Burdenko Neurosurgical Institute, Moscow, Russia

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In accordance with the resolution of the Higher Attestation Commission of the Ministry of Education and Science of the Russian Federation, the Problems of Neurosurgery named after N.N. Burdenko was included in the List of Leading Peer-Reviewed Journals and Periodicals issued in the Russian Federation where the main results of Candidate and Doctor Theses are recommended to be published.
Reconstruction of Complex-Formed Skull Defects with CAD/CAM Titanium and Polyether Ether Ketone (PEEK) Implants

S.A. EOLCHIYAN

Burdenko Neurosurgical Institute, Moscow, Russia

Predictable and stable functional and aesthetic result is the priority for a neurosurgeon dealing with the reconstruction of large cranial bone defects and complex-formed skull defects involving the cranio-orbital region. **Objective:** The paper analyzes the experience with CAD/CAM titanium and polyether ether ketone (PEEK) implants for reconstruction of complex-formed skull defects. **Material and Methods:** In 2005–2013, nine patients (5 females and 4 males) underwent cranioplasty using customized CAD/CAM titanium and PEEK implants according to the high-resolution spiral CT data. Computer-assisted preoperative planning was undertaken in 3 cases to provide accurate implant design. Eight patients out of nine had complex-formed posttraumatic skull defects, mostly in the fronto-orbital region. One-step reconstruction surgery for posttraumatic fronto-orbital defects combined with adjacent deformedities of the orbital roof and the midfacial skeleton was performed in two of these cases. One patient underwent one-step primary cranioplasty after resection of a cranio-orbital fibrous dysplasia focus. Titanium implants were used in four cases while PEEK implants, in 5 cases. The follow-up period ranged from 6 months to 8.5 years (median, 4.4 years). **Results:** The accuracy of intraoperative implant fitting was perfect in all cases. Postoperative wounds healed by primary intention; there were no complications in the series presented. Postoperative clinical assessment and CT data were indicative of high implant precision as well as good functional and aesthetic outcomes in all patients. **Conclusion:** The use of CAD/CAM titanium and PEEK implants allows for optimal reconstruction in the challenging patients with complex-formed and large skull bone defects, reduces surgical injuries and duration, and provides predictable good functional and aesthetic outcomes. Computer-assisted preoperative planning should be undertaken for creating CAD/CAM implants in the cases of postraumatic defects combined with deformities of the adjacent bone structures and benign bone tumors in the cranio-orbital region, which would enable one-step reconstructive surgery with attaining the desired symmetry.

**Keywords:** complex-formed skull defects, cranioplasty, computer-assisted preoperative planning, CAD/CAM implants, titanium, polyether ether ketone (PEEK), fibrous dysplasia, one-stage surgery.

**Abbreviations**

- PM — plastic material
- PEEK — polyether ether ketone
- PMMA — polymethyl methacrylate
- SCT — spiral computed tomography
- STL — stereolithographic
- FD — fibrous dysplasia
- TBI — traumatic brain injury
- NC — numerical control
- CAD — computer-aided design
- CAM — computer-aided manufacturing

Reconstruction of skull defects in patients operated for traumatic brain injury (TBI), tumors, and vascular brain diseases is a challenging issue of reconstructive neurosurgery. The aim of cranioplasty is to restore the integrity and shape of the skull. The surgeon’s priority is to achieve a stable functional and aesthetic outcome of surgery that eliminates the psychological problems of patients, increases the quality of life, and improves social adaptation.

The major problems in restoring the normal contours and configuration of the calvarium arise in the case of large size and/or complex shape defects. The latter comprise defects of the fronto-orbital region, including the superior orbital rim and the orbital roof, which results from the features of its anatomy and aesthetic value. In this regard, an important role is played by selection of a plastic material (PM) and the method for implant simulation. The literature summarizes the experience in application of a large amount of PMs for reconstruction of skull defects (bone autografts, polymethyl methacrylates (PMMs), titanium, ceramics, and other materials) and describes their advantages and disadvantages [2—4, 12, 15, 16, 21, 27, 29, 30].

Simulation of implants during surgery narrows the choice of PMs, reduces the predictability of aesthetic result, and also increases the surgery duration. In recent years, the medical practice has been implemented with modern computer technologies for manufacturing of individual implants to reconstruct skull defects based on spiral computed tomography (CT) data. They enable manufacturing an implant from almost any alloplastic material directly or indirectly [12, 15]. When manufactured indirectly, a computer aided design (CAD) of the implant is created first. Then, an implant mold is produced using the rapid prototyping method [9—11, 17]. This may be exemplified by the method for producing stereolithographic (STL) models of the patient’s skull with the bone defect area and a mold for manufacturing PMMA implants, which was developed at the Research Institute of Laser Technologies (Shatura, Russia) and has been used successfully at the Burdenko Neurosurgical Institute since 1999 [1—4]. An individual PMMA implant is prepared manually according to the

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mold, which could affect its accuracy and requires some experience. The method provides the possibility of reworking the implant on sterile STL models and their fitting to the defect margins using high-speed cutters [3, 4]. A more advanced method is direct industrial fabrication of individual implants from titanium, polymeric materials, and ceramics using different manufacturing technologies: high-speed milling, selective laser sintering, casting on high precision machines equipped with a computer aided manufacturing (CAM) system [13—15, 22]. Therefore, when using the computer aided design and computer aided manufacturing systems (CAD/CAM technologies), an individual implant is created directly, i.e. without an intermediate physical model of its mold and the need for manual modeling on the mold. Manufacturing of a STL model is not required in this case, but it can be used for fitting and evaluating the accuracy of the implant.

The aim of this study was to analyze the experience with the use of individual implants of titanium and a polymeric material, PEEK, manufactured using the CAD/CAM technologies to reconstruct complex skull defects.

**Material and Methods**

Between 2005 and 2013, 9 patients (5 females and 4 males) aged 10 to 44 years (median of 23 years) were operated on who underwent cranioplasty using individual implants of titanium and PEEK manufactured using the CAD/CAM technologies. 8 of 9 patients suffered severe TBI and underwent surgery in the acute injury period in hospitals at the place of the primary hospitalization. 3 patients had signs of pyoinflammatory complications in their medical history (Table). Cranioplasty was carried out in the period from 9 to 38 months after injury. Of 9 cases, 1 female patient with fibrous dysplasia (FD) of the craniovertebral region underwent one-stage surgery with resection of the affected bone tissue and primary plasty of a skull defect.

A skull defect was localized in the fronto-orbital region in 7 cases, in the frontal region on both sides in one case, and in the parietal-temporal region in one case (Table). The minimum defect area was 30 cm², the maximum area was 163 cm². The follow-up period after surgery varied from 6 months to 8.5 years (median of 4.4 years).

**Brief characteristic of operated patients**

<table>
<thead>
<tr>
<th>Case number</th>
<th>Gender/age, years</th>
<th>One-stage interventions with cranioplasty</th>
<th>Localization and size of the skull defect</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>F/24</td>
<td>Reconstructive operation of the zygomatico-orbital complex and the orbital floor</td>
<td>FOR left, SOS, 8.5×3.5 cm</td>
<td>Titanium</td>
</tr>
<tr>
<td>2</td>
<td>M/44</td>
<td>Reconstructive operation of the zygomatico-orbital complex and the orbital floor</td>
<td>Parietal-temporal region right, 11×10.5 cm</td>
<td>Titanium</td>
</tr>
<tr>
<td>3</td>
<td>F/23</td>
<td>Reconstruction of the zygomatico-orbital complex and the orbital floor</td>
<td>FOR left, 6.5×6.5 cm</td>
<td>Titanium</td>
</tr>
<tr>
<td>4</td>
<td>F/23</td>
<td>Reconstruction of the zygomatico-orbital complex and the orbital floor</td>
<td>Frontal region, both sides, 15.5×10.5 cm</td>
<td>Titanium</td>
</tr>
<tr>
<td>5</td>
<td>M/22</td>
<td>Reconstructive operation of the orbital floor</td>
<td>FOR right, 7.0×6.5 cm</td>
<td>PEEK</td>
</tr>
<tr>
<td>6</td>
<td>M/10</td>
<td>Reconstructive operation of the orbital floor</td>
<td>FOR right, 6×5 cm</td>
<td>PEEK</td>
</tr>
<tr>
<td>7</td>
<td>F/16</td>
<td>Reconstructive operation of the orbital floor</td>
<td>FOR, over the midline, 10×6.5 cm</td>
<td>PEEK</td>
</tr>
<tr>
<td>8</td>
<td>M/25</td>
<td>Reconstructive operation of the orbital floor</td>
<td>FOR, over the midline, 6×5 cm</td>
<td>PEEK</td>
</tr>
<tr>
<td>9</td>
<td>F/23</td>
<td>Resection of a FD lesion</td>
<td>FOR right, 8×7 cm</td>
<td>PEEK</td>
</tr>
</tbody>
</table>

Footnote. FOR — fronto-orbital region; SOS — spread to the opposite side.
Fig. 1. Posttraumatic bone defect in the parietal-temporal region right (case 2).

a — axial CT scan before surgery; b — a stage of surgery: a titanium implant is placed in the defect area and fixed with titanium miniscrews along its perimeter; 
c — axial CT scans in the tissue (left) and bone (right) modes; d — 3D SCT after surgery. Restoration of the calvarium configuration and exact fit of the titanium implant to the defect margins are visualized.
Results

In case 4, obliteration of the frontal sinus communicating with the defect area was performed using a free flap on the vascular pedicle from the broadest muscle of the back (in cooperation with the plastic surgeon, V.I. Sharobaro, MD) as the first stage of surgical treatment. A microsurgical anastomosis was placed in the superficial temporal artery and concomitant vein. Muscle flap survival allowed, in addition to frontal sinus obliteration, increasing the thickness and improving the trophism of the soft tissue over the defect. The placement of the titanium implant was performed in 6 months.

All operations were performed under general anesthesia with orotracheal intubation. Coronal incision was used in 8 patients with fronto-orbital (in 7) and bifrontal (in 1) defects. Arcuate incision bordering the defect area was performed in the patient with a defect in the parietal-temporal region. A good fit of the implant to the margins of the bone defect was observed in all cases (Figs. 1b, 3). In 4 patients with titanium implants, the Norian CRS (Salcium phosphate bone cement)
material was used during surgery that was applied over the greater part of the implant and its junctions with the bone defect margins, which ensured the smoothness of the transition to the bone. Margins of PEEK implants in 2 of 5 patients were minimally processed by high-speed cutters to adapt them to the bed, stabilize the position, and make the transition to the bone appear less pronounced as well as reduce compression of the periosteal flap in the area of the defect margin adjacent to the frontal sinus.

In case 3, consequences of a craniofacial injury in the form of a defect of the fronto-orbital region and a deformity of the zygomatico-orbital complex (Fig. 2) required computer assisted planning of surgery. After portions of the calvarium and the middle zone of the facial skeleton that were mirror symmetrical to the defect and deformity areas were selected on the intact side, their imposition on the side of the injury was performed, and the type and extent of the left zygomatic bone dislocation were determined. Next, the virtual reposition of the left zygomatic bone to the anatomically correct position was performed, after which the final design of the implant was generated (Figs. 2a—c). During the surgery, the sequence of surgical manipulations was reverse: first, the placement and fixation of the titanium implant were performed in the defect area with restoration of the normal contour and configuration of the left fronto-orbital region. This allowed using it as the anatomical mold and landmark in one-stage osteotomy and reposition of the zygomatic bone. Fusion of the frontal process of the zygomatic bone to the titanium implant was made by means of a wire suture. Simultaneously, reconstruction of the orbital floor was performed using split bone autografts from the calvarium. According postoperative SCT scans, restoration of the shape and contours of the fronto-zygomatico-orbital region left was observed (Fig. 2e).

In 3 cases with the fronto-orbito-basal localization of the defect, the PEEK implant was used to restore the normal contour and configuration of not only the squama of the frontal bone and the superior orbital rim but also the orbital roof (Figs. 3, 4). In one of them (case 6), the defect of the superior margin and the anterior portions of the orbital roof was combined with the deformity of its posterior portions due to consolidated fracture with displacement of fragments downward, which led to the development of meningoencephalocele and hypophtalmos. Taking into account the objectives of reconstructive intervention, computer planning and simulating of surgery with virtual resection of the deformed portion of the orbital roof was conducted. A corresponding increase in the defect size was taken in consideration upon creating the final implant design. During the operation and according to control SCT, the accuracy of the implant was confirmed.

In case 9, computer assisted planning of surgery was also conducted to perform one-stage reconstruction of the bone defect after removal of a major FD lesion of the cranio-orbital region (Fig. 4). On the basis of the SCT data, virtual resection of the FD lesion was performed. The resection area covered the frontal bone and spread to the superior and lateral margins of the orbit, the roof and the lateral wall of the orbit, and the great wing of the sphenoid bone.

Accordingly to the resulting virtual defect, the computer assisted design of the implant was developed that was later manufactured from PEEK. To determine the correct boundaries for resection of the pathological lesion, a mold was simulated that was fabricated together with a STL model in strict accordance with the shape and curvature of the adjacent margins of the virtual defect (Fig. 4f). During the surgery, after removal of the pathologically changed tissue, the PEEK implant was placed in the formed bone defect and fixed to its margins. A good functional and aesthetic result was obtained (Fig. 4h).

All patients underwent the surgery well; the wound was healed by primary intention. Complications were not observed in any of the cases.

The clinical outcome was assessed by the examination of the reconstruction area and comparison of the symmetry of the reconstructed anatomical area with the intact side. The postoperative SCT data allowed visualization of fit of implants to the defect margins and restoration of the symmetrical skull configuration. To visualize the boundaries and contours of titanium and PEEK implants more accurately, the window parameters were changed (Figs. 1c, 3g–i). According to our own data, the density of the PEEK implant was 160—170 Hounsfield units. Clinical and CT control demonstrated a high accuracy of implants, good functional and aesthetic results in all cases. A subjective evaluation of the operation results by the patients in this case was very high and corresponded to the level of their aesthetic expectations.

**Discussion**

Modified techniques of cranioplasty using STL models and molds of implants have been developed and have been actively used since the late 90s of the last century [9—11, 17]. Alloplastic implants, created by the computer assisted design, have made revolutionary changes in the conceptual approach to cranioplasty and have become a reliable and safe alternative [10, 12, 19]. Nevertheless, there are some problems with the accuracy of implant fabrication according to its mold, regarding preservation of very fine details [26]. The complexity of computer assisted design and manufacturing of the implant grows with increasing the defect size over 100 cm², spreading the defect beyond the midline, and involving the superior margin of the orbit into the defect area [24]. Technological innovations in the computer assisted design and industrial manufacturing of individual implants led to a significant increase in their accuracy and reliability of application [15, 22].

This paper presents the author’s own experience with titanium and PEEK CAD/CAM implants manufactured industrially by NC machines. The practice of application of titanium implants is quite extensive [7, 13—15, 19]. Physical and chemical properties of titanium (high mechanical strength, low specific gravity, lack of magnetic properties, corrosion resistance, non-toxicity, and biological inertness) allow using it for replacing skull defects. Biocompatibility of titanium provides a low risk of inflammatory complications. According to some authors [7, 15], titanium is the best alloplastic material. The disadvan-
Fig. 3. Posttraumatic defect of the frontal bone spreading to the superior orbital rim and the orbital roof on the right side (case 5).

a, b — axial and frontal CT cross sections before surgery; c — computer 3D model of the skull; d — virtual design of the implant for replacing a defect of the fronto-orbital region; e — evaluation of the accuracy of the PEEK implant using a STL model; f — surgical stage: the PEEK implant is placed in the defect area and fixed with titanium miniplates and miniscrews; g—i — axial (g), frontal (h) and sagittal (i) CT slices 1 year after surgery. Restoration of the normal contours and configuration of the frontal bone, the superior margin and the orbital roof on the right side, and exact fit of the PEEK implant to the defect borders are visualized.
Fig. 4. Fibrous dysplasia of the cranio-orbital region right (case 9)

a — 3D SCT before surgery; b—e — stages of computer assisted planning of surgery: b, c — a computer 3D model of the skull before and after virtual removal of the FD lesion with the development of a bone defect; d — design of a mold to define the resection boundaries of the affected bone tissue; e — design of an implant for reconstruction of the postresection bone defect; f — a STL mold to define the resection boundaries of the FD lesion; g — evaluation of the accuracy of the PEEK implant using a STL model; h — 3D SCT: various perspectives after one-stage surgery for removal of the FD lesion and reconstruction of the bone defect with the PEEK implant. Exact fit of the size and shape of the implant to the postresection defect area with restoration of the cranio-orbital region configuration right are visualized.
tages of a titanium implant include the presence of artifacts during CT examination that complicate an estimation of the image of the brain substance adjacent to the skull defect. At the same time, magnetic resonance imaging in the T1 mode provides good visualization of the intracranial structures in the titanium implant projection and the possibility of dynamic control in neurooncological patients [15]. Despite the fact that titanium has a relatively low thermal conductivity compared to other metals, if an implant has a large size, there is a possibility of developing local paresthesias and pains of different nature and intensity, under conditions of low or high ambient temperature, as well as foreign body sensation. A possible adverse thermal effect of a titanium implant on the brain tissue caused by ambient temperature has not been proved so far [15].

In recent years, medical polyether ether ketone (PEEK) has been suggested for using as a biocompatible PM. It belongs to a family of linear aromatic polymers called poly (aryl ether ketones). They have rather widely been used in aerospace, electrical and automotive industry for over 25 years [32]. Excellent mechanical and chemical properties of the material as well as biological safety have quickly led to the development of polymers suitable for production of medical implants that resulted in the creation of PEEK-OPTIMA LT in 1998 [16, 23, 28]. PEEK-OPTIMA LT is a semi-crystalline thermoplastic used for manufacturing of implantable medical devices that were supposed to be in contact with blood or tissues for more than 30 days [16, 23, 28]. Effective resistance, rigidity, and elasticity of the material are comparable to those for an autologous bone [6]. PEEK has an excellent chemical resistance to acids and corrosion, high biocompatibility, the lack of allergic reactions, permeability to radiation at X-ray and CT examination, and the absence of artifacts during MRI. After appearance on the medical market, PEEK has been recognized as a very reliable biocompatible PM, especially in spinal surgery (cages for intervertebral arthrodesis) and orthopedics (hip implants) [16, 20, 23, 28]. The combination of strength, rigidity, elasticity, and the possibility of repeated sterilization without loss of mechanical properties make PEEK be a promising alternative to other alloplastic materials. The main drawback of PEEK, like all alloplastic materials, is associated with the risk of postoperative infection. There are few publications of foreign authors that describe the experience with using CAD/CAM PEEK implants to correct skull defects [8, 22, 27]. Any complications that occur with most alloplastic materials (infection, pyoinflammatory processes, extrusion, foreign body reaction, etc.) have not been described in the literature for the early and long-term outcomes of surgery using PEEK implants.

