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Scientific article

Complex use of energetic surgery in treatment of patients with primary open-angle glaucoma and cataract on the background of pseudoexfoliative syndrome

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BACKGROUND: Glaucoma remains one of the current problems of modern ophthalmology. The combination of glaucoma and cataract is observed in 17–38.6% of cases, and glaucoma with pseudoexfoliative syndrome – in 20–50% of primary open-angle glaucoma cases.

AIM: The aim of this work is to develop an effective and safe technology of complex energetic surgical treatment of the incipient primary open-angle glaucoma stage and cataract on the background of pseudoexfoliation syndrome on the basis of modified laser, hydrodynamic and ultrasound methods' use.

MATERIALS AND METHODS: 187 patients (187 eyes) with the incipient stage of primary open-angle glaucoma, cataract and pseudoexfoliation syndrome were examined. In the main group (111 eyes), selective laser trabeculoplasty followed by femtosecond laser-assisted cataract surgery with hydrodynamic trabeculocleaning was performed. Patients in the control group (76 eyes), after selective laser trabeculoplasty, underwent phacoemulsification according to the standard technique.

RESULTS: The developed technology allowed to reach the hypotensive effect in 35.2% ($t = 23.0$; $p < 0.001$) of baseline intraocular pressure values, of individual intraocular pressure level without adding IOP-lowering medications in 27% of cases, stabilization of visual functions and morphometric indices of the optic disc during 2 years of follow-up in 97.3% of cases unlike the selective laser trabeculoplasty with subsequent phacoemulsification (21.2, 5.3 and 81.6% respectively). The patients of the main group had significantly lower energy expenditure during the stage of phacoemulsification, a lower percentage of postoperative inflammatory reaction was noted, and a persistent hypotensive effect with stabilization of visual functions was achieved based on the results of a two-year follow-up.

CONCLUSIONS: Femtosecond laser-assisted phacoemulsification, performed as part of complex treatment in patients with cataract and incipient stage of primary open-angle glaucoma, is a sparing method that minimizes surgical trauma and achieves a persistent hypotensive effect, reduces intraocular pressure to an individual level and stabilizes visual functions in 97.3% of cases.

Keywords: femtosecond laser-assisted cataract surgery; hydrodynamic trabeculocleanig; selective laser trabeculoplasty; hypotensive effect.

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ECO•VECTOR

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Научная статья

Комплексное применение энергетической хирургии при лечении пациентов с первичной открытоугольной глаукомой и катарактой на фоне псевдоэксфолиативного синдрома

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Актуальность. Глаукома остается одной из актуальных проблем современной офтальмологии. Сочетание глаукомы и катаракты наблюдается в 17–38,6 % случаев, а глаукомы с псевдоэксфолиативным синдромом — в 20–50 % случаев первичной открытоугольной глаукомы.

Цель — разработать эффективную и безопасную технологию комплексного энергетического хирургического лечения начальной стадии первичной открытоугольной глаукомы и катаракты на фоне псевдоэксфолиативного синдрома на основе применения модифицированных лазерной, гидродинамической и ультразвуковой методик.

Материалы и методы. Обследованы 187 пациентов (187 глаз) с начальной стадией первичной открытоугольной глаукомы, катарактой и псевдоэксфолиативным синдромом. В основной группе (111 глаз) выполнена селективная лазерная трабекулопластика с последующей фемтолазер-ассистированной факоэмульсификацией катаракты, включавшей гидродинамический трабекулоклининг. Пациентам контрольной группы (76 глаз) после селективной лазерной трабекулопластики проводили факоэмульсификацию катаракты по стандартной методике.

Результаты. Разработанная технология позволила достигнуть гипотензивного эффекта в 35,2 % ($t = 23{,}0$; $p < 0{,}001$) исходных значений внутриглазного давления, индивидуального уровня внутриглазного давления без применения гипотензивных лекарственных препаратов в 27 % случаев, стабилизации зрительных функций и морфометрических показателей диска зрительного нерва в течение 2 лет наблюдений в 97,3 % случаев в отличие от методики селективной лазерной трабекулопластики с последующей факоэмульсификацией (21,2, 5,3 и 81,6 % соответственно). У пациентов основной группы достоверно ниже были энергетические затраты в ходе этапа факоэмульсификации катаракты, отмечен меньший процент послеоперационной воспалительной реакции, а по итогам двухлетнего наблюдения достигнуты индивидуальный уровень внутриглазного давления и стабилизация зрительных функций.

Заключение. Фемтолазер-ассистированная факоэмульсификация катаракты, выполненная в рамках комплексного лечения у пациентов с катарактой и начальной стадией первичной открытоугольной глаукомы является щадящим методом, позволяет минимизировать травматичность вмешательства, снизить внутриглазное давление до индивидуального уровня и стабилизировать зрительные функции в 97,3 % случаев.

Ключевые слова: фемтолазер-ассистированная факоэмульсификация катаракты; гидродинамический трабекулоклиниг; селективная лазерная трабекулопластика; гипотензивный эффект.

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ЭКО•ВЕКТОР

BACKGROUND

Glaucoma remains one of the most significant disabling diseases. According to the literature, the combination of glaucoma and cataract is registered in 17%–38.6% of cases [1] and that of glaucoma with pseudoexfoliation syndrome (PES) is noted in 20%–50% of cases of primary open-angle glaucoma (POAG) [2–5]. PES leads to the disruption of hydrodynamic processes and an increase in the intraocular pressure; therefore, it is a predisposing factor in glaucoma development [6–8]. The syndrome is accompanied by the presence of pseudoexfoliative material at the angle of the anterior chamber and severe pigmentation of the trabeculum. In some patients with PES, cataract develops actively, which is associated with the development of oxidative stress [9].

