchiel type I) in all patients. Elimination of the venous compression led to the complete disappearance of pain in all cases [7]. Other authors believe that venous compression usually occurs as Burchiel type II (atypical clinical course), i.e. it is accompanied, in addition to attacks, by constant burning pain [21]. According to our data, 7 patients with isolated venous compression had Burchiel type II TN, and 4 patients had Burchiel type I TN.

The mechanism of TN development in the case of arterial compression is explained by a pulsating demyelination effect on the TrN. In the case of venous compression, simple mechanical compression occurs due to adherence of a vein to the arachnoid membranes and nerve sheath, causing deformation of the adjacent nerve, which may also lead to local demyelination and formation of the pathological irritation area.

In the formation of neurovascular compression, a vein may play an independent and assisting role, changing the course of an arterial vessel and creating the preconditions for compression.

It is believed that any vein contacting the TrN anywhere from its exit from the Meckel’s cave to the entrance into the pons can be a conflict factor. According to our data, a vein contacted only the area of TrN from compression of the TrN root by a blood vessel, which is reflected in the International Classification of Headaches Disorders (2013) [1].

The hypothesis of venous compression raises a number of questions about compression features.

According to several authors [19, 20], venous compression is more common in young people. M. Bender et al. [20] (Department of Neurosurgery, The Johns Hopkins University School of Medicine, Table 5. MVD outcomes in patients with venous compression (BNI scale of pain intensity)

<table>
<thead>
<tr>
<th>Group, Subgroup</th>
<th>BNI I</th>
<th>BNI II</th>
<th>BNI III</th>
<th>BNI IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1 (n=11)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1st subgroup (n=7)</td>
<td>7</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2nd subgroup (n=1)</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3rd subgroup (n=3)</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Group 2 (n=29)</td>
<td>20</td>
<td>3</td>
<td>2</td>
<td>4</td>
</tr>
</tbody>
</table>

Table 6. MVD outcomes in patients with venous compression (BNI scale of facial numbness intensity)

<table>
<thead>
<tr>
<th>Group, Subgroup</th>
<th>BNI I</th>
<th>BNI II</th>
<th>BNI III</th>
<th>BNI IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1 (n=11)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1st subgroup (n=7)</td>
<td>7</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2nd subgroup (n=1)</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3rd subgroup (n=3)</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Group 2 (n=29)</td>
<td>22</td>
<td>4</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>
entrance into the pons in 7 of 11 cases. In the remaining 4 cases, a vein came over the TrN surface and opened into the superior petrosal sinus.

The classical MVD procedure involves coagulation and dissection of the superior petrosal vein. If the superior petrosal vein did not contact the TrN and did not interfere with the view and approach to the TrN, we spared the vein. Otherwise, the superior petrosal vein was resected. Coagulation of veins located on the pons brings the risk of complications due to impairment of venous outflow from the brainstem. We believe that coagulation of veins located on the pons is much more dangerous than that of the superior petrosal vein, despite the fact that pontine veins are its branches. The transverse pontine vein has perforants coming to the trunk, and coagulation of the vein is risky and may be accompanied by complications (clinical case 2).

Isolated venous compression is considered as an important risk factor for TN recurrence after MVD [6, 22]. Venous compression, isolated or combined, was reported to be the most frequent cause of these recurrences [23]. Two mechanisms are considered: TrN irritation by a swollen stump of a coagulated vein or the emergence of a new vein due to dilatation or vein regrowth — vein recanalization [6]. We adhere to the same opinion and consider extensive resection of a vein to be important for prevention of TN recurrence. If a vein came along the trunk, and its dissection may be accompanied by neurological complications, we, in some cases, mobilized the vein and placed a Teflon protector. There were no recurrences in our series.

Isolated venous compression in the absence of arterial compression is also considered as an important risk factor for a low efficacy of MVD [24, 25]. In our series, MVD surgery was repeated in 3 of 10 patients in group 1 after 1—2 weeks due to failure of the first operation. A vein contacting the TrN was identified in all cases; after resection of the vein, pain disappeared completely and immediately (BNI I).

In a magnetic resonance imaging (MRI) study, it is more difficult to visualize contact of the TrN with a vein than with an artery; therefore, venous compression may be missed during the preoperative planning of MVD [21, 26]. In modern MRI techniques, detection of a venous vessel is less reliable compared to detection of an arterial vessel. In these cases, careful taking of medical history and intraoperative exploration under MHVR control are important.

Conclusions

Venous compression may play both an independent and assisting role in the TN genesis. When exploring the trigeminal nerve, its proximal portion should be carefully inspected, paying attention to veins that may act as a compression factor. In the case of isolated venous compression, the surgical MVD technique has its own features, the main of which are coagulation and extensive resection of veins compressing the trigeminal nerve root entry zone.

Authors declare no conflict of interest.

REFERENCES


showed that “a vein changed the course of a compressing artery vessels, in a combined impact on the nerve root is insufficiently veins in the development of trigeminal neuralgia. However, the compression may be regarded as evidence of the leading role of surgery was actually divided into two stages due to failure of decompression of the nerve root in single surgery; in 3 cases, venous compression, 29 patients underwent microvascular compression (32 cases). In the group of combined arterial-venous compression (8 cases) and combined arterial-venous depending on the type of neurovascular conflict: isolated compression of the trigeminal nerve root and is of great interest first Russian-language publication that analyzes venous vascular decompression based on dissection of a vein is identical to those for arterial compression of a nerve root; identification of a compressing venous vessel, which are almost neuralgia. There are described the intraoperative criteria for published studies devoted to the surgical treatment of trigeminal compression are well known and analyzed in detail in previously small group of patients. A combined impact of arteries and in the development of neurovascular conflict in a relatively often located at some distance from the artery along the trigeminal nerve root. The paper does not evaluate long-term outcomes of the treatment. A follow-up study is required to determine recurrences, the rate of which in patients with venous compression of the trigeminal nerve root is usually higher than that in arterial compression. An analysis of vascular decompression outcomes will clarify the indications and promote the development of surgical technique modifications to improve outcomes in patients with isolated venous compression. Additional difficulty in the evaluation of outcomes is also associated with inclusion of patients with different types of facial pain (by K. Burchiel) in the study group: typical classical trigeminal neuralgia and the atypical form. The authors use monitoring of the heart rate variability to register early manifestations of the trigemino-cardiac reflex, the development of which during manipulations on a trigeminal nerve root may lead to hemodynamic complications. The trigemino-cardiac reflex is usually inhibited by administration of atropine, and prevention of the reflex is achieved by excluding gross surgical procedures on the trigeminal root. The demyelination area developing in the peribrainstem portion of the nerve root during vascular compression is not a spot, but has a certain length. Therefore, traction and electrothermal effects

Commentary

The leading etiological factor of trigeminal neuralgia is compression of the peribrainstem portions of the trigeminal nerve by vascular structures. In most cases of trigeminal neuralgia, nerve root compression is caused by excessive loops of the cerebellar arteries; however, venous vessels are involved in the development of neurovascular conflict in a relatively small group of patients. A combined impact of arteries and veins on the trigeminal nerve root as well as isolated venous compression are well known and analyzed in detail in previously published studies devoted to the surgical treatment of trigeminal neuralgia. There are described the intraoperative criteria for identification of a compressing venous vessel, which are almost identical to those for arterial compression of a nerve root; vascular decompression based on dissection of a vein is recognized as the most appropriate technique.

The value of this work is related to the fact that this is the first Russian-language publication that analyzes venous compression of the trigeminal nerve root and is of great interest to neurosurgeons. The presented clinical material may be divided, based on the intraoperative findings, in two parts depending on the type of neurovascular conflict: isolated venous compression (8 cases) and combined arterial-venous compression (32 cases). In the group of combined arterial-venous compression, 29 patients underwent microvascular decompression of the nerve root in single surgery; in 3 cases, surgery was actually divided into two stages due to failure of initial arterial decompression. The disappearance of pain after vascular decompression in patients with isolated venous compression may be regarded as evidence of the leading role of veins in the development of trigeminal neuralgia. However, the assumption of an “assisting” role of veins, together with arterial vessels, in a combined impact on the nerve root is insufficiently reasoned. According to the authors, the intraoperative findings showed that “a vein changed the course of a compressing artery or the nerve and exerted an additional compressing effect on the nerve”. Arteriovenous relationships where a thin-walled vein with relatively low intraluminal pressure displaces a relatively thick-walled arterial vessel with high blood pressure seem to be unlikely. In combined compression, a vein usually compresses a nerve root regardless of an artery, and the vein is often located at some distance from the artery along the trigeminal nerve root.

The paper does not evaluate long-term outcomes of the treatment. A follow-up study is required to determine recurrences, the rate of which in patients with venous compression of the trigeminal nerve root is usually higher than that in arterial compression. An analysis of vascular decompression outcomes will clarify the indications and promote the development of surgical technique modifications to improve outcomes in patients with isolated venous compression. Additional difficulty in the evaluation of outcomes is also associated with inclusion of patients with different types of facial pain (by K. Burchiel) in the study group: typical classical trigeminal neuralgia and the atypical form. The use of microvascular decompression in patients with the atypical form of facial pain is accompanied by a significantly lower likelihood of a positive outcome, which again underlines the need and importance to analyze long-term results.
on the nerve fibers both in the proximal and more distal segments of the root will be accompanied by the trigemino-cardiac reflex, induction of which indicates an excessive intensity of surgical manipulations rather than the exact location of a demyelination area and compressing agent.

Complete neurovascular decompression is rarely impossible due to a high risk of hemodynamic complications, which the authors observed in one of the isolated venous compression cases and recommended a patient to undergo stereotactic radiosurgery. In these situations, partial sensory rhizotomy can be performed that will lead to the disappearance of neuralgic pain and eliminate the need for additional destructive surgery.

Yu.A. Grigoryan (Moscow, Russia)
Facial nerve (FN) palsy is accompanied by a gross defect in appearance and other complications, which may lead to severe psychological trauma and social disadaptation. Currently, surgery is the most effective treatment to recover facial muscle functions. This is a great challenge in the case of persistent facial nerve palsy, and any successful surgery may be called a success. The diversity of surgical treatments and the lack of a consistent approach to restoring movement of all facial muscles suggest that the disease treatment problem is far from being solved [1—4].

The study purpose was to evaluate the degree of FN function recovery, following trigeminal neurotization. Trigeminal neurotization was performed in 23 patients within 1 to 10 months after the development of facial paralysis. In most cases, the cause of facial paralysis was surgery for space-occupying lesions of the cerebellopontine angle (95.6%). Outcomes of trigeminal neurotization were evaluated in 17 (73.9%) patients who were followed-up for more than 6 months. In 16 (94.1%) patients, the facial nerve function was recovered to a House-Brackmann grade III—IV. Given the surgery results, we can say that trigeminal neurotization is one of the effective treatments for facial paralysis. In most cases, this technique has provided good outcomes without additional complications, which is important to this group of patients.

Keywords: facial nerve, facial paralysis, trigeminal neurotization.

Abbreviations
FN — facial nerve
CPA — cerebellopontine angle
PCF — posterior cranial fossa
EMG — electromyography
HB — House-Brackmann scale

Facial nerve (FN) palsy is accompanied by a gross defect in appearance and other complications, which may lead to severe psychological trauma and social disadaptation. Currently, surgery is the most effective treatment to recover facial muscle functions. This is a great challenge in the case of persistent facial nerve palsy, and any successful surgery may be called a success. The diversity of surgical treatments and the lack of a consistent approach to restoring movement of all facial muscles suggest that the disease treatment problem is far from being solved [1—4].

The study purpose was to evaluate the degree of FN function recovery, following trigeminal neurotization.

Material and Methods
Twenty three patients (17 females and 6 males) aged from 32 to 76 years (mean age, 50.8 years) with FN paralysis of different etiologies underwent surgery at the Federal Neurosurgical Center in Novosibirsk in the period between 2013 and 2015. In most cases, FN paralysis developed after surgical treatment for space-occupying lesions of the cerebellopontine angle (CPA): 19 (82.6%) patients after removal of vestibular schwannoma, 2 (8.6%) patients after removal of CPA meningioma, 1 (4.4%) patient after removal of CPA cholesteatoma, and 1 (4.4%) patient after severe traumatic brain injury (TBI) associated with a skull base fracture (Table 1).

All tumors of the posterior cranial fossa (PCF) had a large or giant size (mean, 40.1 mm). Anatomical injury to the FN was observed in 18 (78.3%) cases in the course of PCF tumor resection; the FN was anatomically intact but functionally failed in 3 (13%) patients. In 2 (8.7%) patients admitted from other clinics, it was not possible to refine the anatomical integrity of the FN. For this reason, the patients received conservative treatment for 6 months.

The House-Brackmann scale was used to evaluate FN dysfunction before and immediately after surgery as well as 4 and 6 months after surgery. Trigeminal neurotization was performed in patients with House-Brackmann grade VI FN paralysis. Before neurotization, all patients underwent stimulation and needle electromyography (EMG) of the facial muscles. A complete absence of the M-response from the mimic muscles was detected in all cases. We also detected a spontaneous activity in the form of fibrillation potentials of a varying intensity as a manifestation of acute denervation of the mimic muscles (Fig. 1).

Trigeminal neurotization was performed in the patients within 1 to 10 months after the development of FN paralysis. Surgery was performed at early times after FN injury: in 18 patients after 1—2 months and in 5 patients after 6—10 months.

The surgical treatment outcomes were evaluated based on photo and video records that documented the condition of facial muscles in all patients at the preoperative and postoperative stages. Patients from other regions who could not come to the center for examination sent photos and videos 6 months after surgery.
Results

The efficacy of trigeminal neurotization was evaluated in 17 (73.9%) patients (Table 2) with a follow-up period of more than 6 months. At 6 months after surgery, 16 (94.1%) patients recovered FN functions to a House-Brackmann grade III—IV. One (5.9%) patient had no improvement in the FN function.

In this case, good results were achieved in patients with a small (1—2 months) duration of paralysis between FN injury and trigeminal neurotization. All patients in this group improved their condition: the FN function recovered to a House-Brackmann grade III in 8 (66.7%) patients and to a House-Brackmann grade IV in 4 (33.3%) patients. In a group of patients operated on 6—10 months after the development of facial paralysis, 4 (33.3%) patients recovered their condition: the FN function remained unchanged in 1 case and markedly improved in 4 cases. In these patients, recovery of the facial nerve function was less than to a House-Brackmann grade IV.

There were no early and late surgical complications; wounds healed by first intention.

Clinical case

A 54-year-old male patient (Table 1, case 16) underwent surgery for a giant vestibular schwannoma, 53×42×38 mm in size. During tumor resection, anatomical injury to the FN occurred. Intraoperatively, a complete interruption of conduction in the nerve was detected by intraoperative EMG monitoring. One month later, the patient underwent stimulation and needle EMG of the facial muscles (Fig. 1a), which revealed signs of FN neuropathy with complete impairment of impulse conduction in the nerve and gross denervation of the mimic muscles.

Trigeminal neurotization of the FN was performed 35 days after resection of the PCF tumor. Figure 2 presents images for HB grade VI facial muscle paralysis before surgery (Fig. 2a) and for dynamics of recovery at 4 months (Fig. 2b) and 6 months (Fig. 2c) in the form of FN function improvement from HB grade VI to grade III. According to the needle EMG data, positive improvements occurred after 6 months: there emerged signs of compensatory reinnervation of the facial muscles, being more pronounced in the orbicularis oris muscle (Fig. 3).

Discussion

The FN was the first nerve subjected to reinnervation to recover its function. This type of surgery was performed

Table 1. Clinical characteristics of patients with PCF tumors

<table>
<thead>
<tr>
<th>Patient</th>
<th>Gender</th>
<th>Age, years</th>
<th>Tumor histology</th>
<th>Tumor size, mm</th>
<th>Duration of palsy before trigeminal neutralization, months</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>F</td>
<td>44</td>
<td>Neuroma</td>
<td>37×41×26</td>
<td>6</td>
</tr>
<tr>
<td>2</td>
<td>F</td>
<td>58</td>
<td>Neuroma</td>
<td>32×40×31</td>
<td>8</td>
</tr>
<tr>
<td>3</td>
<td>F</td>
<td>33</td>
<td>Cholesteatoma</td>
<td>54×47×45</td>
<td>5</td>
</tr>
<tr>
<td>4</td>
<td>F</td>
<td>66</td>
<td>Neuroma</td>
<td>32×39×41</td>
<td>10</td>
</tr>
<tr>
<td>5</td>
<td>F</td>
<td>36</td>
<td>Neuroma</td>
<td>39×22×28</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>F</td>
<td>52</td>
<td>Neuroma</td>
<td>40×30×30</td>
<td>1</td>
</tr>
<tr>
<td>7</td>
<td>F</td>
<td>38</td>
<td>Neuroma</td>
<td>43×32×30</td>
<td>3</td>
</tr>
<tr>
<td>8</td>
<td>M</td>
<td>61</td>
<td>Neuroma</td>
<td>37×26×39</td>
<td>1</td>
</tr>
<tr>
<td>9</td>
<td>M</td>
<td>56</td>
<td>Neuroma</td>
<td>21×39×26</td>
<td>5</td>
</tr>
<tr>
<td>10</td>
<td>F</td>
<td>52</td>
<td>Neuroma</td>
<td>40×40×45</td>
<td>1</td>
</tr>
<tr>
<td>11</td>
<td>F</td>
<td>61</td>
<td>Meningioma</td>
<td>39×25×32</td>
<td>1</td>
</tr>
<tr>
<td>12</td>
<td>F</td>
<td>64</td>
<td>Meningioma</td>
<td>32×60×41</td>
<td>1</td>
</tr>
<tr>
<td>13</td>
<td>M</td>
<td>47</td>
<td>Neuroma</td>
<td>42×38×38</td>
<td>8</td>
</tr>
<tr>
<td>14</td>
<td>M</td>
<td>58</td>
<td>Traumatic brain injury</td>
<td>–</td>
<td>7</td>
</tr>
<tr>
<td>15</td>
<td>F</td>
<td>50</td>
<td>Neuroma</td>
<td>39×40×37</td>
<td>2</td>
</tr>
<tr>
<td>16</td>
<td>M</td>
<td>54</td>
<td>Neuroma</td>
<td>53×42×38</td>
<td>1</td>
</tr>
<tr>
<td>17</td>
<td>F</td>
<td>61</td>
<td>Neuroma</td>
<td>41×46×38</td>
<td>2</td>
</tr>
<tr>
<td>18</td>
<td>F</td>
<td>51</td>
<td>Neuroma</td>
<td>26×38×24</td>
<td>1</td>
</tr>
<tr>
<td>19</td>
<td>F</td>
<td>41</td>
<td>Neuroma</td>
<td>30×20×24</td>
<td>2</td>
</tr>
<tr>
<td>20</td>
<td>M</td>
<td>76</td>
<td>Neuroma</td>
<td>35×37×42</td>
<td>5</td>
</tr>
<tr>
<td>21</td>
<td>F</td>
<td>32</td>
<td>Neuroma</td>
<td>44×43×32</td>
<td>1</td>
</tr>
<tr>
<td>22</td>
<td>F</td>
<td>43</td>
<td>Neuroma</td>
<td>28×35×23</td>
<td>2</td>
</tr>
<tr>
<td>23</td>
<td>F</td>
<td>35</td>
<td>Neuroma</td>
<td>25×34×39</td>
<td>2</td>
</tr>
</tbody>
</table>

Table 2. Outcomes of trigeminal neurotization of the FN

<table>
<thead>
<tr>
<th>Duration of facial palsy before trigeminal neutralization, months</th>
<th>Number of patients</th>
<th>Outcomes at 6 months</th>
</tr>
</thead>
<tbody>
<tr>
<td>1—2</td>
<td>12</td>
<td>Improvement to grade III in 8 patients and to grade IV in 4 patients</td>
</tr>
<tr>
<td>6—10</td>
<td>5</td>
<td>Improvement to grade IV in 4 patients, no changes in 1 patient</td>
</tr>
</tbody>
</table>
Findings: EMG — signs of neuropathy of the left facial nerve, with complete impairment of impulse conduction in the nerve and gross denervation of the mimic muscles in the ongoing process stage.
by T. Drobnik in 1879. The surgery involved suturing of the peripheral FN segment with the central segment of the motor nerve where the accessory nerve was used as a donor. V.M. Mints was the first Russian surgeon who performed an anastomosis of the FN in 1903. He also used the accessory nerve as a donor nerve [3, 5]. Soon, other cranial nerves (masseteric, phrenic, and hypoglossal), in addition to the accessory nerve, were used for FN reinnervation [3, 4, 6].

Although extracranial reinnervation of the FN restores the mimic muscle function, it also has serious drawbacks. Transection of a donor nerve is associated with the development of additional neurological disorders that reduce the efficacy of surgery and do not fully satisfy patients and surgeons [4, 6, 7].

According to the literature, the hypoglossal nerve is most commonly used as a donor. The most appropriate site to transect the n. hypoglossus is that next to the point where the descending ramus branches because this preserves innervation of the hyoid muscles. However, this procedure leads to hemiatrophy of the tongue in 100% of cases, which entails speech and swallowing impairments [2, 3, 8, 9]. Given this risk, surgeons are now turning to modified surgery — FN reinnervation with the hypoglossal nerve, with simultaneous hypoglossal nerve reinnervation with its descending branch [3—9]. M. Samii [8] conducted a comparative study of these two FN reinnervation techniques using the n. hypoglossus. The study revealed no significant difference between the techniques in recovery of the FN function. However, simultaneous hypoglossal nerve reinnervation with its descending branch greatly reduced risk of complications, such as tongue hemiatrophy (from 100 to 5.8% of cases) and impairments of swallowing (from 55 to 11.7%) and speech (from 33 to 0%) [8, 9].

FN reinnervation with the phrenic nerve was proposed by F.A. Poemny and F.T. Khitrov in 1949. Transection of the phrenic nerve does not usually entail serious neurological disorders, but causes hardly correctable associated movements synchronized with the breath [3, 5, 6].

Transection of the accessory nerve, in addition to atrophic changes in the trapezius and sternocleidomastoid muscles and reduced strength in the shoulder, also leads to associated movements of the facial muscles, synchronous with arm movements; their elimination requires long-term conservative treatment, which does not always satisfy patients [3, 4, 6].

Also, cross-facial nerve grafting is used when a long sural nerve graft is sutured end-to-side to the FN branches on the healthy side and end-to-end to the FN branches or to the FN trunk on the lesioned side [3, 6]. Because facial mimics is generally symmetrical (particularly, when smiling), the difference in the degree of muscle contraction can be almost imperceptible [10]. However, axonal sprouting through an autograft takes a long time during which irreversible degeneration of the mimic muscles can occur. Therefore, according to A.I. Nerobeev et al. [6, 8, 11], immediate delivery of new pulses from another source is required to provide “first aid” to the nerve.

According to the international literature [1, 4, 6, 12—14], the masseteric nerve is now used as an alternative donor nerve. A paper by B. Hontanilla et al. [14] describes the results of a study involving 23 patients. Trigeminal neurotization improved the FN function to a House-Brackmann grade III—IV in 95% of cases within 6—18 months. A comparison of the efficacy of FN reinnervation using the sublingual and masseteric nerves demonstrated that the results were comparable. The authors noted that reinnervation with the masseteric nerve resulted in better symmetry and a faster onset of movement [15].

According to an analysis of the Russian and international literature, researchers tend to believe that

Fig. 2. Recovery dynamics of FN function.
a — before surgery; b — after 4 months; c — 6 months after trigeminal neurotization.
in the case of injury to the anatomical integrity of the FN, the best outcomes are achieved for surgery at earlier times after FN injury [6, 8, 14, 16]. When the LN is anatomically intact but functionally failed (House-Brackmann grade VI), and there is no spontaneous recovery of its function after 6 months, the reinnervation period may last up to 12 months and depends on outcomes of
needle EMG of the face (presence of an irreversible axonal-demyelinating process) [17, 18].

Trigeminal neurotization has some advantages related to surgery traits of these nerves. The masseteric nerve is the motor branch of the trigeminal nerve and reaches 3 mm in diameter, on average, in the subzygomatic triangle, so its diameter is well matched to that of the extracranial branches of the facial nerve [6, 13, 17]. According to K. Boahene [17], the main advantage of FN reinnervation with the masseteric nerve is their surgical accessibility. During surgery, the trigeminal and facial nerves are connected at the point of their natural intersection on the face (Fig. 4). However, they differ from each other in the depth of localization in soft tissues: the masseteric nerve passes below the LF in the thickness of the masseter muscle. Anatomically, this region is represented by the so-called subzygomatic triangle (Fig. 5) that is limited by the zygomatic bone from above, and two other its sides are the mandible ramus and the temporal branch of the FN (i.e. part of the pes anserinus). The angle bisector is the masseteric nerve. A neural anastomosis is performed in this region [13].

Also, an important advantage is that the facial muscles innervated by the FN and muscles innervated by the trigeminal nerve have a common embryonic origin [17]. R. Collar et al. [13, 15] believe that the trigeminal nerve is perfect for reinnervation of the mimic muscles because the facial nucleus is interrelated to the mesencephalic nucleus of the trigeminal motor nucleus, and these cranial nerves have central connections.

According to some researchers [12, 14, 15, 17], the n. massetericus, as a donor, has less postoperative complications. Some patients lose sensitivity of the ear lobe in the periauricular region [12, 13, 17]. These complications have a significantly smaller effect on the index of patient quality of life compared to complications associated with the use of other nerves.

Conclusion

Treatment of FN injuries is a topical issue of modern medicine. To date, there is no common approach to managing these patients, which would enable recovery of movement of all facial muscle.

Trigeminal neurotization of the FN is one of the alternative treatments for facial paralysis. This technique provides good recovery of the FN function and a low level of additional neurological disorders.

Faster and more effective recovery of the mimic muscle function in anatomical injury to the FN is achieved by reinnervation of the nerve within the optimum time of not longer than 1 month. When the LN is anatomically intact but functionally failed (House-Brackmann grade VI), which is confirmed by needle EMG of the mimic muscles, surgery should be performed in the period from 6 to 12 months.

The choice of a procedure is always the prerogative of the surgeon who should rely not only on the possibility of its technical implementation but also on the advisability in each particular case.