A prerequisite for the safe and secure use of titanium and PEEK CAD/CAM implants is a satisfactory condition of the soft tissues over a bone defect. To achieve a stable long-term result, pre-interventions are needed in some cases to improve the soft tissue condition. In all cases where there is a frontal bone defect, attention is paid to the condition of the frontal sinus. The frontal sinus should either be demarcated from the defect area or be subjected to preliminary cranialization or obliteration. To ensure reliable fronto-basal sealing and demarcation of the bone defect from the frontal sinus, local flaps are often used. Extensive defects of the skull base with a broad communication of the cranial cavity with the paranasal sinuses or covering skin defects may in rare cases require the use of microvascularized free flaps [14, 31].

The cases described in this paper provide an idea of the possibility to use individual titanium and PEEK implants, manufactured using the CAD/CAM technologies, in various clinical situations. Of particular interest is their use in combined complex defects and deformities of the crano-orbital localization as well as in removal of benign bone tumors. In these cases, CAD/CAM implants should be manufactured on the basis of computer assisted planning of surgery, which requires close cooperation between the surgeon and the engineer. Computer assisted planning of surgery was performed in 3 cases. In the first case, the PEEK implant was made with allowance for the planned increase in the fronto-orbital defect due to virtual resection of the deformed portion of the orbital roof. The accuracy of the implant was confirmed during the operation and according to postoperative SCT. In the second case with a fronto-orbital defect and a combined deformity of the zygomatico-orbital complex, a titanium implant was made with allowance for the planned reposition of the zygomatic bone. The implant, placed in the defect area, was used as the mold and anatomical landmark in the one-stage reposition of the zygomatic bone, which facilitated reconstructive intervention with achievement of the desired symmetry.

Therefore, the advantages of using individual CAD/CAM implants were for the first time demonstrated in one-stage interventions for reconstruction of complex fronto-orbital defects and deformities of the adjacent bony structures of the anterior cranial fossa (the orbital roof) and the middle zone of the facial skeleton.

Previously, single studies had already described the experience with one-stage operations for resection of benign bone tumors and primary reconstruction of bone defects with CAD/CAM implants from various PMs [5, 12, 13, 18, 25]. In order to improve the accuracy of intervention, STL molds to define the resection boundaries as well as intraoperative navigation are used. In the present series of cases, one female patient with FD of the crano-orbital region successfully underwent this operation with using the PEEK implant. Computer assisted planning of the operation made it possible to define exactly the resection boundaries of the tumor lesion area, to create the implant design for primary reconstruction of the defect, and to conduct one-stage intervention. This tactics of surgical treatment prevents patient disablment, which is inevitable for the traditional approach with delayed reconstruction of a bone defect.

The use of individual implants manufactured from titanium and PEEK-Optima using the CAD/CAM technologies demonstrated their undeniable advantages that include primarily high accuracy and reliability, reduced injury extent, reduced duration of surgery, and, ultimately, achievement of the predictable stable functional and aesthetic result. A significant deterrent to the widespread use of these implants is their high cost. In the presented cases, it varied from 3000 to 5500 euros. However, one should bear in mind that the possibility of long-
term secure presence in the patient’s body without developing any complications requiring removal of the implant with repeated interventions and assured achievement of the best possible aesthetic effect compensates its high cost.

Further development of the CAD/CAM technologies and a reduction in the cost of production of individual implants will make them more available, which will lead to their extensive use in the neurosurgical practice.

**Conclusion**

1. The use of individual implants manufactured from titanium and a polymeric material, PEEK, using the CAD/CAM technologies optimizes the task of reconstruction of complex skull defects, reduces the injury extent and surgery duration, and provides a predictable, good functional and aesthetic result.

2. The use of CAD/CAM implants, developed on the basis of computer assisted planning of surgery, greatly facilitates one-stage reconstructive interventions with achievement of the required symmetry in complex combined defects and deformities of the cranio-orbital localization.

3. One-stage reconstruction of a skull bone defect using a CAD/CAM implant after resection of an extensive pathological lesion may be the method of choice for treatment of benign bone tumors of the cranio-orbital localization.

**REFERENCES**


Commentary

The paper is devoted to one of the most topical issues of reconstructive neurosurgery — reconstruction of complex defects and deformities of the skull. In the majority of cases, the defects were localized in the fronto-orbital region, which made the author pay special attention to the development of a surgical treatment algorithm to achieve a good functional and aesthetic result.

This paper is the first report in the Russian literature on the use of individual implants from titanium and a polymeric material, PEEK, manufactured industrially using the CAD/CAM technologies. The author convincingly demonstrates the capabilities of computer assisted planning of surgery in cases with a combination of complex defects and deformities as well as upon removal of benign bone tumors of the cranio-orbital localization for the development and production of an implant of the corresponding design. In this regard, special attention should be paid to the described technique of one-stage surgery for removal of an extensive fibrous dysplasia lesion using stereolithography molds to define the resection boundaries and for primary cranioplasty using an individual CAD/CAM implant. This approach, certainly, should be widely implemented in daily practice. This will exclude additional patient disablement and the need for the second stage of treatment for reconstruction of a skull defect, which inevitably leads to an increase in the overall length of hospitalization and treatment cost.

The article is well illustrated by CT scans and intraoperative images that confirm the high accuracy of CAD/CAM implants.

The author convincingly demonstrated the reasonability and advantages of reconstructive surgeries for complex skull defects using titanium and PEEK CAD/CAM implants. To comprehensively and fully assess the advantages and disadvantages of PEEK implants and determine the indications for their use, further clinical studies and analysis of long-term outcomes of the treatment are required.

This work is recommended for publication, because it is of great scientific and practical interest for neurosurgeons.

O.N. Dreval’ (Moscow, Russia)
Efficacy of Optic Canal Decompression in Surgery of Meningiomas of the Chiasmal-Sellar Region


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The first studies focused on the possibility of performing optic canal decompression (OCD) were published as early as in the 1960s (Fukado Y. 1963) and 1980s (Al-Mefty O. 1988). Optic nerve decompression is essential for treating various pathologies causing nerve compression, including meningiomas with parasellar localization. The optimal surgical approach to the canal has not been identified yet. In different clinics, optic canal decompression is performed through various transcranial approaches (intra- and extradural; either with or without zygomatic arch resection) and the transnasal endoscopic approach. We performed a comparative study of the efficacy of different transcranial procedures for optic canal decompression. The study included 112 patients who were operated on in our clinic in 2000–2013. In 20 cases, patients with pituitary adenomas were subjected to extradural resection of the walls (the lateral and partially the lower one) of the optic canal as a stage of the approach to a tumor spreading to the cavernous sinus. We considered this variant of optic nerve decompression to be the most radical and aggressive method for resection of optic canal walls. Intradural optic canal decompression was performed in 50 cases: partial resection of the upper wall of the optic canal was performed in 19 patients with meningiomas; extended intradural optic canal decompression (resection of the upper wall of the optic canal using a high-speed surgical drill, with excision of the falciform ligament and the dural sheath of optic nerve from the orbit to the optic canal entrance) was performed in 30 male and 1 female patients with tuberculomas. The control group (n = 42) consisted of patients with meningiomas who were not subjected to optic canal decompression. In 11 cases, meningiomas were removed from the proximal part of the optic canal; no attempts at removing a tumor from the canal were made in 31 cases. Our study verified the safety of using the high-speed surgical drill for performing both extra- and intradural optic nerve decompression. Intradural optic canal decompression by resecting the upper wall of the optic canal was found to be reasonable when a tumor (meningioma) intertrew into the optic canal. Our findings show that partial decompression of the proximate areas of the optic canals is less efficient than more radical removal of the optic canal roof. Extended intradural decompression is more likely to cause improvement. Extended intradural decompression is a technically simpler procedure than the extradural approach. Neither searching for the ophthalmic artery nor manipulation with it is required when performing this type of trepanation; the artery remains fully covered by the optic nerve. It is reasonable to perform this variant of decompression even if intergrowth of a tumor into the optic canal is suspected. Manipulations with the tumor near the “fixed” nerve (without trepanation of the optic canal) are associated with a high risk and usually fail to provide a positive effect; the attempts at removing a tumor from the canal typically cause vision impairment. Our study gives grounds for proposing extended intradural decompression of the optic canal using a high-speed surgical drill to be performed both to manage meningiomas of the parasellar region and in surgery of neoplasms with other histostructure, which are located in this area and spread into the canal (e.g., chordomas). It can also be used in cases requiring mobilization of optic nerves (e.g., retrochiasmal localization of craniopharyngiomas in patients with anatomically short optic nerves and the “anterior” localization of the chiasm), when optic canal decompression can be extremely useful, since the tumor will be removed through the artificially extended optocarotid triangle.

Keywords: optic nerve, optic canal, transcranial decompression.

The optic canal (OC) (Fig. 1) is a pair formation of the sphenoid bone, 8–16 mm long and 5 to 9 mm in diameter. It is located at the junction between the wings and body of the sphenoid bone. In neurosurgery, the intracranial foramen of the canal is called the entrance, and the orbital foramen is called the exit. Medially and on the inferior side, the canal is separated from the sphenoid sinus cavity by a thin bone; laterally to the canal, the base of the anterior clinoid process is located; the superior wall of the canal is formed by thin sphenoid bone plate continuing to the base of the sphenoid bone wing. The dura mater of the cranial fossa base encloses the optic nerve all throughout the canal and continues to the perilobit. Inside the dural sheath, the nerve and the ophthalmic artery extending from the supraclinoid segment of the internal carotid artery are located [7, 43]. The anatomy of the optic canal, its sheath, and the ophthalmic artery has been described in detail by many authors [19, 28, 29, 39, 53, 56 etc.].

Articles devoted to the possibility of decompression of the bony OC had appeared as early as in the 1960s [26] and 1980s [8]. Decompression of the optic nerve is of great importance in treatment of various pathological conditions causing nerve compression [8]. This procedure is most often required in meningiomas of different localization (tuberculum sellae, sphenoid bone plate, anterior clinoid process, medial portions of the sphenoid bone wings, and OC meningioma), for which tumor spread to the OC is ranged from 70% of cases for sphenoid-orbital and tuberculum sellae meningiomas [6, 32, 45, 55] to 100% for OC meningiomas. In some cases, OC decompression is recommended for fibrous osteodysplasia [12, 18, 23], neuritis, and traumatic injury of the skull base structures that are accompanied by impairment of the OC integrity [6, 32]. An optimal surgical approach to the OC has not been defined yet. The following variants have been suggested throughout the years: transorbital approach in traumatic nerve com-
pression [13]; transconjunctival approach with endoscopic-assisted in traumatic nerve compression [16]; transethmoidal approach to the medial inferior portions of the OC [7, 33, 48]; lateral facial approach to the lateral portions of the OC (in traumatic nerve compression) [34]; supraorbital keyhole approach (in traumatic nerve compression) [17]. In transcranial approaches, canal decompression can be performed both intradurally [38, 44] and intradurally and extradurally in combination with clinoidectomy or without it [10, 21]. To resect the canal walls, various authors have used forceps, high-speed drills, ultrasonic bone destructors, and “water” destructors [4, 15].

So far, in the literature there is no definite attitude to the efficacy and safety of OC decompression. The most anticipated complication of any of the canal decompression vari-

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**Fig. 1. Anatomical structures of the OC region and the approach zones in resection of the canal walls through the various approaches.**

a — a 3D scheme of the OC location. Created using a three-dimensional anatomical atlas. Published with the permission of the three-dimensional anatomical atlas developer http://www.3d4medical.com/, with the condition of non-commercial use. Arrows indicate the optic canals.

b — bone structures of the right optic canal region. Anatomical specimens. Posterior view of the sphenoid bone. OC — the entrance to the optic canal; ACP — anterior clinoid process; SOF — superior orbital fissure; for. rotundum — round hole; PCP — posterior clinoid process.

c — a scheme of the approach zones in resection of the OC walls through various approaches. Anatomical specimens. Posterior view of the sphenoid bone. ON — right optic nerve.

d — relationships of the vascular and nerve structures in the left optic canal region during canal decompression through the transnasal endoscopic approach. Anatomical specimens. ON — optic nerve; OR — dissected dural sheet of the optic nerve and the posterior portions of the orbit; ICA — unfolded medial anterior knee of the internal carotid artery; OA — ophthalmic artery; A1, A2 — corresponding segments of the anterior cerebral artery; M1 — a segment of the middle cerebral artery; VI — abducen nerve in the cavernous sinus cavity.

The color scheme reproduces the location of the listed structures. Blue arrow indicates the direction of abduction of the internal carotid artery knee required for better visualization of the ophthalmic artery origin.
ants is blindness on the surgery side due to mechanical or thermal (if a high-speed drill is used) injury of the nerve and also disturbance of its blood supply [24]. There are many publications devoted to the efficacy of OC trepanation: according to some authors, the vision remains stable or is improved in 90% of cases [27]; the vision is improved in 81% and worsened in 5% [36]; the vision is improved in 70% and worsened in 10% [37]; the vision is improved in 91% upon extradural resection of the anterior clinoid process in combination with extradural canal decompression in tuberculum sellae meningiomas [46]; the vision is improved in 50% upon surgery for sphenoorbital meningiomas [45].

In addition to bony OC decompression, dissection of the dural sheath of the nerve is believed to be very helpful. This is confirmed by studies [47, 49, 54, 57]. According to P. Mortini [47], vision improvement occurs in 97%. In 2009, B. Sade [55] drew attention to the need for dissection of not only the nerve dural sheath but also the falciform ligament of the optic nerve, which is a fibrous ring surrounding the optic nerve at the place of its entrance to the canal.

The possibility to decompress the optic nerve canal through the transnasal approach was discussed by ENT surgeons together with ophthalmologists still in the 90th years of XX century [11, 58]. The development of modern endoscopic technique that provides good, low-traumatic visualization of the skull base structures was the impetus to improve endoscopic approaches to the orbit and OC [5, 14, 30, 40, 50, 59]. These operations were first performed for traumatic optic neuropathy resulting from compression of the optic nerve — compression of the nerve in the canal due to skull base injury [22, 25, 30, 31, 35]. Also, transnasal decompression of the orbit and OC in Grave’s orbitopathy is believed to be efficient [51, 52]. There are already the first results of endoscopic endonasal removal of tuberculum sellae and sphenoid bone plate meningiomas with spread to the OC [9, 41, 42].

Studies [20, 28, 39] devoted to the OC anatomical features in the context of the endoscopic transsphenoidal approach, where the medial wall of the canal is removed for the decompression purpose, have demonstrated that special attention should be paid to protecting the ophthalmic artery from injury, if the approach is used. Furthermore, with the length of the medial wall of the optic canal ranging from 7 to 23 mm, its relatively small portion (28%) is available for decompression. Additional complexities result from significant variability in the optic nerve location relatively to the sphenoid bone sinus, variability in the structure of the ethmoid bone cells, and pneumatization of the anterior clinoid process [29]. We failed to find any papers describing the possibility of dissection of the nerve dural sheath and falciform ligament through the endoscopic transsphenoidal approach.

### Objectives

Based on an analysis of our own data (mainly represented by meningiomas), we found it reasonable to carry out a comparative study aimed at solving the following problems:

- what are the efficacy and risk for different methods of OC trepanation (resection of the canal walls using forceps or high-speed drill)?
- to compare the results of different variants of OC decompression to the situations when OC decompression was not carried out for some reasons.

### Material and Methods

The study included 112 patients operated at the clinic between 2000 and 2013. The main group of the study consisted of 91 patients with chiasmal region meningiomas (tuberculum sellae, plate and diaphragm of the turcica sella, anterior clinoid process; medial portions of the sphenoid bone wings, and optic canal

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Group of patients who underwent OC decompression</th>
<th>Control group</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Type of surgery</strong></td>
<td>Group 1 (n=20)</td>
<td>Group 2 (n=19)</td>
</tr>
<tr>
<td>Extended extradural resection of the superior, medial and partially inferior walls performed by a high-speed drill</td>
<td>Extended intradural resection of the superior wall performed by a high-speed drill</td>
<td>Removal of tumor from the OC without decompression — twisting</td>
</tr>
<tr>
<td>Partial intradural resection of the superior wall performed by forceps</td>
<td>Extended intradural resection of the superior wall performed by a high-speed drill</td>
<td>Intracranial manipulations with tumor without OC decompression and without attempts to remove the tumor from the OC</td>
</tr>
<tr>
<td><strong>Removal of tumor from the OC</strong></td>
<td>Not performed</td>
<td>Performed</td>
</tr>
<tr>
<td>Not performed</td>
<td>Performed</td>
<td>Performed</td>
</tr>
<tr>
<td>Dissection of the falciform ligament</td>
<td>Not performed</td>
<td>Performed</td>
</tr>
<tr>
<td>Not performed</td>
<td>Performed</td>
<td>Not performed</td>
</tr>
<tr>
<td>Dissection of the dural sheath</td>
<td>Not performed</td>
<td>Performed</td>
</tr>
<tr>
<td>Not performed</td>
<td>Performed in a small segment</td>
<td>Not performed</td>
</tr>
<tr>
<td>Nature of pathology</td>
<td>Pituitary adenomas</td>
<td>Meningiomas</td>
</tr>
<tr>
<td>Pituitary adenomas</td>
<td>Meningiomas + tuberculoma</td>
<td>Meningiomas</td>
</tr>
<tr>
<td>Nature of pathology</td>
<td>Meningiomas</td>
<td>Meningiomas</td>
</tr>
<tr>
<td><strong>Fraction of repeated observations in the group</strong></td>
<td>4 (25%)</td>
<td>3 (16%)</td>
</tr>
</tbody>
</table>
| **Footnote:** * — the number of previously operated patients in each group. Operation whose results are included in the study was repetitive.
sheath), chiasmal region tuberculoma (one case, when the tumor looked like and was removed as a meningioma, but the final diagnosis was clarified by an immunohistochemical examination), for whom the tumor spread to the OC was confirmed intraoperatively. In all cases, the tumor was removed through the transcranial intradural approach.

Patients with pituitary adenomas (20 cases) comprised a separate group, in which resection of the OC walls was performed extradurally as a stage in the approach to the tumor spreading to the cavernous sinus.

All patients were divided into groups depending on the type of OC decompression and the variant of removal of the tumor spreading to the OC (Table 1).

The 1st group consisted of 20 patients with pituitary adenomas intergrowing into the cavernous sinus who underwent extradural resection of the superior, lateral and, partially, inferior portions of the OC wall as well as the anterior clinoid process (intradural and extradural approach according to V. Dolenc), which was required for an adequate approach to the sinus. We will not dwell on the technique of this approach, because it was in detail described in the literature [23] and we presented it previously [2, 3].

This type of OC decompression can be considered as the most radical and aggressive method of resection of the OC bony walls.

