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Predictors of visual function recovery in patients with non-traumatic optic neuropathy after surgical treatment

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Background. Non-traumatic optic neuropathy is damage of the optic nerve caused by its progressive compression by a tumor or other hyperplastic process which leads to atrophy and constant visual impairment. Therefore, the optic nerve needs to be decompressed but there are no methods of predicting the results of decompression.
Aim. To identify factors affecting dynamics of visual impairment after decompression and their prognostic value.
Materials and methods. The results of surgical treatment of 64 patients with non-traumatic optic neuropathy were analyzed. All patients were examined using visometry, visual filed test, and ophthalmoscopy. Visual field changes were classified per 7 grades of severity. Determination of predictive significance of quantitative variables for favorable surgical results was performed using ROC analysis. The obtained threshold values were used to identify key predictors of favorable outcome and to develop a prognostic model employing multivariable logistic regression.
Results. The most significant predictors of improvement in vision after surgery are severity of visual field change and visual acuity prior to surgery. These characteristics gave prognostic accuracy of more than 80 % independently of other factors. The least significant characteristic for predicting visual improvement was duration of anamnesis. The final regression model included 3 predictors: duration of visual impairment less than 12 months (3 points), visual acuity >0.1 (4 points), and degree of visual filed change <5 (5 points). For maximal points, calculated probability of improvement in vision is 93.5 %. The model is statistically significant (Wald χ^2 test; $p < 0.001$) and complies with factual data (Hosmer–Lemeshow test; $p = 0.504$). The developed model explains 60.8 % of outcome variability, and accuracy of prognosis is 90.5 %.
Conclusion. Factors affecting dynamics of visual function in patients with compression non-traumatic optic neuropathy after microsurgical decompression of the optic nerve were identified. Identification of these predictors allowed to develop a score for evaluation of probability of vision improvement after surgery.

Keywords: parasellar meningiomas, optic nerve canal, optic neuropathy, optic nerve decompression.

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BACKGROUND

Optic neuropathies are a group of diseases of varying etiologies caused by damage of the optic nerve, ultimately resulting in its atrophy. In Russia, neuropathies are typically classified according to their pathogenetic mechanism as glaucomatous and non-glaucomatous. Glaucomatous optic neuropathy develops as a result of primary damage of the retinal ganglion cells caused by increased intraocular pressure, causing ascending atrophy of the optic nerve.

In non-glaucomatous neuropathies, the axons of the ganglion cells that form the optic nerve are affected, leading to disruption of axoplasmic flow and the delivery of neurotrophic substances to the retinal ganglion cells, as well as the development of descending atrophy [1].

Compression of one or more segments of the optic nerve by a tumor accounts for 10 % of all non-glaucomatous optic neuropathies [2].

The rarer cases include nerve compression due to fibrous dysplasia, Wegener's granulomatosis, mucocele of the paranasal sinuses, aneurysm, or dolichoectasia of the internal carotid artery [3, 4]. To preserve the vision in this group of patients, it is necessary to eliminate the compression of the nerve by resecting one or more walls of its canal and opening the falciform ligament, which cuff-like encircles the optic nerve.

The first description of such type of operation was done by W.E. Dandy [5]. A large number of observations have been conducted dedicated to the dynamics of visual impairment in patients after decompression; however, a unified approach to both preoperative examination and evaluation of surgical results has not been developed yet, that determines the relevance of the present study.

Aim of study – to determine the factors influencing the prognosis of vision recovery after optic nerve decompression in patients with compressive non-traumatic optic neuropathy.

MATERIAL AND METHODS

The analysis of the surgical treatment results in patients with visual impairments caused by non-traumatic compression of the optic nerves in the canal was conducted from May 2015 to March 2025 at the Department of Neurosurgery No. 5 of the Almazov National Medical Research Center.

All patients preoperatively underwent an ophthalmological examination as well as in the early postoperative period, including measurement of corrected visual acuity, assessment of the visual field for red and white colors using Forster perimetry, and fundus examination.

All patients also underwent preoperative brain magnetic resonance imaging (MRI) with intravenous contrast with 1 mm slice thickness, as well as CISS imaging to detect optic nerve compression in the canal. Postoperatively, a head multislice computed tomography (CT) was performed.