Authors declare no conflict of interest.
The article of authors from the Novosibirsk Federal Neurosurgical Center is dedicated to a very topical issue, namely preservation of the facial nerve function in surgery of cerebellopontine angle (CPA) tumors, usually — acoustic neuromas, less often — meningiomas and cholesteatomas of this localization. It is a common rule of world neurosurgery that the percentage of facial nerve preservation after removal of CPA tumors is a certain measure of the neurosurgeon competence and skills, while the major principle guiding the surgeon upon removal of these tumors is to think about the patient’s face throughout the operation. However, regardless of neurosurgeon skills and his adherence to certain principles and standards in total removal of large or giant tumors (e.g., acoustic neuromas of more than 30 and 40 mm, respectively), it is actually impossible to avoid some injury to the facial nerve. In this regard, the neurosurgeon, when removing large tumors (in the article, the authors described primarily patients with large tumors), is always in a dilemma: either to limit surgery to subtotal or partial tumor resection, which reduces the risk of facial nerve injury, or to resect the tumor completely and to recover the facial nerve function in the postoperative period.

The latter task is extremely difficult. It is not reduced only to some manipulations or operations on peripheral nerves, although this is a key point in recovery of the facial nerve function. The success of the whole treatment depends on the fact whether or not reinnervation of an injured facial nerve happens. No less important task is to restore functions of the psychologist and often the psychiatrist, especially in the case of young women, should participate in rehabilitation of the graphic and anatomic research. Ch1 Annals of Plastic, Reconstructive and Aesthetic Surgery. 2011;3:17-23. (In Russ.).


surgery is a big mistake. We should not use the traditional opposite side. Movements is very important to the patient, which is completely be considered as a good result. In addition, synchronization of movements to a House-Brackmann grade III and IV should not happens to the marginal mandibular ramus that often branches facial nerve trunk with the masseteric nerve in all cases, what procedures are performed, whether it is possible to connect the synchronization of facial movements.

What remains to do neurosurgeons? Quite enough! First, to encourage neurologists, ENT specialists, and ophthalmologists to make the early diagnosis of cerebellopontine angle tumors at the Burdenko Neurosurgical Institute.

I consider it my duty to thank the authors for their desire to improve the patient quality of life and recommend them to accept the comments. For our part, we will be ready to train a specialist in the complex treatment of facial nerve injury.

Commentary

There is no doubt that the authors used a modern technique for facial nerve reinnervation, but reading the article leaves a certain dissatisfaction.

Neurosurgery, like cardiac surgery, belongs to a group of very complex disciplines where qualitative assessments of surgery outcomes are characterized by some simplification because the patient’s life is at stake: whether the patient survives after surgery, having some improvement, or not.

Of course, removal of a large brain tumor and survival of the patient simultaneously with elimination of the disease-associated symptoms are a great success of the surgeon. However, after the patient has received the right to live on, he expects full rehabilitation and improvement in the quality of life; partial relief provided by outdated surgery is re-evaluated and no longer satisfactory. The paper underestimates this phenomenon and demonstrates some satisfaction with the fact that if muscles are somehow move, then it is good. It is worth recalling that there are 14 to 18 mimic muscles, some of which do not have their own name, or, like the Riolan’s and Horner’s muscles, are known only to ophthalmologists. Perhaps, it is needless to say that injury even to a single facial muscle affects synchronization of facial movements.

The authors do not describe how surgical and anastomosis procedures are performed, whether it is possible to connect the facial nerve trunk with the masseteric nerve in all cases, what happens to the marginal mandibular ramus that often branches early, and the masseteric nerve does not reach it. Restoration of movements to a House-Brackmann grade III and IV should not be considered as a good result. In addition, synchronization of movements is very important to the patient, which is completely impossible without involvement of the facial nerve from the opposite side.

I think that this underestimation of the final result of surgery is a big mistake. We should not use the traditional phrase: “Compared to the baseline condition...”. Today, we should strive to bring everything to the perfection, if not, then to the maximum possible result — it is a must!

Performing an anastomosis with the maseteric nerve without a subsequent complex rehabilitation plan and without simultaneous “cross-facial nerve grafting”, which is the hammer mechanism for synchronization of movements, breaks the opportunity for patients to undergo further neuroplastic surgery because repeated surgical approaching to the anastomosis area is associated with its injury and cancellation of results.

It is time to realize that there are medical specialties that are independent and also important to the patient’s life, e.g. reconstructive and maxillofacial surgery, that have more modest, but socially important, goals.

Formation of special teams of experts experienced with these “small” problems is more useful at major medical centers. We have had a similar close alliance with the Burdenko Neurosurgical Institute for 2 years, and all patients with symptoms of facial nerve injury are immediately referred to the Central Research Institute of Dental and Maxillofacial Surgery where, after a comprehensive examination, they receive an individual and optimal surgical rehabilitation. The concept “rehabilitation” includes not only surgery but also special exercises, medication support, instrumental stimulation, etc. A care bundle enables achieving almost complete recovery of movement symmetry and, in some successful cases, synchronous blinking.

I consider it my duty to thank the authors for their desire to improve the patient quality of life and recommend them to accept the comments. For our part, we will be ready to train a specialist in the complex treatment of facial nerve injury.

A. I. Nerobeev (Moscow, Russia)
Mini-orbitozygomatic craniotomy in surgery for supratentorial aneurysms and tumors of the anterior and middle cranial fossae

R.S. DZHZHDZHKHADZE, O.N. DREVAL, V.A. LAZAREV, R.L. KAMBIEV

Neurosurgery Department, Russian Medical Academy of Postgraduate Education, Moscow, Russia; Inozemtsev City Clinical Hospital, Moscow, Russia

Progress in microneurosurgical techniques, neuroanesthesiology, and intraoperative imaging enables surgery using small incisions and craniotomy, in accordance with the keyhole surgery concept. Supraorbital craniotomy is the most widespread minimally invasive approach. There are a number of supraorbital craniotomy modifications, regarding different soft tissue incisions and the extent of craniotomy. We present the first results of using mini-orbitozygomatic craniotomy for aneurysms of the anterior circle of Willis and space-occupying lesions of the anterior and middle cranial fossae performed through an eyebrow incision.

Material and methods. Forty-five patients were operated on using mini-orbitozygomatic (MOZ) craniotomy in the period between March 2014 and December 2015. Fifteen supratentorial aneurysms were clipped, and 30 space-occupying lesions were resected. Most patients had unruptured aneurysms (10 patients). Five patients had a history of SAH. The aneurysm localization was as follows: 8 anterior communicating artery aneurysms, 4 aneurysms of the internal carotid artery in the area of the posterior communicating artery orifice, and 3 ophthalmic aneurysms. The Hunt—Hess scale was used to evaluate the patients’ condition, and the Fisher scale was used to quantify SAH volume. Surgery was performed 14 days after SAH, on average. Contrast-enhanced MRI of the brain was the diagnostic method of choice in a group of patients with space-occupying lesions within the anterior and middle cranial fossae. In some cases, patients underwent CT with reconstruction for assessment of the skull base bone structures. The mean age of patients was 58.3 years.

Results. All aneurysms were completely excluded from the cerebral blood flow. No serious complications and deaths in a group of aneurysm patients occurred. Complete tumor removal was performed in 28 patients. Two patients having pituitary macroadenomas with supra- and parasellar spread underwent subtotal resection due to adenoma invasion into the cavernous sinus. Mortality in this group was 3.3% (1 patient). Postoperative complications were evaluated after 2 weeks and 6 months. The postoperative cosmetic result after 3 and 6 months after surgery was assessed by patients as excellent.

Conclusion. Mini-orbitozygomatic craniotomy is an alternative to classic approaches and can be assistive in surgery for skull base aneurysms and tumors. Selection of candidates for this keyhole surgery should be based on their critical assessment.

Keywords: mini-orbitozygomatic craniotomy, keyhole, eyebrow incision, minimally invasive surgery.

There are many approaches to the aneurysms of the anterior portion of the Willis artery and structures of the anterior and middle cranial fossae. Neurosurgeons had to strike a balance between the need to minimize trauma to tissues, on the one hand, and adequate separation of anatomical structures, on the other, so that both of these factors contributed to the favorable outcome of neurosurgical intervention [1—4]. In most cases, classic neurosurgical approaches in the form of pterional craniotomy or more extended frontoorbitozygomatic craniotomy provides adequate contact with operation object [5—10]. However, traditional approaches are associated with both soft tissue trauma and exposure of a large area of the cerebral cortex, whose dissection is unnecessary. Several-hours-long operation during wide craniotomy with retractors (often two) always implies damage not only due to the retraction trauma, but also due to thermal effect, intense light from the microscope, irrigating solutions, cotton wool balls, coagulation, and other factors [11—15].

The improvement of microneurosurgical technique, neuroanesthesiology, and intraoperative imaging makes it possible to perform operations through small incisions, a minor craniotomy (i.e. in accordance with the keyhole-surgery concept) with encouraging results. Modern possibilities of minimally invasive neurosurgery enable neurosurgeons to feel comfortable, operating on a wide range of neurosurgical diseases, including skull base aneurysms and tumors.

Among the whole variety of minimally invasive approaches, supraorbital craniotomy is the most widely used one. There are a lot of modifications of supraorbital craniotomy, including various soft tissue incisions and the extent of craniotomy itself [16—20].

This article reports the results of the use of the mini-orbitozygomatic (MOZ) craniotomy through the incision along the eyebrow in patients with aneurysms of the anterior portions of the Willis artery and space-occupying lesions of the anterior and middle cranial fossa.

Material and methods

From March 2014 to December 2015, MOZ craniotomy was used to operated on 45 patients (mean age 54.3 years). Clipping of 15 supratentorial aneurysms and resection of 30 space-occupying lesions was carried out. Locations of aneurysms were distributed as follows: 8 aneurysms of the anterior communicating artery (ACA), 4 aneurysms of the internal carotid artery (ICA) at the...
mouth of the posterior communicating artery (PCA), and 3 ophthalmic aneurysms. Male to female ratio was 1:2. Ten patients had unruptured aneurysms. Five patients had a history of subarachnoid hemorrhage (SAH). Surgery was conducted on the average 14 days after SAH. The patients’ state was assessed on the Hunt–Hess scale, SAH volume was assessed on the Fisher scale. All patients with aneurysms underwent preoperative native and 3D CT angiography. The surgical approach was selected after careful evaluation of the topographic and anatomic features and location of aneurysms. All aneurysms clipped from the MOZ approach were small and medium-sized, no more than 15 mm in diameter.

In the case of complex large and giant aneurysms, more extensible approaches were considered as a method of choice, from classical pterional craniotomy to various options of orbitozygomatical approach. We also did not consider MOZ craniotomy in decompensated patients (Hunt–Hess IV—V), in cases of massive SAH, and large parenchymal hematomas accompanied by cerebral edema and intracranial hypertension. Most of these patients underwent both clipping and extensive decompression.

In the group of patients with space-occupying lesions within the anterior and middle cranial fossae, contrast-enhanced MRI of the brain was the diagnostic method of choice. In some cases, patients underwent CT reconstruction to assess the state of the skull base bone structures. The average age of patients was 58.3 years.

The distribution of patients with space-occupying lesions within the anterior and middle cranial fossae is shown in the Table below.

**Surgical techniques**

Patients are placed on the operating table in the supine position with their head raised above the heart, the head thrown down and turned to the opposite side by 15—60°, depending on the pathology. In the case of aneurysms of the middle cerebral artery, the head is rotated by no more than 10—15°. In the case of aneurysms of the supraclinoid portions of the ICA, rotation by 20—30° is sufficient. In the case of aneurysms of the complex of the anterior cerebral artery (ACerA) — ACA, head rotation angle in the opposite direction is no less than 40—60°. In this case, zygomatic process is the highest point of the head. This position enables gravity-driven retraction of the frontal lobe from the walls of the anterior cranial fossa, facilitating the subsequent subfrontal approach. Eyebrow region is treated with antiseptic solutions, followed by skin incision directly along the eyebrow, from the level of the pupillary line and then laterally within the eyebrow, sometimes extending several millimeters outwards (Fig. 1).

Supraorbital nerve and artery, frontal branch of the facial nerve, and superficial temporal artery are always intact. Further, subperiosteal dissection is carried out from the level of the supraorbital opening to the frontozygomatic suture in order to separate the frontal and temporal muscles, and orbital muscle of the eye. The temporal fascia is dissected by means of monopolar coagulation, and the temporal muscle is separated from the attachment points at the level of the anterior temporal line. Sufficient subperiosteal dissection of the supraorbital portion of the frontal bone, the edge of the orbit, and zygomatic process of the frontal bone with visualization of the fronto-zygomatic suture is important. During dissection, special attention is paid to preserve of the periosteum and periorbital tissue.

Burr hole is applied posterior to the temporal line immediately above the base of the anterior cranial fossa, at a key point. MOZ craniotomy involves the roof of the orbit, the portion of the frontal bone, and about 1.0—1.5 cm of the zygomatic bone. Single MOZ bone flap is sawed using craniotome and high-speed drill. Bone defect diameter is about 30—35 mm. First saw cut is done from above in the frontal bone. It is C-shaped and directed towards the roof of the orbit. Further sequence of operations depends on the surgeon’s preference. From the side of the orbit, whose contents is protected with a spatula, we also do a saw cut using craniotome towards the line of the previous cut. In the vicinity of the zygomatic process, saw cut towards the key point can be done with either craniotome or a small (2 mm) diamond burr, while protecting the contents of the orbit with a spatula. The roof of the orbit is opened using chisels. After osteotomy with burr and osteotribe, we resect sharp edges in the area of the orbital roof and then resection of the roof proceeds to the bone thinning area. This approach can also be used to preform extradural resection of the anterior clinoid, if necessary. In the case of pathology at the middle cranial fossa, we additionally resect the wings of the sphenoid bone. The extent of resection depends on the location, extent, and spread of the paraplasma. Large frontal sinuses are not a contraindication for this approach. When they are opened, mucosa is removed, coagulated, and the defect is then closed with a periosteal flap. If penetration into the frontal sinus is small and mucosa is not damaged, it is sufficient to treat this field with surgical wax. The dura mater is opened by a semi-elliptic cut with its base directed towards the orbit. Classic microsurgical technique is then used with adequate lighting and sufficient extension of the surgical field. Dissection of the Sylvian fissure is a mandatory requirement. Then we gradually open the opto-carotid triangle, chiasmal cistern, Liliequist membrane, terminal plate of the third ventricle, and other suprasellar and parasellar cisterns in order to drain the cerebrospinal fluid and achieve maximum relaxation of the brain. These maneuvers provide an additional space for manipulation with microinstruments and dynamic retraction of the brain.

The further surgical technique is determined by location of the pathology. Additional control methods, such as intraoperative angiography and endoscopic assistance,
Distribution of patients depending on the morphological structure of the tumor

<table>
<thead>
<tr>
<th>Pathology</th>
<th>Number of patients</th>
</tr>
</thead>
<tbody>
<tr>
<td>Olfactory meningioma</td>
<td>9</td>
</tr>
<tr>
<td>Meningioma of the tubercle of sella turcica</td>
<td>5</td>
</tr>
<tr>
<td>Meningioma of the anterior clinoid</td>
<td>3</td>
</tr>
<tr>
<td>Meningioma of the wing of the sphenoid bone</td>
<td>3</td>
</tr>
<tr>
<td>Craniopharyngioma</td>
<td>3</td>
</tr>
<tr>
<td>Cavernoma of mediobasal region of the frontal lobe</td>
<td>3</td>
</tr>
<tr>
<td>Pituitary macroadenoma</td>
<td>2</td>
</tr>
<tr>
<td>Suprasellar epidermoid</td>
<td>1</td>
</tr>
<tr>
<td>Metastasis of adenocarcinoma</td>
<td>1</td>
</tr>
</tbody>
</table>

are an important tool in the keyhole surgery for aneurysms (Figs. 2 and 3).

At the end of the operation, dura mater is tightly closed and sutured to the bone around the periphery to eliminate the epidural accumulation of blood. The bone flap is placed to its position and fixed with mini-plates or titanium retainers. In some cases, cut area obliteration with rapidly polymerizing plastics is possible to provide more favorable cosmetic effect, although in most cases classic bone flap fixation is sufficient. Temporal fascia and muscle are sutured to the periosteum. Subcutaneous tissue and skin are closed in layers. Given the small size of skin incision, postoperative drainage is not used.

**Results**

All aneurysms were totally excluded from blood flow, which was confirmed by both intraoperative dissection of aneurysms followed by indocyanine green angiography control and control 3D spiral CT angiography in the postoperative period. Endoscopic assistance was used in all patients. There were no serious complications or deaths in the group of patients with aneurysms. There were no intraoperative aneurysm ruptures either.

Total tumor resection was performed in 28 patients. Of these, 2 patients with suprasellar and parasellar spread of pituitary macroadenomas underwent subtotal resection due to cavernous sinus invasion. Mortality in this group was 3.3% (1 patient) with pituitary macroadenoma due to thromboembolic complications on the 5th day after surgery and revitalization.

Postoperative complications were evaluated in 2 weeks and 6 months. Periorbital edema was observed in all patients and was not regarded as a complication, since it completely regressed within 3—5 days after surgery. The weakness of the frontalis muscle and hypoesthesia in the frontal region were observed in 13 (28.9%) patients, and completely regressed in all of them by the time of...
examination 6 months after the surgery. Neither atrophy of the temporal muscle, nor significant retraction at the region of craniotomy was observed.

After resection of olfactory meningiomas, 3 (6.6%) of patients had unilateral anosmia, which did not regress by the time of examination in 6 months. There were no cases of postoperative liquorhea. Cosmetic outcome of the surgery in 3 and 6 months was rated by patients as excellent.

Discussion

The use of the supraorbital subfrontal and transfrontal approaches was first reported by F. Krause in 1908 [21]. In 1912 and in 1913, L. McArthur and C. Frazier modified the subfrontal approach by adding the osteotomy of the superior edge of the orbit. C. Frazier believed that expansion of craniotomy enabled smaller frontal lobe retraction and provided wider view of deep structures [22, 23]. W. Dandy’s pituitary approach was improved by M. Yasargil and, in recent decades, it is a standard approach in the surgery of the base of the anterior and middle cranial fossae and parasellar space [9, 24].

The emergence of adequate neuroimaging, modern microscopes, and neuroendoscopy provided conditions to minimize surgical approaches, select individual surgical approach for each patient, strictly depending on the pathology. This led to the development of the keyhole surgery concept. A. Perneczky is a pioneer of modern keyhole neurosurgery. He popularized the minimally invasive neurosurgery, formulated basic ideas of the keyhole concept and its possibilities under modern conditions.

Fig. 2. Surgical stages of ACA aneurysm clipping.

a — spiral computed tomography (CT) angiography shows saccular aneurysm of the ACA, condition after SAH; b — Intraoperative view after MOZ craniotomy and dura mater opening; c — left optic nerve is visible; d — aneurysm separation phase (★ — the body of the aneurysm, 1 — A1 segment of the ACerA, 2 — A2 segment of the ACerA on the left; e — aneurysm clipping is done; f — intraoperative fluorescence angiography: an aneurysm is excluded from the circulation, ACerA branches are contrasted.
Perneczky et al. [12-14, 17, 19] implemented and widely used supraorbital craniotomy through an incision along the eyebrow in the treatment of numerous skull base lesions and adapted it for the treatment of supratentorial aneurysms and parasellar tumors. The advantages of this technique include minimum exposure of the brain, reduced subfrontal retraction, reduced operation time, and therefore reduced incidence of associated complications. Potential disadvantages of the supraorbital approach include limited surgical field for microtools, inadequate lighting, and significant complication in the case of intraoperative rupture of the aneurysm. Additional resection of the roof of the orbit was suggested to enhance the operative field and to provide more freedom in operating with microtools, as well as capability of polypositioning of microscope viewing angle [15, 16, 25—28].

Some authors [26—30] reported good cosmetic results of MOZ craniotomy in patients with supratentorial aneurysms and neoplasms in the anterior and middle cranial fossae. There are independent publications reporting the results of anatomical works on cadaver and phantom models, comparing MOZ and supraorbital approaches. For example, M. Lawton et al. [26] pointed out that MOZ approach along the eyebrow reduces the depth and enhances the volume of the surgical field. The authors state that MOZ approach can be effective in the case of proper selection of candidates, were increase in surgical space is required. According to R. Spetzler et al., MOZ approach does not provide increased surgical space, but rather improves vertical view. In this regard, the authors advise to use MOZ approach in the cases, where vertical view should be improved, such as ACA, ICA, and the apex of the basilar artery [3].

The impressive clinical data on the use of MOZ approach to aneurysms and neoplasms of the skull base were reported by L. Warren et al. [30] in 2008. The authors demonstrate the effectiveness and safety of MOZ approach, as well as low incidence of associated complications, as exemplified by 105 operated patients. A. Dare et al. [28] also noted the low incidence of postoperative complications and good cosmetic results based on the follow-up studies.

In our series, MOZ approach provided direct view of the structures of the anterior and middle cranial fossae and parasellar space. Early brain relaxation after extensive opening of subarachnoid cisterns and Sylvian fissure results in significant minimization of the frontal lobe traction. In cases with aneurysms of the anterior portions of the Willis artery, we placed a retractor on the frontal lobe just before the aneurysm neck dissection and clipping.

Currently, the data available in the world literature are insufficient for objectification and popularization of MOZ approach for extensive use in the skull base surgery. Based on the analysis of the results of our study, including the results observed 6 months after surgery, we came to the conclusion that our observations agree with similar published studies of international authors, and thus confirm the validity of the use of MOZ craniotomy in the surgery for supratentorial aneurysms and neoplasms of the anterior and middle cranial fossae.

**Conclusion**

Mini-orbitozygomatic craniotomy is an alternative to the classic approach and can be a great tool in surgery of aneurysms and skull base tumors. The main advantages of MOZ approach include not only cosmetic effect, but also additional space for the use of microtools, better view, and reduced depth of the surgical field in the broad spectrum of skull base and orbit pathologies. Critical evaluation in required when selecting candidates for such keyhole surgery. Further development of the methodology and accumulation of experience are required to declare the advantages of MOZ approach over classical or pterional orbitozygomatic craniotomy. At this stage, it is clear that MOZ approach enables minimization of surgical trauma and associated complications.

**Authors declare no conflict of interest.**
REFERENCES


Commentary

This paper focuses on the use of the modern minimally invasive approach in the skull base surgery. In this study, the authors fully implement the principles of keyhole neurosurgery laid by A. Perneczky et al.

The article provides detailed description of the surgical technique and focuses on the key points. The clinical material includes 45 cases of skull base tumors and aneurysms. It should be noted that the authors very carefully selected the patients subject to the demonstrated techniques. 28 tumors out of 30 were removed totally. The results of surgical treatment were assessed at different times of the postoperative period and can be considered as success, since significant complications were very rare in this series. One death had reasons not directly related to surgical procedures.

The present work is an example of a well-executed modern research based on series of high-level surgeries. The authors convincingly demonstrated that, with proper patient selection, mini-orbitozygomatic craniotomy does not limit the possibilities of the surgeon, but also provides favorable conditions to achieve the objectives of the operation, along with significantly reduced surgical trauma and the risk of possible complications.

We have no significant comments on this work. In our view, the term “minimally invasive surgery” is not entirely appropriate. We adhere to the concept of “minimally traumatic and maximally invasive surgery”, because this interpretation is most consistent with the philosophy of keyhole concept.

We congratulate the authors on good results and wish them further success. In the future, it would be interesting to see new publications, comparing the outcomes of surgical treatment of two similar groups of patients, who were operated on using traditional principles and keyhole concept.

V.A. Cherekaev, D.A. Gol’bin (Moscow, Russia)
The mediobasal temporal region (MTR) lies on the cerebellar tentorium and arches around the brain stem. It is located near the neural and vascular structures whose damage is accompanied by the development of pronounced neurological deficit. Surgical management of vascular and tumor neoplasms located in the MTR is performed through various approaches. The surgical approach is typically chosen based on the arrangement of the pathological focus with respect to the long axis of the temporal lobe. Special surgical approaches have been designed to properly visualize the anterior, middle, and posterior one-thirds of the MTR. These approaches can be subdivided into the anterior, lateral, and posterior ones depending on the orientation of the surgical corridor towards the medial surface of the temporal lobe. Each surgical approach to a certain portion of the MTR has its own advantages. However, it is also accompanied by specific neurological complications caused both by direct damage to the temporal lobe and by hemodynamic disorders as a result of manipulations with arteries and veins. Resection of the pathological structures located in the MTR is performed through single-stage or multiple-stage use of several approaches that ensure the most total degree of resection [1—10].

The supracerebellar transtentorial approach (SCTTA) provides the posteroinferior approach to the MTR and is a modification of the supracerebellar subtentorial approach to neoplastic and vascular pathological structures residing in the median and dorsolateral regions of the tentorial notch [2, 4, 8, 11]. The technical features and the results of using the SCTTA to the MTR and perimesencephalic cistern have been reported in studies carried out by several research groups. All publications emphasized the advantages of the SCTTA that make it possible to visualize the posterior one-third of the MTR; however, it still remains a question under discussion whether it is possible to perform safe resection...
of the middle, and especially the anterior, one-thirds of the median temporal region [12—17].

In this study, we present the surgical technique and the outcomes of using the paramedian SCTTA in patients with different lesions of the MTR and discuss the limitations and advantages of the approach used.

**Materials and Methods**

Between May 2009 and January 2016, the paramedian SCTTA was used in 18 patients (13 females and 5 males, aged 19—57 years); in 10 of them, the pathological neoplasms were located on the left side (Table 1).

Prior to surgical intervention, all the patients with a history of symptomatic epilepsy underwent MRI of the brain and video-EEG. MRI examination was carried out using 1.5 and 3 Tesla MRI scanners in the T1-weighted mode, with and without contrast enhancement, T2-weighted, FLAIR, and SWAN modes in the coronal, axial, and sagittal planes (slice thickness 1 mm, gap 0 mm). 19-Channel video-EEG monitoring of the background activity was performed in 14 patients (monopolar deflection with the differential ear electrodes using the international 10—20 placement system). Intraoperative ECoG of the MTR surface was recorded for 8 patients with symptomatic epilepsy. ECoG was recorded using the electrodes (Auragen strip electrode, Integra NeuroSciences) mounted into a flexible silicon grid structure consisting of electrodes 5 mm in diameter with the 1 cm interelectrode distance. Frameless stereotactic navigation for intraoperative determining the borders of pathological neoplasms was used in 3 cases. All the patients underwent CT scanning of the brain on postoperative day 1. Follow-up MRI examination of the brain and video-EEG were performed within the first week after surgery. The outcomes of surgical treatment were assessed on the basis of the neurological status of the patients including evaluation of the fields of vision and according to the ILAE scale.