Since these patients were not detected with the tumor spread to the optic canal, its dorsal sheath was not opened, and the falciform ligament was not dissected. The results obtained in this group of patients were used only to demonstrate the potential possibility to perform wide decompression of the OC and the relative safety of its performance using a high-speed diamond drill.

The 2nd group included 19 patients with meningiomas who underwent partial intradural resection of the superior OC wall. Resection was performed by Kerrison forceps, the bone was removed at the entrance to the OC through 6—8 mm from the entrance. After dissection of the DS covering the canal roof, the latter was exposed, which was then resected using Kerrison forceps. Additionally, the falciform ligament was dissected. In some cases, this was supplemented by dissection of the dural sheath of the optic nerve in initial portions of the canal. After achieving the relative mobility of the optic nerve, the tumor residuals were removed from under the nerve and from the OC. If it was revealed that the tumor infiltrated the DS into the OC, the surgery was terminated at this point.

2. We used a high-speed drill for more complete resection of the OC walls.

The approach to the tumor did not differ from that described above. After this, the suprasellar portion of the tumor was usually partially removed leaving its fragment near the optic nerve, the canal of which was planned to be trepanated. After dissection of the DS covering the canal roof, the latter was resected using a high-speed diamond drill all through the canal up to the orbit. An example of this is the clinical observation 1 (Figs. 2, 3).

Initially, we used a diamond ball of 3 mm in diameter, but in this case a partial injury (contusion) to DS of the optic nerve occurred. Later, the use of a ball of 5 mm in diameter provided more safe surgery and injury to the nerve dural sheath no longer occurred. To reduce the risk of thermal injury to the nerve, we cooled the bone resection area with saline.

In almost all cases, we found that the nerve, in the falciform ligament region, usually had a pronounced bend (90°) due to its tumor-produced compression from below. In the bend region, after dissection of the falciform ligament, a sulcus was revealed on the nerve surface, which was the result of nerve stranulation by this fibrous ring. Furthermore, we found that often in the absence of explicit signs of the meningioma spread to the optic canal and in the presence of high acuity of vision and normal visual fields, the tumor may already be in the optic canal, and it may be located within the dural sheath of the nerve.

In 7 repeated observations, due to the pronounced cicatricial adhesion developed after the first operation, we could not detect either intracranial segments of the optic nerves or the nerve inputs to the canals. To avoid traumatic micropreparation upon identification of the entrance to the OC, its de-
Fig. 2. Stages of extended intradural decompression of the left optic canal and removal of the tumor. An example of the traditional decompression — trepanation in the direction from the entrance to the canal to the orbit. Clinical observation 1.

a — a scheme of the meningioma location relative to the left optic nerve. Created using a three-dimensional anatomical atlas. Published with the permission of the three-dimensional anatomical atlas developer http://www.3d4medical.com/, with the condition of non-commercial use.

b — meningioma located above the left optic nerve: 1 — tumor; 2 — bone of the superior OC wall covered by the DS; 3 — L-shaped probe used to find the entrance to the OC; 4 — suction.

c — resection of the medial portions of the superior OC wall: 1 — tumor; 2 — optic nerve after trepanation of the OC; 3 — diamond drill; 4 — suction.

d — preparation for dissection of the falciform ligament and dural sheath of the nerve: 1 — tumor; 2 — optic nerve after trepanation of the OC; 3 — falciform ligament; 4 — suction; 5 — L-shaped probe.

e — removal of the tumor from under the optic nerve: 1 — tumor; 2 — optic nerve after trepanation of the OC and dissection of the DS; 3 — dissector; 4 — suction.

f — removal of the tumor from under the optic nerve: 1 — tumor; 2 — optic nerve; 3 — tweezers; 4 — suction.
compression was performed at the first stage. In these cases, we started searching for the OC not in the canal entrance projection but at the base of the anterior clinoid process. Upon meningiomas, the bone in this area is often thickened to a few millimeters and is compacted so much that before identification of the OC or dissection of the clinoid process cavity, we had to resect a fairly large amount of the bone. Only after identification of the OC, we continued resection of its roof in two directions: backward (towards the entrance) and forward (towards the orbit). An example of this is the clinical observation 2 (Figs. 4, 5). We used the same procedure of searching for the OC in two primary observations of anterior clinoid process meningiomas where the optic nerve was completely covered by the tumor. Trepanation of the canal and dissection of the dural sheath of the nerve allowed us to prior manipulation with the tumor to find the nerve and to trace its course over the tumor surface. In these cases, visual deterioration was not observed. Despite this complex search for the OC, the entire procedure took no more than 15—20 min.

In 4 cases, we found that the tumor spread into both OCs. Full trepanation of the left OC through our preferred right sided approach was successful in 2 cases only, so we did not include evaluation of changes in the left eye vision in the tables. It can only be noted that the left eye vision was not deteriorated in all 4 cases (Fig. 6).

Since the OC is adjacent to two air cells (the air cell of the pneumatized anterior clinoid process is located laterally, and the sinus cavity and the ethmoidal labyrinth cells are located medially), a deviation of the bone resection direction from the OC course can lead to their opening and, consequently, to the development of postoperative nasal liquorhea. In 4 cases, before identification of the OC, we entered the air cell of the anterior clinoid process and only after that, continuing resection of the bone, we identified medially the OC. In order to prevent nasal liquorhea, the entire air cell of the anterior clinoid process communicating with the cavity of the sphenoid sinus was tightly packed with TachoComb. The Tissucol glue was additionally used only in one case. Postoperative liquorhea was not observed in our series of observations.

### Table 2. Changes in visual function after various types of OC decompression after operation depending on the initial severity of visual impairments on the side of decompression

<table>
<thead>
<tr>
<th>Type of canal trepanation</th>
<th>Severity of impairments</th>
<th>Changes in visual functions after surgery, %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>no changes</td>
</tr>
<tr>
<td>Group 1 — extended extradural trepanation by a drill (n=20)</td>
<td>Moderate* n=14 (70%)</td>
<td>10 (71.4)</td>
</tr>
<tr>
<td></td>
<td>Hard n=6 (30.0%)</td>
<td>3 (50.0)</td>
</tr>
<tr>
<td></td>
<td>Decompression n=0</td>
<td></td>
</tr>
<tr>
<td>* There were no impairments n=10 (50.0%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group 2 — intradural partial trepanation by forceps (n=19)</td>
<td>Moderate n=5 (26.3%)</td>
<td>3 (60.0)</td>
</tr>
<tr>
<td></td>
<td>Hard n=4 (21.1%)</td>
<td>1 (25.0)</td>
</tr>
<tr>
<td></td>
<td>Decompression n=10 (52.6%)</td>
<td>5 (50.0)</td>
</tr>
<tr>
<td>Group 3 — intradural extended trepanation by a drill (n=31)</td>
<td>Moderate n=4 (12.9%)</td>
<td>3 (75.0)</td>
</tr>
<tr>
<td></td>
<td>Hard n=14 (45.2%)</td>
<td>2 (75.0)</td>
</tr>
<tr>
<td></td>
<td>Decompression n=13 (41.9%)</td>
<td>7 (53.8)</td>
</tr>
<tr>
<td>Group 4 — removal of tumor from the OC without decompression — twisting (n=11)</td>
<td>Moderate n=1 (9.1%)</td>
<td>1 (100.0)</td>
</tr>
<tr>
<td></td>
<td>Hard n=3 (27.3%)</td>
<td>1 (33.3)</td>
</tr>
<tr>
<td></td>
<td>Decompression n=7 (63.6%)</td>
<td>1 (14.3)</td>
</tr>
<tr>
<td>Group 5 — intracranial manipulations with tumor without OC decompression and without attempts to remove the tumor from the OC (n=31)</td>
<td>Moderate n=12 (38.7%)</td>
<td>9 (75.0)</td>
</tr>
<tr>
<td></td>
<td>Hard n=3 (9.7%)</td>
<td>3 (100.0)</td>
</tr>
<tr>
<td></td>
<td>Decompression n=16 (51.6%)</td>
<td>6 (37.5)</td>
</tr>
</tbody>
</table>
Fig. 3. Removal of meningioma of the left anterior clinoid process region. Clinical observation 1.


d—f — control MRI in 2010.

g—i — MRI in 2013, before re-operation with OC trepanation and removal of the tumor. Arrows indicate the tumor location.
Method for result evaluation

We evaluated only changes in visual acuity of the eye on the OC trepanation side before and after surgery as well as in catamnesis.

Based on the evaluation scheme proposed by Prof. B.A. Kadasheva in 1992 [1], we ranked the severity of visual disturbances into three grades:

1 — moderate with visual acuity of 1.0 through 0.51;
2 — hard with visual acuity of 0.5 to 0.11;
3 — decompensation with visual acuity of 0.1 to 0.

This allowed us to evaluate the efficacy of different types of OC decompression, which was especially important in the group of patients with the residual vision (patients with decompensation of the visual functions, which was associated in 10 cases with pronounced atrophy of the optic discs). In this situation, the question always arises, whether this rather complex surgical procedure should be performed or the affected area of the canal with the virtually blind nerve should be irradiated to prevent disease recurrence?

Furthermore, we evaluated the risks and benefits of OC trepanation in the first two categories of patients in whom a reduction in the vision was not so pronounced.

We did not conduct more detailed evaluation of the vision changes, including the state of the visual fields, because it was impossible to unambiguously differentiate the causes of visual deterioration — the result of OC decompression or manipulations in the chiasmal region when removing the intracranial portion of the tumor?

Due to the insufficient number of observations, we presented our data in Tables 2—4 in the actual form (number of cases and %) to facilitate the perception. However, when making conclusions based on Table 3, we used the one-tailed Fisher's test with the significance level of 5% ($F=0.05$) for verification and significance.

Results

Tables 2 and 3 present changes in the vision after various operations immediately before discharge (Table 2) and in catamnesis (Table 3) when the vision in some patients continues to improve with time (catamnesis period is indicated in Table 3).

We already said above that the 1st group (patients with pituitary adenomas intergrowing into the cavernous sinus) was used only to prove relative safety of extended OC decompression using a high-speed diamond drill.

It is important to clarify here that this group underwent combined intradural and extradural interventions, in which the tumor was first removed from the chiasmal region through the intradural approach, and only then extended extradural resection of the bones, including the OC walls, was performed to approach the sinus.

Therefore, to judge reliably the causes of visual improvement or deterioration immediately after surgery is not possible, because they are most likely associated with removal of the intradural portion of the tumor (Table 2). However, a high rate of visual improvement (up to 80%) in catamnesis (Table 3) indicates that extended resection of the OC walls is very safe to the optic nerve, if the surgeon is experienced enough.

Evaluation of the results in the 5th group demonstrated that intracranial manipulations with a meningioma on the background of its intergrowing into the OC that were performed without OC decompression and without attempts to revise the OC did not lead, as expected, to a reduction in the vision in most cases. Before surgery, visual impairments were pronounced or decompensated in more than half of the cases. Removal of the intracranial portion of the tumor did not cause visual deterioration or provided visual improvement obviously due to elimination of compression of the chiasm and intracranial segments of the optic nerves (Table 2). However, significant deterioration occurred in 5 patients (Table 2). This was most likely due to separation of the tumor fragments from the basal surface of the nerve that were tightly fused with it, which resulted in hemodynamic disturbances. For example, follow-up evaluation of the vision in the period of up to 55 months and a comparison of the vision state with the preoperative level revealed a decrease to 10.1% of the fraction of patients in whom treatment resulted in vision improve-
Fig. 4. Stages of extended intradural decompression of the right optic canal. An example of decompression upon the initial absence of anatomical landmarks for the location of the canal entrance. Trepanation in the region of the anterior clinoid process base to search for the optic canal with its subsequent extension along the canal. Clinical observation 2.

a — a scheme of the meningioma location relative to the right optic nerve. Created using a three-dimensional anatomical atlas. Published with the permission of the three-dimensional anatomical atlas developer. http://www.3d4medical.com/, with the condition of non-commercial use.

b — meningioma located above the right optic nerve: 1 — tumor; 2 — bone of the superior OC wall covered by the DS.

c — preparation for resection of the base of the anterior clinoid process and search for the OC: 1 — tumor; 2 — orbital roof covered by the DS; 3 — bone of the superior OC wall after removing the DS.

d — a scheme of resection of bones in the OC region. 3D reconstruction of spiral CT: 1 — resection area of the base of the anterior clinoid process to detect the OC; 2 — resection of the superior OC wall toward the orbit; 3 — resection of the superior OC wall towards the entrance to the OC. The top of the process is connected to the sphenoid bone body by an “optic strut” stricture.

e — optic nerve surrounded by the DS. The superior OC wall was resected all over: 1 — tumor; 2 — optic nerve after trepanation of the OC and before dissection of the DS; 3 — cells of the spongy substance of the anterior clinoid process after partial resection of its base.

f — falciform ligament and tumor under the DS of the optic nerve: 1 — tumor; 2 — optic nerve; 3 — falciform ligament. Arrows indicate incision edges of the DS of the optic nerve, under which a thin layer of the tumor is located. The moment of the DS dissection onset and identification of the tumor is demonstrated at the upper right corner of the image.

g — falciform ligament dissection: 1 — tumor; 2 — optic nerve; 3 — dissected falciform ligament.

h — optic nerve after OC decompression and removal of a tumor layer covering the OC. Intraoperative image: 1 — tumor; 2 — optic nerve; 3 — spongy substance of the anterior clinoid process after partial resection of its base.
The vision remained unchanged (75%)
in 60% of patients, the vision remained unchanged (Table 3).

Evaluation of the results in the 4th group demonstrated that removal of the tumor by twisting from the OC without preliminary OC decompression resulted in significant and persistent impairment of the vision. After removal of the tumor from the OC, a reduction in the vision occurred in 71.4% of cases (Table 2). Improvement in the vision was observed in 14.3% of cases. Evaluation of the vision condition in catamnesis in comparison with the preoperative level in the period of up to 100 months revealed that the proportion of patients with decreased visual acuity remained unchanged (75%).

Partial OC trepanation using forceps (group 2) did not change the vision in patients in 50% of cases and was accompanied by its deterioration in 20%. The vision remained unchanged in most of the patients in the follow-up period of up to 98 months after surgery (Table 3).

In the third group, extended intradural resection of the superior wall throughout the entire OC, using a high-speed diamond drill, combined with dissection of the falciform ligament and opening the DS surrounding the nerve provided the best result that allowed us to start the application of this technique in cases of continued growth of meningiomas when OC decompression was the main purpose of surgery. Visual deterioration was not observed in the group of patients with de-table 3. Changes in the visual functions on the side of OC decompression in catamnesis compared to the preoperative level

<table>
<thead>
<tr>
<th>Type of canal trepanation</th>
<th>Severity of visual impairments before surgery</th>
<th>Visual acuity in catamnesis on the trepanation side</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1 — extended extradural trepanation by a drill</td>
<td>Moderate (n=13) 11 (84.6%) improvement</td>
<td>1 (7.7%) deterioration</td>
</tr>
<tr>
<td>Catamnesis is known in 18 (90%) of 20 months</td>
<td>Hard (n=5) 0 improvement</td>
<td>4 (80.0%) deterioration</td>
</tr>
<tr>
<td></td>
<td>Decompensation (n=0) 0</td>
<td>1 (20.0%) deterioration</td>
</tr>
<tr>
<td>Group 2 — intradural partial trepanation by forceps</td>
<td>Moderate (n=1) 1 improvement</td>
<td>0 deterioration</td>
</tr>
<tr>
<td>Catamnesis is known in 8 (42.1%) of 19 months</td>
<td>Hard (n=1) 0 improvement</td>
<td>1 (100.0%) deterioration</td>
</tr>
<tr>
<td></td>
<td>Decompensation (n=6) 4 (66.7%)</td>
<td>1 (16.7%) deterioration</td>
</tr>
<tr>
<td>Group 3 — intradural extended trepanation by a drill</td>
<td>Moderate (n=3) 2 improvement</td>
<td>0 deterioration</td>
</tr>
<tr>
<td>Catamnesis is known in 15 (48.4%) of 31* months</td>
<td>Hard (n=3) 1 improvement</td>
<td>1 (33.3%) deterioration</td>
</tr>
<tr>
<td></td>
<td>Decompensation (n=9) 3 (33.3%)</td>
<td>6 (66.7%) deterioration</td>
</tr>
<tr>
<td>Group 4 — removal of tumor without OC decompression — twisting</td>
<td>Moderate (n=1) 1 improvement</td>
<td>0 deterioration</td>
</tr>
<tr>
<td>Catamnesis is known in 6 (54.5%) of 11 months</td>
<td>Hard (n=1) 0 improvement</td>
<td>1 (100.0%) deterioration</td>
</tr>
<tr>
<td></td>
<td>Decompensation (n=4) 0</td>
<td>1 (25.0%) deterioration</td>
</tr>
<tr>
<td>Group 5 — intracranial manipulations with tumor without OC decompression and without attempts to remove the tumor from the OC</td>
<td>Moderate (n=6) 3 improvement</td>
<td>1 (16.7%) deterioration</td>
</tr>
<tr>
<td>Catamnesis is known in 19 (61.3%) of 31 months</td>
<td>Hard (n=3) 3 improvement</td>
<td>2 (33.3%) deterioration</td>
</tr>
<tr>
<td></td>
<td>Decompensation (n=10) 6 (60.0%)</td>
<td>3 (30.0%) deterioration</td>
</tr>
</tbody>
</table>

Note. * — In 10 cases, recent time of operation did not allow obtaining follow-up data.

Table 4. Evaluation of changes of the visual functions on the side of extended intradural OC decompression (group 3) depending on the severity of optic nerve atrophy and the severity of visual impairment

<table>
<thead>
<tr>
<th>Stage of visual impairments (severity of optic nerve atrophy)</th>
<th>Severity of visual impairment</th>
<th>No changes</th>
<th>Improvement</th>
<th>Deterioration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Early, 16 (51.6%) of 31</td>
<td>Moderate (n=4) (25%) 3 (75.0%)</td>
<td>0</td>
<td>1 (25.0%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Hard (n=9) (56.2%) 0</td>
<td>6 (66.7%)</td>
<td>3 (33.3%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Decompensation (n=3) 1 (33.3%)</td>
<td>2 (66.7%)</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Late, 15 (48.4%) of 31</td>
<td>Moderate (n=5) (33.3%) 2 (40.0%)</td>
<td>2 (40.0%)</td>
<td>1 (20.0%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Decompensation (n=10) 6 (60.0%)</td>
<td>4 (40.0%)</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>
Fig. 5. Removal of tuberculum sellae meningioma with spreading to the right optic canal. Clinical observation 2.

d—f — MRI after the first surgery. 2010.
g—i — MRI of the tumor progression in the form of its spreading in the structure of the skull base and towards both OCs. 2013. The left eye was blind before the first operation. Light perception in the right eye was saved. Single arrow indicates the tumor fragments compressing the right optic nerve; double arrows indicate the tumor fragments compressing the left optic nerve.