A total of 75 patients underwent optic nerve decompression were initially recruited for the study. In the majority of cases (74.6 %), the cause for visual impairment was parasellar meningiomas (tubercle and diaphragm of the sella turcica, sphenoid bone, anterior clinoid process, and cavernous sinus). Another 12 % were meningiomas whose matrix was located outside the chiasmatic-sellar region but grew into the optic canal (cranio-orbital and sphenopetroclival meningiomas).

The optic nerve decompression was performed for giant craniopharyngiomas and pituitary macroadenomas in 4 % of cases to minimize traction of the optic nerves and chiasm during tumor mobilization and removal. Finally, the remaining 9.4 % of patients suffered from rare conditions with varying etiologies and prognoses, including malignant neoplasms of the paranasal sinuses, fibrous dysplasia, Wegener's granulomatosis, and benign intracranial hypertension.

Although the pathogenesis of visual impairment was the same in all patients (a disproportion between the optic canal volume and its contents), only patients with meningiomas were included in the study to improve sample homogeneity. Group 1 included 64 patients who underwent optic nerve decompression during tumor removal.

Among them three patients underwent repeat surgery due to tumor recurrence in 15, 68, and 98 months after the initial surgery. Additionally, in three cases, decompression of both optic nerves was performed during a single operation. The control group consisted of 43 patients with parasellar meningiomas and visual impairment who underwent tumor removal without optic nerve decompression.

To assess the severity of visual impairment, an original approach for interpreting the ophthalmological examination results was used. According to the degree of visual acuity reduction, patients were divided into the following groups: grade 0 (visual acuity with correction 0.9–1.0); grade I (0.4–0.8); grade II (0.2–0.3); grade III (0.05–0.1); grade IV (0.04 and less). This approach was based on the classification of amblyopia according to E.S. Avetisov [6].

The evaluation of the perimetry results according to Forster was carried out on the basis of other classifications of changes in the visual field, in particular the scale of the severity of visual impairments used by the Russian medical and social assessment and the classification of N.K. Serova and I.V. Zhadenova [7]. Our approach to assessing the severity of changes in the visual field consisted of identifying the following degrees (Table 1).

The visual impairment score (VIS) was used to assess the severity of patients' social maladjustment in patients [8]. The dynamics of visual impairment were analyzed in a total of 137 eyes, 70 of which were after optic nerve decompression. Improvement in visual function was defined as a decrease in the degree of visual acuity loss and/or the degree of visual field change; deterioration was defined as an increase in the degree.

An ophthalmological examination was performed in the early postoperative period and in 6 months after surgery on an ambulatory basis, assessed by a neurosurgeon and a neuro-ophthalmologist. The final treatment outcome was determined in 6 months as improvement or no improvement.

The obligatory stage of the surgery was optic nerve decompression with the technique using in our department: arachnoid dissection of the intracranial segment of the optic nerve; opening of the dura mater at the base of the anterior cranial fossa in the area of the roof of the optic nerve canal; resection of the superior and/or lateral walls of the optic nerve canal using a high-speed diamond burr and Kerrison rongeurs; dissection of the falciform ligament and/or dura mater along the course of the optic nerve. Optionally, extra- or intradural anterior clinoidectomy was performed.

The surgical results were assessed based on the dynamics of visual impairment after surgery. If the degree of visual acuity and/or field loss improved, the result was considered as "an improvement"; if there was no change or negative dynamics, the result was considered as "no improvement". Cases of severe deterioration of initial visual function after surgery, including amaurosis, were considered as complications of surgical treatment.

The statistical analysis was performed using SPSS 26, ROC analysis was conducted to determine the predictive value of quantitative variables for a favorable surgical outcome. The optimal threshold value was determined based on the Youden index. These threshold values were then used to identify the key predictors for favorable outcome and construct a prognostic model using multivariate logistic regression.

The model quality was assessed using the Wald χ^2 test. The model fit to the input data was assessed using the Hosmer–Lemeshow test. The model information content was represented as the Nigelkirk coefficient of determination. ROC analysis was performed to evaluate model quality. A threshold of $p < 0.05$ was considered statistically significant.

RESULTS

At stage 1, a comparative ROC analysis of quantitative variables was performed separately in the groups with and without decompression (Table 2). The duration of the medical history, baseline visual acuity, the degree of visual acuity loss, visual fields, and baseline VIS scores were significant predictors for postoperative vision improvement in patients who underwent decompression, but they were not significant predictors in those without decompression.

At stage 2, the threshold values of predictors were calculated in the decompression group (Table. 3).