**Surgical technique of the paramedian supracerebellar transtentorial approach**

Surgical interventions were carried out for sitting patients, with their heads kept in the neutral position. The 8—10 cm long vertical paramedian (the midpoint of the line connecting the external occipital protuberance and the mastoid process) incision of skin and aponeurosis was made so that its upper one-third lied above the nuchal line. Holes were drilled in lateral direction from the inion and medial direction from the asterion, and the dura mater was exfoliated from the bone to reduce the risk of damaging the sinus wall. Craniotomy, 4—5 cm in diameter, exposing the transverse sinus was performed above the cerebellar hemisphere. The dura mater was dissected in an arc-shaped manner, with the base facing the transverse sinus. It was then fixed with separate sutures that lifted the lower edge of the sinus in order to widen the view. The arachnoid adhesions between the cerebellum and the wall of the transverse sinus were transected, thus ensuring visualization of the inferior surface of the cerebellar tentorium. Thin veins between the superior surface of the hemisphere and the cerebellar tentorium were transected after coagulation. Large venous trunks located both near the midline and in the most lateral portions of surgical approach were preserved to prevent venous infarction. Vein preservation was monitored during the entire surgical intervention and was ensured by the integrity of the arachnoid sheath covering the sites of inflow of the great cerebral vein and the superior petrosal vein.

After minor caudal retraction of the cerebellum, posterolateral regions of the midbrain, the trochlear nerve, branches of the superior cerebellar and the posterior cranial arteries lying under the arachnoid sheath were visualized. In the tentorial notch, laterally with respect to the midbrain, the medial-posterior portion of the parahippocampal gyrus was exposed (Fig. 1a). The ambient cistern was cut open above the trochlear nerve to ensure CSF drainage, which resulted in additional caudal displacement of the cerebellum and increased the manipulation angle. The trochlear nerve was traced along the tentorial notch, until its entrance into the dura mater in the forward direction and medially from the petrous apex.

The cerebellar tentorium was dissected after pre-coagulation and formation of a triangular flap. The incision was started in the posterior portions of the cerebellar tentorium next to the transverse sinus and was made 1 cm medially of the superior petrosal sinus, up to the free edge of the notch, leaving a 2—3 mm margin at the spot where the trochlear nerve enters the dura mater. Prior to dissecting the tentorium, the basal vein was identified near the tentorial notch: this vein can be injured in case of the relatively rare variant of its inflow in the tentorial sinus. The tentorium was additionally cut parallel to the transverse sinus to form a flap that was moved out of the way with a retractor, along with the tentorium. Choice of the variant for cerebellar dissection depended on location of large veins moved from the superior cerebellar surface to the tentorial venous sinuses whose visualization was improved when the jugular veins were compressed. If there were no important tentorial sinuses and movable veins, partial dissection of the cerebellar tentorium was performed, facilitating the wider exposure of the basal portions of the temporal lobe (see Fig. 1b). After the tentoriotomic stage of surgical intervention had been completed, the posterior one-third of MTR represented by the finite sections of the parahippocampal and fusiform gyri separated by the collateral sulcus, as well as the initial portions of the lingual gyrus were visualized. An electrode was placed on the mediobasal surface of the temporal lobe to record an electrocorticogram (see Fig. 1c).
Tumor resection started with coagulation and dissection of the pial membrane in the zone where the tumor lay closest to the surface of the parahippocampal gyrus (Fig. 2a). Small tumor structures with appreciably clear borders were resected en bloc after perifocal dissection with the brain tissue. In the remaining cases, step-by-step resection was performed by fragmentation and ultrasonic aspiration. Resection of the pathological tissue was always accompanied by cutting open the cavity of the temporal horn of the lateral ventricle at various points (see Fig. 2b).

Hippocampus, together with the parahippocampal gyrus, was resected along the choroidal fissure. The internal carotid artery, the anterior choroidal artery, and the initial segments of the anterior and middle cranial arteries were exposed after resection of the amygdala and the uncus (see Fig. 2c). Resection of the basal portions of the temporal lobe near the inferomedial wall of the temporal horn of the lateral ventricle corresponding to the hippocampus and the parahippocampal gyrus was challenging because of the absence of proper visualization due to the lower arrangement of the middle cranial fossa floor with respect to the upper edge of the petrous pyramid. This challenge was overcome by gradually lifting the basal portions of the temporal lobe directly forwards and laterally with respect to the petrous apex using several cotton swabs or a thin dissecting spatula after the temporal horn of the lateral ventricle was opened. This surgical procedure allowed one to move upward step-by-step the basal portions of the anterior one-third of the MTR and perform safe resection thereof involving coagulation of the pial vessels. If pathological activity was detected during ECoG registration in the cortex regions directly adjacent to the pathological neoplasm, the medial structures of the temporal lobe were additionally resected along the inferior horn of the lateral ventricle.

In two cases of intraventricular meningiomas (Fig. 3a), the lateral ventricular trigone was accessed through the collateral sulcus in the posterior one-third of the MTR. Dissection of the groove between the parahippocampal and fusiform gyri allowed us to open the ventricular cavity and visualize the tumor node together with the vascular plexus (see Fig. 3c). Hypertrophied arteries and veins were coagulated together with the vascular plexus; subsequent transection of these vessels ensured safe dissection of the tumor node from the ventricular walls. In both cases, intracapsular reduction of tumor size was carried out, followed by total gross resection (see Fig. 3b, d).

Hypertrophied temporal branches of the PCA were visualized during resection of AVM (Fig. 4a, c). After the dissection, they were coagulated and transected near the choroid glomus to preserve blood supply to the medial portions of the occipital lobe. Subsequent perifocal dissection that included transection of the relatively thin arteries and veins was followed by occlusion of the major venous outflow pathway and removal of AVM (see Fig. 4b, d).

As a result of coagulation of the edges of tentorial incision, it is usually impossible to recover the integrity of the cerebellar tentorium. Only in one case, we managed to put the incision edges together with several separate sutures. In 3 cases, a catheter was inserted into the ventricular lumen and the resection cavity to provide external CSF drainage; the catheter was removed the next day. The wound was closed routinely after suturing the dura mater and fixing the bone flap.

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**Fig. 1. Stages of the supracerebellar transtentorial approach to the MTR.**

a — anatomical landmarks before dissection of the cerebellar tentorium; b — visualization of the MTR after dissection of the cerebellar tentorium; c — an ECoG electrode was placed in the MTR.

*Footnote.* IV — the trochlear nerve.
Table 1 lists the main clinical data of the patients with lesions in the MTR after the surgery.

The clinical presentation included epilepsy in 14 cases. Thirteen of these patients had complex partial and secondary generalized seizures that semio logically and electroencephalographically correlated with the area of morphological lesion of the MTR revealed by MRI; one more patient had simple partial temporal lobe seizures. In most cases, no neurological symptoms were observed in the seizure-free period. Only one patient developed hemiparesis and mild ataxia.

In the remaining cases: one patient had slow progression of contralateral hemiparesis; one patient had visual disturbance as a result of the earlier intracranial hemorrhage; two patients had moderate hypertension.

MRI of the brain showed that the pathological structures were located in the anterior one-third of the MTR in 5 patients; in the anterior and middle one-thirds, in 2 patients; in the middle one-third, in 5 patients; in the middle and posterior one-thirds, in 2 patients; in the posterior one-third, in one patient; in the anterior, middle, and posterior one-thirds, in one patient, and within the ventricular trigone, in 2 patients. The neoplasm size ranged from 12 to 46 mm. Gross total resection of tumors was confirmed in 16 patients; subtotal resection, in 2 patients (Fig. 5).

Intraoperative ECoG revealed no typical epileptiform complexes in 3 patients. Five patients out of 8 had regular typical pathological interictal activity manifesting as sharp waves and spikes (polyspikes) with frequency of over 1—2 per second in the epileptogenic lesion area and in the irritative zone. Resection of cortical regions in the MTR, where the typical ECoG signs of an epileptic focus remained after the neoplasm had been removed, resulted in complete attenuation of pathological activity (Fig. 6).

In the early postoperative period, EEG detected the increasing slow-wave activity associated with the intervention performed as a sign attesting to diffusion irritation of the cerebral cortex, along with the decrease in the index of paroxysmal activity of an epileptic focus (13 patients) or total absence of epileptiform discharges (1 patient).

Anticonvulsant therapy was recommended in all the cases in accordance with seizure type; monotherapy was prescribed to 7 patients. By the time when analysis was performed, it was possible to assess the outcomes of surgical treatment of epilepsy 6 and 12 months after the surgery using the ILAE outcome scale only in 5 cases. The ILAE class I outcome (complete seizure freedom and absence of auras) was achieved in 4 patients; class II outcome (only rare auras, no other seizures), in one patient.

No additional neurological symptoms or signs were observed after surgical intervention in 15 cases; however, one patient among them had regression of hemiparesis that existed before the surgery. Assessment of visual function showed no additional visual field defect in the patients operated on. Moderate contralateral hemiparesis was detected in one patient after partial resection of astrocytoma; it was probably caused by manipulations involving the perforating branches of the posterior cranial artery. The neurological symptoms were transient and regressed within the nearest 5 days after surgery. Similar neurological disorders manifesting as mild transient contralateral hemiparesis combined with ipsilateral partial oculomotor nerve palsy were found in the patient with mesial temporal sclerosis. Transient neurological symptoms detected by MRI were caused by ischemic changes in the thalamo-mesencephalic area.

![Fig. 2. Resection of the tumor of the MTR.](image)

a — tumor of the middle one-third of the MTR; b — the cut-open temporal horn of the lateral ventricle; c — resection of the anterior one-third of the MTR.

Footnote. * — posterior clinoid process; TH — temporal horn of the lateral ventricle.
One patient developed hemorrhagic cerebellar infarction and occlusive hydrocephalus within the first day after resection of hemangioblastoma. After removing the hemorrhagic detritus from the upper portions of performing cerebellar hemisphere and external ventricular drainage, patient’s condition improved and she was discharged 3 weeks later, while having mild hemiataxia.

Discussion

The MTR is conventionally subdivided into the anterior, middle, and the posterior one-thirds [1, 12, 13]. The anterior border of the MTR is the beginning of the rhinal sulcus that separates the parahippocampal gyrus and uncus from the occipitotemporal gyrus that lies in more lateral direction. The line separating the anterior and middle portions of the MTR runs through the posterior edge of the uncus with the subjacent amygdala, which corresponds to the inferior choroidal point (the point where the anterior choroidal artery enters the vascular plexus of the ventricular horn). The anterior splenial line (a vertical line drawn through the anterior edge of the splenium) projected onto the posterior edge of the quadrigeminal plate and the pulvinar is the border separating the middle and the posterior portions of the MTR. The posterior portion of the MTR is limited by the parietotemporal line directly in front of the lingual gyrus at the level of the posterior edge of the cingulate gyrus (a virtual line connecting the parieto-occipital sulcus and the preoccipital notch).

The approaches to the MTR, which lies around the midbrain within the tentorial notch area, are subdivided into the lateral, anterior, and posterior ones. The lateral approaches (transcortical and transventricular ones) ensure adequate visualization only of the anterior and middle portions of the mediobasal temporal lobe structures, while resection of the posterior portion is associated with a high risk of damaging the language zone and the optic tract. Using the lateral subttemporal
approach does not damage neocortical structures and fibers of the optic nerve; however, since the cerebellar tentorium is inclined, the approach to the posterior one-third of the MTR requires significant retraction of the temporal lobe and is characterized by a high risk of damaging the vein of Labbé. The lateral suboccipital-supratentorial approach for exposing the posterior portion of the MTR is accompanied by visual disturbance because of the deflection of temporal lobe. The anterio-superior approaches, including the pterional transsylvian and transtemporal ones, allow one to resect the anterior and middle portions of the MTR. The drawbacks of these approaches consist in the fact that the posterior portion of medial temporal structures cannot be exposed without damaging the inferolateral segments of the insula and the relatively high risk of ischemic disruptions caused by surgical interventions involving vessels in the basal cisterns. The interhemispheric parieto-occipital approach is used for visualizing only the posterior one-third of the MTR, whereas retraction of the temporal lobe from the cerebellar tentorium and the cerebral falx in order to widen the manipulation angle results in the development of vision problems [1—10, 12—17].

In 1976, K. Voigt and M. Yasargil [18] were first who reported the use of the SCTTA for removing the cavernous angioma of the left parahippocampal gyrus in a patient with epilepsy. They demonstrated that dissection of the cerebellar tentorium ensures good visualization of the MTR, which made it possible to successfully resect the angioma with perifocal hematoma. Later, M. Yasargil [19] used this approach in two patients with parahippocampal dysplasia and in one patient, with oligodendroglioma.

Y. Yonekawa et al. [17] used the SCTTA in 16 patients: 4 of them had vascular pathology; one patient had recurrent epileptic seizures after selective anterior amygdalectomy; and 11 patients had tumors of the MTR of different histological structure.

U. Türe et al. [15] presented the anatomical justification and clinical experience of using SCTTA in 15 patients with various lesions in the MTR. Mesial temporal sclerosis was detected in 6 patients; gliomas, in 7 patients; and cavernoma of the posterior one-third of

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Fig. 4. AVM in the posterior one-third of the MTR.

a — CTA before surgical intervention; b — CTA after total resection of the AVM; c — separation of the vascular malformation node; d — after the AVM was resected, the cavity of the expanded temporal horn of the lateral ventricle is visualized.
Fig. 5. MRI scans recorded before and after surgical treatment.

a — tumor in the anterior one-third of the MTR; b — tumor in the middle one-third of the MTR; c — tumor in the middle one-third with additional resection of the anterior one-third of the MTR.

the MTR, in 2 patients. In the reported group, 8 patients had pharmacoresistant epileptic seizures. MRI confirmed the macroscopic gross total resection of tumors, cavernomas, and amygdalohippocampal structures, which had a stable antiepileptic effect. Complications of surgical treatment manifesting as aggravation of neurological deficit and visual field defect were observed.
in none of the cases. Continued tumor growth was detected in 3 patients; they were reoperated [15].

J. de Oliveira et al. [13], after having examined the anatomical features of the MTR region, summarized the outcomes of using the SCTTA in 12 patients. Gliomas and cavernomas were found in 6 cases; the remaining patients had vascular pathologies (AVM and aneurysms of the posterior cranial artery). Good outcomes were achieved in all patients; all tumors and AVMs were subjected to gross total resection and the aneurysms were clipped. Postoperative disturbance in visual function was revealed in one patient only [13].

A.N. Konovalov et al. [12] analyzed the outcomes of using the SCTTA in a group consisting of 20 patients with tumors of the MTR. In all cases, tumors manifested as epileptic seizures; only 3 patients had preoperative homonymous hemianopsia. Tumors were anaplastic astrocytomas in two patients and benign gliomas, in the remaining patients. Gross total resection of tumors was achieved in 8 cases; subtotal, in 11 cases; and partial, in one case. Complications of surgical intervention were observed in 4 patients: cerebellar edema accompanied by hydrocephalus in 2 cases and hemiparesis caused by vascular reasons, in 2 cases. The use of the SCTTA in this group of patients was accompanied by development of visual disorders manifesting as homonymous upper-quadrant hemianopsia in 4 patients and complete homonymous hemianopsia in one patient [12].

The SCTTA is used to manage gliomas and cavernomas of the MTR, mesial temporal sclerosis; less frequent, AVM, P2 and P3 aneurysms, as well as to perform posterior cranial artery revascularization (Table 2). Single clinical cases of using the SCTTA in patients with meningiomas of the cerebellar tentorium, thalamic tumors, and epidermoid cyst of medial temporal localization have been reported; a series of petroclival meningiomas has also been presented [20—26].

The SCTTA is associated with the risk of emergence of venous cerebellar infarctions caused by thrombosis, coagulation, and transection of the venous outflow pathway during supracerebellar dissection. These complications are very rare. However, authors of all the publications emphasized the possibility of developing brain tissue swelling and intracranial hematomas and pointed to the need to preserve the large veins that can be moved to the tentorium from the cerebellar surface.

When using the paramedian SCTTA, no dissection of the large median venous trunks that form the great cerebral vein is required to visualize the tentorial notch, which allows one to avoid direct or traction injury to veins in the anterosuperior portions of the vermis cerebelli. The integrity of the arachnoid sheaths is among the key criteria of prevention of venous infarction during caudal cerebellar retraction.

Most studies indicate that transection of the veins that can be moved between the tentorium and the superior surface of the cerebellar hemisphere is relatively safe. Sometimes there can be one or two small venous trunks in case of paramedian direction toward the tentorial notch; rupture of these veins typically has no consequences. This can be explained by the fact that there is a wide anastomotic network in the cerebellar grooves, which connects the median (the great vein) and lateral venous (the superior petrosal vein) complexes [27]. In this case it is most reasonable to try to maximally preserve the veins being moved by the so-called arachnoid dissection, when only thin vessels are dissected.

**Fig. 6. Intraoperative ECoG.**
a — electrocorticogram before tumor resection. Pathological activity is represented by frequently seen sharp waves and polyspikes; b — electrocorticogram after tumor resection and amygdalohippocampectomy. Pathological epileptiform activity completely attenuated.
Hemorrhagic infarctions of the cerebellar hemisphere develop after transection of large veins in some cases as it took place in one of our observations. If such venous collector is revealed, one of the alternatives to preserve it is to dissect the cerebellar tentorium in the form of a flap, preserving the site where the vessel becomes the tentorial venous sinus. The arrangement of venous sinuses deep in the cerebellar tentorium is important for choosing the direction and extension of tentoriotomy, which allows one to preserve the significant venous outflow pathway [28]. According to T. Matsushima et al. [29], who subdivided the tentorial sinuses into four groups, when using the SCTTA, one should take into account the localization and direction of these large venous channels flowing into the transverse and straight sinuses. Tentorial venous sinuses are the intradural continuation of the veins moved from the cerebellar hemisphere and vermis cerebelli, and in rare cases, vein of the cerebral peduncle and the basal vein, which enter the cerebellum at the tentorial notch. The entries of the veins moved from the cerebellar hemisphere, as well as the intratentorial sinuses themselves, most often lie in the medial and middle one-thirds and the posterior half of the cerebellar tentorium [28, 29]. The relatively safe tentoriotomy, in terms of preserving venous outflow, consists in dissection of the cerebellum towards its notch along the border between the median and lateral one-thirds of the tentorium; the transversal portion of the incision should be made approximately at the midline between the transverse sinus and the tentorial notch. Tentoriotomy, either linear or as a triangle-shaped flap, in most cases ensures adequate exposure of the MTR for subsequent surgical manipulations. As demonstrated by our experiment, dissection of a portion of the tentorium has widened the approach to the posterior portion of the MTR and improved visualization of the key anatomical landmarks, which is consistent with the statement by J. de Oliveira et al. [13] about the advantages of resection of cerebellar tentorium prior to its dissection.

Resection of tumors in the MTR is performed by step-by-step dissection and internal decompression of a pathological neoplasm. The pial membrane of the parahippocampal gyrus is dissected immediately above the tumor or along its border with the brain tissue, up to the collateral sulcus. Identification of neoplasms can be complicated because there are no visible changes in the pial membrane; in such cases, the site of corticotomy is determined using a navigation system. Tumor nodes are resected subpially to prevent both the mechanical and coagulation-induced injury to the midbrain, adjacent vessels, and cranial nerves. Branches of the posterior cranial artery that continue and run in the MTR are separated and preserved, thus preventing the development of ischemic lesions in the temporal lobe.

Resection of tumors is usually accompanied by opening the lateral ventricle whose walls are a key anatomical landmark for the following surgical manipulations. The hippocampus and the parahippocampal gyrus should be removed along the choroidal line, up to the anterior pole of the temporal horn. Resection of the amygdaloid body in the anteriormost portion of the MTR also involves subpial aspiration; the cavity resulting from the resection is actually an anterior continuation of the temporal horn. Resection of the uncus—amygdaloid complex results in exposure of the supraclinoid segment of the internal carotid artery with branches originating from it. Dissection of these branches in the cisternal space should be carried out with extreme care, to avoid traction and coagulation-induced injury. Visualization of the internal carotid artery with the initial segments of the middle and anterior cerebral arteries, as well as the cisternal section of the oculomotor nerve located in the posterolateral direction, within the anteriormost portions of the operation theater is a key landmark indicating that the anterior border of the MTR has been reached.

Y. Izci et al. [30] demonstrated that the separation of the collateral sulcus within 13 mm results in penetration of the lateral ventricle near its trigone through the collateral eminence. This approach is the shortest and functionally the safest one because the visual pathway does not lie on the basal and medial surface of the vestibule of the lateral ventricle [5, 31]. Hence, in the observations where the tumor spread into the lumen of the inferior horn, we identified the pathological focus after opening the ventricle and visualizing its walls and the vascular plexus. H. Marcus et al. [32] reported two cases of meningiomas of the lateral ventricle trigone that have been successfully resected through the SCTTA and pointed out the advantages and limitations of the procedure used. The authors emphasized the technical challenges associated with the surgical intervention, the need to use endoscopic assistance to improve the illumination of the deep and narrow wound, as well as neuronavigation-guided monitoring to ensure adequate orientation. Our experience in using the SCTTA to resect intraventricular meningiomas has shown that there are no significant surgical difficulties during resection of tumors from the ventricular trigone area. After opening the ventricle through the collateral sulcus, one needs to perform clear identification, coagulation, and transection of the hypertrophied branches running in the medial-lateral direction towards the vascular plexus to ensure tumor devascularization. Significant fragmentation of the tumor node was required in both cases to achieve gross total resection through small-size encephalotomy and tentoriotomy.

Some authors, when using the unilateral SCTTA, perform bilateral suboccipital craniotomy to provide optimal cerebellar relaxation [12, 18, 19, 22]. Another research group prefers unilateral craniotomy, since, according to Y. Yonekawa et al. [17], the bone flap does not cover the foramen magnum and the site where the...
Our experience has demonstrated that the greatest approach was used both for tumor resection and for possibility of using the SCTTA to resect the anterior portions of the MTR. However, the petrous pyramid also prevents the optimal visualization of the posterolateral fossa floor with respect to the superior surface of the septum malformations (if these malformations are revealed, strictly horizontal position is used) but also is largely determined by the preferences and expertise of neurosurgeons and anesthesiologists [12, 13, 15—17, 20, 25, 30, 32].

The sitting position on the operation table is preferable for patients in a lying position, thus reducing the risk of air embolism. The choice of intraoperative patient’s positioning not only depends on presence of interatrial septum malformations (if these malformations are revealed, strictly horizontal position is used) but also is largely determined by the preferences and expertise of neurosurgeons and anesthesiologists [12, 13, 15—17, 20, 25, 30, 32].

The SCTTA is usually considered to be an approach to the posterior and middle one-thirds of the MTR, since surgical manipulations on the anterior structures (the uncus, the amygdaloid body, and the hippocampal head) are rather complicated because of the anteromedial curving around the midbrain of the medial surface of the temporal lobe. The lower position of the middle cranial fossa floor with respect to the superior surface of the petrous pyramid also prevents the optimal visualization of the anterior portion of the MTR. However, the possibility of using the SCTTA to resect the anterior structures has been demonstrated in several publications; the approach was used both for tumor resection and for selective amygdalohippocampectomy.
An advantage of amygdalohippocampectomy performed using the SCTTA is the possibility to resect not only the anterior structures, but also the posterior one-third of the MTR, which cannot be performed through the anterior and lateral approaches [7, 9, 10]. A.N. Konovalov et al. [12] used the SCTTA to resect amygdala and the hippocampal head in one case; in 2 cases, resection of the anterior structures was achieved by widening the manipulation angle by retracting the occipital lobe. The authors suggest that it is reasonable to use the SCTTA for resecting pathological neoplasms in the posterior and the middle one-thirds of the MTR and emphasize that a combination with the infraoccipital approach should be used for resection of the anterior portion because of the high risk of traction injury to the cerebellum [12].

P. Jittapiromsak et al. [3] compared the posterior transtentorial approaches and demonstrated that the supracerebellar and the suboccipital approaches enable visualization of the posterior and the middle one-thirds of the parahippocampal gyrus to the same extent. However, the downward orientation of the suboccipital approach facilitates visualization of the anterior portions of the MTR but complicates the exposure of the posterior portions of the MTR. In order to resect the anterior-basal portions of the temporal lobe, U. Türe et al. [15] lifted the parahippocampal gyrus with cotton swabs to move it upward, into the field of vision. A similar procedure of resection of the temporal structures was used in the group of patients presented by us during resection of the anterior one-third of the MTR.

The SCTTA establishes the forward-oriented surgical corridor to the MTR structures and can be used as the main approach in patients with isolated lesions of the medial temporal structures. The SCTTA has certain advantages over the most common conventional approaches to the MTR as it provides access to the MTR without disrupting the venous outflow from the lateral segments of the temporal lobe and without damaging the brain tissue as a result of retraction or encephalotomy. For the neoplasms lying in the posterior portion of the MTR, the SCTTA is an alternative to the posterior interhemispheric approach. According to U. Türe et al. [15], this approach is the optimal one if a tumor resides in the middle portion. The SCTTA always ensures good visualization of the posterior one-third and the adjacent posterior half of the middle one-third of the MTR; however, examination of the temporal uncus and the internal carotid artery as a landmark is possible only in

<table>
<thead>
<tr>
<th>Authors, year, reference</th>
<th>Total number of patients</th>
<th>Nosological entities — number of patients</th>
</tr>
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<tr>
<td>1. Voigt K., Yasargil M.G., 1976 [18]</td>
<td>1</td>
<td>cavernoma — 1</td>
</tr>
<tr>
<td>3. Uchiyama N. et al., 2001 [22]</td>
<td>1</td>
<td>medial tentorial meningioma — 1</td>
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<tr>
<td>4. Yonekawa Y. et al., 2001 [17]</td>
<td>16</td>
<td>temporal lobe glioma — 10, metastasis in the temporal lobe — 1, hippocampal sclerosis — 1, aneurysms of the PCA (2) and SCA (1) — 3, moyamoya disease — 1</td>
</tr>
<tr>
<td>7. Otani N. et al., 2008 [23]</td>
<td>4</td>
<td>thalamic cavernoma — 4</td>
</tr>
<tr>
<td>17. Grigoryan Yu.A. et al., the present study</td>
<td>18</td>
<td>temporal lobe glioma — 9, hemangioblastoma — 1, cavernoma — 3, mesial temporal sclerosis — 1, ventricular trigone meningioma — 2, AVM — 2</td>
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Table 2. Review of the literature on the use of the supracerebellar transtentorial approach
patients with mesial temporal sclerosis or small-sized neoplastic lesions without significant perifocal edema. Our clinical experience proves the other researchers’ opinion that the SCTTA allows one to perform resection of both the posterior and the middle one-third of the MTR [12, 13, 15—17]. Although U. Türe et al. [15] consider the SCTTA to be a universal approach to the entire SCTTA, it should be emphasized that selective resection of the anterior structures (the uncus, the amygdala, and the hippocampal head) is complicated and is related to the need of performing vascular dissection in the ambient cistern. In the series of cases presented by use, resection of the anterior one-third of the MTR was considerably facilitated after the inferior horn of the lateral ventricle had been opened, which allowed performing surgical manipulations with respect to the intraventricular anatomical landmarks.