See continued Fig. 5 on the next page
compensated vision at discharge, while improvement occurred in 46.2%. Also, visual deterioration did not occur in catamnesis up to 50 months. Improvement was observed in 66.7% of cases.

Of 7 patients operated previously, the optic nerve was not found in any of them during the second (our) operation, neither before nor after OC trepanation (in these patients, after dissection of the nerve DS only a solid tumor in the canal lumen was identified, inside of which single nerve fibers likely remained that provided the residual vision), improvement in visual acuity was observed in 3 cases and there were no changes in 4 cases.

Evaluating the significance of differences in the frequency of improvement and deterioration of vision in patients with decompensation using the one-tailed Fisher’s test (F), we found the following patterns:

1. Visual deterioration in patients with decompensation occurs significantly more frequently upon attempts to remove a tumor from the OC without preliminary OC decompression compared to extended intradural decompression (F = 0.014) (comparison of the 3rd and 4th groups).

2. Extended intradural OC decompression has a tendency to more frequent visual improvement compared to partial OC.
Rис. 6. Partial removal of disseminated meningioma of the parasellar localization with spreading into the canals of both optic nerves. Clinical observation 3.

a–c — MRI before surgery.

d–f — control spiral CT on the first day after surgery. Presentation of partial removal of the tumor.

g — 3D reconstruction of the sphenoid bone body and medial portions of the sphenoid bone wings. Presentation of extended intradural trepanation of the right OC (indicated by arrows).

h — 3D reconstruction of the sphenoid bone body and medial portions of the sphenoid bone wings. Presentation of partial intradural trepanation of the left OC. Large arrow indicates the direction of drill action upon resection of the canal roof through the right sided subfrontal approach. Small arrows indicate the margin of partially resected hyperostosis.
decompression performed by forceps (F – 0.084) (comparison of the 2nd and 3rd groups).

In the third group, we also evaluated changes of the visual functions depending on severity of optic nerve atrophy. Improvement in the vision was observed in 40% of cases in patients with the late stage of visual disorders and in 66.7% of patients with the early stage of visual disorders and also with a pronounced decrease in the vision (Table 4).

Conclusion

The present study on parasellar region meningiomas revealed that intradural decompression of the canal via resection of the superior OC wall is advisable when the tumor intergrown into the OC.

According to the outcomes, partial decompression of the initial portions of the OC performed by forceps is clearly behind more complete resection of the OC roof performed by a high-speed drill. The latter procedure much more frequently results in improvement even in cases of a preoperative pronounced reduction in the vision (Tables 3, 4).

The results of OC decompressions performed both intradurally (group 3) and extradurally (group 1) provide a reasonable basis to assume that the use of a high-speed drill is a safe procedure that does not cause mechanical or thermal injury to the optic nerve. Extended intradural decompression is technically much easier than the extradural approach, which implies resection of a significant amount of the skull base bones. In this case, intradural trepanation does not imply the search for and manipulations on the ophthalmic artery, which remains fully covered by the optic nerve.

Manipulations on the tumor near the “fixed” nerve (without OC trepanation) are risky and usually do not provide a positive effect. In this case, attempts to remove the tumor from the canal often lead to visual deterioration. Therefore, they can be considered undesirable and even dangerous.

Extended resection of the OC roof by a drill is advisable to be used even at suspicion on tumor in-growth in it. For example, in this series of observations (group 3), we found a tumor inside the dural sheath of the optic nerve in all 3 patients with high visual acuity and normal visual field.

The efficacy of extended intradural OC decompression in patients with severe optic atrophy demonstrated a high potential in application of this technique even in situations previously considered prognostically unfavorable.

The efficacy of trepanation of the infero-medial canal wall, which can be performed through the transnasal endoscopic approach, requires clarification. It can certainly be used in traumatic nerve compression and inflammatory processes when there is no need for dissection of the dural sheath of the nerve. In situations with the tumor spread into the optic canal, bone decompression alone seems to be only a half-measure, and the location of the ophthalmic artery on the basal surface of the nerve and a high variability of this location make attempts to dissect the dural sheath of the nerve through this approach be extremely risky.

This study suggests performing extended intradural OC decompression using a high-speed drill not only in parasellar region meningiomas but also in surgery for tumors of different histostructure, but with the same localization, spreading into the canal (e.g., chordomas) or in situations that require mobilization of the optic nerves (for example, cases of the retrochiasmal localization of craniopharyngiomas with the anatomically short optic nerves and the “frontal” localization of the chiasm) where OC decompression can be extremely useful, because it will allow removing the tumor through the artificially extended opticocarotid triangle.

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The intradural decompression made by high speed drill with additional falciform ligament cutting and the dural sheet opening is reported in the literature to be effective. Moreover extradural and intradural decompression as described by myself is more effective.

I think this paper is a proof that the microsurgical decompression of the optic nerve is needed in tuberculum sellae meningiomas. My suggestion is to adopt the technique I described recently through the FTOZ approach in order to improve the results more and more.

The paper is interesting.

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Optic Nerve Decompression in Treatment of Neoplasms Involving the Optic Canal

N.V. LASUNIN, V.A. CHERKEAEV, N.K. SEROVA, D.A. GOL’BIN, A.V. KOZLOV, A.I. BELOV, N.N. GRIGOR’EVA, K.YU. KRYLOV, D.S. SPIRIN

Burdenko Neurosurgical Institute, Moscow, Russia

Neoplasms extending into the optic canal (OC) are a diverse group consisting of more than 15 histological types. Elimination of optic nerve compression is crucial for favorable visual outcome. **Material and Methods.** We performed a prospective analysis of 97 patients with different neoplasms affecting the optic canal who were operated on at the Neuro-oncology Department of the Burdenko Neurosurgical Institute in 2010–2012. The extent of resection and the recurrence rates were determined by pre- and postoperative CT and MRI studies. **Results.** 97 patients (78 females and 19 males) were involved in the study. Mean age was 49.4 years. The mean follow-up was 15.9 months (range: 1–36 months). Total resection was achieved in 54 patients (55.6%); gross total resection, in 40 patients (41.2%); partial resection, in 3 patients (3.2%). Thirty patients underwent postoperative stereotactic radiation therapy. There was no recurrence in a series of observations. Vision disturbances were the main presenting symptoms in 50 patients (51.5%). Ten patients (10.3%) initially had normal visual status. Visual improvement after surgery was seen in 37% of patients with visual disturbances. Visual deterioration occurred in 19% of patients. Transient visual deterioration occurred in one patient with recovery to the base level over time. The visual outcome was affected by the preoperative duration of symptoms and the stage of visual disturbances according to the fundus changes. **Conclusion.** Optic nerve decompression is a crucial step in surgical management allowing one to optimize the clinical outcome and prevent tumor recurrence.

**Keywords:** optic canal, decompression, neoplasms involving optic canal, optic nerve.

The orbital bony skeleton consists of 7 bones, including frontal, ethmoid, lacrimal, sphenoid, zygomatic, palatine and maxillary ones. Only the sphenoid bone in involved in formation of OC walls. The OC roof is formed by the lesser wing of the sphenoid bone and the base of the anterior clinoid process; the medial wall is formed by the jugum and the body of the sphenoid bone; the lateral wall is represented by optic strut and anterior clinoid process; the floor is formed by jugum sphenoidal and the optic strut. Bony structures are not the only components of OC. A significant portion of its roof (posterior areas) is formed by reduplication of the dura mater (DM), the falciiform ligament connecting the anterior clinoid process with jugum sphenoidal. The anterior areas of OC are circumferentially formed by the common tendinous ring, which is the site where the eye muscles are attached to the orbital apex.

According to different authors [2, 4, 14, 20, 22, 25, 26], the probability of recovering the visual function in patients with tumors spreading into the OC varies from 25 to 91%, depending on tumor size, its location, growth direction, initial visual acuity, duration of symptoms and surgical techniques used. ON decompression is an important stage of the surgery in this situation, both facilitating complete tumor resection and providing the best clinical outcome. The approaches for decompression may vary, including transcranial (intra- or extradural combined versions) and extracranial (transnasal, transsphenoidal) ones. Surgical procedures may include removal of bony canal walls, dissection of the common tendinous ring and dissection of the ON sheath [19, 25].

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In our study we discuss the variants of spread of skull base tumors to the OC, indications for decompression, treatment outcomes and their correlation characteristics. An algorithm for selecting a surgical approach was suggested.

**Material and Methods**

The study group included 97 patients (78 females and 19 males) with tumors spreading into the OC who were operated on at the N.N. Burdenko Neurosurgical Institute in 2010–2012. The patients were aged 6 to 80 years with median of 50 (42; 57) years. Medical history median was 14 (9; 48) months. The clinical picture of the disease in all the patients is shown in Table 1. The histological structure of the tumors is shown in Fig. 1. The tumor localization and variants of their spread into the optic canal are shown in Figs. 2 and 3.

The study included only patients with confirmed tumor spreading to the walls or lumen of the OC. If canal involvement in the pathological process had not been confirmed intraoperatively, the patients were withdrawn from the study.

The series included 4 patients with tumors spreading to both OCs. A total of 7 patients had previously been operated on in other hospitals and were admitted with relapses of the disease.

All patients underwent computed tomography (CT) or magnetic resonance imaging (MRI) during the early postoperative period to detect postoperative complications and assess the radicality of surgical treatment. The biopsy material obtained during surgeries was subjected to histological examina-

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**Fig. 1.** Tumor localization and variants of their spread into the optic canal are shown in Figs. 2 and 3.

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**Fig. 2.** Localization of tumors spreading into the optic canal taking into account the frequency of involvement of the adjacent areas.

**Fig. 3.** Variants of tumor spread (directions are shown with arrows).
tion. All patients underwent comprehensive pre- and postoperative neuro-ophthalmic examination. Scheduled periodic neuro-ophthalmic examinations were performed during the late postoperative period. Ophthalmic examination included assessment of visual acuity, visual fields, oculomotor and pupil functions, study of the ocular fundus, and eye biomicroscopy.

The nature of tumor growth, its relation to the ON, the degree of ON involvement into the neoplastic process, its form (“early”, i.e. before tumor resection, or “late”, i.e. after tumor resection) and localization (what canal walls have been removed) of decompression and radicality of tumor resection were evaluated based on the data from the pre- and postoperative CT and MRI examinations and analysis of surgery protocols.

The follow-up period ranged from 1 to 33 months with a median of 18 (12; 25) months.

Surgical approaches used in oncotomy and, if necessary, ON decompression are shown in Table 2.

The orbitozygomatic approach was used to remove tumors located mainly laterally with respect to OC. The frequency of using this approach depended largely on the spread of cancer. However, the viewing angle provided by this approach also ensured the most convenient possibility for performing transcranial OC decompression. Our experience shows that this approach provides visibility and possibility for dissection in the area of OC, ON, the internal carotid artery, laterally in the region of the cavernous sinus, and the chiasmosellar area.

This access provides both the extradural and intradural approaches.

The supraorbital approach (according to O. Al-Mefty) was primarily used in patients with midline tumors, including meningiomas of the tubercle and diaphragm of the sella turcica and jugum sphenoidale. The benefits of this access include attenuated approach to the structures of the orbital ring, the lateral orbital wall, and orbital roof.

We used osteoplastic lateral orbitotomy in cases of cranioorbital neoplasms with predominantly intraorbital localization. The amount of resection of the wings of the sphenoid bone was determined by spread of the process. Despite the fact that this approach is the least traumatic one among transcranial surgical approaches and requires no significant resection of bone structures, it provides a good visibility of the lateral portions of the orbit and enables dissection in the retrolubar space.

The bilateral subfrontal approach was used only in 3 cases, when giant meningiomas of the base of the anterior cranial fossa, spreading to the tubercle and diaphragm of the sella turcica, were observed.

During the transcranial approach, removal of the anterior clinoid process and resection of the upper and lateral walls of the OC were performed extra- or intradurally using an operating microscope. Osteoplastic trepanation was followed by resection of the greater and lesser wings of the sphenoid bone with opening of the superior orbital fissure (Fig. 4). Further extradural grinding of the optic canal roof using a Zimmer high-speed drill (Germany) was performed (Fig. 5), followed by resection of the anterior clinoid process (Fig. 6). All manipulations were carried out extradurally with continuous lavage with saline to avoid thermal damage to the OC.

Intradural OC decompression was performed in 5 cases. It was performed using the same principles mainly after the supraorbital access in cases of neoplasms located medially with respect to the OC.

The endoscopic endonasal approach was used in 9 cases. Bilateral access to the sphenoid sinus and anterior sphenoidotomy were performed through the ipsilateral middle nasal passage using the transethmoidal approach and the bilateral paraseptal approach to visualize the OC from the tuberculum sellae to the orbital apex. The “two surgeons — four hands” technique was used. Decompression of the OC and the inferomedial wall of the orbital apex was carried out using a power bur with continuous lavage with saline. At least 180° of the ON circumference was released from the top of the orbit to the projection of the middle portion of the chiasm onto the chiasmatic groove. Dissection of the ON sheath was not performed.

Copious lavage during OC reaming is very important to prevent thermal damage to the ON.

## Results

Tumor spread into the OC or hyperostotic lesions of its walls was observed in all 97 cases. The lesions were bilateral in 4 cases, so the total number of the affected canals was 101.

The orbitozygomatic approach was used in 31 cases, when the tumor spreads to the wings of the sphenoid bone, cavernous sinus, infratemporal fossa and in cases of extended orbitophenopetrocrival tumors. All patients in this group underwent OC decompression.

The supraorbital approach was used in 14 patients with tumors of the base of the anterior cranial fossa, the tubercle and diaphragm of the sella turcica, and the jugum and the body of the sphenoid bone. The bifrontal approach was performed in 3 cases. In 5 cases tumor was removed from the canal by dislocating the tumor nodule without grinding OC.

### Table 1. Clinical characteristics of patients

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Numeric expression</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender (M/F)</td>
<td>19/78</td>
</tr>
<tr>
<td>Age, years</td>
<td>6—80, Me 50 (42; 57)</td>
</tr>
<tr>
<td>The duration of follow-up, months</td>
<td>1—33, Me 18 (12; 25)</td>
</tr>
<tr>
<td>The term of medical history, months</td>
<td>1—240, Me 14 (9; 48)</td>
</tr>
<tr>
<td>Guiding preoperative symptoms</td>
<td></td>
</tr>
<tr>
<td>visual impairment</td>
<td>50</td>
</tr>
<tr>
<td>exophthalmos</td>
<td>18</td>
</tr>
<tr>
<td>oculomotor disorders</td>
<td>5</td>
</tr>
<tr>
<td>headache</td>
<td>7</td>
</tr>
<tr>
<td>paroxysmal symptoms</td>
<td>4</td>
</tr>
<tr>
<td>local pain</td>
<td>7</td>
</tr>
<tr>
<td>other</td>
<td>6</td>
</tr>
</tbody>
</table>
bony walls because of shallow penetration of tumor into the canal and the absence of infiltration of the ON sheath.

Osteoplastic lateral orbitotomy was used in 8 cases, including 4 cases of resection of sphenoid bone wings and OC decompression.

CT and/or MRI were performed in the first day after surgery to evaluate the radicality of tumor resection. Gross total resection was performed in 54 (55.7%) cases; subtotal, in 40 (41.2%) cases; and partial, in 3 (3.1%) cases.

No postoperative relapses were observed after gross total resection of the tumor.

Radiation therapy for 3 to 20 months was used in 30 (69.8%) of 43 patients who underwent subtotal or partial tumor resection. Control over tumor growth was observed after stereotactic radiotherapy. A total of 7 patients are planned for radiotherapy, the rest are under dynamic follow-up.

Ophthalmologic symptoms were the leading ones during the preoperative stage in 75.3% of patients. Visual disturbances were observed in 51.5% of patients (Fig. 7). The data on the visual function status during pre- and the postoperative periods are shown in Table 3.

Visual function was intact in 10 patients before surgery. In 4 patients, a decrease in visual acuity was observed during the postoperative period due to trophic corneal disease. A decrease in visual acuity to ≥0.1 was observed in 31 patients in the preoperative period. A more pronounced decrease in visual acuity (<0.1) in the preoperative stage was observed in 39 patients.

Only one patient in the group with amaurosis (17 patients) demonstrated slight vision recovery. No negative dynamics was observed during the postoperative period in the group with normal preoperative visual functions. These two groups of patients were excluded from further statistical calculations, as both of them demonstrated no changes after decompression.

Improved visual acuity was observed in 31.4% of patients with visual impairment, while visual acuity remained at the preoperative level in 47.1% of patients. Considerable deterioration was observed only in 7% of patients. In 1 case with high preoperative visual functions a moderate decrease in visual function followed by rapid recovery was observed.

An improvement in visual function was observed in 22.7% of patients in the total study group; stable visual functions, in 60.8% of patients.

The postoperative outcome depended on the duration of preoperative symptoms (Fig. 8) and the stage of the ON disc changes according to fundoscopic examination (Fig. 9).

Patients with improvement had a shorter period of clinical symptoms (12 (6; 24) months), as compared to those who had no improvement (24 (12; 66) months). In addition, patients with improved visual function in the postoperative pe-
period demonstrated earlier stage of optic disc changes during preoperative examination.

Patients’ age, severity of visual impairment in the preoperative period and the degree of OC involvement did not correlate with visual function outcome.

No surgically associated deaths were recorded in the study group.

Persistent oculomotor deficit developed in two patients.

Discussion

Tumor spread into the OC in patients with cranioorbital neoplasms has been discussed in many publications. However, these studies mainly focus on meningiomas of the sellar tubercle. Meanwhile, the spread into OC may be represented in a wide group of tumors of different histological nature and localization (the base of the anterior cranial fossa, the tubercle and diaphragm of sella turcica, wings of the sphenoid bone, cavernous sinus and the external part of the middle cranial fossa, orbit and sphenoid sinus).

According to the literature, the frequency of pronounced visual disturbances does not exceed 5% in cases of optic nerve compression outside the canal [3]. Meanwhile, the spread into the OC is the most common way of optic nerve exposure that causes disturbance of visual function in this group of patients. In our study, 56 (57.7%) of 97 patients had low (<0.1) visual acuity due to spread of the tumor into the OC according to neuro-ophthalmic examination. Therefore, both radical tumor resection and OC decompression play a crucial role in achieving optimal clinical outcome.

The need for OC decompression, execution time of decompression during surgical treatment, and the method of OC decompression were being discussed as early as over 130 years ago [11]. These questions still remain debatable [3]. Many authors [10, 12, 22] suggest extradural approach and decompression at early stage of surgical treatment, relying on the data on the favorable clinical outcome, high final visual acuity, and good surgical results. It is argued that early release of the optic nerve enables safe manipulations in its proximity during tumor resection [20, 22]. Furthermore, extradural clinoidectomy expands the surgical corridor and increases the viewing angle in the surgical wound, thus providing an additional advantage [12, 17]. This is particularly important when removing large tumors with significant lateral spread and involvement of the cavernous sinus. Wider approach allows the surgeon to carry out manipulations from more favorable positions, provides better visualization of the internal carotid artery and its branches. Other authors [16, 27] mention the importance of removing the tumor from the medial region of the OC to achieve good result in visual acuity, indicating that this part cannot be removed extradurally.