The threshold values obtained from the ROC analysis were used to transform the quantitative variables into the categorical predictors, which were then included in a multivariate logistic regression analysis to identify the key factors for postoperative visual improvement.

The final regression model included three predictors, which explained a combined 60.8 % of the outcome variability: duration of visual impairment less than 12 months, visual acuity >0.1, and visual field change <5 (Table 4). The model was statistically significant (Wald χ^2 test; $p < 0.001$) and consistent with the actual data (Hosmer–Lemeshow test; $p = 0.504$). Using this model ensured a prediction accuracy of 90.5 % (Fig. 1).

By reducing the regression coefficients to a common denominator and rounding them to the nearest whole number, each predictor was assigned a score. The resulting three-factor scale was calculated for each patient in the studied database. To assess the quality of the predictive scale, an analysis of the estimated and actual probabilities of improved outcome after surgery for the studied sample was conducted (Table 5).

All predictors had variance inflation factor values less than 2, indicating the absence of a significant contribution of multicollinearity to the estimation of regression coefficients (Table 6).

DISCUSSION

More than 100 years have passed since W. Dandy first performed the optic nerve decompression. During this long period, the attitudes and approaches to this technique have evolved. Currently, it is practically mandatory for the surgical removal of tumors in the chiasmatic-sellar region.

Table 1. Severity of visual field changes per Förster perimetry

Severity grade	Description
0	Normal (no narrowing for the red or white targets)
I	Narrowing of the visual field for the red target less than 30 degrees on the temporal meridian or less than 20 degrees elsewhere with the white target within normal limits
II	Narrowing of the visual field for the white target on one or several meridians up to 40 degrees from the fixation point with abnormal visual field limits for the red target
III	Narrowing of the visual field for the white target less than 40 degrees but no more than 20 degrees and/or relative central scotomas with abnormal visual field limits for the red target
IV	Narrowing of the visual field for the white target less than 20 degrees but no more than 10 degrees and/or absolute central scotomas of size below 10 degrees with abnormal visual field limits for the red target
V	Narrowing of the peripheral visual field limits up to the fixation point in the form of quadrant- or hemianopsias and/or absolute central scotomas of size above 10 degrees with abnormal visual field limits for the red target
VI	Marked central and/or peripheral defects of the visual filed (up to residual visual filed) with absence of red color perception
VII	Complete absence of white color perception with preserved or absent light perception

Table 2. Results of analysis of predictive significance of quantitative characteristics depending on the performance of optic nerve decompression (area under curve [95 % confidence interval])

Characteristic	With decompression	Without decompression	Difference
Age at the time of surgery	0.419 [0.269; 0.569]; *p* = 0.29	0.661 [0.526; 0.796]; *p* = 0.019	–0.242 [–0.444; –0.04]; *p* = 0.019
Duration of anamnesis, months	0.729 [0.606; 0.851]; *p* <0.001	0.618 [0.479; 0.758]; *p* = 0.096	0.11 [–0.075; 0.296]; *p* = 0.244
Visual acuity prior to surgery	0.764 [0.631; 0.898]; *p* <0.001	0.623 [0.488; 0.759]; *p* = 0.074	0.141 [–0.049; 0.331]; *p* = 0.146
Severity of visual impairment prior to surgery	0.744 [0.611; 0.876]; *p* <0.001	0.623 [0.488; 0.757]; *p* = 0.075	0.121 [–0.068; 0.310]; *p* = 0.21
Severity of visual field change prior to surgery	0.765 [0.639; 0.891]; *p* <0.001	0.526 [0.386; 0.666]; *p* = 0.714	0.239 [0.050; 0.427]; *p* = 0.013
Total VIS prior to surgery	0.752 [0.629; 0.875]; *p* <0.001	0.487 [0.347; 0.627]; p = 0.855	0.265 [0.079; 0.451]; *p* = 0.005

***Note.** VIS – visual impairment score.*

Table 3. Results of analysis of quantitative predictors

Переменная Variable	AUC ± SE	*p*	Cut-off	Se/Sp, %
Age at the time of surgery	0.581 ± 0.076	0.29	≤50	73/52
Duration of anamnesis, months	0.729 ± 0.062	<0.001	≤12	71/68
Visual acuity prior to surgery	0.764 ± 0.068	<0.001	≥0,1	84/72
Severity of visual impairment prior to surgery	0.744 ± 0.068	<0.001	≤2	78/72
Severity of visual field change prior to surgery	0.765 ± 0.064	<0.001	≤5	87/64
Total VIS prior to surgery	0.752 ± 0.063	<0.001	≤30	80/68