The degree of freedom of surgical manipulations using the SCTTA is limited by the slope of the cerebellar tentorium [3, 33]. Our experience has demonstrated that at large slope ratios, adequate visualization of the MTR may require increased caudal retraction of the cerebellum. Hence, the choice of the SCTTA for resection of pathological neoplasms in the MTR is most reasonable if the cerebellar tentorium is flat. It should also be taken into account that surgical manipulation within the superior wall of the temporal horn, which is well-visualized using the SCTTA, result in visual disorders because of disruption of Meyer’s loop [5, 9, 10]. Hence, the SCTTA stops being advantageous over the superior and lateral approaches in case of tumor lesions affecting the middle one-third of the MTR and accompanied by the already developed visual field defects. Furthermore, if a patient had preoperative vision disorders manifesting as hemianopsia, there is almost no difference between the SCTTA and the suboccipital supratentorial approach, which results in vision field defect because of retraction of the occipital lobe.

When choosing a surgical technique for resecting tumors in the MTR, one should bear in mind the certain ergonomic problems associated with the narrowness and deepness of this approach, length of the tools being used, as well as the need to operate a surgical microscope and use navigation equipment and endoscopic instruments [12, 15, 32].

Authors declare no conflict of interest.

REFERENCES


This study is based on the experience of using the supracerebellar transtentorial approach to the mediobasal temporal region in 18 patients: in 17 cases, to resect tumors and AVM; in one case, in patients with mesial temporal sclerosis for selective amygdalohippocampectomy. The key idea why this approach is used is minimizing the operational trauma and the risk of neurologic deficit during manipulations on the brain tissue. This surgical technique allows one to avoid traction of the cerebellar vermis and damaging its veins. The corridor of the supracerebellar transtentorial approach is limited by two anatomical structures: the crest of the petrous part of the temporal bone and the lower edge of the transversal sinus. If the torcular is not malpositioned upwards (which is a very rare phenomenon), the angle of the attack on the mediobasal surface of the temporal lobe is only enough in the best case scenario to illuminate and manipulate, more or less confidently, within its posterior and, partially, the middle one-thirds. The anterior one-third, which includes the hippocampal uncus, the entorhinal cortex, and the neocortical portion of the basal regions of the temporal lobe is hardly guessable as it cannot be seen behind the crest of the petrous part of the temporal bone. Even after pulling the lower end of the transversal sinus upward, as suggested by the authors, we failed to provide the adequate corridor so as to be able to confidently and safely manipulate on these structures. It cannot go unmentioned that the strictly unilateral approach that the authors insist on makes the wound even narrower. Illumination is worse deeper in the wound, while the lateral portions of the middle cranial fossa become inaccessible as they remain hidden behind the remnants of the tentorium and the petrous part of the temporal bone. Endoscopic assistance may come in handy in this situation, and the authors mention the importance of this method. However, it is unclear whether they have used it or not.

In either case, the authors were successful in almost all the cases, did not have any serious problems or complications, and share generously the nuances of their surgical technique, which

Commentary

Both statements are debatable. The corridor of the supracerebellar transtentorial approach is limited by two anatomical structures: the crest of the petrous part of the temporal bone and the lower edge of the transversal sinus. If torcular is not malpositioned upwards (which is a very rare phenomenon), the angle of the attack on the mediobasal surface of the temporal lobe is only enough in the best case scenario to illuminate and manipulate, more or less confidently, within its posterior and, partially, the middle one-thirds. The anterior one-third, which includes the hippocampal uncus, the entorhinal cortex, and the neocortical portion of the basal regions of the temporal lobe is hardly guessable as it cannot be seen behind the crest of the petrous part of the temporal bone. Even after pulling the lower end of the transversal sinus upward, as suggested by the authors, we failed to provide the adequate corridor so as to be able to confidently and safely manipulate on these structures. It cannot go unmentioned that the strictly unilateral approach that the authors insist on makes the wound even narrower. Illumination is worse deeper in the wound, while the lateral portions of the middle cranial fossa become inaccessible as they remain hidden behind the remnants of the tentorium and the petrous part of the temporal bone. Endoscopic assistance may come in handy in this situation, and the authors mention the importance of this method. However, it is unclear whether they have used it or not.
will be greatly appreciated by readers. Hence, it is reasonable to publish this article; however, I would refrain from recommending using the supracerebellar transtentorial approach for resection of tumors in the hippocampal uncus and for temporal lobectomy in patients with epilepsy. The approach is convenient indeed if one needs to manipulate on the base of the temporal lobe, but only within its posterior and middle one-thirds. If the tumor affecting the lingual gyrus and the parahippocampus infiltratively grows forward into the uncus and towards the temporal pole and one would like to complete its resection at the same stage, it is easier and safer to move the wound into the supratentorial space, under the occipital lobe, as we have done in our two case reports. The already formed wound corridor, which usually intercommunicates with the temporal horn in a situation like this one, will minimize traction of the temporal lobe. In the cases when patients with temporal lobe epilepsy are involved and resection of the medial temporal complex is required, it is more reasonable and reliable to use the conventional and well-reproducible approaches (anterior temporal lobectomy, transsylvian or subtemporal selective amygdalohippocampectomy).

My conclusion regarding the authors’ stance on the question under discussion is as follows: this approach can theoretically be used but requires extra skills and surgeons without proper expertise should not repeat it (as they warn on TV for some kinds of extreme sports: it is possible but should not be imitated without proper training).

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Endoscopic Transsphenoidal Resection of Pituitary Adenomas Invading the Cavernous Sinus


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Introduction. Pituitary adenomas are benign growths that invade the cavernous sinus (CS) in 10—15% of cases. There are different types of microsurgical and endoscopic approaches enabling resection of tumors from the CS cavity that is a relatively small and hard to reach anatomical structure comprising eloquent neurovascular structures.

Material and methods. A study group included 97 patients with pituitary adenomas (PAs) invading the CS. PAs were resected using an endoscopic technique: adenomas were resected from the CS cavity through a standard endoscopic endonasal transsphenoidal approach in 62 cases; a lateral extended transsphenoidal endoscopic approach was used in 35 cases. A control group included patients with PAs spreading into the laterosellar region who were operated on using microsurgical extra-intradural (n=14) and transsphenoidal (n=149) approaches. In the study group, the degree of PA invasion into the CS cavity was determined using the Knosp scale.

Results. In the study group, total tumor resection was achieved in 49 (50.5%) cases, subtotal resection in 39 (40.2%) cases, and partial resection in 9 (9.3%) patients. In the case of visual disorders (n=70), vision improvement was achieved in 41.4% of cases. Vision deterioration was detected in 11.4% of cases; no vision changes were in 47.1% of cases. Patients (27.8%) who had not had visual impairments before surgery had no negative changes in vision in the postoperative period. The development/augmentation of oculomotor disorders in the study group occurred in 14 (14.4%) cases. In the study group, hormonal remission of the disease in patients with hormone-active PAs was in 26.7% of cases (n=12). There were no cases of nasal liquorhea, meningitis, and death in the study group.

Conclusion. Endoscopic endonasal transsphenoidal resection of PAs invading the CS is a more efficient and safer surgical technique compared to microsurgical extra-intradural approach. The lateral extended transsphenoidal endoscopic approach enables resection of PAs with massive invasion into the CS (Grade III and Grade IV, Knosp scale) and has less postoperative complications compared to the extra-intradural approach (p<0.05).

Keywords: lateral extended transsphenoidal endoscopic approach, pituitary adenoma, cavernous sinus.

Abbreviations
PA — pituitary adenoma;
ACTH — adrenocorticotropic hormone;
ICA — internal carotid artery;
IGF-1 — insulin-like growth factor;
CS — cavernous sinus;
LETEA — lateral extended transsphenoidal endoscopic approach;
PRL — prolactin;
STH — somatotropic hormone;
EETA — endoscopic endonasal transsphenoidal approach

Pituitary adenomas account for about 10% of all intracranial tumors. Despite the fact that these tumors are mostly benign, they can infiltrate the dura mater and destroy bony structures of the skull base [1].

Distribution of PA to the CS cavity occurs in 10—15% of cases [2—5]. Tumor resection from the CS cavity is a challenge for the surgeon. This is due to the fact that the CS is a relatively small and difficult to reach anatomical structure, which includes important neurovascular structures: cavernous segment of the internal carotid artery and cranial nerves [6].

PAs typically penetrate into the lumen of the CS through its medial wall. The tumor fills the sinus cavity and then it can spread beyond the cavity through the slit-like openings, which serve as natural entrances for the oculomotor, trochlear, and abducens cranial nerves. In this situation, PA growth into the sinus cavity often causes upward and outward displacement of the ICA, oculomotor nerve, and trochlear nerve, and lateral and downward displacement of the abducens nerve with the first branch of the trigeminal nerve [7].

There are various types of microsurgical and endoscopic approaches, which can be used to remove tumors from the CS cavity.

Transcranial microsurgical techniques can be used with subfrontal, pterional, fronto-temporal, orbitozygo-
matic, and other basal approaches. However, the study of M.A. Kutin in 2003 has shown that V. Dolenc’s extradural approach is the method that enables the most radical resection of the tumor with massive CS invasion. Extradural tumor resection results in fewer postoperative complications compared to intradural microsurgical approach [1, 2, 8, 9]. However, transcranial techniques are generally quite traumatic and do not enable PA resection with required radicality. Moreover, manipulations in the sinus cavity directly through its lateral wall, where the oculomotor nerves and the first branch of the trigeminal nerve are located, are the general drawback of intracranial techniques.

The use of microsurgical transsphenoidal approaches enables tumors resection from the CS cavity through its medial wall. However, only blind manipulation in the CS are possible, which can cause damage to the cranial nerves and ICA. Therefore, in the case of massive tumor growth into the CS cavity, safe transsphenoidal resection of the tumor located lateral to the internal carotid artery is a challenging problem [10—13].

The use of the endoscope in the transsphenoidal surgery has improved the visualization of the surgical wound, providing a panoramic and well-lit view. The use of optics with different view angles enabled tumor resection “around the corner” (including tumors located lateral to the internal carotid artery) under direct visual control [14—19].

Further improvement of surgical skills has led to the development of the extended transsphenoidal endoscopic approaches, which enabled tumor resection not only from the CS cavity, but also from the medial portions of the middle cranial fossa [16, 17].

**Materials and methods**

The study included 97 patients with PAs invading the CS (study group).

The comparison group included patients with PAa with laterosellar growth, who were operated on using microsurgical extradural and intradural \((n=14)\) and transsphenoidal \((n=149)\) approaches, since these two methods, according to M. Kutin, were the most effective ones in terms of resection radicality and postoperative complications [8].

The study group included patients older than 15 years. Of these, there were 38 males ages 16 to 77 years (median, 44 years) and 59 females ages 15 to 72 years (median 52 years). The study group and comparison group were fully matched in basic parameters (age, sex, tumor size, hormonal activity). The only significant difference was that the number of patients with prolactinomas was higher in the study group than in the comparison group (31.3% vs. 4.1%). This is due to the fact that most patients with PRL-secreting tumors are currently successfully treated conservatively with dopamine agonists.

The degree of PA invasion into the CS cavity in the study group was determined according to Knosp Scale [20]. This classification is based on the relationship between the tumor and cavernous segment of the ICA (Fig. 1).

Coronal MRI slices at the mid-sella level are used to assess the degree of invasion. At this level, cross section clearly shows supracavernous and cavernous segments of the ICA. In coronal slices, three lines (medial, tangent, intracarotid, and lateral) are drawn through the intracavernous and supracavernous segments of the ICA.

Grade 0 is characterized by the absence of invasion into the CS cavity (normal arrangement of the ICA and venous spaces). In the case of Grade I, the tumor spreads beyond the medial line, but not beyond the intracarotid line (in most cases, the medial venous space is not visible). In the case of Grade II, the tumor extends beyond the intracarotid line, but not beyond the lateral line. In the case of Grade III, the tumor extends beyond the lateral line. In the case of Grade IV, complete involvement/encircling with tumor occurs.

In our series, Grade I invasion to the sinus cavity was observed in 11 (11.3%) cases, Grade II — 22 (22.7%), Grade III — 23 (23.7%), Grade IV — 41 (42.3%).

We used 0°, 30°, 45°, 70° rigid 4 mm endoscopes without using microscope, rhinoscope, and postoperative tamponade of the nasal cavity for tumor resection. In 62 cases, PA was resected from the CS cavity through the standard endoscopic endonasal transsphenoidal approach (EETA); in 35 cases, lateral extended transsphenoidal endoscopic approach (LETEA) was used.

In the case of the standard EETA, PA was resected from the CS cavity through the defect in its medial wall (Fig. 2). LETEA, which was carried out by further resection of bone structures above the CS, enabled tumor resection through the anteroinferior wall of the sinus, lateral to the cavernous segment of the internal carotid artery (Fig. 3).

Radicality of the surgery was assessed using contrast-enhanced MRI of the brain 3—4 months after the surgery. In the case of total resection, no residual tumor was found. Resection was considered subtotal, when more than 80% of the initial tumor volume was removed. In the case of partial resection, less than 80% of tumor volume was removed. After resection of hormone-active PAs, radicality of the surgery was assessed using contrast-enhanced MRI of the brain along with data from the postoperative studies of the level of tropic pituitary hormones.

The significance of differences in the results was assessed using \(\chi^2\) test with a minimum value of the variable of 0.05. When the values between 0.05 and 0.01 were used, the difference between the samples was significant, with values of less than 0.01, it was highly significant.
Results

The main parameters of surgical intervention are shown in Table 1.

1. Radicality of the surgery

In the study group, the total tumor resection was achieved in 49 (50.5%) cases, subtotal — 39 (40.2%), partial — 9 (9.3%) cases.

The rate of total resection of soft adenomas was 57.6% \( n=38 \), partial resection — 3.03%. In the group of moderately solid tumors, the proportion of partial resection increased, being 13.0% \( n=3 \), and the number of operations with total resection decreased, being 47.8% \( n=11 \). In patients with solid tumors, total resection failed in all cases. The resulting difference in the rate of total resection of soft and solid PAs is statistically significant \( p<0.05 \).

Fig. 1. Diagram of the frontal MRI slices. Knosp grading of the cavernous sinus cavity invasion by pituitary adenoma.

1 — medial tangent line; 2 — intercarotid line; 3 — lateral tangent line; 4 — tumor; 5 — cavernous segment of the ICA; 6 — suprACLINOID segment of the ICA; 7 — cavernous sinus cavity; 8 — sphenoid sinus.

a — tumor invasion up to the intracarotid line corresponds to Grade I invasion; b — tumor invasion up to the lateral line — Grade II invasion; c — tumor invasion beyond the lateral line — Grade III; d — complete encirclement of the cavernous segment of the ICA by the tumor — Grade IV invasion.

In the study group, where the standard EETA was used, the rate of total PA resection (46.8%) was significantly higher \( p<0.05 \) compared to that in patients, who underwent microsurgical transphenoidal tumor resection (25%) (see Table 1).

In patients with PAs, who were operated on using LETEA, more total resection of tumors was achieved as compared to the group of patients, where resection was carried out through the extradural and intradural approach (57.1 and 35.7%, respectively). However, the resulting differences are not statistically significant because of the small number of cases \( n=0.17 \).

2. The dynamics of neurological status

Various severity of visual disturbances was observed in 70 (72.2%) out of 97 study group patients before the surgery.

In cases with preoperative visual disorders, vision improvement was achieved in 41.4% (29) patients. Visual
In the study group, emergence/augmentation of oculomotor disturbances was observed in 14 (14.4%) cases. No newly developed oculomotor disturbances were observed in the case of Grade I tumors invasion; in patients with Grade II invasion, impairment was detected in 1 (4.5%) out of 22 cases; in patients with Grade III invasion — 5 (21.7%) out of 23 cases, Grade IV — 8 (19.5%) out of 41 cases. Therefore, neurological deficit is significantly ($p<0.05$) more likely to occur in the case of Grade III and Grade IV PA invasion into the CS, rather than Grade I and Grade II invasion.

In the cases where standard EETA was used, oculomotor nerve impairment was observed in 3 (4.8 %) out of 62 cases and manifested in the form of the complex impairment of the cranial nerves III and VI. These complications were more common after transsphenoidal microsurgical resection and occurred in 12 (8.1%) cases (see Table 1). However, these differences were not statistically significant ($p=0.40$).

After LETEA, oculomotor nerve dysfunction was observed in 11 (31.4%) of 35 cases. Oculomotor nerves injury was significantly less common ($p<0.05$) compared to extra-intradural approach (see Table 1).

It is worth noting that oculomotor nerve dysfunction was reversible in 66.7% of cases in the group of patients, where the tumor was resected using LETEA, and in 50% of cases in the group of patients operated on through the extradural and intradural approach.

After tumors resection using microsurgical transsphenoidal approach, the worsening/emergence of neurological deficit due to ischemia of the brain matter or subcortical diencephalic area was observed in 1.3% of the cases; after extradural and intradural approach — in 14.3% of cases. The resulting difference in the incidence of postoperative complications after transsphenoidal microsurgical and standard endoscopic surgeries was not statistically significant ($p=0.11$). However, after PA resection using the LETEA, hemispheric symptoms were significantly less common than after tumors resection using the transcranial extradural and intradural approach ($p=0.02$).

3. Dynamics of endocrine status

The following hormonal remission criteria were used in patients with acromegaly: decrease in STH level after surgery<1 ng/ml, STH level below 0.4 ng/ml during the oral glucose tolerance test and normal level of IGF-1. The criteria for remission of Cushing’s disease included postoperative symptoms of adrenal insufficiency, reduced blood level of cortisol<50 mmol/l on day 1—3 after the operation (without treatment with hydrocortisone); normal levels of ACTH and cortisol, as functions were observed between the study group and comparison group (see Table 1).

The following hormonal remission criteria were used in patients with acromegaly: decrease in STH level after surgery<1 ng/ml, STH level below 0.4 ng/ml during the oral glucose tolerance test and normal level of IGF-1. The criteria for remission of Cushing’s disease included postoperative symptoms of adrenal insufficiency, reduced blood level of cortisol<50 mmol/l on day 1—3 after the operation (without treatment with hydrocortisone); normal levels of ACTH and cortisol, as
well as decreased blood level of cortisol of less than 50 nmol/l during the night test with 1 mg dexamethasone 1—3 months after the surgery.

In the study group, hormonal remission of the disease occurred in 12 cases (26.7% of the total number of hormone-active PAs) \((n=45)\): in 11 patients out of 39 with a STH-producing and in 1 out of 2 cases with ACTH-secreting adenomas. We failed to normalize hormone production in all patients with prolactinoma, which necessitated administration of dopamine agonist therapy in the postoperative period (Table 2).

The development of hormonal remission after surgery depended on the degree of pituitary adenoma invasion into the CS cavity. In patients with Grade I invasion, remission was observed in 60% of cases, Grade II — 33.3%, Grade III — 22.2%, Grade IV — 5.9% (Fig. 4). In patients with massive invasion (Grade III and Grade IV), PA remission was significantly more rare than in patients with moderate (Grade I and Grade II) PA invasion into the sinus \((p<0.05)\).

According to our data, in the group of patients with large and giant hormone-active PAs, remission after surgery was significantly \((p<0.05)\) more rare compared to small and medium-size tumors (Fig. 5).

Remission rate after resection of hormone-active adenomas was not studied in the comparison group, and therefore we cannot compare the effectiveness of microsurgical and endoscopic techniques for resection of hormone-active PAs.

Postoperative diabetes insipidus was observed in 5 study group patients (5.2%). The results were somewhat worse in the comparison group, where PAs were resected using microsurgical transsphenoidal approach and signs of diabetes insipidus were observed in 15 patients (10.1%) (see Table 1).

In general, emergence or augmentation of hypopituitary disorders, including development of diabetes insipidus, was significantly more frequent after microsurgical operations \((p<0.005)\).

4. Complications of surgical treatment

No cases of liquorrhoea were reported in the study group, as well as after extradural and intradural approach. After microsurgical transsphenoidal approach, postoperative nasal liquorrhoea was observed in 10 (6.7%) patients and developed significantly more frequently than with standard EETA \((p<0.05)\).

There were no cases of meningitis in the study group. After microsurgical operations (transsphenoidal resection), meningitis developed in 3 (2.01%) patients. However, there was no statistically significant difference compared to endoscopic techniques \((p=0.26)\).

The incidence of hemorrhagic complications that required reoperation or caused worsening of neurological deficit was not significantly different after microsurgery and endoscopic surgery \((p=0.20)\). In the study group, this complication was observed in 1 (1.03%) case; after microsurgical resection of PA — in 6 (3.7%) cases.

Damage to the cavernous segment of the ICA is one of the most serious and potentially lethal complications of CS surgery. There was no damage to the cavernous segment of the ICA in the treatment group and comparison group.

In the comparison group, the overall mortality was 3.7% \((n=6)\) (see Table 1). In the study group, there were no lethal cases, indicating more safe tumors resection using endoscopic technique \((p<0.05)\).
Discussion

The use of endoscopic techniques in transsphenoidal surgery provides a panoramic view of the surgical field under good light conditions, while endoscopic endonasal transsphenoidal approach is minimally traumatic and not only improves the radicality of surgical treatment, but also reduces the number of postoperative complications and time required for postoperative rehabilitation of patients as compared to other types of operations [14—16, 18, 19].

Both standard endoscopic endonasal transsphenoidal approach and lateral extended transsphenoidal approach can be used to resect PAs spreading into the laterosellar region. Standard EETA enables PA resection from the CS cavity through the defect in its medial wall. Lateral extension of the bone resection beyond the bottom of the sella turcica, LETEA, provides approach to the CS region lateral to the ICA and enables tumor resection from the most lateral and anteroinferior regions of the sinus.

Tumor growth into the CS cavity reduces the proportion of radical operations and increases the number of postoperative complications. According to P.L. Kalinin [16], the number of total resections of PAs invading the CS cavity is much lower (51%) than in the absence of laterosellar tumor spread (86.9%).

The number of total resections of PAs is also affected by the degree of tumor invasion into the CS cavity (according to Knosp Scale). G. Woodworth et al. [21] reported the presence of statistically significant (p=0.04) difference between the amount of total resections of PAs with Grade I and Grade II invasion compared to resections of tumors with Grade III and Grade IV invasion (84.6 and 66.6%, respectively).

In our study, the proportion of totally resected PAs was 50.51% (n=49). Meanwhile, total resection of the tumors with massive invasion into the CS cavity

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Table 1. The results of surgical treatment of patients in the study group and comparison group

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Study group (n=97)</th>
<th>Comparison group (n=163)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Standard EETA (n=62)</td>
<td>LETEA (n=35)</td>
</tr>
<tr>
<td><strong>Radicality of surgical treatment</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total resection</td>
<td>46.8% (n=29)</td>
<td>57.1% (n=20)</td>
</tr>
<tr>
<td>Subtotal/partial resection</td>
<td>53.2% (n=33)</td>
<td>42.9% (n=15)</td>
</tr>
<tr>
<td><strong>Visual disorders</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Preoperative</td>
<td>74.2% (n=46)</td>
<td>68.6% (n=24)</td>
</tr>
<tr>
<td>No response after surgery</td>
<td>61.3% (n=38)</td>
<td>62.9% (n=22)</td>
</tr>
<tr>
<td>Improvement after surgery</td>
<td>30.7% (n=19)</td>
<td>28.6% (n=10)</td>
</tr>
<tr>
<td>Worsening/emergence after surgery</td>
<td>8.1% (n=5)</td>
<td>8.6% (n=3)</td>
</tr>
<tr>
<td>Mors</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td><strong>Oculomotor disorders</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Preoperative</td>
<td>11.3% (n=7)</td>
<td>8.6% (n=3)</td>
</tr>
<tr>
<td>Worsening/emergence after surgery</td>
<td>4.8% (n=3)</td>
<td>31.4% (n=11)</td>
</tr>
<tr>
<td><strong>Hypopituitary disorders</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Worsening/emergence after surgery</td>
<td>4.8% (n=3)</td>
<td>5.7% (n=2)</td>
</tr>
<tr>
<td>Emergence of diabetes insipidus</td>
<td>6.5% (n=4)</td>
<td>2.9% (n=1)</td>
</tr>
<tr>
<td><strong>Complications</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Postoperative nasal liquorrrhea</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Postoperative meningitis</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Postoperative hematoma</td>
<td>1.6% (n=1)†</td>
<td>0%</td>
</tr>
<tr>
<td>Hemispheric symptoms</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Mortality</td>
<td>0%</td>
<td>0%</td>
</tr>
</tbody>
</table>

Footnote. †Data on the radicality of tumor resection are available for 60 patients. ²—postoperative degree of visual impairment is known in 148 patients. * — hematomas that required reoperation. ** — hematomas, which caused worsening of neurological deficit.
(Grade III and Grade IV) was significantly more rare \( (p<0.05) \).

The study by Zhao et al. [22], evaluating the results of surgical treatment of PAs, shows that the degree of total resection of solid tumors is lower than that of soft tumors (50 and 64.1%, respectively). In our study, total resection of solid adenomas was significantly more rare compared to soft adenomas \( (p<0.05) \).

However, it is worth noting that regardless of tumor density and hormonal activity, we did not attempt to remove the tumor from the CS cavity in the cases, when the only well-seeing eye was located on the side of invasion (4 cases). We performed necessarily non-radical surgery in order to minimize the risk of damage to the cranial nerves, while in the case of the extradural approach, manipulations in the CS cavity are carried out through its lateral wall, where cranial nerves are located, which can significantly reduce the rate of hormonal remission of the disease \( (p<0.05) \).

Increased invasion of hormone-active PAs into the CS cavity significantly reduced the rate of hormonal remission of the disease \( (p<0.05) \).

In the study by H. Nishioka et al. [23], hormonal remission of the disease was observed in 90% of cases with Grade I and Grade II invasion, in 68.2% of cases with Grade III invasion, and none cases with Grade IV invasion.

PA was resected “around the corner” under direct visual control using 30°, 45°, and 70° endoscopes and with good operating wounds illumination, which explains the higher rate of total resection of tumors in the study group compared to the group of patients operated on using microsurgical techniques. Similarly to endoscopy, extradural approach enables tumor resection from the CS cavity under direct visual control, which explains the absence of statistically significant differences in the radicality, when using these techniques.

The dynamics of the visual function is one of the major indicators of safety and efficacy of surgical treatment of patients with PAs. According to P.L. Kalinin [16], the use of endoscopic transsphenoidal adenomectomy techniques results in improvement of visual functions in the same number of cases, as with standard microscopic techniques. However, the use of endoscopic technique reduces the incidence of deterioration of visual function compared to the results of conventional microscopic transsphenoidal operations.