Based on our experience, none of the methods can be used alone for OC decompression. First, the decision heavily depends on tumor localization and its spread into the OC. Tumors located mostly lateral to the optic nerve (75% according to our study), such as meningiomas of the wings of the sphenoid bone, tumors of the cavernous sinus, the external part of

![Fig. 6. Resection of the anterior clinoid process.](image)

1 — optic nerve, 2 — anterior clinoid process, 3 — lesser wing of the sphenoid bone.

![Fig. 7. Clinical presentation of the disease.](image)
the middle cranial fossa and the lateral parts of the orbit, usually lead to compression of the optic nerve from its lateral and upper walls. The best and at the same time minimally invasive approach to these tumors is provided by osteoplastic lateral orbitotomy with extradural removal of the anterior clinoid process and OC decompression. The orbitozygomatical access is appropriate in case of propagation of the process from the OC to the inferior orbital fissure, pterygopalatine and infratemporal fossa. Difficulties may arise in connection with a large number of anatomical variants of this complex area. However, extradural removal of the anterior clinoid process and OC decompression are currently routine procedures that can be performed quickly and safely enough.

Tumors located predominantly medially to the optic nerve (25% in our series), such as tumors of the base of anterior cranial fossa, jugum sphenoidale and tubercle of the sella turcica, are usually removed through the unilateral subfrontal, pterional or bilateral subfrontal approaches. They usually spread into the OC medially and/or superiorly and have a greater chance of bilateral propagation (4% in our series). Intradural decompression provides good decompression of the medial part of the OC in such a situation, which is difficult to achieve extradurally.

The transnasal OC decompression technique is a new one, but it has already shown its advantages in recent years. This technique combines the traditional transnasal approach to the sphenoidal sinus structures (as in the case of removing pituitary tumors) and removal of the structures forming the medial and superomedial walls and floor of the OC [21]. The advantages of this technique include less traumatic surgery combined with the possibility to perform more advanced OC decompression. Furthermore, M. Locatelli and A. Kassam [18] suggest that, in most cases, transnasal approach provides better visualization and hence is potentially more secure. In our practice, tumor resection and OC decompression were performed using the transnasal endoscopic approach in 9 cases with medial loca-

**Table 3. The condition of visual function in examined patients in pre- and postoperative period**

<table>
<thead>
<tr>
<th>Degree of visual impairment</th>
<th>Preoperative period (number of patients)</th>
<th>Postoperative outcome (number of patients without the dynamics of visual function in the group)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Norm</td>
<td>10</td>
<td>18 (10)</td>
</tr>
<tr>
<td>(1&gt;x&gt;0.1)</td>
<td>31</td>
<td>25 (17)</td>
</tr>
<tr>
<td>(x≤0.1)</td>
<td>21</td>
<td>18 (10)</td>
</tr>
<tr>
<td>(x≤0.01)</td>
<td>18</td>
<td>10 (6)</td>
</tr>
<tr>
<td>Blindness</td>
<td>17</td>
<td>26 (16)</td>
</tr>
</tbody>
</table>

**Fig. 8. Relationship between the postoperative outcome and duration of preoperative symptoms.**

\[ r=-0.28, \ p=0.03 \]
OC decompression was carried out from the intraorbital portion of the OC to the projection of the midpoint of the chiasm onto the chiasmat groove at the expense of the medial wall, floor and partially roof of the canal and adjacent structures of the skull base.

The main disadvantages of this technique include the risk of nasal liquorhea in the postoperative period and the risk of damaging the great and perforating vessels in the case of the medial approach.

The risk of nasal liquorhea is in most cases associated with well-developed prechiasmatic cistern (Guthikonda, 2010). There were no cases of significant dura mater defects or nasal liquorhea in our series of transnasal decompressions.

The risks of damaging the great vessels are primarily associated with misorientation in the wound during the surgical approach or when performing decompression in such a situation when the classical landmarks on the way towards the optic nerve cannot be identified or visualized, as well as in situations when these landmarks are displaced, changed or destroyed due to tumor growth or previous surgeries. However, it is not an absolute limitation of the approach when using modern navigation methods. We used Fiagon magnetic navigation systems in two cases because of obscure anatomical landmarks and in one case because of tumor spreading accompanied by extensive bone destruction. Magnetic navigation allowed us to clearly identify the localization of critical structures and to perform full-scale decompression.

Thus, when carefully studying the patient’s radiological data at the surgery planning stage and using the well-proven transnasal approach and intraoperative magnetic navigation, we had no complications associated with damage to the critical chiasmosellar structures in our practice of transnasal optic nerve decompression.

Full-scale optic nerve decompression includes excision of bony walls of the canal, dissection of the falciform ligament, and, in some cases, dissection of the optic nerve sheath. The latter stage of the operation is the most controversial one because of the risk of liquorhea [6, 18]. It is important to implement these three conditions to ensure a good clinical outcome. Advocates of mandatory nerve sheath dissection use adhesive compositions to prevent liquorhea [7]. In our series we used optic nerve sheath dissection only in 7 cases, when clear visual changes in the sheath surface were observed or a tumor fragment was suspected to localize directly under the sheath.

Extradural decompression sometimes is not sufficient and should be complemented with the intradural one. Terms of intradural decompression are determined by tumor size, its relation to the optic nerve and the possibility of tumor dissection in the contact area [3, 12]. Early decompression without clear visualization of the dissection plane may lead to disruption of blood supply to the optic nerve and, as a consequence, to ischemic damage to the optic nerve, which in most cases results in irreversible blindness. According to our observations, it is usually easier to start the dissection from the chiasm to-

![Fig. 9. Relationship between the postoperative outcome and the stage of optic nerve changes according to fundoscopic examination.](image-url)
wards the entrance of the nerve into the OC. This method provides easier dissection by arachnoid spaces visualized in the area of chiasm and also makes it easier to visualize and preserve sources of blood supply to the optic nerve and chiasm.

The structures of the frontal portion of the optic tract are very vulnerable sources of blood supply. The intracranial portion of the optic nerve and chiasm receive supply from perforating arteries that run directly from the vessels of the frontal part the Willis’ circle. These perforates are the only source of blood supply to the fibers of the lower portion of the chiasm [5, 15]. The intraorbital and intracanal parts of the optic nerve receive blood supply from the central retinal artery directly or through its smaller branches. [18] These vessels are very vulnerable and prone to spasms even after a minor injury. In addition, the risk of vasospasm after rough manipulation plays an important role. Rapid progressive decrease in visual acuity within a day after the operation in one of our observations is likely to be associated with vasospasm caused by manipulations near the optic nerve.

Some authors [1, 10] suggest the use of the pterional approach; however, many authors [12, 25] believe that it does not provide sufficient viewing angle, requires greater traction of the brain, which leads to difficulties in removing tumors affecting the dura mater and the bone structures. Therefore, the cranio-orbital approach has undeniable advantages.

According to the results of our work, the supraorbital and orbitozygomatic approaches to the skull base provide the desired visibility while being safe. In addition, they do not increase the morbidity. The advantages of these approaches include the sufficient viewing angle of the zone of interest in conjunction with the minimal traction of the brain due to the presence of additional space owing to resection of the orbital walls and cautious traction of its contents. These approaches provide several corridors for manipulations and may increase the likelihood of complete resection of the tumor with intradural and intracranial proliferation. In our series, total removal of the tumor was achieved in 54 (56%) cases and subtotal, in 40 (41%) cases.

Optic nerve decompression and tumor removal from the OC play an important role in achieving optimal clinical outcome and increasing surgery radicality. Many authors [19, 24] suggest that tumor recurrence in such a situation is associated with non-radical removal of OC tumor in the previous surgery. In our series of observations, seven patients who had not been subjected to OC revision during the first surgery were operated on. In addition, signs of visual impairment may be significantly delayed in rarely observed relapses after previous OC decompression due to the absence of risk of nerve compression in the narrow bone canal.

Our study has demonstrated that adequate optic nerve decompression is an effective method for preservation (47.1%) or improvement (31.4%) of visual function in the postoperative period. Despite the rather aggressive resection of bone structures during optic nerve decompression, the morbidity associated with the surgical treatment is minimal.

According to many authors [9, 13, 27, 28], factors affecting the treatment outcome include patients’ age, tumor size, degree of visual disorders in the preoperative period, and the duration of symptoms.

According to our study, the severity of visual impairment in the preoperative period, tumor size and patients’ age did not influence the clinical outcome (postoperative visual acuity). Restoration of visual function after surgery correlated with the duration of visual impairment in the preoperative period. Patients with a shorter medical history had significantly higher chances of visual function recovery after surgery (Fig. 10). Significant correlation between the probability of regression of visual impairment in the postoperative period and the stage of optic disk changes in patients with visual acuity >0.1 was revealed.

Conclusions

1. Optic nerve decompression and resection of tumor spreading in it are extremely important stages of surgical treatment of these neoplasms. They are of key importance both for preventing the relapses and providing optimal clinical outcome.

2. In our study we have revealed a group of factors that enable preoperative prediction of the effectiveness of optic nerve decompression. These factors include the duration of visual impairment in the preoperative stage and optic disk changes.

3. The choice of surgical approach depends on tumor localization (medial, lateralized or lateral), predominant location (extra- or intracranial), and the direction of optic nerve compression in the canal (from above/outside or medially/ below) and is a debated issue that requires further research to develop a differentiated algorithm.

REFERENCES


Decompression of the optic nerve in the canal was suggested in the late 19th century, but the great interest to this topic has arisen and has been persisting since the 1960s. Development of surgical techniques and modern endoscopic technology enabled elimination of optic nerve compression from all directions. Nevertheless, plenty of questions still remain open. What decompression length is required? Is decompression achieved by sole resection of the bony structures of the canal effective? Is resection of the optic nerve sheath required? What canal segment should be subjected to decompression to achieve the best outcome? Is decompression of the optic canal required and in which situations? It is extremely difficult to conduct statistically significant studies even taking into account the concentration of patients with compression of the optic nerves in one neurosurgical center. The study presents the results of various types of decompression at the expense of the lateral, medial and superior walls of the canal in 97 patients with tumors of different histological natures of propagating into the OC. The study focuses on identifying the relationship between the surgical treatment outcomes and some preoperative factors. As for drawbacks of this study, the effectiveness of decompression itself has been proved long ago; however, the nuances for surgical technique providing the best results are still a very controversial issue. In my opinion, it is a significant drawback of the work. No algorithm for deciding in favor of surgery has been proposed. The surgical technique of optic nerve decompression through various surgical approaches itself is described poorly, although this section could be one of the main ones in the article. It is also noteworthy that there almost no data on complications and their statistical data have been reported. The complication rate is up to 10% even in the best world series of observations (Prevedello et al., Pittsburgh). In my opinion, it is appropriate to compare the results of stereotactic radiation therapy of meningiomas and surgical treatment. Overall, the study is, perhaps, the largest series of decompressions published at the moment. The identified regularities will allow for predicting clinical outcomes of surgical treatment, while description of the surgical technique will allow one to clearly define the indications for the choice of surgical approach.

A.Kh. Bekyashev (Moscow)
Endoscopic Assistance in Surgery of Cerebellopontine Angle Tumors

V.K. POSHATAEV, V.N. SHIMANSKY, S.V. TANYASHIN, V.V. KARNAUKHOV

Burdenko Neurosurgical Institute, Moscow, Russia; Clinical Hospital №1 of the Administration of the President of the Russian Federation, Moscow, Russia

A total of 33 patients with cerebellopontine angle tumors underwent surgery using different types of endoscopic assistance at N.N. Burdenko Neurosurgical Institute (Moscow, Russia) during the period of 2010–2012. All patients were operated on through the retrosigmoid suboccipital approach in semi-sitting and prone positions. 30° and 70° endoscopes were used during the surgery. Endoscopic assistance allowed us to increase the completeness of tumor removal and to reduce the risk of postoperative complications by retaining the anatomic integrity of cranial nerves and vascular structures in the base of the posterior cranial fossa. These benefits made it possible to maintain and improve quality of life in patients with CPA tumors in the postoperative period.

Keywords: endoscopic assistance, acoustic neuroma, vestibular schwannoma, meningioma, cholesteatoma, cerebellopontine angle.

The endoscopic technique is currently one of the topical issues in surgery of the skull base tumors. Over the past 10 years, there has been an increased interest in studying the efficacy of endoscopic assistance (EA) in surgery of tumors of the posterior cranial fossa (PCF) and, in particular, cerebellopontine angle (CPA) tumors. Despite the large number of publications on this topic [1—10], no consensus has been reached regarding the use of endoscopy in surgery of tumors of this region. However, only a small percent of publications compare the results obtained using endoscopy with similar groups of patients according to nosological characteristics, where no endoscopic assistance was used.

The objective of this study was to perform a comparative and descriptive analysis of treatment outcomes in patients with CPA tumors who underwent surgical treatment using EA.

Material and Methods

The study included a series of 33 patients (24 females, 9 males) aged 15—68 years (mean age 44 years), who underwent surgery for cerebellopontine angle tumors using endoscopic assistance in the N.N. Burdenko Neurosurgical Institute in 2010—2012. The series included 23 (70%) patients with vestibular schwannomas, 4 (12%) patients with differently localized meningiomas of PCF, 5 (15%) patients with epidermoid cyst, and 1 (3%) patient with lipoma of the CPA. The patients were prospectively included in the study group provided that the tumors were resected by a single team of surgeons. The main exclusion criteria were severe somatic diseases, whose presence could affect the outcome of surgical intervention, regardless of the features of surgical intervention. Patients’ data are given in Table 1.

The control group of patients who underwent the resection of CPA tumors without endoscopy was formed to analyze the effectiveness of the EA in removing CPA tumors. This group included 25 patients with acoustic neuroma and 5 patients with PCF meningioma (9 males and 21 females aged 15—70 years, mean age, 47.4 years). All patients in the control group were also operated on in 2010—2012 in the N.N. Burdenko Neurosurgical Institute (see Table 1).

All patients underwent magnetic resonance imaging (MRI) of the brain. In patients with vestibular schwannomas and meningiomas spreading into the internal auditory canal, computed tomography (CT) was performed in the “bone” mode to assess the internal auditory canal (IAC) on the side of the tumor and to visualize the position of the superior bulb of the internal jugular vein.

Rigid 30° and 70° endoscopes with the Hopkins rod-lens system 2.7 mm in diameter and 12 cm long were used for EA. A mechanical locking mechanism was used in 5 cases to fix the endoscope when performing endoscopically controlled manipulations.

Statistica for Windows v.10 software package was used for statistical analysis. The outcomes of surgical treatment were processed. The following methods were used for analysis: χ², Pearson’s χ², maximum likelihood χ², etc. for contingency tables. The generally accepted value p < 0.05 was used as a criterion of statistical reliability of the data.

Results

All patients in our series underwent surgery through the retrosigmoid suboccipital approach; the surgery was performed in patient in the semi-sitting position on the operating table. The facial nerve stimulator (Medtronic NIM 3.0) was installed in 23 cases when preparing the patients for the surgery. The installation procedure requires neither special neurophysiological equipment nor the presence of a specialist in the operating room. An endoscopy equipment rack was also prepared prior to the surgical approach, taking into account the length of the optical fiber and the cable of the endoscope camera.

Endoscopic inspection of the resected tumor bed and the lumen of the IAC was performed after the main phase of the
intervention (resection of the major part of the tumor and trepanation of the posterior wall of the IAC) to control the completeness of resection of the intracanal part of the tumor. No inspection of the posterior wall of the IAC was required when removing epidermoid cyst of CPA. However, control over arachnoid cisterns was required to detect any residual tumors. If any neoplasm remainders were detected in CPA cisterns, they were removed under endoscopic control. In addition, the position of the facial nerve fibers was monitored under endoscopic control when needed. It should be noted that the endoscopic inspection has eliminated the need for additional retraction of the cerebellar hemisphere and manipulation with neurovascular structures for inspecting CPA cisterns, obtaining an additional viewing angle and enhancing illumination of the surgical wound.

We managed to apply EA in all patients of the main study group. In one case episodes of unstable hemodynamics accompanied by a significant decrease in blood pCO2 were observed after the parastem part of cholesteatoma capsule had been removed. This circumstance made it necessary to promptly perform the final phase of the surgery and hindered the full-scale endoscopic inspection of CPA cisterns.

It should also be noted that the residual tumor was found in 23 cases when EA was carried out without extra traction of the cerebellum. The residual part of the tumor was resected in 18 patients. In one case, total resection of the tumor was hindered because of the presence of pronounced tumor matrix invading into IAC in a patient with meningoima of the posterior surface of the petrous pyramid of the temporal bone. In another case it was because of the extremely tight adhesions of the tumor capsule to the root of the facial nerve in a patient with vestibular schwannoma. Both endoscopic exploration of the tumor bed and endoscopically controlled surgical procedures (tumor resection, location of the facial nerve at the point of its entrance into the IAC, etc.) were used in all cases of additional tumor resection.

The total tumor resection was achieved in 72% of cases in this group. The factors hindering total resection of the tumors were not related to specifications of microsurgical technique or endoscope, but rather to the characteristics of tumor growth, its spread to the skull base and intimate adhesion to the neurovascular structures. The latter fact was detected only with EA in all cases.

More importantly, in 70% of cases only EA allowed us to reveal tumor remainders. For example, in patients with vestibular schwannomas it was this technique that allowed us to detect residual tumor in IAC at the intraoperative stage, ensure safety of the planned additional reaming of the IAC posterior wall, and remove tumor remainder under endoscopic control. In patients with CPA cholesteatoma, this technique allowed to reveal and remove tumor fragments that were inaccessible to the microscopic field of view (they were often found on the posterior surface of cranial nerve roots).

These manipulations were also undoubtedly important for preventing postoperative aseptic meningitis.

When comparing the groups of patients in terms of the incidence of facial nerve palsy, this complication was more common in patients in the control group (p=0.0035). The House–Brackmann score of 1 to 2 was suggested as a favorable outcome, while the other results (score of 3—6) were regarded as significant development of facial nerve palsy.

Less radical tumor removal was also observed in the control group (57%). Tumor remainder was detected according to the control MRI as compared to the study group (30% of surgeries were characterized as subtotal), p=0.0179 according to the χ² test (Table 2).

The assessment of the outcomes according to Karnofsky scale has shown that the median quality of life index was 75.33 in the control group (standard deviation ± 8.60), while being 80.6 in patients of the main group (Fig. 1). The Mann–Whitney test has shown that this difference is statistically significant (p=0.01).