***Note.** AUC – area under curve; SE – standard error; VIS – visual impairment score.*

Table 4. Regression model

Предиктор Predictor	B ± SE	*p*	ОШ [95 % ДИ] OR [95 % CI]	Баллы Points
Duration of anamnesis less than 12 months	1.43 ± 0.7	0.042	4.16 [1.05; 16.46]	3
Visual acuity prior >0,1	1.84 ± 0.75	0.015	6.3 [1.44; 27.66]	4
Severity of visual field change <5	2.41 ± 0.78	0.002	11.14 [2.40; 51.64]	5

***Note.** B – regression coefficient; SE – standard error; OR – odds ratio; CI – confidence interval.*

This opinion is shared by the majority of both Russian and international neurosurgeons [9–14].

However, the surgical outcomes, specifically the percentage of vision improvement, vary significantly across the different series. We believe this is due to the influence of modifiable and non-modifiable factors associated with the peri- and intraoperative periods, and not just the presence of optic nerve decompression.

Thus, the number of studies have demonstrated the relationship between the patient's age and the dynamics of visual impairment after surgery [15–22]. According to various authors, patient age over 40, 50, and 60 years is the factor that statistically significantly reduces the likelihood of vision improvement after removal of parasellar meningiomas [16–19, 21, 22].

In their opinion, this may be due to greater resistance to ischemia caused by compression of the microvessels supplying the optic nerves in young patients, while older people are more likely to have concomitant ophthalmological diseases and tolerate surgery worse due to the greater sensitivity of the optic nerves to ischemia [16, 22]. In our study, patient age under 50 years had a positive effect on

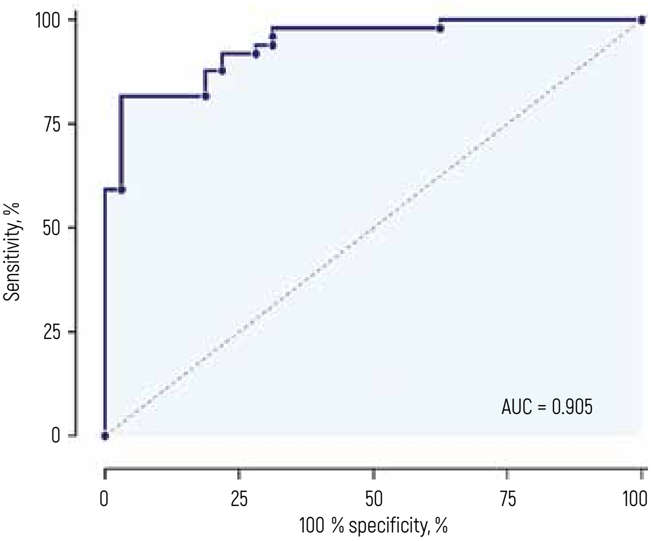

Fig. 1. ROC-curve of the final regression model. AUC – area under curve

Table 5. Calculated and factual probability of visual function recovery after surgery

Total score	Calculated probability, %	Calculated probability, %
0	5.2	0 of 4 (0 %)
3	18.0	2 of 10 (20 %)
4	30.4	2 of 6 (33.3 %)
5	46.5	2 of 5 (40 %)
7	63.4	3 of 5 (60 %)
8	77.5	9 of 11 (81.8 %)
9	87.3	8 of 9 (88.9 %)
12	96.5	19 of 20 (95 %)

Table 6. Results of predictor multicollinearity assessment

Predictor	η^2, %	VIF	Tolerance
Duration of anamnesis less than 12 months	6.14	1.02	0.98
Visual acuity prior to surgery >0.1	12.86	1.05	0.95
Severity of visual field change <5	28.42	1.05	0.95

treatment outcome. However, the low sensitivity and specificity of this predictor did not allow this factor to be included in the prognostic model.

The duration of the anamnesis as the factor influencing the postoperative dynamics of visual functions has been noted in the significant number of studies [10, 16–18, 20, 22–25]. Obviously, in the case of gradual compression of the nerve by the tumor, optic nerve atrophy progresses over time, and at a certain point, ophthalmological disorders become irreversible.