In our study, the incidence of visual improvement was higher as compared to the results obtained in the control group (see Table 1). However, no statistically significant difference was fond.

The incidence of oculomotor disturbances during tumor resection from the CS cavity 14.4% of cases \( (n=14) \). Oculomotor disturbances develop after surgery were mostly functional and resolved within few months after the operation.

In general, our study was similar to previous studies in terms of the incidence of postoperative oculomotor disturbances. For example, M. Kitano et al. [5] reported damage to the oculomotor nerve in 27% of cases after tumor resection through the lateral extended transsphenoidal approach.

Oculomotor nerve dysfunction was significantly more common in the case of massive PA invasion (Grade III and Grade IV) compared to mild (Grade I and Grade II) invasion \( (p<0.05) \). In the study by W. Couldwell et al. [12], damage to the cranial nerves during the transsphenoidal operations was observed in 4% of cases, only after tumor resection from the CS cavity.

The incidence of emergence/worsening of oculomotor disorders after endoscopic transsphenoidal operations is almost the same as the incidence of oculomotor disorders after microscopic transsphenoidal tumor resection. This is despite the possibility of much more active endoscopic surgical procedures in the CS cavity for more complete tumor resection.

Endoscopic resection using LETEA is carried out through the anteroinferior wall of the CS with no cranial nerves, while in the case of the extradural approach, manipulations in the CS cavity are carried out through its lateral wall, where cranial nerves are located, which can

### Table 2. Hormonal remission rate after resection of hormone-active pituitary adenomas with different hormonal activity in the study group

<table>
<thead>
<tr>
<th>Type of hormone-active PA</th>
<th>The result of endoscopic transsphenoidal resection of hormone-active PA</th>
<th>Remission</th>
<th>No remission</th>
</tr>
</thead>
<tbody>
<tr>
<td>STH ( (n=39) )</td>
<td>28.2% ( (n=11) )</td>
<td>71.8% ( (n=28) )</td>
<td></td>
</tr>
<tr>
<td>PRL ( (n=4) )</td>
<td>0% ( (n=0) )</td>
<td>100% ( (n=4) )</td>
<td></td>
</tr>
<tr>
<td>ACTH ( (n=2) )</td>
<td>50% ( (n=1) )</td>
<td>50% ( (n=1) )</td>
<td></td>
</tr>
<tr>
<td>Total ( (n=45) )</td>
<td>26.7% ( (n=12) )</td>
<td>73.3% ( (n=33) )</td>
<td></td>
</tr>
</tbody>
</table>

**Fig. 4.** Hormonal remission rate after operation depending on the degree of cavernous sinus invasion by pituitary adenomas in the study group.
result in their injury. Therefore, the emergence of oculomotor disturbances after endoscopic surgery using LETEA was significantly more rare compared to extradural and intradural approach ($p<0.05$).

According to the topographical and anatomical study, increased risk of damage to the cranial nerve VI can occur, when removing tumors from the posteroinferior and anteroinferior portions of the sinus lateral to the cavernous segment of the ICA, damage to the cranial nerve III — from the posterosuperior and anterosuperior portions, also lateral to the internal carotid artery (Fig. 6).

There were no significant neurological disorders in the form of hemispheric and/or psychiatric symptoms in our study, which can be explained by the possibility of more radical tumor resection using endoscopic techniques and manipulations under good visibility conditions, as well as the absence of brain matter traction.

The structure of complications after endoscopic transsphenoidal operations is generally the same as after the standard microscopic transsphenoidal operations.

The safety of transsphenoidal techniques, both microsurgery and endoscopy, has been also confirmed by other studies. In the study by P.L. Kalinin [16], severe neurological disorders have been observed in 1.2% of cases, and according to A.Yu. Grigor’ev [24], hemisyndrome and/or mental disorders after transsphenoidal microsurgical tumor resection were observed in 2.9% of patients.

In patients where the tumor was removed from the extradural and intradural approach, severe neurological disorders were observed in 14.3% of cases, and the incidence of hemispheric and/or psychiatric symptoms was significantly more frequent as compared to the group of patients operated using LETEA ($p=0.02$).

Robust plastic repair of postoperative defects is one of the urgent problems of transsphenoidal surgery, particularly in the case of extended transsphenoidal approach, since the lack adequate repair of a skull base defect leads to the development of potentially dangerous complication, nasal liquorhea.

For example, in the study of B. Zhao et al., liquorhea was observed in 5.6% of cases.

There were no cases of nasal liquorhea in our study. The use of endoscopic technique significantly reduces the rate of postoperative nasal liquorhea after transsphenoidal resection of PAs compared to the results of standard microscopic operations ($p<0.05$).

Damage to the ICA is a rare but potentially fatal complication that occurs in 0—3.8% of cases [25, 26].

Damage to the internal carotid artery during the endoscopic transsphenoidal tumor resection was avoided due to the use of intraoperative Doppler. The need to use this technique in the standard transsphenoidal operations was firstly due to the lack of anatomical landmarks in the sphenoid sinus cavity, which are required to determine the correct pathway of the approach (16 cases), and...
secondly, in order to assess the extent of safe resection when trying to remove the laterosellar solid tumor (7). When using the lateral extended transsphenoidal endoscopic approach (26 cases), this technique enabled us to determine the boundaries of DM incision and safely manipulate in the laterosellar space.

According to A.Yu. Grigor’ev [24], mortality after transsphenoidal adenomectomy was 1.9%. In the study of P.L. Kalinin, 7 of 434 patients died in the hospital after endoscopic endonasal transsphenoidal resection of PA (mortality was 1.6%) [16].

There were no lethal outcomes in the study group; endoscopic method significantly reduces the incidence of lethal outcomes compared to the microsurgical transsphenoidal resection ($p$<0.05).

**Conclusion**

Endoscopic endonasal transsphenoidal resection of PA invading the CS is more effective and safe method of surgical treatment compared to microsurgical techniques. The use of endoscopic technique results in significantly ($p$<0.05) more radical tumor resection with lower mortality compared to the results of transsphenoidal microsurgical operations.

Panoramic view of the surgical wound and the possibility of tumor resection “around the corner” under the direct visual control facilitates radical surgical treatment, reduces the number of postoperative complications (reduces the incidence of oculomotor nerve injury, postoperative liquor rhrea, etc.) and deaths.

Additional resection of bone structures (bony prominences of the ICA, the posterior cells of the ethmoid bone, posterior wall of the maxillary sinus, and the base of the pterygoid process) during the transsphenoidal operation provides approach to the tumor located lateral to the cavernous segment of the ICA (extended lateral approach). The use of LETEA improves the results of treatment in those cases, where an adenoma spreads lateral to the cavernous segment of the ICA (Grade III and Grade IV) with fewer postoperative complications compared to extradural and intradural approach ($p$<0.05). Even if there are secondary tumor nodules derived from the CS, LETEA can be a good alternative to the extradural and intradural approach.

The risk of damage to the cavernous segment of the ICA is a serious problem of the LETEA. Various navigation methods should be used to prevent this complication, in particular ultrasonic Doppler examination, an informative method that visualizes ICA in the tumor stroma and determines safe boundaries of dura mater incision in the projection of the CS, when using this approach.

Given the possibility of meningitis in the postoperative period, one should always keep in mind appropriate plastic repair of skull base defects formed after surgery and prevention of septic complications.

Adequate surgeon’s experience in standard endoscopic adenomectomy (150—200 operations) and compulsory training in the anatomical laboratory are required to perform the “extended” transsphenoidal endoscopic interventions (including resection of laterosellar tumors).

**Authors declare no conflict of interest.**

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Implementation of minimally traumatic endoscopic transphenoidal approach into neurosurgical practice resulted in a significant step forward in the development of transphenoidal surgery.

Endoscopic transphenoidal resection technique, which is used for resection of both pituitary adenomas and other perisellar tumors (craniopharyngiomas, chordomas, meningiomas, neurinomas), is currently widely used in neurosurgery.

Anatomical features of the cavernous sinus, which includes the important neurovascular structures, complicate the surgical treatment of laterosellar tumors, and tumor invasion into the sinus cavity severely limits surgical activity.

Transcranial microsurgical techniques used for resection of tumors, invading the cavernous sinus, are quite traumatic. Their main drawback lies in the removal of the tumor from the cavernous sinus cavity through its lateral wall, where the oculomotor nerves are located, which increases the likelihood of their damage. Microsurgical transphenoidal approaches do not enable resection of tumors located lateral to the cavernous segment of the internal carotid artery and safe resection of tumors in the case of massive ingrowth into the cavernous sinus cavity.

In this study, the prospective study was carried out using a large group of patients (97 patients) with pituitary adenomas invading the cavernous sinus. The patients were operated on using the endoscopic transphenoidal technique.

It was found that radicality of pituitary adenoma resection and the incidence of oculomotor disturbances depend on the extent of tumor invasion into the cavernous sinus cavity and the density of the tumor.

The authors have shown that the technique of endoscopic transphenoidal resection of pituitary adenomas with laterosellar growth is significantly (p<0.05) more safe and increases the proportion or radical operations compared to microsurgical tumors resection. Furthermore, in the surgical treatment of pituitary adenomas invading the cavernous sinus, transphenoidal endoscopic approach is the treatment of choice for small tumor invasion into the cavernous sinus cavity (Grade I and Grade II on the Knosp Scale), while in the case of massive invasion into the cavernous sinus structures (Grade III and Grade IV on the Knosp Scale), extended endoscopic approach is required.

Complications in the form of oculomotor disturbances were observed in 14.4% of cases and resolved within a few months after surgery. The authors have shown the absence of such catastrophic complications as damage to the cavernous segment of the internal carotid artery, which is likely due to the improved visualization when using the endoscope.

In general, a positive trend with the improvement of endocrine function was reported, especially in patients with ACTH- and STH-producing tumors. In the case of prolactinomas, the situation is less clear. There is no information about preoperative treatment of patients with prolactinomas using dopamine agonists and the reason why surgical treatment was chosen rather than hormonal therapy in patients with PRL-secreting tumors.

However, despite the remarks, the structure of the article is fully consistent with the generally accepted principles of scientific material presentation. The literature review describes the relevance and status of the problem. The article includes a sufficient number of references to Russian and international sources. Conclusions fully meet the objectives of the work and the results obtained.

A. Grigoryan (Macon, GA, USA)
Melanocytoma (a cellular blue nevus) is a well-differentiated tumor of low malignancy grade that is derived from leptomeningeal melanocytes of the neuraxis [1, 2]. In the spinal cord, melanocytomas present as intradural extramedullary lesions. We present a rare case of intramedullary location of melanocytoma.

Case description

A 28-year old female patient was hospitalized due to complaints on pain and numbness in the neck, back of the head, and in the upper extremities. The symptoms aggravated over 3 years. Conservative therapy gave no effects. Cutaneous manifestations of the disease were not detected on examination. The functional status at admission was 1 point on the McCormick scale. Neurological status included segmental disorders as C2—C3 hyperalgesia dermatomes and night dysesthesia pain in the collar zone, which was not aggravated by the Valsalva maneuver (2 points on DN4 scale). Extremity strength was 5 points. There were autonomic seizures similar to hyperventilation syndrome manifested as rapid breathing, shortness of breath, and fear.

MRI data: intramedullary mass at the level of C1—C2 segments on the left, well-circumscribed, with homogeneous contrast material accumulation (Fig. 1). Intramedullary ependymoma was the most probable diagnosis.

The patient underwent surgery in the sitting position; endotracheal anesthesia and rigid fixation with a Mayfield holder were used. Midline incision of soft tissues at level of the craniovertebral transition region was made. Laminectomy of C1 vertebra was performed. A subpial tumor of inky color was found after linear opening of the dura mater using the DREZ approach from the left side (Fig. 2).

Myelotomy in the zone of maximum bulging of the tumor was performed. A soft structureless black colored tumor was found — melanocytoma? The internal decompression of the tumor led to the opportunity to dissect peripheral fragments from the spinal cord matter. The tumor was resected totally (Fig. 3).

The main phase of the operation ended with the control of hemostasis. Surgicel gauze was left in the surgical bed of the tumor. Dorsal fixation prophylaxis was made. The dura mater was sewn and sealed. Stitching in layers of soft tissues was made using intradermal suture. Aseptic bandage was placed.

The postoperative course was favorable with no aggravation of neurologic symptoms. The patient was discharged from the hospital on the 7th day after the operation. Histological examination: the presented material contains a small glial tissue fragment containing clusters of cells at the center, with hemosiderin loaded optically empty cytoplasm (Fig. 4a). Clusters of cells form alveolar structures. A small cluster of spindle-shaped cells with hemosiderin deposits are adjacent to a fragment of glial tissue, there are also perivascular clusters of spindle-shaped cells in glial tissue. Immunohistochemical study revealed a positive expression of melanocytic markers (S-100, melan A, HMB45) (Fig. 4b) in spindle-shaped cells and perivascularly. Expression of the GFAP gliofibrillar acidic protein (Fig. 4c) in the adjacent glial tissue and expression of type IV collagen in vessel walls were also detected. The Ki-67 proliferation marker labeling index is about 3% (Fig. 4d). The morphological features and immunophenotype of the tumor were greater compatible with those for melanocytoma.

Based on control MRI study 2 years after the operation, no tumor recurrence was found (Fig. 5).

Discussion

The history of studying the issue. In 1972, C. Limas and F. Tio [3] were the first to reveal melanocytoma by electron microscopy. According to these authors, the tumor originated from leptomeningeal melanocytes rather than from cells of the dura mater, as had been thought previously. Nevertheless, the term “meningeal melanocytoma” was still the official term.

Pathogenesis. Melanoblasts develop from the neural tube during early embryogenesis and later migrate to the...
skin, eyes and the inner ear [4]. Normally, these cells can also be found in the pia and arachnoid sheaths [5]. On the 10th week of gestation, they transform into immature melanocytes [6]. Melanocytes can lead to pigmentation of meninges in projection of ventral surface of the pons, cerebral peduncles, Sylvian fissure, and spinal cord [7]. Individual melanocytes may occur in grooves at the base of the skull and upper cervical level [8]. According to A. Botticelli et al. [9], similar “meningeal melanosis” may be a predisposing factor in formation of melanocytoma or melanoma of the central nervous system (CNS).

Incidence. Primary pigmented neoplasms of the CNS consist of a wide spectrum of neoplasms ranging from well-differentiated melanocytoma to malignant melanoma [10]. Differential diagnostics is made to distinguish malignant melanoma, melanocytic Schwannoma, pigmented meningioma, melanoblastosis, and blue nevus of spinal roots [11—15]. In rare cases, melanocytoma may be associated with Ota’s nevus [9]. Based on data by F. Roser et al. [16], single cases of transition from melanocytoma to primary malignant melanoma were described. A few diagnostic criteria available and the discrepancies in terminology cause lack of reliable information on incidence of melanocytomas in the world literature. Thus, according to E. Horn et al. [17], no more than 20 cases of spinal cord and cranial melanocytomas have been described. Intramedullary localization was found in only 17 cases. A review by V. Rahimi-Movaghar and M. Karimi [18] shows 95 cases of meningeal melanocytomas, 45 of which were intracranial. According to M. Abbott et al. [19], one can reliably state on presence of melanocytoma only in 13 of the above mentioned cases. Based on these data, melanocytomas are very rare. Most often they represent intradural extramedullar lesions and much rarer these tumors are extradural or represent melanocytomas of spinal nerve roots [20]. Intracranial tumors have infratentorial localization in cerebellopontine angle, cerebral medullary cistern, and Meckel’s cave [21].
According to K. Winston et al. [13], there is no any prevalence by gender and age among patients. Based on other data, melanocytomas slightly dominate in female patients. The average age of patients is 45 years. Intracranial location is typical for young patients. It should be noted that melanocytomas almost never occur in children. The duration of symptoms before establishing the diagnosis varies from 3 months to 10 years [18].

**Diagnostics.** In CT, meningeal melanocytomas appear as isodense or slightly hypodense extracerebral lesions, not well-circumscribed, adjacent to the dura mater and actively accumulate contrast material [18].
On MRI, melanocytomas differ from other intracranial tumors by high signal intensity (hypointense) on T1-weighted images and low signal intensity (hyperintense) at T2 mode, with a homogeneous contrast enhancement [22]. Y. Uematsu et al. [23] believe that this phenomenon is caused by presence of stable free radicals in melanin. Thus, MRI is important in preoperative diagnostics.

Treatment. Total resection of melanocytoma leads to stable remission and recovery [10, 13]. After incomplete resection, tumor recurrence is possible even after radiation therapy [24]. D. Rades et al. [25] report that recurrence-free period of 5 years after radical resection is achieved in 78% of cases, while after incomplete removal only in 22%. K. Winston et al. [13] recommend surgical intervention even in case of recurrence. E. Horn et al. in a study [17] in 2008 described different biological behaviors of melanocytomas including periods of recurrence, malignant transformation and metastasis.

According to another study, despite that resection of extramedullary melanocytomas is simpler in surgical aspect, they are significantly more aggressive and incidence of early recurrence is higher than in case of intramedullary tumors [26].

Conclusions

It is evident that not all pigmented tumors are malignant. The median survival after surgery for primary CNS melanoma is 1 month [8]. Median survivals can be 6—9 months in patients with melanoma metastases [27]. Since the course of the disease and prognosis in patients with pigmented tumors of the CNS differ significantly, establishing a precise histological diagnosis and radical resection of the tumor are key factors for outcomes in patients with melanocytomas.

Authors declare no conflict of interest.

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Melanocytomas are extremely rare tumors. Modern literature describes about 30 cases of these neoplasms and whether this is the presence of melanocytoma is questionable in some of these cases. These benign tumors arising from meningeal melanocytes show diffuse spread throughout the pia mater, mainly in the upper cervical spine and the posterior fossa. Intramedullary melanocytomas are found only in the cervical and upper thoracic regions of the spinal cord. They are classified as pigmented meningiomas. Differential diagnostics is most complicated in the case of pigmented Schwannomas and malignant melanomas. These are commonly “soft” and well-circumscribed tumors with definitive dissection plane. This paper presents a detailed description of a rare clinical case of intramedullary melanocytoma at the craniovertebral transition level in a 28-year-old woman. This paper includes data of objective neurological examination and neuroimaging data. The stages of microsurgical operation of the tumor resection, the histological structure and immunohistochemistry of the resected tumor are described in detail. A positive expression of the HMB-45 melanocytic marker is pathognomonic sign of melanoma. Two-year catamnesis of the disease and control MRI with intravenous contrasting confirm that the tumor had been radically removed. The paper also provides a brief discussion of the issue with a detailed analysis of world literature data through history. In conclusion, the authors emphasize the undoubted importance of radical surgical treatment of intramedullary melanocytomas, which provides a stable remission of the disease and recovery. This paper is well illustrated. Since the paper shows current trends in the search for the best ways to improve diagnostics and surgical treatment techniques of these rare tumors, the paper is informative and intriguing for practicing neurosurgeons.

V. S. Klimov (Novosibirsk, Russia)
The incidence of failure of implanted systems for the drainage of cerebrospinal fluid (CSF) may reach 81% [1, 2]. Due to the post-implantation dependence of a patient on a properly functioning shunt system, failure of this system can lead to serious consequences. Dependence on shunt is a collective term that includes a variety of components, the key of which are resorption of cerebrospinal fluid and disturbance of the elastic properties of the brain that have adjusted to manner of the shunt functioning [3, 4]. The presence and nature of shunt failure can be judged on the basis of a comprehensive assessment of a variety of indicators: complaints, anamnesis, neurological status, radiology of a shunt, CT and/or MRI of the brain, as well as ultrasound examination of the abdominal cavity and the heart [5—9]. Clinical and paraclinical signs of shunt malfunction may differ [10—13]. Ventricular dilatation is the most common, but not a prerequisite for disruption of cerebrospinal fluid (CSF) drainage [1, 2, 14, 15]. Apparent ventricular dilatation or progressive ventricular enlargement definitely indicate shunt malfunction. However, in 9% of cases, shunt malfunction occurs without ventricular dilatation [2], which complicates diagnostics and may delay making a decision of treatment.

The “small” sizes of ventricles in shunt failure are associated with subependymal gliosis due to prior ventriculitis [2, 4, 16]. The informative value of CT in shunt failure diagnostics in children is low and does not exceed 16% [17]. It becomes obvious that ventriculomegaly cannot be relied upon in the diagnosis of CSF shunt failure [18]. Identification of shunt failure in doubtful cases requires extra diagnostic examinations, including invasive procedures, such as CT ventriculography, radiography or radionuclide shuntography and others [6, 13, 19]. Establishing the diagnosis of shunt failure in these cases can take several weeks to several months [18]. Absence of ventricular enlargement after shunt failure, in addition to complexity of diagnostics, can cause some technical difficulties during re-implanting or substitution of a ventricular catheter. Catheterization of non-dilated ventricles requires a lot of experience of the surgeon and/or equipping of the operating room with navigation systems. Hence, the statement of shunt failure in absence of ventricular enlargement and subsequently consideration of the indications for surgical intervention is a laborious and challenging process [6, 18, 20—23].

**Case report of shunt failure without ventricular enlargement**

A girl aged 7 years was admitted to the Neurosurgical Department of the Tashkent Regional Diversified Medical Center complaining of headache attacks, nausea, repeated vomiting, and inability to walk, which, according to his mother, made the girl moody and not eating.

From the medical record, it is known that pregnancy and childbirth proceeded with pathology. Ultrasound examination had revealed an increased size of the fetal head. She was born at 8 months of gestation. After the birth, rapid growth of the head circumference was observed. At the age of 3 months the girl was diagnosed with congenital hydrocephalus. According to the medical history, congenital hydrocephalus in the child was accompanied by an inflammatory process of bacterial and viral etiology. The absence of brain ventricle enlargement was shown not to exclude a probability of shunt malfunction. In this case, a specific phenomenon, an intraparenchymatous cerebrospinal fluid “lake” surrounding a ventricular catheter, was observed. Shunting recovery did not lead to a significant reduction in the phenomenon size. Causes underlying this phenomenon require further investigation.
with “hydrocephalus”. Neuroimaging revealed internal hydrocephalus with an Evans index of 0.48 and a retrocerebellar cyst (Fig. 1).

Diagnostic ventricular and lumbar punctures showed dissociation in CSF pressure at different levels (180 and 80 mm water column, respectively). Liquorograms found no inflammatory changes of CSF (protein — from 0.033 to 0.165 g/l, cytosis — from 0 to 1.3). Bacteriological examination of the lumbar portions of the CSF revealed Streptococcus pyogenes, which was sensitive to several antibiotics. In ventriculography, the retrocerebellar cyst was found to be a communicating cyst (Fig. 2). The child’s blood test showed high antibody titers to cytomegalovirus (IgM-AT>3.0, it is up to 0.42 units in the norm). The infectious disease specialist concluded on “Cytomegalovirus infection (confirmed by enzyme-linked immunosorbent assay)”. Concomitant viral infection and the presence of pathogenic microorganisms in the lumbar portion of the CSF were temporary contraindications to CSF shunt surgery. A course of antiviral and antibiotic therapy was prescribed to the patient. After arresting the signs of viral and latent bacterial infections, at an Evans index of 0.54 and the head circumference of 50 cm, ventriculoperitoneostomy was performed. After surgery, the girl’s condition has stabilized. Control neuroimaging revealed some regression of hydrocephalus (Fig. 3), and a slow process...
of “melting of the brain” and reduced ventricle size attracted attention.

The girl started to talk and walk in 1.5 years and attended a kindergarten from 3 years. After 2.5 years after surgery at age of 3 the girl was urgently admitted to hospital with complaints of intermittent headache, nausea, and repeated vomiting. The clinical presentation was dominated by hypertensive and brain stem symptoms. Head circumference was 51.7 cm. The excess of CSF was evacuated with difficulty through the pump-valve and the pump-valve was good to refill. During forced pumping of the pump by palpation, swelling was detected along the shunt, in the chest under the collarbone (the place of the supposed breakage of a peritoneal catheter).

Radiography revealed no distinct pattern of breakage or bending of the shunt components (shunt catheters are not impregnated with barium). MRI has attracted attention by absence of ventricular enlargement: the Evans index — 0.34; the III ventricle width — 10 mm (Fig. 4).

After revision and re-implantation of a peritoneal catheter (there was an intraluminal occlusion of the catheter) the patient’s condition has stabilized. Subsequently, standard health examination with a control tomography was conducted.

Nine months before the current admission, signs of shunt system malfunction had not been identified during a regular outpatient examination. According to multi-slice computed tomography (MSCT), the Evans index was 0.32 and the III ventricle width was 2 mm (Fig. 5).

Over time (after 6.5 years after primary surgery and 4 years after re-implantation of a peritoneal catheter) the patient was hospitalized due to suspected occurrence of acute shunt failure. From the medical record it is known that the onset was acute, 2 days before admission there was sudden nausea, headache, and decreased appetite. The patient stopped walking the day before admission.

Objective data: the patient’s condition was severe; the pulse was 62 and rhythmic. The patient was in consciousness, but drowsy, hypertensive and characteristic brain stem symptoms were noted. Head circumference is 53 cm. The excess of CSF was evacuated with difficulty through the pump-valve and valve filling was good. A swelling (probably, leaks along the drainage...
Fig. 6. MSCT during the current shunt failure.

a — a series of axial slices; b — a series of sagittal reconstructions; c — a series of frontal reconstructions. Grooves and gyri of the brain smooth. The ventricles of the brain expanded relatively insignificant.
Fig. 6. Continued.
c — a series of frontal reconstructions. Grooves and gyri of the brain smooth. The ventricles of the brain are dilated relatively insignificantly.

Fig. 7. MSCT 7 days after shunt surgery, a series of axial slices.
The pattern of grooves and gyri became clear. The size of ventricles of brain has decreased. The low-density area along the ventricular catheter is visualized.
the neck area above the collarbone was found during forced pumping of the pump by palpation, which was followed by a temporary improvement.

MSCT revealed an insignificant (compared with images made 9 months before), hardly noticeable dilatation of the lateral and III ventricles. Notice the low-density area in the brain parenchyma along the trajectory of the ventricular catheter (that was not observed in the previous tomograms). The low-dense area had an irregular shape, clear boundaries and a density of +6 HU. In the lateral ventricles, CSF had a density of +5 HU. The length of the indicated zone from the valve was 21 mm; the width reached 21 mm (Fig. 6). Ophthalmoscopy revealed optic disc edema with areas of hemorrhage, vein dilatation and tortuosity.

We suppose that CSF takes the path of least resistance as it flows through the ventricular catheter as compared to rigid ependyma of the ventricles, and that this presentation is indicative of the presence of mechanical failure of the shunt that caused intracranial hypertension without significant dilatation of the brain ventricles.