**Discussion**

Plenty of illustrative studies confirming the effectiveness of endoscopy in surgery of CPA tumors have been published in world literature [1—3, 5, 8, 9]. The possibility of inspecting the zones that turn out to be “blind” for microscopic examination (in particular, IAC) is the main advantage of this method. Several authors [4] have also hypothesized that resection of the posterior wall of the IAC is optional if EA is used. It should be noted that this suggestion is valid only for tumors minimally spreading into the IAC. Since there were no such patients in our series, trepanation of the posterior wall of IAC was required in 100% of cases.

Despite the large number of publications, the studies comparing the treatment outcomes with and without the use of EA are very scarce. Moreover, there are no publications discussing the results obtained in mixed groups of patients over the last

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**Table 1. Comparative characteristics of the study and control groups**

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Study group (EA)</th>
<th>Control group (no EA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (median), years</td>
<td>44</td>
<td>47.5</td>
</tr>
<tr>
<td>Sex (M/F)</td>
<td>9/24</td>
<td>9/21</td>
</tr>
<tr>
<td>Preoperative Karnofsky score (median)</td>
<td>80</td>
<td>76.5</td>
</tr>
<tr>
<td>Vestibular schwannoma</td>
<td>23</td>
<td>25</td>
</tr>
<tr>
<td>Meningioma</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Cholesteatoma</td>
<td>5</td>
<td>0</td>
</tr>
</tbody>
</table>

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10 years. This fact can partly explain the absence of clear indications for EA depending on tumor type. According to Y. Kumon et al. [6], both more radical surgical intervention and fewer relapses during the postoperative period were observed in the group where this method was used. The authors have found no statistically significant differences in the frequency of preservation of “useful” hearing and facial nerve function. We have found such a difference in our series (p<0.05), which had its effect on the comparative outcomes of the surgeries in terms of patients’ quality of life. Preservation of the facial nerve function was also important because most of the patients operated on were women.

Based on these results, we have elaborated an EA algorithm for resecting CPA tumors (Fig. 2). Primary inspection of neoplasms in this position is possible only when tumors are smaller than 20 mm in size. Furthermore, it is often difficult to use the endoscopic technique to remove large and giant tumors because of significant bleeding. Since the existing tools cannot enable effective hemostasis using only an endoscope, the surgeon has to return to the standard microsurgical technique. Moreover, the use of EA is inappropriate in case of large tumors, since surgical treatment is initially assumed to be subtotal.

The maximum effectiveness of EA was observed for surgery of epidermoid cyst of CPA. This is due to the features of the postoperative tumor bed. The deformed brain retains its position throughout the operation and thereby forms the space required for inspection. Endoscopy enables detection of tumor fragments in IAC cisterns that are inaccessible for inspection with an operating microscope (Fig. 3). Application of this pro-

Table 2. Comparative characteristics of the outcomes of surgical treatment in the study and control groups

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Study group (EA)</th>
<th>Control group (no EA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total resection, %</td>
<td>72</td>
<td>61</td>
</tr>
<tr>
<td>VIII cranial nerve paresis</td>
<td>18</td>
<td>40</td>
</tr>
<tr>
<td>Postoperative Karnofsky score (median)</td>
<td>81</td>
<td>75</td>
</tr>
</tbody>
</table>

Fig. 1. Comparison of the outcomes in the study and control groups according to the Karnofsky score.

Fig. 2. EA algorithm.
Fig. 3. The stages of tumor resection.

a — tumor size reduction; b — general view of the surgical wound after the main body of the tumor had been resected; c — endoscopic inspection of CPA cisterns (70° endoscope) — tumor remainder was found on the posterior surface of the facial nerve; d — resection of tumor remainder; e — endoscopic control: no data indicating the presence of the residual tumor; e — general view of the surgical wound after the tumor mass had been removed.
**Fig. 4. Stages of tumor resection.**

a — tumor size reduction, identification of the facial nerve; b — trepanation of the posterior wall of the internal auditory canal; c — resection of the intracanal meningioma; d — identification of CN VII in the auditory nerve channel; e — endoscopic view of the skull base (70° endoscope); f — control of CN VII integrity (endoscopic view).
Рис. 5. Stages of tumor resection.
a — general view of CPA: vestibular schwannoma with the root of facial nerve spreading on its surface can be seen (there is an electrode of NIM stimulator on the nerve); b — the stage of tumor resection; c — surgical wound view: no residual tumor is detected; d — endoscopic inspection of the cerebellopontine angle cisterns (30° endoscope): tumor remainder was found adjacent to the facial nerve; e — resection of the residual tumor from the posterior surface of the facial nerve; f — control of the completeness of tumor resection and examination of the internal auditory canal (endoscopic view). The tumor was totally removed.
procedure in case of resection of vestibular schwannomas allowed one to inspect the IAC and remove tumor remainders when they were found, thereby achieving higher radicality of surgical treatment. Inspection of the area of trepanation of the IAC posterior wall to detect bone defects made us apply preventive measures to avoid liquorreha and in some cases perform plastic repair of the resulting defects (Fig. 4). When removing meningiomas of the posterior surface of the temporal bone, including those spreading into the IAC, endoscopy allowed us to estimate the degree of invasion of the tumor tissue into the bone structures, as well as to find the source of bleeding, which often falls out of the “field of view” of the microscope (Fig. 5).

Surgery radicality depended not only on tumor size and its relation to the brain structures, but also on the degree of neoplasm invasion into the IAC.

EA was an efficient way to identify the residual tumor; in some cases it was endoscopic inspection that changed the surgery tactics because of the increased risk of cranial nerve trauma as a result of further tumor resection.

The EA is an effective technique used in CPA tumor surgery. It enables safe CPA inspection, assessment of the radicality of tumor resection and the extent of bone resection in the case of IAC trepanation. These features reduce the risk of postoperative complications and allow one to achieve higher radicality of oncotomy, and therefore preserve and, in some cases, improve patients’ quality of life.

Certain experience is required for simultaneous using microsurgical equipment and an endoscope; furthermore, special perception is required for endoscopic view of CPA anatomy. Therefore, our first experience confirms the need for special training.

REFERENCES


Commentary

This study is the first one in Russian literature that has distinguished the groups of patients in which the use of endoscopic assistance in surgical treatment of cerebellopontine angle tumors is indicated, is advisable and is ineffective. The schemes of preparing the operating room and the endoscopic assistance technique at different stages of tumor resection have been discussed.

The author reports the scheme of the procedure, illustrates the effectiveness of the method in cerebellopontine angle tumor surgery, which is related to the possibility of intraoperative control of the radicality of tumor resection, as well as inspection of cerebellopontine angle structures without additional traction of the cerebellar hemisphere.

The study has demonstrated the possibility of intraoperative control of the radicality of tumor resection and inspection of cerebellopontine angle areas with restricted visibility to reduce the development of postoperative complications. The effectiveness of endoscopic assistance in surgery of cerebellopontine angle tumors has been proved.

The information provided in the article by V.K. Poshataev et al. is relevant to neurosurgeons, as well as specialists in related disciplines, i.e. oncologists, neurologists, and radiologists.

A.O. Gushcha (Moscow, Russia)
PET using $^{11}$C-methionine in recognition of pseudoprogression in cerebral glioma after combined treatment

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The purpose of the study was to evaluate the value of PET using $^{11}$C-methionine (PET-Met) for distinction between true glioma progression and pseudoprogression (PsPr). 72 patients with treated cerebral glioma investigated by PET-Met were identified from prospective database. Entry criteria included new or progressive MR imaging enhancing lesions within first 6 months after irradiation and definite final diagnosis on the basis of the pathological study (n=17) or clinical-radiological follow-up on an average 16 months. PET examinations were assessed by visual inspection and calculating $^{11}$C-methionine uptake index (UI).

Results. Pseudoprogression was defined as early radiological progression with subsequent regress or stabilization, without salvage therapy. 42 patients were considered to exhibit PsPr and 30 patients had true glioma progression. In PsPr group PET scans were either negative (n=6) or slightly increased tracer uptake (UI range 1.2—2.0) was seen in the site of contrast-enhanced lesion. The UI was 1.48±0.39 (mean±SD). In comparison with pretreatment PET 15 patients showed decrease $^{11}$C-methionine uptake on an average by 26%. In recurrence group PET-Met showed abnormal high focal $^{11}$C-methionine uptake in the lesion. The UI was 2.54±0.84 (range 1.54—5.4). An UI threshold value of greater than 1.9 optimized differentiation between glioma progression and PsPr with sensitivity of 83.5% and specificity of 97.0%. Conclusion. Metabolic characteristics of PsPr included negative tracer accumulation or slightly increased $^{11}$C-methionine uptake in the contrast-enhancing lesion with UI less than 1.9.

Keywords: PET, $^{11}$C-methionine, pseudoprogression, recurrent glioma.

The current standard of care for patients with malignant cerebral gliomas, primarily glioblastomas (GBs), includes the maximum possible amount of tumor resection followed by radiation therapy (RT) with the concomitant or adjuvant use of cytotoxic drugs, most commonly temozolomide (brand name temodal). During the period from 2000 to 2010, this approach increased 2-year survival of glioblastoma patients from 10 to 40% [13]. At the same time, it was found that the dynamic control, in the nearest months after RT completion, using magnetic resonance imaging (MRI) with the contrast enhancement (CE) technique may reveal neuroradiological signs of edema and contrast rising in the resected tumor bed. Approximately in half of these patients, contrast rising reflects true tumor progression. However, in the other half, CE eventually decreases or remains constant while continuing the same therapy, which indicates the transient nature of disorders [4]. This paradox, known as pseudoprogression, is often observed with addition of temodal during radiation regimen, but can develop after isolated RT or radiosurgery [5, 9, 16]. For the first time, the phenomenon of transient radiological changes was mentioned by W. Hoffman et al. in 1979 [12] and was more fully described in the publication by M. De Wit et al. in 2004 [10]. Studies in recent years, in the era of the new standard of glioblastoma treatment using temodal, have demonstrated that the frequency of pseudoprogression is 19—28.9% of the total number of patients [15, 20—22]. Usually, pseudoprogression occurs within the first 3 months after completion of treatment (60% of patients), but it can also develop in a period of several weeks up to 6 months after radiotherapy [8]. Pseudoprogression is a serious clinical problem that significantly complicates the diagnosis of continued growth of cerebral tumors and the tactics of patient treatment. Traditional neuroradiological methods do not allow differentiating between true tumor progression and pseudoprogression [23]. Currently, the most affordable and conventional method to differentiate between these states is dynamic MRI control. An analysis of serial MRI examinations documents the phenomenon of pseudoprogression in the case of reducing the contrast area or its disappearance. The use of functional techniques of MRI or positron emission tomography (PET) is promising, however, the assessment of their informative value in solving one of the key problems in monitoring of glioma treatment has just begun [14, 18].

The aim of this work was to develop metabolic criteria for pseudoprogression of brain gliomas using PET with $^{11}$C-methionine and to study the informative value of the method for differentiation between true glioma progression and pseudoprogression.

Material and Methods

A prospective analysis of the results of PET with $^{11}$C-methionine was performed in 72 patients (35 males and 37 females) aged from 3 to 68 years (36±19 years) with brain gliomas after combined therapy of the primary tumor (54 patients) or its continued growth (18 patients). The inclusion criteria were signs of the early development of radiological progression in the primary tumor bed in the form of the emergence or increase of CE during a MRI examination in the period from 1 to 6 months after RT completion. The first PET examination in 23 patients was performed before treatment. In the remaining 49 cases, it was performed, if continued tumor growth was suspected. The final diagnosis was based on the
Clinical and radiological characteristics of patients with pseudoprogression and continued growth of glioma

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>pseudoprogression</th>
<th>continued growth of glioma</th>
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<tbody>
<tr>
<td>Histostructure of glioma, abs.:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>benign glioma</td>
<td>11</td>
<td>6</td>
</tr>
<tr>
<td>An. ASC/ODG/ependymoma</td>
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<tr>
<td>Previous treatment, abs. (%):</td>
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<tr>
<td>RT and CT</td>
<td>9 (21.4)</td>
<td>6 (20.0)</td>
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<td>RT and temodal</td>
<td>21 (50.0)</td>
<td>12 (40.0)</td>
</tr>
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<td>RT</td>
<td>6 (14.3)</td>
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<tr>
<td>RS</td>
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<tr>
<td>CE localization, abs. (%):</td>
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<td></td>
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<tr>
<td>near postoperative cyst</td>
<td>18 (42.9)</td>
<td>13 (43.3)</td>
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<td>13C-methionine UI (mean ± standard deviation)</td>
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<td>2.54±0.84</td>
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<tr>
<td>Observation, months (mean ± standard deviation)</td>
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<td>8.4±5.5</td>
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<td>progression of tumor</td>
<td>12</td>
<td>19</td>
</tr>
<tr>
<td>death</td>
<td>0</td>
<td>9</td>
</tr>
</tbody>
</table>

Footnote. An. — anaplastic; ASC — astrocytoma; ODC — oligodendrogliaoma; RT — radiation therapy; CT — chemotherapy; RS — radiosurgery.

results of a histopathological examination after repeated operation (n=16) or autopsy (n=1) as well as the results of follow-up, including MRI and PET. The mean follow-up period after detection of the radiological progression of glioma was 16±10 months (from 1 to 44 months). A total of 225 PET examinations were performed.

PET examinations were performed on a Scanditronix PC 2048 positron emission scanner (Sweden) designed to scan the head. The scanner enables simultaneous acquisition of 15 axial slices with the interslice distance of 6.5 mm. The spatial resolution of the camera was 6.5 mm. The studies were conducted in the dynamic or static scanning mode. The correction of emission data for the heterogeneity of medium permeability to gamma ray was performed using software. Some patients were examined on Philips Gemini TF positron emission and computed tomography (PET-CT) scanners with the PET scanner spatial resolution of 5 mm.

A radiopharmaceutical drug (RPD), L-(methyl-13C)-methionine (13C-methionine) was synthesized in the radiochemical laboratory of this Institute by methylation with L-homocysteine thiolactone and isolation of the final product by solid phase extraction [1].

An image analysis was performed on a workstation using software developed specially for the scanner. Resulting PET images were visually evaluated as positive or negative based on the 13C-methionine accumulation level in accordance with the location of a positive contrast lesion on MRI scans as well as in other brain structures. The level of RPD accumulation exceeding that of the unaffected brain portions was considered positive (elevated). A semi-quantitative analysis was to determine the uptake index (UI) for 13C-methionine that was calculated by dividing the RPD concentration in the region of interest by the activity value in the contralateral cortex.

A statistical analysis included descriptive statistics for all variables: the calculation of group mean values, standard deviation, and median. Conventional indicators of the method informative value were calculated according to standard formulas. To evaluate the statistical significance of quantitative indicator differences between the selected groups, the non-parametric Mann-Whitney test was used. The level of p<0.05 was considered as significant.

Results

The mean term for emergence of signs of the radiological progression on MRI scans after RT completion was 3.7±1.8 months (median of 4 months). Based on the final diagnosis, patients were divided into two groups: the changes were considered as pseudoprogression in 42 patients, and true progression of glioma was diagnosed in 30 patients.

Pseudoprogression is defined as an early radiological progression in the area of the primary tumor localization, usually followed by regress or stabilization of the changes based on the results of follow-up for at least 6 months. In 39 patients, the
previously selected chemotherapy or surveillance was con- 

tinued. In 3 patients, bevacizumab was additionally used for treat-

ment. Upon true tumor progression, patients had unsatisfactory 

outcome with the neurological deficit progression as well as 

radiological and metabolic disorders with the spread of lesions 

into the adjacent portions of the brain or histologically con-

firmed tumor growth. The main characteristics of the groups 

are summarized in the Table.

In the group of patients with pseudoprogression, the PET 

results were negative in 6 patients (Fig. 1). In the remaining 

36, moderately increased uptake of $^{11}$C-methionine in the area 

of positive contrast cerebral lesion was observed. UI was within 

1.2—2.0 often in combination with an ametabolic region, 

caued by necrosis, coinciding in the localization with the 

contrast region on a MRI scan. In 12 patients who were exam-

ined before treatment and during the radiological progression, 

a reduction in the level of $^{11}$C-methionine tumor uptake oc-

urred by 26%, on average, with a possible decrease in the 

lesion size due to the lack of RPD accumulation in the area of 

radiation injury (Fig. 2). A histopathological examination after 

re-operation in 6 patients demonstrated a combination of ra-

diation pathomorphism and individual glioma cells.

Follow-up results. According to the PET data, 38 patients 

were observed with regress or stabilization of positive contrast 

anomalies on the MRI scan and the metabolic activity in the 

region of interest in the first 6 months of follow-up. Despite 

the fact that the early RT effect is usually transient in nature, 

4 patients had augmentation of radiation injury in the form of 

CE progression with the development of large radiation ne-

crosis or the emergence of new lesions of postcontrast en-

hancement of the MRI signal. 12 patients developed local 

($n=8$) or distant ($n=4$) continued glioma growth in 18 months, 

on average, (range of 13 to 44 months) after the first PET.

30 patients were diagnosed with true progression of the 

tumor in the form of a large lesion of high $^{11}$C-methionine 

uptake that coincided in the location with the contrast area on 

the MRI scan (Figs. 3, 4). $^{11}$C-methionine UI ranged from 1.54 

to 5.4 and was statistically significantly different from that in 
pseudoprogression (Fig. 5). Upon comparison with the PET 

pattern obtained prior to treatment or in the immediate post-

operative period ($n=11$), the emergence of a new site of high 

RPD uptake, when the previous PET pattern after total glioma 

resection was negative ($n=2$), or an increase in size of the high 

RPD accumulation site, often with a simultaneous UI increase, 

was detected.

Fig. 1. Pseudoprogression of glioblastoma.

After total resection of glioblastoma and 4 months after chemoradiotherapy, the contrast area near the wall of a postsurgical cyst of the right temporal lobe appeared on the MRI scan (a). Upon PET with $^{11}$C-methionine, negative methionine uptake eliminated progression of glioma (b). 24 months later, a significant reduction in the contrast area on the MRI scan was observed (c) with a stable negative PET pattern (d).
As it follows from the results, the metabolic characteristic of pseudoprogresion includes negative or moderately increased uptake of $^{11}$C-methionine with UI of less than 1.9 in accordance with the location of a positive contrast lesion in the MRI scan. The threshold UI value of more than 1.9 enabled differentiation between continued tumor growth and its pseudoprogresion with the sensitivity of 83.5% and the specificity of 97.0%.