In a number of studies, the anamnesis of less than 6–7 months was the factor positively influencing postoperative visual functions; in other studies, the similar association was demonstrated for a duration of visual impairment of less than 12 months [10, 17, 18, 20–25]. The anamnesis of more than 12 and 24 months reduced the likelihood of vision improvement and increased the likelihood of its deterioration after surgery [10, 17, 23]. This predictor was also confirmed in our study. Thus, the duration of symptoms of less than 12 months increased the likelihood of vision improvement after surgery by more than 4 times.

The initial parameters of visual function (visual acuity and field of view) reflect the state of the visual analyzer and the degree of optic neuropathy before surgery and are the factor influencing the postoperative dynamics of visual impairment [15, 17, 18, 21, 24, 26–34]. Ophthalmological examination of such patients has long been routine practice, including determination of maximum visual acuity with correction, visual field by manual or computer perimetry, and fundus examination.

However, the methodology for interpreting changes based on preoperative examination data varies among authors. Some researchers focus solely on visual acuity, ignoring visual field defects [21, 28]. Others take visual field changes into account and note that severe defects are the prognostically unfavorable factor [29, 32]. In our study, visual acuity >0.1 increased the likelihood of postoperative vision improvement by more than 6 times. Similar results have been obtained in other studies [16, 21, 28].

Some studies have proposed the original scales for assessing visual impairment; however, they share a common drawback: they assign a total score for both eyes, which is then used to determine the degree of visual impairment [8, 19, 35]. This approach may be useful for patients with bilateral visual impairment due to meningiomas of the tubercle and diaphragm of the sella turcica, pituitary adenomas, and craniopharyngiomas; however, it is not applicable to visual impairment in one eye, since the assigned score does not reflect the degree of optic neuropathy.

Furthermore, the visual acuity assessment using Snellen or Golovin–Sivtsev charts does not fully reflect visual efficiency, i. e., the percentage of the surrounding world that a person sees. Thus, an improvement in visual acuity by 0.1

with an initial acuity of 0.7 increases visual efficiency by only 4 %, whereas a deterioration of the same 0.1 with an initial acuity of 0.2 reduces visual efficiency by 29 % [36].

Therefore, in our study, we relied on E.S. Avetisov's classification of amblyopia. According to this classification, visual acuity values within a given degree differ by no more than 20 % in effectiveness. Therefore, a change in visual acuity of at least one degree indicates improvement or deterioration.

We proposed the gradations of visual field impairment based on existing classifications. The particular emphasis was made on assessing the visual field to red color, as perimetry has been shown to be more sensitive to the red color in the early diagnosis of compressive nontraumatic optic neuropathy [37].

Thus, the occurrence of red-field visual loss with normal white vision enabled early diagnosis in 8 patients, which was reflected in treatment outcomes – in all patients the detected changes regressed immediately after surgery. Patients with red-field visual loss reported improved vision after surgery in only 2 out of 10 cases, while in 1 case, vision deteriorated to the point of amaurosis on the decompressed side.

Finally, the number of authors point out that tumor size influences the dynamics of visual impairment after surgery. However, in our opinion, this indicator is inappropriate to compare for parasellar tumors with different matrix locations. For example, meningiomas of the tubercle sellae cause visual impairment at relatively small sizes, whereas meningiomas of the planum sphenoidale or sphenoid wing meningiomas reach large sizes before manifesting ophthalmological symptoms.

Furthermore, the optic nerve decompression technique influences the surgical outcome. Three questions remain controversial in the literature:

1) should decompression be performed before or after tumor removal;
2) does anterior clinoidectomy, in addition to the standard decompression technique, improve the prognosis for visual recovery;
3) should the tumor be removed from the optic nerve canal.

There is insufficient research data to provide a definitive answer to these questions. In our opinion, the surgical team's experience and established preferences play a leading role, directly impacting their ability to make appropriate decisions regarding both the extent of tumor removal and the method of optic nerve decompression.

We believe that if a tumor is found in the canal that is intimately fused with the nerve sheath, the radicality of the operation should be reduced by leaving part of the tumor in the canal, since attempts for its radical removal are highly likely to result in deterioration of vision.

CONCLUSION

Our study identified factors influencing visual function dynamics in patients with non-traumatic compressive optic neuropathy following microsurgical optic nerve decompression. The identified predictors included the duration of the patient's medical history and the severity of visual impairment before surgery.

Identifying these predictors allowed us to develop a scoring scale for assessing the likelihood of vision improvement after surgery. It also demonstrated the need for a unified approach to assessing visual impairment in neurosurgical patients to develop a generally accepted surgical treatment strategy and evaluate short- and long-term outcomes.

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