The patient underwent an operation: “revision and re-implantation of a peritoneal catheter of a ventriculoperitoneal shunt”. Former peritoneal catheter was encrusted with lime; it became breakable and hardly functioned, including due to dislodge from the abdominal cavity where it was originally placed (since the last re-implantation of peritoneal catheter the girl has grown by more than 20 cm).

The patient’s condition improved after a shunting operation. Neurological symptoms regressed. According to the control MSCT, 7 days after the operation the appearance of subarachnoid slits was observed, sizes of ventricles were close to its original state (the Evans index — 0.34; the III ventricle width — 3 mm), but the sizes of the low-density area along the ventricular catheter were unchanged (Fig. 7). It should be noted that at the time of performing the control MSCT the patient had not yet been verticalized. MSCT two months after shunt surgery was without dynamics, the Evans index — 0.34; the III ventricle width — 2.5 mm (Fig. 8). By this
moment, the girl was verticalized completely and led an active lifestyle.

Standard health examination and periodicity of regular examinations of patients with shunts to a certain extent provide objective data on dynamics of shunt functioning and thus facilitate physicians to make an adequate decision under certain clinical situations (which are sometimes not always associated with shunt failure). The most informative and, in our view, necessary components of standard health examination, in addition to neurological status, include tomography (CT or MRI) with planimetric indices, radiography of a shunt, anthropometry (with the obligatory measurement of the child growth), as well as palpation study of the nature of drainage and valve filling (these procedures can be performed by trained and instructed parents). Ophthalmoscopy, EEG, abdominal ultrasound examination and other studies are less informative, but no less important in this respect.

The purpose of this description of the case is to show the possibility of shunt occlusion without tomographic evidence of developed ventriculomegaly, as well as to draw attention to this clinical phenomenon in order to prevent delays in the diagnosis of shunt failure.

Authors declare no conflict of interest.

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A methodology for evaluation of clinical guidelines

Data/evidence classes and recommendation levels were applied in accordance with the evidence-based medicine criteria approved by the American Association of Neurological Surgeons (AANS). Data classes are based on evaluation of the research design, and the level of recommendation is based on the quality of research and consensus of expert opinions [1] (Table 1).

1. Patient categories under the guidelines

These recommendations apply to adult patients with newly diagnosed metastatic brain lesions without leptomeningeal and pachymeningeal lesions. The guidelines do not apply to patients with tumors highly sensitive to chemotherapy and radiotherapy: leukemia, lymphoma, and germ cell tumors.

2. General issues

The rate of brain metastatic lesions is steadily growing. At the least estimate, 8—10% of patients with malignant tumors develop symptomatic brain metastases. According to the data of population cancer-registries, the rate of brain metastases (BMs) accounts for 8—10% of all cancer cases. The BM rate for different locations of the primary tumor is as follows: 19.9% in lung cancer, 6.5% in melanoma, 6.5% in kidney cancer, 5.1% in breast cancer, and 1.8% in colorectal cancer [2].

The vast majority of BMs are caused by hematogenous spread of tumor cells from the primary site. In the brain, metastases are mainly localized at the boundary between the gray and white matter as well as at the junction of the middle cerebral and posterior cerebral artery territories.

Melanoma and small cell lung cancer have the highest metastatic potential among malignant tumors. In these cancers, brain metastases develop by the second year of follow-up in 80% of patients with a disseminated process. In this case, melanoma metastases have the worst prognosis for tumor control and survival [2].

According to the autopsy data, 25—40% of cancer patients are not diagnosed with BMs during the lifetime. Brain metastases manifest as a solitary lesion in approximately 37—50% of patients; 50—63% of patients have multiple metastases localized in different anatomical brain structures: in the parenchyma, dura or pia mater, subarachnoid space, and cerebral ventricles. Supratentorial metastases amount to 80—85% of cases; cerebellar metastases occur in 10—15% of cases; brainstem metastases occur in 3—5% of cases; meningeal metastases amount to 1—2% of cases. This distribution likely depends on blood supply to the brain [3].

Advances in oncology have resulted in an increased duration of patient’s life and, therefore, in an increased rate of the BM diagnosis. The development of BMs is a factor of the poor prognosis: the median survival in patients with inoperable BMs is only 51 days. Therefore, effective therapy and local control of BMs are of paramount importance for prognosis and quality of life in patients [4].

3. Clinical examination and follow-up

3.1. Mandatory amount of examination

3.1.1. Physical examination and taking disease history and family history.
3.1.2. Neurological examination.
3.1.3. Ophthalmologic examination with assessment of intracranial hypertension.
3.1.4. Contrast-enhanced MRI of the brain.
3.1.5. Electroencephalography.
3.1.6. Chest X-ray.
3.1.7. Ultrasound of the abdomen, pelvis, and peripheral lymph nodes.
3.1.8. Skeletal scintigraphy.
3.1.9. Clinical blood test.
3.1.10. Biochemical analysis of blood, including liver and renal function indicators.

3.2. Examination on detection of the primary extracranial site

3.2.1. CT and MRI of the primary lesion area.
3.3. Examination on an undiagnosed primary site

3.3.1. CT of the chest, abdomen, and pelvis, or diffusion-weighted MRI of the whole body, or positron emission tomography (PET) of the whole body.

3.3.2. Colonoscopy and gastroscopy.

3.3.3. Blood test for tumor markers.

3.3.4. The efficacy of radiotherapy/stereotactic radiotherapy (SRT)/radiosurgery (RS) is assessed 1.5 months after treatment completion; further control is performed every 3 months during the first year.

3.3.5. If the course of disease does not require to change the patient’s management, brain MRI with intravenous contrast-enhancement and follow-up examinations are performed after treatment:
- during the first year — every 3 months;
- during the second year — every 6 months;
- starting with the 3rd year — once a year;
- efficacy of drug treatment is evaluated every 2—3 cycles of chemotherapy or every 2—3 months during targeted therapy. The treatment is conducted until disease progression.

4. Diagnostics of BM patients

The diagnosis is confirmed by MRI. In this case, the standard for visualization of brain metastases is a study using only gadolinium contrast enhancement.

Computed tomography is required when bone structures are affected as well as for subsequent 3D planning of stereolithographic models in the case of extensive lesions.

Contrast-enhanced CT for detection of intracranial metastases should be performed only if MRI is not available.

CT perfusion is a dynamically developing technique that largely complements performed examinations, including MRI. CT perfusion in cancer patients is used for a differential diagnosis in the case of ischemic changes in the brain, lymphomas, meningiomas, hemangioblastomas, and some other processes possessing specific hemodynamic properties that can be differentiated by CT perfusion.

4.1. Brain MRI modes

4.1.1. Before intravenous administration of a contrast agent: T1, T2, diffusion-weighted imaging (DWI), and FLAIR.

4.1.2. After intravenous administration of a contrast agent: SPGR (vibe) + fatsat (0.7 mm) in the axial projection, or T1 in axial, sagittal, and frontal projections, with the minimal slice gap.

4.1.3. The geometry of axial projections should be identical for all pulse sequences.

4.2. Additional MR sequences

4.2.1. SWI — a small number of hypointense inclusions is typical of metastases (except melanoma and colon cancer).

4.2.2. MR spectroscopy — metastatic tumors are characterized by a peak of the Lip-Lac complex, a rare moderate increase in the Cho peak, a reduction in other peaks.

4.2.3. ASL MRI perfusion — like in the case of CT perfusion, elevated perfusion parameters are observed.

4.2.4. MR tractography — metastases deform cerebral tracts. Pronounced perifocal edema associated with tumor growth often hides the tracts, which may be incorrectly interpreted as their destruction.

4.3. Differential diagnosis of residual tumor and post-radiation necroses

Radiation-induced brain injury is accompanied by damage to the blood-brain barrier, vasculitides, and microbleeds. These changes cause active contrast uptake during T1-weighted MRI, and the changes manifest identically to those in the tumor process.

4.4. Studies used for a differential diagnosis between post-radiation changes and residual metastatic tumor

4.4.1. CT perfusion identifies actively functioning vascular structures of the tumor, which indicates its viability. Because radiation has a long-term effect on the tumor vessels, CT perfusion should be used not earlier than 1 month after treatment. It is desirable to have CT perfusion data obtained before treatment.
4.4.2. PET with 11C-methionine, 18F-tyrosine, and 18F-choline has a number of peculiarities. All agents have high specificity for detection of very small residual tumor fragments. A dynamic decrease in the rate of radiopharmaceutical agent uptake relative to that of brain tissue indicates therapeutic pathomorphism in metastatic tumor tissue. The advantage of [18F]-isotope based agents is their longer half-life period, which enables their use in dynamic and multi-stage scanning. This sequential scanning provides additional information on metabolic changes in the tumor.

4.4.3. Application of 18F-fluorodeoxyglucose is advisable only for large lesions with a large solid component.

4.5. Whole body examination in BM patients

Information on dissemination of the cancer process through the whole body is important for choosing treatment tactics. In this case, patients may be divided into two groups: patients in whom primary manifestation of disease was in the form of brain injury, and patients in whom metastases occurred after or during treatment of an extracranial malignant tumor. At present, PET with 18F-fluorodeoxyglucose is the “gold standard” of whole-body examination; however, the technique cannot be used for screening purposes due to its high cost and low availability.

DWI is an alternative, to some extent, to PET in whole-body examination. Whole-body DWI, despite its low specificity, has good sensitivity for detection of abnormal foci. This technique is advisable for use in patients with primary manifestation of disease in the brain, as an extension of brain scanning. If suspected tumor lesions are identified, whole-body DWI can be supplemented by targeted MR scanning of a particular organ.

5. Prognostic factors in BM patients

Overall survival of BM patients and planning of treatment depend on clinical factors (patient age, Karnofsky index, neurological deficit), clinical and biological factors of the tumor, amount of brain injury (number, total volume of BMs, and their localization in the brain), mass effect, and extracranial disease activity. These factors have been the basis for developing functional scales of an overall survival prognosis in BM patients, which largely determine the amount of therapy.

Currently, a preferred scale for evaluating an overall survival prognosis in BM patients is a recursive partitioning analysis (RPA) that is based on a multicenter analysis of 4,259 BM patients. The RPA scale is based only on statistically significant prognostic factors of overall survival of BM patients (Table 2) [5].

6. Literature data

6.1. Surgical resection

Surgical resection followed by whole-brain radiation therapy (WBRT) is the standard of treatment for single resectable brain metastases. A retrospective analysis of treatment of 13,685 patients hospitalized for surgical resection of brain metastases demonstrated a decrease in hospital mortality from 4.6% in 1988—1990 to 2.3% in 1997—2000 [6].

A study by R. Patchell et al. [7], 95 patients with single BMs were randomized into surgical resection and combined treatment (surgical resection and postoperative WBRT) groups.

WBRT was associated with a sharp reduction in tumor recurrences (18% vs. 70%; \( p < 0.001 \)) and death due to neurologic complications (14% vs. 44%; \( p = 0.003 \)). Overall survival was same in both groups.

In the case of multiple BMs, the role of surgery is limited to obtaining biopsy material or eliminating mass effect symptoms caused by large BMs. However, there are some retrospective data [8, 9] demonstrating an increase in overall survival after surgical resection of BMs in certain patients with a good prognosis and limited (up to 2—3) metastases.

7. Stereotactic radiosurgery

Progress in stereotactic radiosurgery was accompanied by the development of a minimally invasive technique for BM treatment. Patients undergoing RS avoid the risk of postoperative complications associated with surgery. According to the RTOG 90-05 data, if dose/volume ratios are followed, late side effects, such as edema and necrosis after RS, are rare.

A retrospective analysis demonstrated that a low total BM volume (<10 cm³), not the BM number, is a predictor of the best survival [7, 10].

Therefore, application of RS may be effective in patients with multiple BMs (up to 10 foci) but with a small total volume of brain metastases (up to 10 cm³). Other predictors of overall survival of patients after RS include young age, a Karnofsky index of more than 80%, and systemic control of disease [9, 11, 12].

In a randomized trial involving 132 patients with 1—4 BMs and a maximum diameter of less than 3 cm, RS in addition to WBRT did not increase the median overall survival compared to use of RS as an independent treatment option (7.5 vs. 8.0 months, respectively). However, the 1-year intracranial recurrence rate was lower in a WBRT and RS group (47% vs. 76%; \( p < 0.001 \)) [13].

In another study, enrollment of patients (a total of 58 patients with 1—3 BMs) was stopped because of significant worsening of neurocognitive impairments in a RS and WBRT group compared to a radiosurgery group (52% vs. 24%, respectively). The twelve-month recurrence-free survival rate was 27% for WBRT and 73% for combination of RS and WBRT [14].
In a study by W. Chang et al. [15], 359 patients with 1—3 BMs who underwent surgical resection or RS were randomized into postoperative WBRT and postoperative follow-up groups. The rate of recurrences and deaths from intracranial progression in the WBRT group was lower compared to that in the follow-up group, but overall life span was similar in both groups. A conducted meta-analysis showed no improvement in overall survival in patients who underwent WBRT in addition to RS.

Retrospective comparative studies demonstrated that overall survival after RS and WBRT and after surgical resection and WBRT was same [16—18].

A randomized controlled study by Muacevic A. et al. [19] evaluated radiosurgical treatment compared to surgical resection and WBRT. The study was stopped early because of poor recruitment of patient. Finally, 64 patients with single BMs who underwent RS were subjected to less invasive intervention and demonstrated survival and local control rates similar to those in a group of surgical resection and WBRT. However, the rate of distant metastases was higher in the RS group.

8. Whole-brain radiation therapy

WBRT was the main treatment for BMs for a long time. At present, WBRT is still effective in certain clinical situations (when surgical resection or RS is not possible or when WBRT is used as a component of combination treatment for multiple BMs).

Three randomized studies examined the efficacy of surgical treatment combined with WBRT in patients with single BMs.

A study by R. Patchell et al. [20] demonstrated that survival after surgery and subsequent WBRT increased compared to that after WBRT alone. Overall survival was 40 weeks in a combined treatment group and 15 weeks in a WBRT group (p<0.01). The rate of intracranial recurrences was 20% in the combined treatment group and 52% in the WBRT group (p<0.02).

A study by S. Vecht et al. [21] showed longer survival in a combined treatment (surgical resection and WBRT) group. The longest overall survival was observed in patients with a good prognosis: the median survival in them was 12 months compared to 7 months in a group of patients with a poor prognosis.

The efficacy of radiosurgical boost in addition to WBRT was evaluated in two published randomized controlled trials.

In a multicenter study RTOG 95-08, 333 patients with 1—3 BMs were randomized into a WBRT and RS group and a WBRT group. The combined treatment was demonstrated to be advantageous for single BMs (6.5 months vs. 4.9 months; p=0.04) in terms of overall survival. This advantage was not observed in patients with 2—3 BMs [22].

Therefore, the combined treatment (WBRT in combination with surgical resection or RS) in comparison with WBRT alone leads to improved clinical outcomes in the treatment of patients with a good prognosis and single BMs. However, in patients with inoperable BMs, multiple BMs, or a poor prognosis, WBRT is the method of choice both as independent treatment option and as part of combination therapy.

9. Doses and fractionation regimens of BM radiotherapy

9.1. Whole-brain radiation therapy

There are data (class 1 data, level 1 recommendations) indicating that changes in a WBRT dose/fractionation schedule do not lead to significant differences in the median overall survival, local control, or rate of neurocognitive changes after treatment compared to those of a “standard” WBRT fractionation regimen: a total boost dose (TBD) of 30 Gy, a fraction dose (FD) of 3 Gy in 10 fractions, or TBD of 37.5 Gy, FD of 2.5 Gy in 15 fractions.

An increase in FD of WBRT by more than 3 Gy leads to an increase in the rate of neurocognitive disorders.

There are very limited data but no evidence of any level, which would be the basis to recommend a change in the dose and fractionation regimen of WBRT, depending on the histological structure of the tumor.

9.2. Radiosurgical treatment

Radiosurgical treatment is the delivery of a high radiation dose to the lesion in one fraction, with minimal exposure of normal tissue. The indication for RS is the presence of BMs with a maximum diameter of less than 3 cm, without clinical manifestations of the mass effect.

Equipment needed for RS is as follows: “Gamma Knife” and “CyberKnife” devices and a linear accelerator with a micro-multileaf collimator.
According to the RTOG 90-05 data, the maximum permissible radiation doses for radiosurgical treatment of BMs are as follows:

- 15 Gy for BMs with a maximum diameter of 3.0—3.5 cm (level 1 recommendations);
- 18 Gy for BMs with a maximum diameter of 2—3 cm (level 1 recommendations);
- 24 Gy for BMs with a maximum diameter of up to 2 cm (level 1 recommendations);
- radiation dose for each lesion is normalized in such a way that the volume of normal brain tissue exposed to a dose of more than 12 Gy is less than 10 cm³.

9.3. Stereotactic radiotherapy in the hypofractionated regimen

Stereotactic radiotherapy is the delivery of a high radiation dose using stereotactic navigation in a limited number of fractions (usually, 3—7 fractions). The indication for stereotactic radiotherapy in the hypofractionated regimen is the presence of inoperable BMs of more than 3 cm in diameter. The most often used regimens are as follows: TBD of 24 Gy in 3 fractions, 30—35 Gy in 5 fractions, and 35 Gy in 7 fractions (level 3 recommendations).

10. Combined treatment of patients with a limited number (≤3) of BMs

10.1. A group of patients with a good prognosis (Karnofsky index, ≥80; RPA, 1—2; ECOG, 0—1; no or a limited number of extracranial metastases; controlled manifestations of extracranial disease; potential for systemic treatment).

10.1.1. WBRT compared to combination of surgical resection and WBRT in patients with newly diagnosed solitary resectable BMs

A group of combined treatment (surgical resection and WBRT) has better overall survival, local recurrence, and distant metastasis rates compared to those in a group of WBRT as an independent treatment option (class 1 data, level 1 recommendations). Combined treatment (surgical resection and WBRT) is recommended for solitary resectable metastases in patients with a good prognosis (level 1 recommendations). There is no enough evidence to recommend this option for patients with a poor prognosis (Karnofsky index, <70; ECOG, 2—3), disseminated extracranial disease, and multiple brain metastases (not recommended).

10.1.2. Combination of WBRT and surgical resection compared to surgical resection in patients with newly diagnosed solitary resectable BMs

A group of combined treatment (surgical resection and WBRT) has better overall survival, local recurrence, and new (distant) metastasis rates compared to those in a group of WBRT as an independent treatment option (level 1 recommendations). Combined treatment (surgical resection and WBRT) is recommended for solitary resectable metastases in patients with a good prognosis (level 1 recommendations).

10.1.3. Combination of RS and WBRT compared to WBRT in patients with newly diagnosed resectable solitary BMs, with a maximum lesion diameter of less than 3 cm, without mass effect

A group of combined treatment (RS and WBRT) has better overall survival, local recurrence, and new (distant) metastasis rates compared to those in a group of WBRT as an independent treatment option (level 1 recommendations).

10.1.4. Combination of RS and WBRT compared to combination of surgical resection and WBRT in patients with newly diagnosed solitary resectable BMs, with a maximum lesion diameter of less than 3 cm, without mass effect

Both surgical resection in combination with WBRT and RS in combination with WBRT are effective treatment options that provide similar rates of survival, local recurrences, and new (distant) metastases.

10.1.5. Combination of RS and WBRT compared to WBRT in patients with newly diagnosed 1—3 BMs with a maximum lesion diameter of less than 3 cm, without mass effect

A group of combined treatment (RS and WBRT) has better overall survival, local recurrence, and distant metastasis rates compared to those in a group of WBRT as an independent treatment option (level 2 recommendations).

10.1.6. Combination of RS and WBRT compared to RS in patients with newly diagnosed 1—3 BMs with a maximum lesion diameter of less than 3 cm, without mass effect

RS as an independent treatment option provides equivalent survival rates compared to those of combined treatment (RS and WBRT). There are conflicting data (classes 1 and 2) about the risk of distant metastases in the case of RS as an independent treatment option.

11. Combined treatment of patients with multiple (≥4) BMs

11.1. A group of patients with a good prognosis (Karnofsky index, ≥80; ECOG, 0—1; no or a limited number
of extracranial metastases; controlled manifestations of extracranial disease; a potential for systemic treatment).

11.1.1. Combination of RS and WBRT compared to WBRT in patients with a maximum lesion diameter of less than 3 cm, no mass effect
A group of combined treatment (RS and WBRT) has a better rate of local recurrences and distant metastases compared to that in a group of WBRT as an independent treatment option (level 2 recommendations).

11.1.2. Combination of RS and WBRT compared to RS in patients with a maximum lesion diameter of less than 3 cm, no mass effect
There are data (classes 2 and 3) showing that RS as an independent treatment option provides overall survival rates equivalent to those of RS and WBRT combination (level 3 recommendations).

RS can be used as an independent treatment option if regular careful follow-up is performed for early detection of local recurrences and distant metastases, followed by repeated RS (level 3 recommendations).

11.2. A group of patients with a poor prognosis (Karnofsky index, ≤70; ECOG, 2—3; multiple extracranial metastases; uncontrolled manifestations of extracranial disease; no potential for systemic treatment).

11.2.1. There are single studies (class 2 and 3 data) demonstrating an advantage of WBRT over supportive therapy (level 3 recommendations).

12. An algorithm for treatment of BM patients

12.1. A limited (≤3) number of BMs (see Flow chart 1)

12.2. Multiple (>4) BMs (see Flow chart 2)

13. The recommendations of an experts’ group for making a decision in treatment of BM patients

The goal of BM treatment is to prevent patient’s death from intracranial disease progression, reduce neurological symptoms, or avoid their development, with the patient’s quality of life being preserved as long as possible.

Treatment of BMs is an important component of complex treatment of cancer patients, which provides a higher life span.

Treatment standards should be chosen focusing on the best prognosis for a particular patient and based on the data proven in prospective randomized or cohort studies. The standards should be regularly reviewed in the light of new research.

In a significant number of cases, the existing range of BM therapies avoids mortality due to intracranial progression, preserves quality of life, and extends the time of overall survival in certain categories of patients.

In this case, local treatments (surgery and stereotactic radiotherapy (SRT); hypofractionation and RS) are of the greatest importance. An important feature of SRT is the possibility of its multiple repeated use for control of local recurrences and treatment of new distant metastases.

Below, we present the BM treatment principles adopted by a RUSSCO (Moscow, Russia) group of experts. It should be noted that despite the relevance of these approaches to clinical practice at most centers fitted with radiosurgical and surgical equipment, prospective clinical studies regarding some statements have not been conducted, and, accordingly, the level of their formal evidence is presently low. Therefore, the proposed treatment options are strictly advisory because they belong to level 3 recommendations (based on the opinion of some experts and retrospective analysis data).

13.1. Clinical factors affecting the choice of treatment tactics

The presence of lesions causing clinical manifestations of the mass effect or other lesions suitable for surgical treatment.

Important clinical factors that determine a disease prognosis and treatment tactics are as follows: the age, Karnofsky index, number and total volume of BMs, control of the primary tumor, and extracranial metastases.

Currently, biological characteristics of the tumor (status of EGFR and ALK genes in lung cancer, the Her2 gene in breast cancer, the Kras gene in colorectal cancer, and the Braf gene in melanoma) have an important prognostic value in the case of BMs.

13.2. Surgical treatment

Surgical treatment is indicated for metastatic lesions causing clinical manifestations of the mass effect that is accompanied by signs of intracranial hypertension, dislocation of the midline structures, and extensive perifocal edema involving the adherent brain lobes and contralateral hemisphere as well as if there is a risk of blockade of the cerebrospinal fluid pathways. Surgical treatment is aimed at creating conditions for further complex treatment of the patient.

The feature of BM surgery is en bloc resection of the metastasis with the surrounding perifocal and perivascular area. This resection technique reduces the risk of local recurrence.

Surgical treatment is indicated for a limited (≤3) BM number and a resectable lesion of more than 3 cm in diameter. The best rates of overall survival are achieved in patients with a high performance status (>80) and control of an extracranial tumor process. It should be noted that a low performance status in some patients is due to consequences of the mass effect and may be improved after surgery.

In the case of solitary metastases (one brain metastasis, no extracranial manifestations of disease), surgery is indicated for metastases of more than 3 cm. Surgical treatment may be used for metastases of less than 3 cm, which are located in the functionally important areas, with clinical manifestations (neurological symptoms)
and no response to the steroid test (administration of dexamethasone at a dose of 8 to 24 mg/day, treatment duration of up to 5 days).

In the case of single metastases (one brain metastasis, there are manifestations of extracranial disease), the indications for surgical treatment are similar to those for treatment of solitary metastases. However, the treatment is more effective if there is control of extracranial metastases and a potential for systemic treatment.

Surgical treatment may be indicated for multiple BMs, with a lesion of more than 3 cm in diameter, underlying severity of the patient’s condition. The prerequisites of good treatment outcomes include a high performance status, control of extracranial manifestations of disease, and/or a potential for systemic treatment.

Surgical treatment aimed at creating conditions for further complex treatment of the patient is indicated for multiple BMs with metastatic foci causing clinical manifestations of the mass effect accompanied by signs of intracranial hypertension, dislocation of the midline structures, and extensive perifocal edema involving the adherent brain lobes and contralateral hemisphere as well as if there is a risk of blockade of the cerebrospinal fluid pathways.

Surgical treatment may be used in the case of local recurrence after previous treatment.

13.3. Whole-brain radiation therapy

Postoperative WBRT is used in the case of multiple (>10) BMs or leptomeningeal dissemination, regardless of the BM number.

In the case of radiosensitive tumors (breast cancer, lung cancer), WBRT is advisable for more than 5 BMs.

Preventive WBRT reduces the development of metastatic brain lesions in small cell lung cancer patients who have responded to previous chemotherapy (level 1 recommendations). FD of 2.5 Gy in 10 fractions is considered the optimal dosing regimen. An increase in TDB to 36 Gy is accompanied by a significant increase in neurotoxicity (especially in patients older than 60 years). TDB of WBRT should not exceed 30 Gy when it is applied together with chemotherapy.

For the purpose of treatment or prophylaxis, WBRT is used as an independent method or in combination with surgical resection or RS.

As an alternative to surgical treatment, WBRT is used as an independent treatment option or in combination with stereotactic radiotherapy (RS or hypofractionation, depending on a clinical situation).

13.4. Radiosurgery as an independent treatment option

RS is an adequate alternative to surgery in certain clinical situations. In this case, the choice of RS is related to the amount of local irradiation, which depends on the maximum lesion volume (or a total volume of adjacent lesions).