Discussion

Despite wide recognition of the pseudopropgression phenomenon, this term is not clearly defined, and a pathological substrate of pseudopropgression is not completely unique. The published data, including pathological and radiological correlations, are extremely scarce. M. Chamberlain et al. [7], using a histological examination of surgical specimens of 7 patients, characterized pseudopropression as treatment-induced necrosis without signs of the tumor tissue. Given the fact of the frequent development of radiation effects in glioblastomas with methylation of the promoter region of the MGMT gene (O$^\alpha$-methylguanine-DNA methyltransferase), necrosis can be caused by highly effective chemoradiotherapy [3]. The development mechanism of this effect was proposed by A. Chakvarti et al. [6] who found that temodal enhances the glioblastoma response to radiation in the presence of methylation of the MGMT gene promoter by damaging the DNA double helix, which is a critical factor of cell death under the influence of irradiation. Monitoring of neutron capture RT with boron compounds (BNRT) revealed large necroses and individual viable cells with a low proliferative activity in tissue samples of 5 operated patients suspected for early progression of malignant glioma that allowed the authors of [17] to consider pseudoprogeness as radiation-induced intratumoral necrosis developing in the subacute phase after BNRT. The pathomorphological picture after combined treatment of glioma is known to include a combination of radiation pathomorphism of the tissue and residual/progressive tumor [19]. In the presence of tumor tissue, the precise delineation of the residual tumor and its progression is the key factor to make a decision on further treat-
Fig. 3. Continued growth of anaplastic oligodendroglioma.
MRI scan 3 months after radiosurgery for recurrent glioma of the right parietal lobe. A contrast enhancement in the intervention region was detected (a). High $^{11}$C-methionine uptake (UI=2.44), on PET (b) and combined PET/CT (d) scans, coinciding in the localization with a postcontrast increase in the MRI signal documents the true progression of glioma confirmed during reoperation.

Fig. 4. Continued growth of glioblastoma of the right temporal lobe.
MRI scan 6 months after RT with concomitant use of temodal. A new ring-contrast focus appeared in the surgery region (a, b — arrow). During PET, a focus of high $^{11}$C-methionine uptake (UI=2.0) was detected that coincided with EC, which indicates continued growth of glioblastoma (c, d — dotted arrows) verified by surgery.
ment. It is assumed that the pathological changes in pseudoprogression include elements of radiation-induced necrosis and viable tumor cells with a lower cell density and proliferative activity in comparison with a primary tumor prior to treatment [11]. This hypothesis includes two interacting pathological processes leading to pseudoprogression: transient vascular lesion and antiproliferative effect of tumor treatment. The concept of pseudoprogression is terminologically close to well-known early radiation damage of the brain, and the current concept suggests using the term “pseudoprogression” instead of early radiation damage [4].

From a practical point of view, the emergence or expansion of the contrast area in the irradiated tumor bed arouses reasonable suspicion of its progression, and determination of the origin of this phenomenon becomes the main task. Evaluation of the treated tumor metabolic status can provide substantial assistance in interpretation of the negative dynamics of the radiological picture. The use of PET with $^{11}$C-methionine upon suspicion of continued tumor growth is based on pathophysiological differences between the actively growing tumor tissue and brain responses to therapy: increased transport and metabolism of the amino acid in the proliferating tumor and, conversely, a low level of metabolism in treatment-induced brain lesions [2]. As our results demonstrated, which are consistent with the pathomorphological data, two main types of pseudoprogression are possible. After total glioma removal, the development of CE on the post-contrast MRI scan in the nearest months after RT in combination with a negative PET pattern can be considered as an isolated subacute brain’s response to chemoradiotherapy. However, in cases of incomplete glioma removal or conservative treatment of the tumor, radiation injury develops within or near the tumor residue, i.e. a combination of radiation pathomorphism and survived glioma cells occurs. In these cases, the PET examination in the region of interest detects a moderately elevated level of RPD accumulation, often in combination with an ametabolic focus caused by the development of radiation-induced necrosis. A more accurate estimation of the glioma metabolism is possible upon follow-up by comparison with baseline, prior to the start of therapy. The oncostatic and oncolytic effect of effective therapy, along with the development of therapeutic pathomorphism, causes a decrease in the metabolic glioma activity, and the divergence arises between the progression of structural pathology and regress of its metabolic characteristic. A typical combination of the increased permeability of the blood-brain barrier, which is reflected in the CE phenomenon on the post-contrast MRI scan, and the lack of high metabolism during a PET examination indicate the development of the subacute radiation reaction.

**Conclusion**

Therefore, there is currently an urgent need to select additional neuroimaging techniques that would identify glioma pseudoprogression, because incorrect interpretation of the origin of early radiological progression may lead to unnecessary and potentially dangerous surgery or undue abandonment of highly effective therapy in almost half of patients with a progressive structural lesion. In this aspect, PET with $^{11}$C-methionine is a promising biomarker for differentiating between true progression of cerebral glioma and pseudoprogression. A low metabolic tumor activity and its reduction upon the dynamic PET control allow excluding continued tumor growth and interpreting the CE development of as the radiation effect.

**REFERENCES**


It should be recognized that the present study is devoted to the actual research topic set out in the title as well as to the most modern and understudied approaches to solving problems set in the study: positron emission tomography (PET) of the brain using radiolabeled methionine.

In general, the presented data are important and allow one to clarify the situation, where clinicians and neuroradiologists can not answer the question whether it is radiation-induced necrosis or tumor progression. And yet, there are a number of important questions to the authors (debatable questions that, in our opinion, are very significant, especially within the framework of the presented topic of “pseudoprogression of glioma”).

First, pseudoprogression of glioma is a concept formulated upon the analysis of results of a study by Stupp et al. [1] on the use of temozolomide chemotherapy and radiotherapy in patients with glioblastoma. According to the concept developed in the world, the issue is an increase in the contrasted portion of a lesion (on a brain MRI scan with contrast performed for 2–3 weeks after the end of this chemoradiation therapy) within the radiation therapy area that later decreases or at least is not increased in the course of continued adjuvant therapy. A separate discussion could be suggested for this issue that, unfortunately, was not sufficiently reflected in studies of domestic authors (neurosurgeons, neurooncologists, neuroradiologists), but this discussion is beyond this commentary. However, it can definitely be inferred from the clinical data provided by the author that they are too heterogeneous regarding the use of the term “pseudoprogression”. Rather, early radiation reactions at different times after radiotherapy (this term is also used in the article) are concerned, not pseudoprogression as such.

Second, the algorithm of clinical decisions on the basis of an examination using MRI with contrast and PET with methionine is not completely clear, which patients and why were decided not to be operated on, and which patients and why were decided not to be operated on.

Third, as far as we can judge, the conclusion on the “threshold uptake index of more than 1.9” that provides a “differentiation between continued tumor growth and its pseudoprogression with the sensitivity of 83.5% and the specificity of 97.0%” is the most important. But in the light of the two above comments, it is, first, not pseudoprogression, but an early radiation reaction, and, second, it is not completely clear how this specificity of this threshold value was proved and how much it is reasonable. We are well aware, based on clinical collaboration with the authors, that when they examine patients who are under our surveillance that the uptake index of 1.6 or even 1.5 means tumor growth rather than progression. Is it really only in 3% of patients? Or we are wrong, and this specificity is related only to the early radiation reactions (according to the authors, to pseudoprogression), but not to all cases of radiation reactions?

So, without projecting the indirect discussion with the authors, we will formulate the main things, in which we agree with, and in which we do not fully agree with the authors.

The possibility of using brain PET with methionine provides us with very important, and often key, information about the “tissue events” in the area of the tumor that was subjected to surgery, radiation therapy, or chemotherapy. It should be taken into account before determining the indications for re-intervention. The tentative threshold radiopharmaceutical uptake index of 1.9 is also important data.
However, it would be incorrect to use the term “pseudoprogression” for all cases of contrasting in the area of interest in different (albeit more or less early, up to 6 months) periods after radiotherapy. This term is considered in connection with just-performed radiation (or chemoradiation) therapy; in the other periods, to our opinion, the term “radiation reaction” is more appropriate, while the terminological question of its time (early, middle, or late) should be addressed to experts of radiation therapy of gliomas. There are more questions about the threshold value. I am afraid that it is a too large threshold value, i.e., I believe that 1.9 and higher mean almost certainly progression, but what the situation is with 1.7—1.8 values? Is it really only 3% of patients in whom progression was observed? We think that, giving credit to brain PET with amino acids, it is necessary to develop a more comprehensive algorithm for evaluation of the event of progression/radiation injury with allowance for both neuroimaging and clinical parameters.

For instance, within another large study (published later then this paper was submitted to our editorial board), AVA-Glio [2], researchers proposed a clinical and neuroimaging algorithm (without PET, so it can be improved) for determining pseudoprogression. Probably, this experience should be used as a starting point in developing an algorithm based on the data of PET with met-hionine.

In conclusion, I would like to thank the authors for the very important and complex topic, for their presented data and an interesting discussion with the scientific literature. The article, undoubtedly, is of considerable scientific and methodological interest for specialists who are engaged in neuro-oncology.

REFERENCES


G.L. Kobyakov (Moscow, Russia)
Malignant B-cell Lymphoma of the Anterior Visual Pathway


Burdenko Neurosurgical Institute, Moscow, Russia

This work is aimed at studying the optimal diagnosis methods and features of clinical signs of malignant B-cell lymphoma of the anterior visual pathway and choosing the most reasonable treatment approach. Over the past decades, the incidence rate of primary B-cell non-Hodgkin’s lymphoma of the brain in immunocompetent patients has been steadily increasing both in Russia and abroad. It should be mentioned that anterior visual pathway structures are affected by lymphoma rather rarely. That is probably why this problem has been poorly discussed in foreign literature and no case reports at all have been found among Russian publications. Six immunocompetent patients with lymphomas of the chiasmic-sellar region were identified and examined in 2002—2012. All patients underwent neuro-ophthalmological examination and contrast-enhanced MRI. Four patients had multiple primary lymphomas that affected the anterior visual pathway structures and other brain regions. The diagnosis was verified by stereotactic biopsy of the hemispheric focus. Two patients had an isolated lesion of the chiasmatic-sellar region, so glioma of the optic chiasm was initially suspected. These patients were subjected to open biopsy and partial resection of the tumor. Immunohistochemical analysis of the biopsy material was performed in all cases. Two patients received combination therapy; intra-arterial high-dose methotrexate preceded by rupture of the hemato-ophthalmic barrier and whole brain radiotherapy using a Primus linear accelerator. Patients with lymphoma of the anterior visual pathway had various neuro-ophthalmic symptoms. Ophthalmic pathologies developed both quickly and slowly; amaurosis suddenly developed in some cases. Intra-arterial high-dose methotrexate proved to be inefficient. Vision was either improved or stabilized by subsequent radiotherapy. Malignant B-cell lymphoma of the anterior visual pathway can emerge either as an isolated neoplasm or can be combined with other hemispheric foci. Ophthalmic disorders in these patients are nonspecific and need to be differentiated from malignant glioma of the optic chiasm. We consider radiotherapy to be the most effective method for treating these patients.

**Keywords:** primary central nervous system lymphoma, B-cell lymphoma of the anterior visual pathway, radiotherapy, chemotherapy.

Primary B-cell non-Hodgkin’s lymphoma of the brain was first described by P. Bailey in 1929 as a “perivascular sarcoma” [4]. Since then, there has been continuous interest in this problem. On the contrary, over the past decade the number of immunocompetent patients with primary central nervous system lymphoma (PCNSL) has been steadily increasing both in Russia and abroad [3, 9, 11]. PCNSL is a lymphoproliferative tumor of hematopoietic origin [11].

The most common sites of PCNSL localization include the frontal lobes, corpus callosum, and the periventricular region. The lesions are often multifocal. In this case, the process can additionally involve other parts of the brain, subcortical nuclei, cerebellum, and brain stem structures. The structures of the anterior visual pathway (AVP), namely, the optic nerves, the chiasm, and the optic tract are rarely affected by B-cell lymphoma. Some authors [8, 16] suggest that lymphomas in these sites are more common in patients with acquired immune deficiency syndrome. We have found scarce reports on AVP lymphoma in immunocompetent patients in the world literature [5, 7, 14, 15], which are, as a rule, based on 1–2 case reports. This issue has not been discussed in Russian literature.

The study is aimed at investigating the optimal diagnosis methods and features of clinical signs of malignant B-cell lymphoma of the anterior visual pathway and choosing the most reasonable treatment method.

**Material and Methods**

Six immunocompetent patients with B-cell non-Hodgkin’s AVP lymphoma were monitored at the N.N. Burdenko Neurosurgical Institute, Russian Academy of Medical Sciences, during the period from 2002 to 2012. The information about these patients is shown in Table 1. All the patients underwent contrast-enhanced T1-weighted magnetic resonance imaging (MRI) of the brain. Lymphoma was multifocal in 4 patients and, apart from AVP structures, involved other brain areas. To verify the diagnosis, the patients underwent stereotactic biopsy of hemispheric foci using the computed tomography calculations (CT-STB). In two patients with suspected optic chiasm glioma, open biopsies were taken with the partial removal of the tumor, which proved to be lymphoma. All the patients underwent immunohistochemical (IHC) study of the biopsy material, which revealed positive expression of leukocyte common antigen CD45 and B-lymphocyte antigen CD20. After the diagnosis had been verified, different tactics of patient management were used (Table 1).

We used AVP visometry, perimetry (manual, kinetic and automatic static on automated Humphrey field analyzers 745i, USA), biomicroscopy of the anterior segment of the eye and the vitreous humor, and ophthalmoscopy with mydriasis to examine lymphoma patients. Examination using spectral domain optical coherence tomography (SD-OCT) (RTVue 100,
paresis of her left hand (score of 4) reduced performance, followed by the headache, diplopia, and before the admission the patient developed weakness and re
tical structures, spreading into the third ventricle
rosurgical Institute with diagnosed tumor of the right subcor
most interesting ones
line visual function in patients with AVP lymphoma and its
“Optovue”, USA) was available for only one patient
Results and Discussion
Let us focus on two clinical cases, which we find to be the
Clinical case No. 6 (see Table 1).
A 49-year-old female patient K. was admitted to the Neu
rosurgical Institute with diagnosed tumor of the right subcorti
cal structures, spreading into the third ventricle. Two months
before the admission the patient developed weakness and re
duced performance, followed by the headache, diplopia, and
pareisis of her left hand (score of 4). No neuroophthalmologi
cal symptoms were observed. Contrast-enhanced MRI revealed
a bulk neoplasm in the area of the right basal ganglia spreading
into the third ventricle, which moderately accumulated the
contrast agent and was accompanied by extensive perifocal
edema (Fig. 1). The patients underwent CT-STB of the tumor.
The results of emergency biopsy have shown malignant
glioma; however, the IHC results have shown primary B-cell
lymphoma of the CNS with positive expression of CD20,
CD45, and CD79a. Intra-arterial chemotherapy (IACT) using
methotrexate with reversible hyperosmotic opening of the
blood-brain barrier (BBB) was started. The patient experienced
sharp visual deterioration in her right eye to 0.05 after the third
IACT session. The ophthalmoscopic picture imitated anterior
ischemic optic neuropathy. Vasodilator therapy had no effect.
After one month the visual acuity of the right eye was at the
level of light perception, and the visual acuity of the left eye
was 1.0 with defects in the temporal half of the visual field

<table>
<thead>
<tr>
<th>Patient No.</th>
<th>Sex</th>
<th>Age, years</th>
<th>Year of diagnosis</th>
<th>Type of cerebral involvement</th>
<th>Methods of diagnosis verification</th>
<th>Histological diagnosis</th>
<th>chemotherapy (CT)</th>
<th>Modality radiation therapy (RT)</th>
<th>other</th>
</tr>
</thead>
</table>
| 1           | M   | 50         | 2002             | Multifocal                 | CT-STB of the tumor of the pell
|             |     |            |                  |    |ucid septum                 | Open biopsy of the tumor of the chiasm | Biopsy No. 5321-22/02 lymphoma | IACT No. 6 + 2 courses of CT with Te
|             |     |            |                  |    |                              |                          | CD10213               | 33 Gy          |                |
| 2           | M   | 64         | 2006             | Only chiasm               | CT-STB of the tumor of the chiasm | Biopsy No. 3024/06 lymphoma | IACT No. 6 | Primus, 11 fractions, TDR=33 G
|             |     |            |                  |    |                              |                          |                    |                |                |
| 3           | F   | 59         | 2007             | As above                  | CT-STB of the tumor of the occipital region | Biopsy No. 1545-46/07 lymphoma | IACT No. 6 | Community-based therapy |
| 4           | F   | 80         | 2011             | Multifocal                | CT-STB of the tumor of the occipital region | Biopsy No. 27170-76/11 lymphoma | IACT No. 6 | Community-based therapy |
| 5           | M   | 50         | 2011             | As above                  | CT-STB of the tumor of the temporal region | Biopsy No. 3818-23/11 lymphoma | IACT No. 6 | Community-based therapy |
| 6           | F   | 49         | 2012             | As above                  | CT-STB of the tumor of the basal ganglia | Biopsy No. 33632-36/12 lymphoma | IACT No. 6 | Community-based therapy |

| Table 1. Information about patients with primary brain lymphoma |
|------------------------|------------------------|------------------------|------------------------|------------------------|
| Patient No. | Sex | Age, years | Year of diagnosis | Type of cerebral involvement | Methods of diagnosis verification | Histological diagnosis | chemotherapy (CT) | Modality radiation therapy (RT) | other |
| 1           | M   | 50         | 2002             | Multifocal                 | CT-STB of the tumor of the pellucid septum | Biopsy No. 5321-22/02 lymphoma | IACT No. 6 + 2 courses of CT with Te
|             |     |            |                  |    |ucid septum                 | Open biopsy of the tumor of the chiasm | CD10213               | 33 Gy          |                |
| 2           | M   | 64         | 2006             | Only chiasm               | CT-STB of the tumor of the chiasm | Biopsy No. 3024/06 lymphoma | IACT No. 6 | Primus, 11 fractions, TDR=33 G
|             |     |            |                  |    |                              |                          |                    |                |                |
| 3           | F   | 59         | 2007             | As above                  | CT-STB of the tumor of the occipital region | Biopsy No. 1545-46/07 lymphoma | IACT No. 6 | Community-based therapy |
| 4           | F   | 80         | 2011             | Multifocal                | CT-STB of the tumor of the occipital region | Biopsy No. 27170-76/11 lymphoma | IACT No. 6 | Community-based therapy |
| 5           | M   | 50         | 2011             | As above                  | CT-STB of the tumor of the temporal region | Biopsy No. 3818-23/11 lymphoma | IACT No. 6 | Community-based therapy |
| 6           | F   | 49         | 2012             | As above                  | CT-STB of the tumor of the basal ganglia | Biopsy No. 33632-36/12 lymphoma | IACT No. 6 | Community-based therapy |

| Table 2. Dynamics and characteristics of visual impairment |
|------------------------|------------------------|------------------------|------------------------|------------------------|
| Patient No. | Visual acuity at admission | Development of visual impairment | Dynamics of visual impairment at early stage of the disease | Dynamics of visual function at late stage of observation |
| 1           | OD=0.01—0.02 OS-zero | Slow | Negative, amaurosis of the left eye | No follow-up available |
| 2           | OD=0.1 OS=0.1 | Rapid | No dynamics after open biopsy | No dynamics |
| 3           | OD=0.5 OS=0.6 | Slow | No dynamics after open biopsy | No follow-up available |
| 4           | OD-zero OS-arm movement | Rapid | No dynamics | No follow-up available |
| 5           | OD=0.9 OS=0.1 | Sudden | Negative, unilateral amaurosis after IACT | Positive dynamics after radiation treatment |
| 6           | OD=0.1 OS=0.1 | “ “ | Negative, unilateral amaurosis after IACT | Stabilization of visual functions after radiation treatment |
Ocular fundus demonstrated pale optic discs with clearly defined margins. Kestenbaum sign was observed in the right eye (Fig. 3). SOCT has revealed peripapillary nerve fiber layer thinning and the thinned retinal ganglion cell complex manifesting as an increased level of focal and global losses. These changes were more pronounced in the right eye (Fig. 4). Thus, the patient developed signs of involvement of the visual pathway at the base of the brain with the development of practical blindness in her right eye. Contrast-enhanced MRI revealed thickening of the chiasm (Fig. 5), which was due to AVP lymphoma. The community-based whole brain radiation therapy was performed according to the scheme suggested by the radiologist of the Neurosurgical Institute (20 fractions 1.8 Gy each; the total dose of radiation (TDR)=36 Gy). Post-radiotherapy MRI showed no continued growth of the tumor in the right hemisphere and no accumulation of contrast agent in the chiasm (Fig. 6). Visual function of the only sighted left eye were stable for 6 months, the right eye was blind. The patient was prescribed with protracted chemotherapy with temozolomide.