RS is limited to the volume of brain tissue (including BMs) exposed to a dose of 12 Gy, which should not exceed 15 cm³. This approximately corresponds to the limitation of an exposed lesion size to less than 14 cm³, which is a convenient parameter for calculating the radiation dose. When it is difficult to calculate a volume, a maximum lesion diameter of less than 3 cm (14 cm³) is an alternative to calculating the volume.

The direct indication for RS is a limited (<3) number of metastases (lesions with a maximum diameter of less than 3 cm). However, patients with multiple (3—10) BMs are also candidates for RS.

As an independent treatment option, RS requires careful monitoring for early detection of recurrences, followed by radiosurgical treatment.

Another treatment option is combination of RS and WBRT, which is often used for multiple metastatic lesions (>10 BMs). In this case, RS is used for lesions larger than 1 cm in diameter, with simultaneous or subsequent application of WBRT. The radiosurgical dose should not exceed 18 Gy for simultaneous use of RS and WBRT.

Stereotactic radiotherapy in the hypofractionated regimen is recommended for use to treat large inoperable lesions or metastatic conglomerates (>3 cm in diameter).

13.5. Stereotactic radiotherapy in the hypofractionated regimen

SRT of brain metastases may be considered as an effective method to achieve a certain level of local control of large (>3 cm in diameter) BMs. For large tumors, this indicator may be improved if higher total radiation doses are delivered in a larger number of fractions in the hypofractionated regimen.

A phase II prospective study by Ammirati et al. confirmed the efficacy of SRT with TDB=30 Gy delivered in 5 fractions. The biologically equivalent dose (BED) was calculated as 40 Gy (FD=2 Gy) for acute effects and as 60 Gy (FD=2 Gy) for late effects, assuming a ratio of α/β=10 Gy for acute effects and α/β=2 Gy for late effects (level 2 recommendations). This study enabled application of equivalent (in BED) hypofractionation regimens: 3 fractions of 8 Gy, TDB=24 Gy; 5 fractions of 6 Gy, TDB=30 Gy; 7 fractions of 5 Gy, TDB=35 Gy.

According to published studies and our experience, adjuvant SRT on the resected tumor bed may probably replace preventive WBRT in certain clinical situations. Delivery of high TDBs to the minimum volume of surrounding normal brain tissues around a resected metastasis bed improves local control from 70% (for WBRT) to 85.5% (for stereotactic radiation therapy) and has a low toxicity level.

The indications for SRT in the hypofractionated regimen are as follows:

- BMs of more than 2.5 cm in diameter;
Limited brain metastases

Patients with a good prognosis

BMs without mass effect

Patients with a poor prognosis

Resectable BMs ≥ 3 cm in diameter and/or the mass effect

BMs with a maximum diameter of less than 3 cm

BMs with a maximum diameter of more than 3 cm

Whole-brain radiation therapy (level 1 recommendations)

Surgery in combination with WBRT (level 1 recommendations)

Radiosurgery in combination with WBRT (level 1 recommendations)

Radiosurgery in combination with WBRT in certain clinical situations

Surgery in combination with radiosurgical irradiation of the bed and unresected lesions (level 3 recommendations)

Radiosurgery as an independent treatment option (level 2 recommendations)

Stereotactic radiotherapy in the hypofractionation regimen with/without WBRT (level 3 recommendations)

Flow chart 1. Algorithm for making decision in the case of limited brain metastases.

Multiple brain metastases

Patients with a good prognosis

Resectable lesion of more than 3 cm in diameter and/or the mass effect

BMs without mass effect

Whole-brain radiation therapy (level 1 recommendations)

Surgery in combination with WBRT (level 2 recommendations)

Surgery in combination with radiosurgical irradiation of the bed and unresected lesions (level 3 recommendations)

Radiosurgery (or hypofractionation) with/without WBRT (level 3 recommendations)

Patients with a poor prognosis

Whole-brain radiation therapy (level 1 recommendations)

Symptomatic treatment

14. Drug therapy

14.1. Antitumor drug therapy

Application of systemic antitumor therapy (targeted and chemotherapy) at the first stage of treatment is possible in patients with asymptomatic brain metastases who are sensitive to systemic treatment: patients with breast cancer (in the case of Her-2 overexpression), non-small cell lung cancer (in the case of an EGFR mutation or ALK translocation), small cell lung cancer, and ovarian cancer.

The choice of a drug regimen for treating a patient with a metastatic process in the brain depends primarily on the morphology and biological characteristics of the primary tumor as well as on the regimen of antitumor drug therapy conducted before detection of brain metastases.

The effect of drug treatment is assessed every 2—3 cycles of chemotherapy and every 2—3 months during targeted therapy. The treatment is conducted until disease progression.

During targeted therapy, in the case of an isolated brain metastasis or tumor progression in the brain, targeted therapy may be continued in combination with local control of brain tumor lesions (neurosurgical treatment, SRT or RS, whole-brain radiation therapy).

14.2. Steroid therapy

14.2.1. Steroid therapy compared to no therapy in treatment of BM patients without clinical symptoms and mass effect

There are no data for steroid therapy to be recommended in this clinical situation.

14.2.2. Patients with BMs and moderate mass effect-associated symptoms

Steroid therapy (dexamethasone) is recommended for elimination or temporary relief of symptoms associated with increased intracranial pressure and secondary cerebral edema. The initial dose of dexamethasone is 4—8 mg/day.

14.2.3. Patients with BMs and severe mass effect-associated symptoms

Steroid therapy (dexamethasone) is recommended for temporary relief of symptoms associated with increased intracranial pressure and secondary cerebral edema. The initial dose of dexamethasone is ≥ 16 mg/day.

14.2.4. The duration of corticosteroid therapy

Dexamethasone doses are gradually reduced during 2 weeks or more, based on individual clinical symptoms and allowing for complications of steroid therapy.

In some clinical situations, long-term/permanent use of dexamethasone at maintenance doses (0.5—4.0 mg/day) is possible.

A dose reduction or cancellation of dexamethasone before surgical removal and/or radiation treatment is not recommended.

Authors declare no conflict of interest.

REFERENCES


Brain metastases are a serious complication of cancer. According to various sources, the rate of symptomatic brain lesions amounts to 10% of cancer patients. Progress in drug treatment led to an increase in overall survival of patients and, therefore, to an increase in the rate of brain metastases. On the other hand, opportunities in treatment of patients with brain metastases (BMs) are expanding. Microsurgical treatment, stereotactic radiotherapy, and radiosurgery techniques are actively implemented. Therefore, the development of clinical guidelines reflecting the current standards of treatment of BM patients, based on the data of randomized trials, is an urgent and topical task.

The present clinical guidelines were developed using the evidence-based medicine criteria approved by the American Association of Neurological Surgeons (AANS). The presented approach to evaluation of conducted studies enables the doctor to determine very clearly the importance of a treatment option (or combination of options).

The clinical guidelines apply to patients with BMs of solid tumors. Unfortunately, these guidelines do not reflect the issues of treatment of patients with leptomeningeal and pachymeningeal lesions. It would be optimal to develop clinical guidelines for treatment of patients with metastatic CNS lesions of the central nervous system, which would reflect all issues related to treatment of both brain metastases (including meningeal lesions) and spinal cord and spinal column metastases.

The authors described in detail the algorithm for examination of BM patients, including basic and additional MRI sequences; differential diagnosis of radiation injuries and post-radiation recurrences, as well as issues of a PET study.

The section “Prognostic factors in BM patients” describes the RPA scale. Undoubtedly, this is an important scale for prognosis of overall survival in this group of patients, but the scale was developed after analysis of BM treatment outcomes and whole-brain radiation therapy. In next editions of the clinical guidelines, it would be preferable to use the GPA scale that reflects significance of the morphological diagnosis, performance status, number of brain metastases, and dissemination of extracranial disease.

The section “Doses and fractionation regimes of BM radiotherapy” describes the classic fractionation regimes of whole-brain radiation therapy and refers to RTOG protocol 90-05 for calculating a “safe” radiation dose for radiosurgery. It is necessary to note the presence of guidelines for application of the hypofractionated regimen of stereotactic radiotherapy for treatment of large metastases; however, the authors do not specify limitations and tolerance levels of brain tissues for this radiation technique. This section describes the general principles for dose selection during radiation therapy, but lacks a description of how to perform radiation therapy using various instruments. It is important to develop guidelines for conducting radiation (or surgical) treatment of brain metastases, which would describe in detail treatment techniques.

In general, the clinical guidelines for treatment of patients with brain metastases is an important document that allows the doctor of any speciality (oncologist, neurosurgeon, radiotherapist) to make the most optimal therapeutic decision.

E.S. Polovnikov (Moscow, Russia)
Modern Treatments for Degenerative Disc Diseases of the Lumbosacral Spine. A Literature Review


Burdenko Neurosurgical Institute, Moscow, Russia

Many researchers consider degenerative diseases of the spine as a pandemic of the XXIst century. Herniated intervertebral discs of the lumbosacral spine occur in 61% of patients with degenerative spine diseases. Of these, 15% of patients have herniated discs at the L2—L3 level, 10% of patients at the L3—L4 level, and 40% of patients at the L4—L5 and L5—S1 levels. A high cost of conservative treatment of degenerative spine disease symptoms and its low efficacy in reducing the intensity and duration of pain necessitate the development of new methods of surgical treatment. In this paper, we analyze the literature data on minimally invasive spine surgery and demonstrate the main advantages of percutaneous endoscopic surgical techniques.

Keywords: endoscopic discectomy, degenerative spine disease, herniated intervertebral disc.

History of the endoscopic technique for removal of herniated lumbar discs

M. Burman was the first who reported a potential use of endoscopy in spinal surgery [1]. He used a 9.5 mm diameter endoscope to examine the cauda equina in cadavers. The author concluded that technical imperfection of the equipment prevented the use of endoscopy in clinical practice, but he predicted potential application of this technique for refining the diagnosis.

L. Pool [2] used a modified otoscope with illumination to examine roots in herniated discs and some other spinal canal diseases. The first endoscopic biopsy of intervertebral disc tissue through the posterolateral approach was performed by C. Ottolenhi et al. [3].

P. Kambin [4] developed a technique for posterolateral needle nucleotomy. The operation was performed under X-ray control, without endoscopic assistance. The author provided detailed argumentation for a reduced risk of injury to the spinal nerve when approaching the lumbar disc laterally, at a distance of about 9—10 cm from the midline, in parallel to the disc endplates. The annulus fibrosus was perforated at 10 or 2 o’clock. This secure operative approach to the intervertebral disc was called the “Kambin’s triangle”. Over time, the new concept became a modified arthroscopic approach for lumbar discectomy.

In 1983, B. Hausmann [5] used an arthroscope to explore the contents of the intervertebral space after discectomy through the laminctomy approach. A. Schreiber [6] applied an endoscopic-assisted technique for conventional microdiscectomy. During approaching, instruments and an endoscope were located on opposite sides. Intraoperatively, a surgeon removed the disc, and an assistant monitored the process using the endoscope.

D. Ditsworth [7] proposed a percutaneous transforaminal (foramenoscopy) approach. He used a unportal approach with a small fiberoptic endoscope and a 6-mm working channel.

In 1997, A. Yeung [8] proposed a commercial version of equipment for posterolateral endoscopic discectomy—the Yeung endoscopic spinal system (YESS), and T. Hoogland proposed a similar system—the transforaminal endoscopic surgical system (TESSYS).

In 1995, J. Destandau [9] reported the use of endoscopic discectomy through the posterior approach and presented a special set of instruments for this intervention. In 2007, the Karl Storz company (Germany) produced a commercial version of the Destandau’s instruments (Table).

In 2009, the Karl Storz company released an Easy-Go endoscopic system that was developed by J. Oertel et al. [10] to perform discectomy through the posterior approach (Table).

Therefore, the rapid progress in endoscopic surgery for herniated discs has occurred in the recent decades when the main range of advanced endoscopic spinal systems has been developed.

Endoscopic interventions are less traumatic and accompanied by a lower intensity of postoperative pain. Compared to endoscopic surgery, microsurgery has no obvious advantages regarding the amount of nervous structures decompression and, furthermore, takes longer time.

Modern endoscopic spinal systems

The market of neurosurgical instruments used for endoscopic discectomy provides retractors and instruments from Destandau, Easy-Go, and Smart companies as well as more modern systems from...
SpineTIP TESSYS (Germany), YESS, and Vertebris companies (Table).

A METRx system includes a tubular retractor that has angulated optics and is movable in the insert, which makes the full space created by the tubular retractor to be available for manipulations with the use of an operating microscope.

A kit of the Destandau instruments includes an oval conical tube, obturator, operating insert with channels for an endoscope, suction cannula, and nerve root retractor and a working channel, as well as a special set of Kerrison punches, etc. This system uses an 18-cm rigid endoscope, 4 mm in diameter, with end optics. The system is purely endoscopic and cannot be used with an operating microscope.

Systems Smart and Easy-Go are similar in design features and consist of a set of dilators, working tube with an attachable angular (30°) endoscope, and endoscope holder. The endoscope is introduced through a separate channel, at an angle to the operating tube, in the Smart system and through a special channel in the tube in the Easy-Go system. The latter system is most widespread, and its name reflects the idea of creating a set of instruments, which would enable easy transition from microsurgical discectomy to endoscopic discectomy. These two systems can be used both in endoscopic interventions and in combination with an operating microscope.

YESS, Vertebris, and TESSYS systems for transfemoral endoscopic discectomy are fundamentally different in their design from the previous systems. Surgery is performed through a skin puncture under X-ray and endoscopic control. The successive use of a guiding needle and tubes enables placing a foraminoscope with a working channel for punches and performing discectomy. In addition, special reamers and burs for foraminoplasty and a Trigger Flex laser for hemostasis, cicatrization, and thermodiscoplasty can be used. The Vertebris system can also be used for interlaminar discectomy.

SpineTIP (Transforamonal Interlaminar Posterolateral) is a system for percutaneous endoscopic discectomy and is similar to the above systems, but has several different design features: 6.2 to 6.8 mm ID operating tubes enable discectomy through both transfemoral and interlaminar approaches using a Hopkins endoscope.

It should be noted that manufacturers constantly upgrade existing systems, producing new, more easy-to-use versions. There are some new trends in the choice of an endoscopic discectomy technique.

The Destandau endoscopic discectomy technique was greatly popular, as evidenced by a large number of publications in 2004—2010 [11—16]. Subsequently, the number of similar publications clearly reduced, reflecting the loss of interest in this technique.

Kits for portal endoscopic discectomy are widely used in clinical practice. Training in the portal spinal surgery technique is part of the simulation training standards for neurosurgery residents in the United States [17]. Systems for percutaneous endoscopic discectomy, which reduce invasiveness of surgery, have been especially actively implemented in clinical practice in recent years [18].

The efficacy of endoscopic discectomy

All minimally invasive spine surgeries may be divided into three types: microsurgical discectomy, tubular discectomy (microendoscopic discectomy), and percutaneous endoscopic discectomy (truly endoscopic discectomy).

S.K. Akshulakov et al. [19] indicated the following positive differences of endoscopic discectomy from microscopic discectomy: a smaller skin incision, less soft tissue injury on approach, a lower pain intensity in the early postoperative period, potentially earlier hospital discharge, and full rehabilitation for a shorter period of time.

Magnetic resonance imaging showed no significant differences in the amount of decompression after endoscopic discectomy and after microdiscectomy [20]. At the same time, the results of a comparative analysis of inflammation and pain markers in a study by L. Pan et al. [21] confirmed significant advantages of the percutaneous endoscopic technique compared to the microsurgical technique.

Among the disadvantages of endoscopic techniques, C. Schizas [22] indicates low image quality that does not, compared to microscopic imaging, provide adequate 3D and depth information. The authors also note the fact that modern systems, compatible with an operating microscope, have been specifically designed to neutralize the weak point of endoscopy. An endoscope visualizes anatomical structures that are beyond the borders of a tubular retractor; intraoperatively, the tube can be used as a retractor, which enables exploration of the surgical field at different viewing angles by tilting the tube in the direction opposite to that of the viewing angle to provide access to a large part of the interarch space. Tube inclination is accompanied by associated inclination of instruments, which enables manipulating instruments under visual control and changing the viewing angle with no risk of disorientation.

U. Schick et al. [23] investigated the degree of nerve root irritation during endoscopic discectomy and during traditional open discectomy using a neurophysiological technique. The study showed that the endoscopic technique was associated with a significantly lower number of mechanically evoked potentials both at the approaching step and at the root mobilization step, i.e. endoscopic discectomy caused less irritation of the nerve root compared to traditional open discectomy. D. Shi et al. [24] also noted a smaller skin incision and less tissue injury associated with microendoscopic discectomy. M. Brock [25] demonstrated that patients who underwent
### Modern endoscopic spinal systems for lumbar discectomy

<table>
<thead>
<tr>
<th>System name</th>
<th>METRx</th>
<th>Destandau Endospine</th>
<th>Smart</th>
<th>EasyGo</th>
<th>YESS</th>
<th>Vertebris</th>
<th>TESSYS</th>
<th>SpineTIP</th>
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</thead>
<tbody>
<tr>
<td>Appearance of an endoscopic system under operation</td>
<td><img src="image1" alt="METRx" /></td>
<td><img src="image2" alt="Destandau Endospine" /></td>
<td><img src="image3" alt="Smart" /></td>
<td><img src="image4" alt="EasyGo" /></td>
<td><img src="image5" alt="YESS" /></td>
<td><img src="image6" alt="Vertebris" /></td>
<td><img src="image7" alt="TESSYS" /></td>
<td><img src="image8" alt="SpineTIP" /></td>
</tr>
<tr>
<td>Manufacturer</td>
<td>Medtronic, USA</td>
<td>Karl Storz, Germany</td>
<td>Karl Storz, Germany</td>
<td>Karl Storz, Germany</td>
<td>Richard Wolf, Germany</td>
<td>Richard Wolf, Germany</td>
<td>Joymax, USA</td>
<td>Karl Storz, Germany</td>
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<tr>
<td>Approach</td>
<td>Posterior</td>
<td>Posterior</td>
<td>Posterior</td>
<td>Posterior</td>
<td>Transforaminal</td>
<td>Transforaminal</td>
<td>Transforaminal posterior, posterolateral</td>
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<td>Features of intraoperative visualization</td>
<td>Possibility of combined use of a microscope and an endoscope</td>
<td>Endoscope only</td>
<td>Possibility of combined use of a microscope and an endoscope</td>
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<tr>
<td>Endoscope in use</td>
<td>Endoscope VA 25°, OD=4 mm, L=10 cm</td>
<td>Hopkins, VA=0°, OD=4 mm, L=18 cm</td>
<td>Hopkins, VA=0°; 30°, OD=4 mm, L=18 cm</td>
<td>Hopkins, VA=30°; OD=4 mm, L=9.5 cm; 12 cm</td>
<td>Discoscope, VA=20°; 70°, WC=2.7 mm, L=20.5 cm</td>
<td>Discoscope, VA=20°; 70°, WC=4.1 mm, L=20.5 cm; 16.5 cm</td>
<td>Foraminoscope, VA=30°, WC=3.7 mm, L=20.8 cm</td>
<td>Hopkins, VA=25°, OD=6.6 mm, L=25.7 cm</td>
</tr>
</tbody>
</table>

*Footnote: VA — viewing angle, WC — work channel diameter, OD — outer diameter, L — endoscope length.*
endoscopic surgery received a smaller amount of opioid analgesics.

Current publications include several studies that compare results of endoscopic and microsurgical discectomy.

M. Arts et al. [26, 27] presented the results of a multicenter randomized trial that included 167 patients after tubular microdiscectomy, and 161 patients after microsurgical discectomy. The authors found that the duration of tubular discectomy was 11 min shorter, on average, than the standard microsurgical technique. There was no significant difference in the duration of postoperative hospital stay, rate of postoperative complications, and changes in the pain intensity evaluated using various scales.

B. Garg et al. [28] analyzed the treatment outcomes in 55 patients operated on by means of the microendoscopic technique using the EASY-GO system and 57 patients operated on using the classic technique. The authors observed significant differences between the groups in the following parameters: the duration of surgery (84±36 min vs. 56±33 min), amount of intraoperative blood loss (41±12 mL vs. 306±120 mL), and duration of postoperative hospital stay (3±1 bed-day vs. 12±3 bed-days). According to the Oswestry scale, there were no statistically significant differences between the groups with respect to changes in the pain intensity or quality of life in the postoperative period.

J. German et al. [29] evaluated the treatment outcomes in 172 patients (45 patients were operated on endoscopically, and 123 patients underwent classic surgery) and found no statistically significant differences between the groups in the duration of surgery and the rate of postoperative cerebrospinal fluid leakage. In the case of microendoscopic discectomy, there was a decrease in the duration of postoperative hospital stay, intraoperative blood loss, and need for narcotic analgesics in the postoperative period.

J. Harrington et al. [30] analyzed the results of 31 endoscopic and 35 standard lumbar discectomy operations. For minimally invasive surgery, the authors found no differences between the groups in the duration of surgery, blood loss, complication rates, and outcomes, but noted a statistically significant decrease in doses of analgesics in the postoperative period.

O. Righesso et al. [31] demonstrated the advantage of portal endoscopic discectomy over the microsurgical technique regarding the intensity of pain in the operating area, number of days spent by the patient at a hospital, and operating time.

Y. Ryang et al. [32] performed discectomy in two groups of patients: a tubular retractor was used in 30 patients, and the standard technique was applied in 30 patients. There were no statistically significant differences in the following parameters: an increase in muscle strength, decrease in the pain intensity, and changes in the quality of life, which were evaluated using the visual analogue scale as well as Oswestry and SF-36 scales. Intraoperative blood loss and the rate of postoperative complications were lower in the group of patients operated on using the tubular retractor.

In a study by M. Arts et al. [33], the mean value of life quality that was evaluated using the Oswestry scale was 65% before surgery and 22.3% vs. 15% after microendoscopic discectomy and the traditional technique, respectively.

M. Arts et al. [34] compared the cost effectiveness of microsurgical and endoscopic discectomy techniques and made an unequivocal conclusion that microendoscopic discectomy was more cost-effective. The opposite conclusion was reached by M. Van den Akker et al. [34] who analyzed the treatment results in 325 patients and did not find statistically significant differences in the cost of treatment using microsurgical and microendoscopic discectomy techniques.

In the available literature, we found 8 publications comparing the results of percutaneous endoscopic discectomy and microsurgical discectomy.

V.A. Byval’tsev et al. [35, 36] conducted a comparative analysis of the treatment results in 748 patients operated on using microsurgical and microendoscopic techniques. According to the Oswestry scale, there were no significant differences 3 months after discectomy. Regarding the intensity of pain associated with surgery, statistically less intense pain at discharge was in patients after endoscopic discectomy compared to patients after microsurgery.

A.E. Simonovich et al. [12] analyzed the treatment results in 330 patients operated on using the Destandau endoscopic technique and 964 patients operated on using the classic technique and found no significant differences in the duration of surgery (38.8±10.8 min vs. 45.5±30.9 min), duration of postoperative hospital stay (7.2±2.1 bed-days vs. 9.2±3.2 bed-days), rate of postoperative complications, and completeness of pain regression, which was evaluated using the VAS and Oswestry scale, in the postoperative period.

I.N. Shevelev et al. [14] revealed the advantages of Destandau endoscopic discectomy (31 patients) compared to microsurgery (37 patients): in the first group, patients’ quality of life after surgery was better, and the duration of hospital stay was shorter (4.54±0.27 bed-days vs. 6.3±0.19 bed-days).

H. Chen et al. [18] compared the treatment outcomes in 18 patients after percutaneous endoscopic discectomy and 25 patients after microsurgery. The authors revealed the advantages of endoscopic discectomy that took shorter operating time and resulted in more rapid regression of pain.

M. Kim et al. [37] evaluated the results of surgical treatment in 915 patients (301 patients after percutaneous endoscopic discectomy and 614 patients after microsurgical discectomy). The authors considered the endoscopic intervention to be a reasonable alternative to
open surgery, except cases of pronounced caudal migration of a sequestrum and L₅—S₁ disc herniation in patients with a high-riding iliac wing.

D. Lee et al. [38] analyzed the treatment results in 30 patients after percutaneous endoscopic discectomy and 30 patients after open microdiscectomy and found similar clinical results, with the endoscopic technique being less traumatic.

S. Ruetten et al. [39] compared the treatment outcomes in 178 patients who underwent either full endoscopic transforaminal/interlaminar discectomy or an open microsurgical intervention. While the clinical outcomes of surgery were similar, the authors indicated the advantages of endoscopic interventions, such as reduced operating time (22 min, on average, for endoscopic surgery vs. 43 min for microsurgery) and a reduced period of disability (25 days after endoscopic surgery vs. 49 days after microsurgery).

A study by W. Liu et al. [40] was devoted to a comparative analysis of endoscopic discectomy techniques only. The authors compared the long-term results of surgical treatment in 104 patients who underwent percutaneous endoscopic discectomy and 82 patients who underwent microendoscopic discectomy, which were evaluated using Oswestry, SF-36, and JOA scales. The duration of hospital stay, rate of complications, and treatment costs were demonstrated to be smaller for the percutaneous endoscopic technique than for microendoscopic discectomy.

K. Choi et al. [41] conducted a comparative analysis of technically different operations performed using percutaneous endoscopic discectomy techniques. The authors compared techniques of intralaminar and percutaneous transforaminal endoscopic discectomy for L₅—S₁ herniated discs. The authors found that the transforaminal technique was preferable in the case of foraminal, central, and recurrent herniation, while the intralaminar technique was preferable in the case of paracentral and sequestrated herniation with migration of a sequestrum. M. Kim et al. [37] studied factors affecting the rate of recurrent disc herniation and found that coagulation of edges of annulus fibrosus defects during endoscopic discectomy reduced the risk of recurrence.

D. Lee et al. [38] analyzed outcomes in patients with recurrent disc herniation who were treated using open microdiscectomy and percutaneous endoscopic discectomy after previous open microdiscectomy. The study included 100 patients who underwent previous open microdiscectomy and were re-operated using open microdiscectomy or percutaneous endoscopic discectomy. The authors concluded that the percutaneous technique was more advantageous compared to open microdiscectomy in terms of shorter operating time and hospital stay. There were no statistical differences among patients of different groups in the intensity of pain and the amount of decompression.

Under similar long-term outcomes and in the absence of statistically significant differences with respect to the amount of decompression of neural structures and patients’ quality of life, full endoscopic discectomy is more preferable due to shorter operating time and better tolerance by patients compared to microsurgical discectomy.

**Conclusion**

Therefore, percutaneous endoscopic discectomy is applicable in routine neurosurgical and orthopedic practice. This technique greatly surpasses the classic technique of herniated disc removal because it reduces operating time and does not require a recovery period after surgery. Despite the need to learn endoscopic discectomy, this technique is widely introduced into the practice of orthopedists and neurosurgeons throughout the world, and perhaps in the future, this will be the method of choice for discectomy.