Clinical case No. 5 (see Table 1). Patient K. aged 50 years was admitted to the Neurosurgical Institute with suspected primary lymphoma of the brain. The disease debuted with development of severe mnestic disorders, inappropriate behavior, followed by drowsiness, lethargy, and speech disorders. A restricted examination revealed no visual impairment. Contrast-enhanced CT revealed a large focal neoplasm localized in the left medial temporal region and a small neoplasm in the chiasmatic-sellar region (CSR) (Fig. 7). CT STB of the tumor nodule in the left temporal region was performed. Lymphoma was diagnosed using IHC.
The patient received steroid therapy (dexamethasone 8.0 mg/day) started from the 4th day of exposure. Radiotherapy was satisfactorily tolerated. A course of stereotactic radiotherapy was then performed as a “boost” using a Cyber-Knife robotic linear accelerator on lymphoma foci in the underhorn of the left late-

Fig. 4. SD-OCT: peripapillary nerve fiber layer thinning (Optic Nerve Head Map). Thinning of the retinal ganglion cell complex (GCC Significance), OD — right eye (top), OS — left eye (bottom), T — the temporal side, N — the nasal side.
The patient has developed focal vision in his left eye (visual acuity OS=0.2, field of vision was narrowed in the temporal half) in the beginning of the radiation therapy of the brain using the Primus apparatus. The right eye was virtually blind (visual acuity OD – counting fingers close to the face at narrow field in superior temporal quadrant). The general condition of the patient has improved; regression of mnemonic disorders and aphasia was observed. Visual functions remained stable within 2 years, no signs of continued tumor growth were identified (Fig. 9).

Malignant B-cell lymphoma of the AVP is an extremely rare disease; we observed only 6 patients with this disease over the 10-year period. There have also been scarce reports mostly including one or two cases of isolated lymphoma of the chiasm and optic nerves in the world literature [5, 6, 8, 14–16].

Along with these publications, we have found only one report by Japanese authors on multifocal lymphoma of the chiasm and hypothalamus in a 63-year-old male patient [7]. Multifocal lymphoma predominated in our series of patients (see Table 1). Only 2 patients had isolated involvement of the AVP and malignant glioma of the chiasm was initially suspected in these cases. Both diseases are characterized by progressively reducing visual acuity in elderly patients and nonspecific thickening of the AVP structures observed using contrast-enhanced imaging. We believe that the open biopsy of a tumor followed by IHC analysis of the biopsy material is crucial for differential diagnosis in this case. We have found several reports supporting this concept [7, 14, 16].

In two observations presented above, the hemispheric foci were the first clinical manifestations. Rapid visual impairment occurred during the first sessions of IACT using high-dose methotrexate with reversible hyperosmotic opening of the
Fig. 7. T1-weighted contrast-enhanced CT scan of the brain in the axial projection before treatment. Case No. 5 (see Table 1).
A bulk neoplasm in the left temporal region, thickening of the chiasm (shown with arrows).

BBB. This method of treatment of PCNSL has been successfully used at the N.N. Burdenko Neurosurgical Institute (Russian Academy of Medical Sciences) since the mid-2000s; according to M. Aronov et al. [1, 2], it has proved to be highly effective. This fact raises a question whether the rapid visual impairment during administration of intra-arterial chemotherapy was just a coincidence, when previously clinically “silent” AVP lymphoma has shown its presence, or administration of methotrexate, an antineoplastic cytostatic drug belonging to antimetabolite class and exhibiting a certain degree of toxicity, has triggered rapid development of clinical manifestations of AVP lymphoma. When analyzing this issue we have found the report of a group of authors [10], who studied the complications of intra-arterial treatment of PCNSL using methotrexate and stated the lack of toxicity of this drug with respect to the visual analyzer. T. Ikeda et al. [7] have shared their positive experiences of IACT using methotrexate in a patient with lymphoma of the chiasm and hypothalamus. Therefore, we cannot state unambiguously that there are causal relationships between intra-arterial administration of high-dose methotrexate and development of amaurosis in our patients.

Rapid unilateral visual deterioration in female patient K. (case No. 6, see Table 1) posed a certain diagnostic difficulty for us. The ophthalmoscopic picture of the fundus of the right eye was similar to that typical of anterior ischemic optic neuropathy, which is usually caused by impaired blood flow in the vessels supplying the optic nerve. However, the nature of the following visual field defects of the second eye was clearly indicative of the CSR involvement, which was confirmed by control MRI. M. Strominger et al. [13] faced a similar situation.

Male patient K. (case No. 5, see Table 1) has suddenly developed bilateral amaurosis after the first session of IACT. The ophthalmoscopic picture was normal at first, but the control MRI has revealed the oversized chiasm and optic tracts, which suggested AVP lymphoma. The clinical presentation of the descending optic atrophy developed a month after the manifestation of visual impairment.

The past medical history of the other two patients showed slow development of visual impairment, and another two observations showed quite rapid worsening of the visual function (see Table 2).

PCNSL is a highly malignant brain tumor, which is among the tumors most sensitive to radiotherapy and chemotherapy...
Surgical removal of brain lymphoma does not prolong patient’s life and may result in emergence/aggravation of neurological deficit [9]. Chemotherapy combined with radiological treatment is recognized as the most effective way to treat these patients and provides the longest relapse-free period [9, 12].

After the acute clinical manifestations of AVP lymphoma during the IACT using methotrexate with reversible opening of the BBB, the question has arisen how these patients should be treated. It was decided to interrupt the course of chemotherapy and to perform radiotherapy, whose detailed scheme was presented for case No. 5. The patient with bilateral amaurosis has developed central vision in his left eye after the first several fractions of radiation therapy. The achieved visual acuity and relapse-free period have persisted for 2 years. The whole brain radiation therapy stabilized visual function of the only sighted left eye in case No. 6. No symptoms of continued tumor growth have been observed for 6 months.

**Conclusion**

Malignant B-cell lymphoma of the AVP can occur along with lesions of the other brain structures or as an isolated disease. In the latter case it must be differentiated from malignant glioma of the chiasm in elderly patients. This requires open biopsy of the tumor followed by IHC analysis of the resulting material.

Visual impairments in patients with AVP lymphoma are nonspecific. They may develop slowly or rapidly, and in some cases immediately. No distinctive features of visual field defects have been found.

Radiotherapy is, in our opinion, the most effective method to treat B-cell lymphoma of the AVP.

**Fig. 9.** T1-weighted MRI of the brain 2 years after radiotherapy.

Regression of the multifocal lymphoma.

a — sagittal projection; b — axial projection.
REFERENCES


The Dependence of Lagophthalmos Dynamics on Facial Nerve Repair and Its Intraoperative Monitoring in Neurosurgical Patients

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Over 200 patients with acoustic neuromas and over 100 patients with posterior cranial fossa meningiomas are annually operated on at the N.N. Burdenko Neurosurgical Institute. Intraoperative monitoring of facial nerve function is used in most patients with tumors of the posterior cranial fossa to identify the facial nerve in the surgical wound. If the anatomical integrity of the facial nerve in the cranial cavity cannot be preserved, facial nerve repair is performed to restore the facial muscle function. Intraoperative electrical stimulation of facial nerve has a great prognostic significance for evaluating the dynamics of lagophthalmos in the late postoperative period and selecting the proper method for correction of lagophthalmos. After reinnervation of the facial nerve with the descending branch or trunk of the hypoglossal nerve, sufficient eyelid closure was observed only in 3 patients out of 17.

Keywords: lagophthalmos, intraoperative monitoring of facial nerve function, facial nerve repair.

Material and Methods

A total of 260 patients operated on at the N.N. Burdenko Neurosurgical Institute in 2001—2013 with up to 12-year catamnestic data were examined. All patients were diagnosed with lagophthalmos and/or trophic keratopathy.

According to the objective of the study, 77 cases were selected from the pool of patients. Intraoperative electrophysiological monitoring of facial nerve function was performed in 63 patients during neurosurgical operations in 2007—2013. The postoperative follow-up for these patients was 2—60 months (median, 13 months). A total of 17 patients underwent facial nerve repair. The catamnestic data were collected for the period from 5 months to 12 years (median, 28 months). It should be noted that 3 patients underwent both electrophysiological monitoring of facial nerve function and facial nerve repair after tumor had been removed. Thus, the total number of examined patients was 77.

Among these 77 patients there were 55 women and 22 men aged 6—74 years (median age, 48 years).

Most patients had acoustic neuromas (71 patients, 92%). There were also patients with one of the following conditions (one patient with each condition): pontine astrocytoma, jugular foramen neurona, cholesteatoma of the petrous pyramid, multiple cavernous angiomas of the brain, the combination of cerebellopontine angle neuroma and meningioma, multiple neuromas of the cerebellopontine angle.

All patients were examined by a neurologist, an oto-neurologist, and a neuro-ophthalmologist.

In order to determine the degree of lagophthalmos, we used the previously elaborated classification (Table 1) that uses the amount of corneal exposure as the main parameter (2013).

Palpebral fissure width was measured in patients with lagophthalmos upon attempted eyelid closure by estimating the...
distance between the two most distant points of the upper and lower eyelids.

Intraoperative monitoring of facial nerve function was performed using the Medtronic NIM Neuro 3.0 system.

Results and Discussion

Two groups of patients have been selected: group 1 consisted of 17 patients who had undergone facial nerve repair; group 2 consisted of 63 patients who had been subjected to intraoperative neurophysiological monitoring of facial nerve function.

Facial nerve repair with the descending branch or trunk of the hypoglossal nerve was conducted during the following time periods: 6 patients underwent facial nerve repair right after neurosurgical treatment; 2 patients, 2 months after the operation; 3 patients, 4—5 months after the surgery; and 6 patients, 7—17 months after the surgery.

The dynamics of lagophthalmos during late postoperative period after facial nerve repair were as follows: the prevailing majority of patients (12) exhibited the same degree of lagophthalmos as before corrective surgery; exacerbation of lagophthalmos was observed in 2 cases. Only 3 patients exhibited a reduced degree of lagophthalmos (Table 2).

It should be noted that reduced degree of lagophthalmos was observed in patients who had undergone facial nerve repair right after neurosurgical operation (one case) and 5 months after the operation (two cases).

Since there was no positive dynamics of lagophthalmos and severe trophic keratopathy, four patients underwent partial blood blepharorrhaphy, four patients were subjected to transient drug-induced ptosis. The process was stabilized by prescribing keratoprotective therapy in 6 cases, while the combinations of various correcting methods were used in 3 cases.

The second part of the study was devoted to the analysis of lagophthalmos dynamics in 63 neurosurgical patients who were subjected to intraoperative electrophysiological monitoring of facial nerve function.

Table 3 presents data on functional status of n. facialis according to the House—Brackmann scale before and after surgery in patients subjected to intraoperative electrophysiological identification of the facial nerve. Grade I of facial muscle function according to the House—Brackman scale corresponds to L0 (no lagophthalmos); grades II and III correspond to L0—1, which is characterized by complete eyelid closure with effort (eyelash sign); grades IV—VI (from incomplete eyelid closure to no movement) correspond to L1—4. Grades 3—4 of eyelid closure were accompanied by negative Bell’s phenomenon.

Table 3 demonstrates that impaired function of n. facialis was noted preoperatively in 16 (25.4%) patients before surgery, while postoperative apraxia of eyelid closure was reported in all cases (100%).

We compared various levels of anatomical preservation of n. facialis and the results of its electrophysiological identification during tumor removal (see Figure). A total of 60 out of 63 patients underwent acoustic neuroma removal; there was also one patient with each diagnosis: pontine astrocytoma, jugular foramen neuroma, the combination of cerebellopontine angle neuroma and meningioma.

Four subgroups of patients were formed.

The first subgroup included 43 patients with anatomically preserved facial nerve (sprawled or stretched across the tumor); its stimulation gave positive response. Among this subgroup, 23 (53.5%) patients demonstrated improved eyelid closure, while preserved or impaired lagophthalmos was noted in 20 (46.5%) cases. This subgroup of patients showed no statistically significant difference in facial nerve recovery parameter during the late postoperative period (p=0.2730; p>0.05).

The second subgroup consisted of patients with facial nerve not visualized on tumor surface during surgery. However, the stimulation gave positive response in 10 cases: eyelid closure was observed in 2 patients and lagophthalmos was stabilized in 8 patients.

The third subgroup was characterized by preserved anatomical integrity of the facial nerve; no response was obtained during stimulation in 7 cases: reduction of lagophthalmos was observed in one patient, while 6 patients showed stabilization or impairment of lagophthalmos.

The fourth subgroup included 3 patients with either completely or partially damaged n. facialis fibers exhibiting no re-

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**Table 1. Classification of lagophthalmos**

<table>
<thead>
<tr>
<th>Grade of eyelid closure</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>0—1</td>
<td>Complete eyelid closure, weakened eyelid squeezing</td>
</tr>
<tr>
<td>1</td>
<td>The cornea is completely covered by upper eyelid upon attempted eyelid closure</td>
</tr>
<tr>
<td>2</td>
<td>The lower cornea segment remains uncovered by the upper eyelid (1/5—1/4 of the cornea across the lower limbus) upon attempted eyelid closure</td>
</tr>
<tr>
<td>3</td>
<td>1/3 of the cornea is uncovered by upper eyelid upon attempted eyelid closure</td>
</tr>
<tr>
<td>4</td>
<td>The lower half of the cornea remains uncovered by upper eyelid upon attempted eyelid closure</td>
</tr>
</tbody>
</table>

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**Table 2. Dependence of the dynamics of lagophthalmos on facial nerve repair**

<table>
<thead>
<tr>
<th>Lagophthalmos dynamics</th>
<th>Number of patients</th>
<th>Palpebral fissure width dynamics, mm</th>
<th>Follow-up duration, months</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aggravated</td>
<td>2</td>
<td>5—8</td>
<td>6—8</td>
</tr>
<tr>
<td>Stabilized</td>
<td>12</td>
<td>3—6</td>
<td>7—144</td>
</tr>
<tr>
<td>Became less severe</td>
<td>3</td>
<td>From 3 to weakened eyelid squeezing</td>
<td>32—36</td>
</tr>
</tbody>
</table>

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response to neurostimulation. The patients had aggravated lagophthalmos.

The study demonstrated that the facial nerve function is mostly recovered in late postoperative period in patients whose facial nerve was anatomically preserved during tumor resection and who had a positive response to its intraoperative stimulation.

We did not aim to study the causes of facial nerve dysfunction. What we attempted to do was to determine the dependence of the dynamics of lagophthalmos on facial nerve repair and its intraoperative electrophysiological identification.

**Conclusions**

Thus, according to the results of our study, reinnervation of the facial nerve with the descending branch or trunk of the hypoglossal nerve resulted in improved eyelid closure in only 3 out of 17 cases, while the other patients showed persistent or aggravated lagophthalmos.

Intraoperative electrical stimulation of the facial nerve has a great prognostic value for assessing the dynamics of lagophthalmos during late postoperative period, and hence for selecting a method for lagophthalmos correction: of the improved facial nerve function manifesting as a higher degree of eyelid closure or stabilized lagophthalmos was mostly observed in patients who had a positive response during electrophysiological identification of the nerve or had an anatomically preserved n. facialis. In patients having a negative response to electrostimulation and n. facialis anatomically disrupted, the degree of eyelid closure was higher or remained unchanged.

**REFERENCES**


**Commentary**

Cerebellopontine angle tumors (and acoustic neuromas in particular) are the widespread group of brain tumors that have become more operable and result in minimal intraoperative complications with the development of neurosurgery. Nevertheless, there is still a high percent of facial nerve function impairment during early and late postoperative periods, espe-
cially in patients with solid tumors, resulting in aggravation or development of lagophthalmos and in several cases in severe trophic disorders (neuroparalytic keratitis). This dictates the need for searching for new ways to improve early diagnosis of cerebellopontine angle tumors, for neurosurgical methods for resecting primary tumor sites and implementing corrective surgical repair of the impaired facial nerve trunk.

The authors present the results of their study of interrelationship between the dynamics of lagophthalmos and outcomes of facial nerve repair and its intraoperative electrophysiological identification. A total of 260 patients operated on at the N.N. Burdenko Neurosurgical Institute in 2001–2013 have been surveyed. The modern methods of ophthalmic and neuro-ophthalmic research have been applied, the classification of lagophthalmos has been proposed based on the degree of eyelid closure, objectification of facial nerve function assessment has been made using the House—Brackmann scale in patients before and after neurosurgery with neurophysiological monitoring of n. facialis.

Four subgroups of patients have been formed based on anatomical preservation of the facial nerve and the results of its electrophysiological identification during tumor removal. A decrease in lagophthalmos after reinnervation of the facial nerve has been observed only in 18% of patients. Perhaps the neurosurgeons should take this objective fact into account and consider earlier reconstruction surgery of damaged facial nerve instead of waiting for one year before conducting the surgery. Intraoperative electrical stimulation of the facial nerve has a great prognostic value for the assessing the dynamics of lagophthalmos in the late postoperative period and correspondingly, for selecting the methods for lagophthalmos correction.

It is notable that these complex research methods has been brought into use by this group of authors in Russian neurooncology in the past decade, and the reasonability and importance of these methods have already been proved.

The paper is interesting; it contains significant and useful data that will definitely give grounds for further scientific and practical developments in this field of neuro-ophthalmology and neurosurgery.

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