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REVIEWS


PROBLEMS OF NEUROSURGERY NAMED AFTER N.N. BURDENKO 4, 2016

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The article is devoted to a topical issue — surgical treatment of lumbosacral herniated discs. The rapid development of endoscopic technologies over the last decade puts the neurosurgeon in a complex situation of selecting the most appropriate technique for each particular situation and for each particular patient. The need to reduce surgical trauma to supporting spine structures makes endoscopic surgery a preferred choice. This article provides a detailed literature review of all available minimally invasive techniques, indicating their authors and authors’ experience.

Meticulous comparative evaluation of existing techniques deserves special attention. All data about technical and methodological differences are collected and classified in a table that clearly and concisely presents this tremendous information. This presentation may be used as a strong basis to further develop new techniques and improve existing ones.

The authors have carefully analyzed the international experience in application of endoscopic techniques in spine surgery. They have performed a comparative analysis of various techniques using different evaluation criteria, such as scales for assessment of pain, life quality, and treatment quality, radiographic studies, assessment of blood loss, and assessment of the duration of surgery. It is necessary to note that the authors refer to the experience of founders or undisputed leaders in each particular technique.

In general, the article is of great scientific and practical interest for spinal neurosurgeons.

*S.O. Arestov (Moscow, Russia)*
Hippocampal Sclerosis: Pathogenesis, Clinical Features, Diagnosis, and Treatment

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Hippocampal sclerosis, also known as Ammon horn sclerosis or mesial temporal sclerosis, is usually associated with intractable epilepsy and characterized by specific patterns of neuronal loss and gliosis in the medial temporal lobe structures. Hippocampal sclerosis manifests clinically as epilepsy, often intractable epilepsy; in most cases, this condition is surgically treatable. As the most common histological diagnosis in adult patients subjected to epilepsy surgery, hippocampal sclerosis is characterized by complex pathogenesis and requires a multidisciplinary approach to its diagnosis and treatment. This article reviews the pathologic features, natural history, pathogenesis, and electroclinical and MRI signs of hippocampal sclerosis.

**Keywords:** hippocampus sclerosis, epilepsy surgery, symptomatic temporal lobe epilepsy.

**Abbreviations**

HS — hippocampal sclerosis
FCD — focal cortical dysplasia
RCT — randomized controlled trial
CNS — central nervous system
EEG — electroencephalography

The earliest macroscopic description of densified hippocampus with reduced volume in patients with epilepsy was provided by Bouchet and Cazauvieilh in 1825 [1]. In 1880, Sommer first described the microscopic manifestations of sclerotic hippocampus in epilepsy, noting that the loss of neurons in the hippocampus is segmental in nature, most often affecting the hippocampal CA1 segment or Sommer’s sector [2]. Clinical description of epileptic seizures in patients with temporal lobe pathology was provided by Hughlings Jackson in 1885, and in 1935 Stauder identified a link between HS and clinical presentation of temporal lobe epilepsy. In 1953, Sano and Malamud confirmed the link between hippocampal sclerosis and electroencephalographic signs of temporal lobe epilepsy [1]. In 1950s, the development of surgery techniques for epilepsy made it possible to diagnose HS in vivo. Penfield has described the so-called incisal sclerosis: densification of the hippocampus, the amygdala, and the hamulus, which was observed during temporal lobe epilepsy surgery. Falconer proposed a method for temporal lobectomy (removal of the front 2/3 of the cortex of the temporal lobe and the medial structures) for treatment of temporal lobe epilepsy; in his series of patients hippocampal sclerosis was the most common histological diagnosis. Later, more selective surgical techniques have been proposed, including resection of the medial temporal lobe structures only [1]. Today hippocampal sclerosis is the most common histological diagnosis in adult patients operated on for drug-resistant epilepsies. [3].

The structure of the normal hippocampus

The hippocampus is located in the medial temporal lobe and looks like two nested curved strips of nervous tissue: the dentate gyrus and hippocampus proper (Ammon’shorn, cornu Ammonis, CA). The internal structure of the normal hippocampus is shown in Fig. 1. In histological terms, hippocampal cortex is an archicortex, represented by three layers of neurons [4]. The outermost layer of the hippocampus, which forms the medial wall of the temporal horn of the lateral ventricle, is called “alveus” (tray) and is formed by axons emerging from the hippocampus. It is followed by stratum oriens (represented by axons and interneurons), then by a layer of pyramidal cells, which are the major cellular elements of the hippocampus, and, finally, by the deepest layer, stratum lacunosum and moleculare, represented by dendrites, axons and interneurons (Fig. 1). The proposal by Lorente de No to separate the pyramidal layer into 4 sectors (CA1, CA2, CA3, and CA4) is important for understanding different types of lesions associated with hippocampal sclerosis. The most pronounced layer of pyramidal cells is located in the CA1 sector, which continues into a part of the parahippocampal gyrus, called subiculum (support). The CA4 segment is adjacent to the concave portion of the dentate gyrus. The dentate gyrus is a C-shaped structure with three layers of cells: outer molecular level, middle granular layer and inner layer of polymorphic cells that fuse with the CA4 sector [4] (Fig. 1).

The bottom image shows the same hippocampus. The layer of pyramidal cells in the CA sectors is clearly visible. The dentate gyrus (indicated by arrows) covers CA4 sector, and a layer of granule cells is clearly visible. The triangular arrows point to the deep part of the...
tissue structure in hippocampal sclerosis involve an extraordinary diversity of terms and there are several classifications based on different concepts that describe the same histological substrate.

**Histological structure of the sclerotic hippocampus**

Macroscopically, the sclerotic hippocampus is reduced in volume and has dense texture. Major microscopic characteristics include decline in the number of pyramidal cells in the different layers of the CA and variable degree of gliosis [6]. The granular layer of the dentate gyrus may also experience varying degrees of neuronal density loss, but its overall structure is more preserved than that of CA sectors. Another distinctive histological feature is the absence of neuronal loss beyond the CA sectors, which distinguishes hippocampal sclerosis from its atrophy due to ischemic lesions and neurodegenerative diseases [2]. It has been noted that the neuronal loss in the pyramidal layer of the hippocampus can proceed in several different ways that provided the basis for classification of this pathology. The most widely used classification of hippocampal sclerosis is the one developed by the ILAE Commission [3]. The HS type 1 (expressed or classic) involves the loss of neurons in all layers of the hippocampus (Fig. 2). The type 2 is characterized by neuronal loss predominantly in the CA1 sector, while in the type 3 the only affected area is the CA4 section in the region of transition into the dentate gyrus (so-called ‘end folium’ sclerosis). In addition to the term “hippocampal sclerosis”, a number of other definitions is often used in the literature in order to emphasize that distorted brain tissue structure in histological examination may extend beyond the hippocampus.

For example, the term “mesial temporal sclerosis” is used to describe a condition where the atrophy and gliotic changes are observed in the amygdala and the hamulus in addition to the hippocampus. The analysis of histological material obtained during temporal lobe epilepsy surgery made it apparent that hippocampal sclerosis is accompanied by histopathological changes in the lateral neocortex of the temporal lobe. M. Thom [5] proposed the term “temporal sclerosis” which is characterized by loss of neurons and gliosis in the 2nd and 3rd layers of the temporal cortex. Quite often the neocortex contains heterotypical neurons in the 1st layer of the cortex and the white matter, which is referred to as “microdysgenesia”. In 2011, the ILAE Commission introduced a new classification of focal cortical dysplasia [7], which contained FCD 3a type for cases of hippocampal sclerosis that may be associated with dysplasia of the temporal lobe cortex such as distortion of its laminar structure, which, in turn, is classified as FCD type 1. Microdysgenesia, whose role in epileptogenesis have not been established yet, were classified as minor malformations of the brain cortex, and their presence alongside the diagnosis of hippocampal sclerosis is classified as FCD type 3a. FCD type 3a also includes a

Fig. 1. The internal structure of the normal hippocampus (authors’ own histological study, right panel). Subiculum, a part of the parahippocampal gyrus, passing into the CA1 sector. The dentate gyrus (highlighted in blue) covers the CA4 sector (highlighted in green).

a — alveus; 1 — stratum oriens hippocampal; 2 — pyramidal layer; 3 — hippocampus molecular zone; 4 — molecular layer of the dentate gyrus; 5 — granular layer; 6 — polymorphic layer.

Fig. 2. Sclerotic hippocampus (right panel) is characterized by the absence of pyramidal layer in all segments of the CA (type 1 sclerosis according to the ILAE classification). The granular layer of the dentate gyrus is preserved (marked by arrows).

Hippocampal sulcus that separates the CA sector and the dentate gyrus (authors’ own histological studies).

In hippocampal sclerosis structural changes may vary from minimal ones, limited to one sector of the CA, to rough ones that spread beyond the medial temporal lobe [5]. Descriptions of pathological changes in brain.
combination of the temporal sclerosis and the hippocampal sclerosis. The concept of “dual pathology” is a common one in the literature and involves hippocampal sclerosis combined with potentially epileptogenic lesions of the neocortex, including those outside of the temporal lobe, for example, tumors, vascular malformations, FCD type 2, Rasmussen encephalitis, and a gliotic scar. However, the concept of “dual pathology” is not classified as FCD type 3a. The terminology is even more confusing, because the presence of two epileptogenic brain lesions without hippocampal sclerosis is referred to as double pathology.

To understand the relationships between different departments of hippocampus and pathogenesis of its sclerosis, it is necessary to understand the structure of the polysynaptic intra-hippocampal path that originates from the neurons in the 2nd layer of the entorhinal cortex (located in the front part of the parahippocampal gyrus and in the hamulus area) [4]. The processes of these neurons form a perforator path that goes through the subiculum of the parahippocampal gyrus into the dentate gyrus and contacts the dendrites of the granular cell layer. The neurons of the granular layer form mossy fibers that innervate CA3 and CA4 pyramidal neurons, which in turn through the lateral axons, the so-called Shaffer collaterals, contact the CA1 sector. The abnormal growth of mossy fibers into the dentate gyrus instead of the CA sectors and the resulting formation of excitatory synapses represent one of the pathogenetic stages in HS. From the abovementioned CA segments, the axons enter into the alveus and then in the body of the brain through the hippocampus fimbriae. Given the anatomical and functional relationship between the Ammon horn, dentate gyrus, and subiculum, a number of authors have referred to them by the term “hippocampal formation” (Fig. 3).

**Causes of hippocampal sclerosis, pathogenesis**

The central question in HS etiology is the order of precedence: which occurs first, a structural abnormality of the hippocampus, which triggers chronic drug-resistant epilepsy, or the opposite, continuous abnormal electrical activity eventually leads to sclerosis? It is important to note that a significant portion of patients with drug-resistant epilepsy associated with HS suffered from febrile seizures or other severe CNS pathology in early childhood (injury, anoxia, neuroinfections), which is referred to in the literature as the initial precipitating injury [6]. The acquired character of HS is also supported by those rare observations when abnormality occurs in only one of monozygotic twins, and therefore, the genetic factor is not paramount. [8] Nevertheless, the existence of inherited familial forms of temporal lobe epilepsy (e.g., groups of epilepsy associated with mutations in SCN1a and SCN1b genes, which encode sodium channel proteins) indicates that genetic factors also play a role, causing hippocampal sclerosis without febrile seizures in some of these patients [9]. In consideration of the acquired nature of the disease, it should also be borne in mind that not every type of seizure is associated with

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**Fig. 3. Internal communication in the normal hippocampal formation.**

The dendrites of pyramidal neurons of the CA sector (indicated by a red triangle) come into contact with the dendrites of granule cells of the dentate gyrus. 1 — perforator path (indicated by red line) goes through subiculum into the molecular layer of the dentate gyrus, which is in contact with the dendrites of granule cells (indicated by a circle); 2 — mossy fibers (indicated by purple arrows) go into the dendrites of pyramidal cells of CA3 and CA4 hippocampal sectors; 3 — Shaffer collaterals (highlighted in green) innervate apical dendrites of pyramidal cells of CA1.
the development of HS: autopsy data indicate that the long-term uncontrolled epilepsy with frequent generalized seizures does not lead to neuronal loss in the hippocampus [10], and neither does afebrile epileptic status [11]. On the other hand, febrile epilepticus status is accompanied by MRI signs of hippocampal edema.

Prospective FEBSTAT study may provide the answer to the question how often does the childhood febrile seizures result in HS and drug-resistant epilepsy. It has already been established that 22 out of 226 children with febrile seizures exhibited MRI signs of hippocampal edema, which was the most pronounced in Sommer’s sector (CA1). In 14 of these 22 patients MRI was repeated at various intervals, and the signs of hippocampal sclerosis were identified in 10 of them. Nevertheless, epilepsy was diagnosed only in 16 out of 226 children and in most cases it was not temporal [12]. Therefore, febrile status does not always lead to epilepsy associated with hippocampal sclerosis, although the time interval between the precipitating brain trauma and the onset of temporal lobe epilepsy may be more than 10 years, and there are no follow-up studies of such duration. Genetic research also suggests that the etiology of HS is heterogeneous. The study of genome-wide association showed that febrile seizures with hippocampal sclerosis may be a genetic syndrome, since they are associated with the presence of a specific allele of a single nucleotide sequence adjacent to the sodium channel gene SCN1a. This association was absent for cases of epilepsy with febrile seizures, but without HS [13]. The current consensus is that there is some initial genetic predisposition, which can develop into the hippocampal sclerosis in the presence of a certain damaging factor (double strike hypothesis).

Hippocampal sclerosis has two principal pathological characteristics: a sharp decline in the number of neurons and the hyperexcitability of the remainder of the nervous tissue. Sprouting of the mossy fibers plays a key role in the epileptogenesis in HS: instead of innervation of the CA, the abnormal axons of the granule cells re-innervate molecular neurons of the dentate gyrus through excitatory synapses, thereby creating local electric circuits capable of synchronizing and generating epileptic episode [14]. Increase in the number of astrocytes and gliosis may also play a role in epileptogenesis, since the modified astrocytes cannot adequately carry out glutamate and potassium reuptake. Proinflammatory cytokines such as IL-1β, IL-1, TNFα can also act through the ejection mechanism by increasing glutamate output, reducing reuptake, and inhibiting gamma-aminobutyric acid [14]. A role of herpes virus type 6, whose DNA is found in brain tissue of patients with temporal lobe epilepsy, in the pathogenesis HS has also been discussed [15].

**Fig. 4.** MRI anatomy of normal and sclerotic hippocampus.

a — T2 coronal section. Hippocampal sclerosis on the right: a decrease in volume and the lack of internal structure are evident in comparison with the left hippocampus; b — the same section with explanations. The red line circles hippocampi (visible reduction in volume of the right hippocampus), the blue line circles subiculum on the left. The yellow line in the center of the hippocampus runs along the deepest part of the hippocampal sulcus (this sulcus is not visible on Fig. “a” in the right hippocampus). FG, fusiform gyrus, ITG, inferior temporal gyrus; c — coronal section in FLAIR mode, visible reduction in the volume and hyperintense signal of the right hippocampus.
Clinical presentation and diagnosis

Medical history of epilepsy caused by hippocampal sclerosis is mainly based on numerous studies to assess the effectiveness of surgical treatment of temporal lobe epilepsy. The history often includes a severe CNS pathology in early childhood (usually before the age of 5): febrile seizures, neuroinfections, cranial trauma [6, 16]. Stereotypical seizures begin in a period between 6 to 16 years, and there may be a so-called latent period between the initial precipitant damage and the development of the first epileptic seizure. It is also not uncommon for so-called “silent” period to exist between the first attack and the development of pharmacoresistance. This feature of the disease indicates its progressive nature. Memory loss is a characteristic cognitive deficit in HS, especially in case of uncontrolled seizures [6, 16].

Diagnosis of epilepsy caused by hippocampal sclerosis is based on three main principles. The first one is detailed analysis of the sequence of symptoms in epileptic seizures, or its semiology, which varies based on the areas of the brain affected by epileptic activity [17]. The second one is the analysis of EEG data and their comparison to semiology of the attack. The third one is identification of epileptic lesions on MRI [16]. In terms of semiology of the attack, it is necessary to keep in mind that first of all each of the symptoms alone is not specific, although there is characteristic pattern for progression of the attack [6]. Secondly, the symptoms observed during the attack are the result of the spread of epileptic activity to brain regions associated with the hippocampus, which in itself is clinically asymptomatic. A typical onset of the temporal attack incudes an aura of a rising sensation in the abdomen. It is also possible to experience fear or anxiety if the amygdala is involved at the onset of the attack. The onset of an attack may also involve a feeling of déjà vu [18]. The aura of dizziness or noise is alarming for diagnosis, as it may indicate the extra-hippocampal onset of the attack. The intact ability to name objects and speak during an attack is an important sign for lateralization of the lesion in the non-dominant hemisphere. Changes in consciousness are accompanied by a cessation of activity and a patient has frozen eyesight with eyes wide open (staring). The aura and cessation of activity are followed by orofacial automatisms with chewing, smacking of lips. Often there is also a dystonia of hands contralateral to the sclerotic hippocampus (which is associated with the spread of epiactivity into the basal ganglia) with simultaneous emergence of manual automatism, including shuffling of items by the fingers of the ipsilateral hand. Important lateralizing symptoms also include postictal paresis, which indicates the involvement of the contralateral hemisphere, and postictal aphasia in case of lesions in the dominant hemisphere. These symptoms should be considered in the context of the EEG data.

Video EEG monitoring, comprising simultaneous video recording of an epileptic seizure and brain electrical activity, is the basis of electro-clinical diagnosis in hippocampal sclerosis.

Video EEG monitoring addresses several issues:

1. It excludes pseudo-seizures and non-epileptic paroxysms, including cases when they are combined with real existing epilepsy.
2. It allows thorough evaluation of the semiology of the attack and its comparison with the dynamics of epiactivity: its lateralization and regional localization.
3. Prolonged registration allows elucidation of lateralization and localization of interictal activity.

In terms of a favorable outcome of epilepsy surgery, the most successful option is an overlap of lateralizing and localizing symptoms during an attack with the data of ictal and interictal EEG and MRI. The duration of video EEG monitoring is an essential issue in pre-surgery examination. It has been shown that at a frequency of seizures of 1 time per week the probability that a 30-minute EEG would register a paroxysm is ca. 1% [19], and that the prolonged video EEG monitoring with a median duration of 7 days does not reveal interictal activity in 19% of patients [20]. The selection of the proper duration of video EEG monitoring is essential because it is necessary to record ictal EEG events in order to elucidate indications for surgery. Several epileptologists believe that in case of characteristic clinical picture and medical history combined with signs of hippocampal sclerosis on MRI, registration of ictal events is not essential if it has been established that more than 90% of interictal epiactivity is lateralized in the temporal region on the side of the lesion [21]. In most cases of temporal lobe epilepsy, the resolution of scalp EEG is enough to correctly lateralize the zone of the attack onset and, if the data are consistent with semiology and MRI, to determine the strategy of surgical treatment.

MRI diagnosis of HS is the next fundamental step in pre-surgery examination. It must be conducted according to epilepsy protocol whose basic characteristics include thin slices and high strength of the magnetic field [6]. Cooperation between a radiologist and an epileptologist is required for the optimal MRI examination, because it allows the planning to make provisions for the expected localization of epileptogenic zone. Hippocampal sclerosis has characteristics presentation on MRI: reduced volume of the hippocampus, distortion of the CA layers structure, and hyperintense signal in T2 and FLAIR mode [6] (Fig. 4). It is often accompanied by atrophic changes in the ipsilateral amygdala, the pole of the temporal lobe, the fornix, and the mamillary body. The objectives of high-resolution MRI also include detection of other epileptogenic brain lesions, located outside of the hippocampus, i.e. dual pathology, such as, for example, focal cortical dysplasia. Without accomplishing this goal, an MRI study will be insufficient to make a decision about the surgery, even if it revealed signs of hippocampal sclerosis.
The fundamental point in understanding of the electrophysiology of the medial temporal lobe epilepsy is the fact that scalp EEG on its own does not reveal the epiactivity in the hippocampus, which has been demonstrated in numerous studies using intracerebral electrodes. For epiactivity to appear in the temporal region on the scalp EEG, it has to spread from the hippocampus to the adjacent cortex of the temporal lobe [22]. However, the main clinical manifestations of seizures in the medial temporal lobe epilepsy are associated with the spread of epiactivity to certain parts of the brain associated with the hippocampus: déjà vu is associated with the excitation of the entorhinal cortex, a sense of fear, with amygdala, abdominal aura, with the insula, oralalimentary automatism, with theinsula and the frontal operculum, and dystonia in the contralateral hand, with the spread of excitation in the ipsilateral basal ganglia. [6] These anatomical and electrophysiological features can cause attacks that are very similar to temporal paroxysms, but have extra-hippocampal and extra-temporal causes.

The accumulation of surgical experience in temporal lobe epilepsy made it apparent that the removal of the medial temporal lobe structures successfully eliminates the seizures in 50—90% of patients, however in some cases the frequency of the attacks remain unchanged [6]. Studies of electrical activity of the brain using intracerebral electrodes and analysis of unsuccessful surgery outcomes have demonstrated that in some cases the attacks continue after the removal of the HS due to the presence of more extensive epileptogenic zone which extends beyond the hippocampus. The areas of the brain that are anatomically and functionally related to the hippocampus, such as the insula, orbitofrontal cortex, parietal operculum, and the junction of the parietal, temporal and occipital lobes can produce seizures that are similar to temporal paroxysms in their clinical and EEG presentation. [23] The concept of ‘temporal epilepsy plus’ was proposed to describe the situations where hippocampal sclerosis is combined with extra-temporal initiation of the attack. Therefore it is important to identify indications for invasive EEG studies in temporal lobe epilepsy caused by HS. Alarming symptoms include gustatory aura, aura of vertigo, andnoise. Interictal epiactivity is often localized bilaterally in the temporal areas or pre-central region. Ictally, the epiactivity in “temporal plus” cases is most commonly observed in the anterior frontal, temporoparietal and pre-central areas [24]. Differential diagnosis of temporal lobe epilepsy and the “temporal lobe epilepsy plus” that was conducted by a qualified epileptologist is the key step in planning the surgery and predicting the outcome of treatment.

**Treatment of epilepsy associated with hippocampal sclerosis**

The standard of medical care for patients with drug-resistant medial temporal lobe epilepsy is a referral to a specialized center for pre-surgery examination and surgical treatment. Among the huge number of publications confirming the effectiveness of surgery in temporal lobe epilepsy, it is worth noting two key studies with the highest level of evidence. In 2001, S. Wiebe et al. [25] conducted a randomized controlled trial that demonstrated that in temporal lobe epilepsy associated with hippocampal sclerosis a surgery can eliminate seizures in 58% of cases, whereas a drug therapy is only effective in 8%. Another study was based on the fact that the average duration of the disease in patients who have received surgical treatment is 22 years, and that 10 or more years can pass between the diagnosis of drug-resistant epilepsy and a surgery. In a multicenter randomized controlled study J. Engel et al. [26] have demonstrated that in the medial temporal lobe epilepsy the continuation of drug therapy after a failure of two drugs is not accompanied by remission of the episodes, whereas surgical treatment can be effective in such cases (cessation of seizures in 11 out of 15 patients).

The surgery in temporal lobe epilepsy has two obvious goals: 1) to eliminate the episodes of seizure; 2) to discontinue drug therapy or reduce the dose. According to the literature, ca. 20% of patients stop taking anticonvulsants after the surgery, 50% remain on monotherapy and 30% receive polytherapy. The third goal, which is less obvious, but essential, is to reduce the risk of sudden unexplained death in epilepsy (SUDEP), which is associated with reflexive depression of cardiorespiratory function in patients with drug-resistant epileptic attacks [27].

The objectives of surgery in temporal lobe epilepsy include complete resection of the epileptogenic cortex with maximal preservation of functional brain areas and minimization of the neuropsychological deficits. There are two surgical approaches: temporal lobectomy and selective amygdaloidhippocampectomy. Both types of surgery involve the removal of the hamulus, the amygdala and the hippocampus. Selective access to the medial temple can be achieved through several different approaches. Temporal lobectomy also involves the removal of the lateral cortex of the temporal lobe (3 to 5 cm, depending on the dominancy of the hemisphere). Supporters of a selective approach base their opinion on the fact that preservation of the lateral neocortex minimizes neuropsychological deficits, especially verbal memory decline [28]. On the other hand, as has already been noted, pathological lesions may extend beyond the hippocampus to the amygdala, the pole of the temporal lobe and the lateral neocortex. Invasive EEG examinations by deep electrodes revealed that in 35% of cases of hippocampal sclerosis the epiactivity occur in the pole temporal lobe earlier than in the hippocampus.
The analysis of the data obtained with deep electrodes allowed identification of several types of temporal lobe epilepsy: the medial, medial-lateral, temporopolar and the already mentioned “temporal lobe epilepsy plus”: [23]. Therefore, in choosing a surgical treatment strategy it is necessary to take into account the likelihood of having more extensive epileptogenic zone that goes beyond the sclerotic hippocampus, which might justify greater efficiency of lobectomy [28]. Nevertheless, at the moment there is no class I evidence supporting an advantage of any technique that provides seizure control, neuropsychological outcomes or the need for postoperative administration of antiepileptic drugs, so the choice of surgery depends on the surgeon's preference [28].

If a surgeon has sufficient experience, the temporal lobe epilepsy surgery for hippocampal sclerosis is associated with minimal risk of neurological deficit (persistent hemiparesis in less than 1% of cases, total hemianopsia in 0.4%) [30]. The problem that remains unsolved is the forecast of the risk of post-operative memory deterioration. It is known that approximately 35% of patients demonstrate worse performance in neuropsychological evaluations of verbal memory after resection of the hippocampus in dominant speech hemisphere [31]. The risk of verbal memory decline is increased for late onset, high preoperative indicators during testing, HS of dominant hemisphere, minimal changes in the hippocampal MRI. These circumstances indicate that the epileptogenic hippocampus may still retain functional activity [31, 32]. However it is difficult to determine how verbal memory loss affects the quality of post-operative life. To a large extent the quality of life after the surgery depends on careful control of seizures and elimination of associated depressive and anxiety disorders. Elucidation of the indications for surgery in high-risk patients should be carried out with particular accuracy, since unsuccessful outcome of epilepsy will result in cognitive deficits that would sharply reduce a patient’s quality of life. Therefore, it should be stressed that multidisciplinary approach to each clinical case is an essential prerequisite for surgical management of patients with epilepsy and it requires close cooperation between an epileptologist, a surgeon, a neuroradiologist and a neuropsychologist.

Authors declare no conflict of interest.