Selective laser trabeculoplasty (SLT) is one of the well-known methods for glaucoma treatment, which improves the outflow of the intraocular fluid because of the photothermolysis of pigment granules, which is important for severe trabecular pigmentation in cases of PES. The technique is relevant for the initial stages of glaucoma [10–12].

The IOP-lowering effect of cataract phacoemulsification (PE) in eyes with glaucoma is also widely described in the literature. Most often, the authors associate it with a change in the anatomical and topographic ratios of the structures of the anterior segment of the eyeball [13–15]. Reduction of the intraocular pressure by phacosurgery is mainly achieved by trabeculoaspiration of pseudoexfoliative material and anterior chamber angle pigment, i.e., hydrodynamic trabeculocleaning [16, 17]. Moreover, femtosecond laser-assisted phacoemulsification (FSLAPE) is often preferred in the choice of extraction methods for complicated cataracts in eyes with associated glaucoma and PES [18–20]. This occurs because keratopathies, phacopathies, zonulopathies, and vasculopathies, which often accompany PES, require a more gentle approach and a reduction in the intraoperative energy load.

The described methods of energy treatment are mainly aimed at reducing intraocular pressure by improving the outflow of the intraocular fluid. Accordingly, their combination can contribute to stabilizing visual functions while reducing increased intraocular pressure (IOP) to the individual level of the intraocular pressure in eyes with cataracts associated with the primary initial stage of POAG and PES.

This study aimed to develop effective and safe technology for the complex energy surgical treatment of POAG in its initial stage and cataract in PES by using modified laser, hydrodynamic, and ultrasound techniques.

MATERIALS AND METHODS

The study included 187 patients with complicated cataracts (187 eyes), POAG in the initial stage, and PES, who underwent sequentially the stages of SLT and phacosurgery in the clinic of the Volgograd branch of the Academician S.N. Fedorov Interbranch Scientific and Technical Complex Eye Microsurgery, Ministry of Health of Russia. The patients were 72.5 ± 3.9 (64–81) years old. There were 89 men and 98 women.

The patients were distributed into two groups. The main group included 111 patients (111 eyes) who underwent SLT and, after 1 month, FSLAPE with hydrodynamic trabeculocleaning and intraocular lens (IOL) implantation. The control group included 76 patients (76 eyes) who underwent PE with IOL implantation, without trabeculocleaning, 1 month after SLT. The control and main groups were comparable in age and gender. The mean age of the patients was 72.8 ± 3.5 years in the control group and 72.4 ± 3.9 years in the main group. The control group included 36 men (47.4%) and 40 (52.6%) women, and in the main group 50 (45%) men and 61 (55%) women were enrolled.

Patients in both groups had not previously undergone laser or surgical treatment of glaucoma. In all cases, weakness of the ligamentous apparatus was noted, not exceeding degree I lens subluxation.

The criteria for enrollment of patients for SLT as stage 1 of treatment were POAG in the initial stage, an open anterior chamber angle, degree II–III exogenous pigmentation associated with PES, and failure to achieve the level of individual IOP through IOP-lowering therapy with β-blockers and/or carbonic anhydrase inhibitors. For the next stage of phacosurgery, patients with POAG in the initial stage were selected, including those with an open anterior chamber angle, PES, and a positive IOP-lowering effect from SLT showing itself as a decrease in the IOP to an individually tolerated pressure without the use of IOP-lowering drugs or with the use of β-blockers and/or carbonic anhydrase inhibitors.

All patients underwent a comprehensive ophthalmological examination, which included visual acuity testing, static automated perimetry, optical coherence tomography of the optic nerve head (ONH), tonometry, tonography, endothelial microscopy, ultrasound biometry, and biomicroscopy. The acoustic density of the lens was determined by ultrasonic biomicroscopy on a Sonomed Vu Max device (USA) with a 35-MHz probe. Based on data on lens density in patients who underwent femtolaser assistance, the femtolaser energy was selected for phacofragmentation. A photographic recording of the gonioscopic presentation at the stages of diagnosis and treatment was performed, followed by a colorimetric assessment of the anterior chamber angle pigmentation.

At the beginning of the study, all patients received IOP-lowering therapy. Further, subject to the selection criteria, patients underwent SLT according to standard technology using a combined laser system SLT&YAG Tango (Ellex Medical Pty Ltd, Australia). Four weeks before and after the laser surgery, photorecording of the gonioscopic presentation of the intact zone and the zone subjected to SLT was performed within one image using a slit lamp with a lower illuminator, which comprised a digital photovideo system (HS-7000–5× + HIS5000 U, 10.0 M, Huvitz, South Korea). A colorimetric assessment of the change in the state of the anterior chamber angle after laser surgery was performed using the graphic editor Paint and the obtained photographic images of the intact zone of the anterior chamber angle and the SLT zone.

PE was performed 1 month after SLT using the ultrasonic tip of the Centurion Vision System phacosystem (Alcon, USA) and an auxiliary chopper-manipulator bimanually according to the Phaco chop method (Nagahara).

For femtolaser assistance, a LenSx femtolaser (Alcon) was used. The stages of femtoassistance and PE were performed within the same operating room. Upon completion of the stages of femtoassistance, the patient was transported to the operating table equipped with a microscope to perform PE. The capsulotomy formed by the laser was freed from the excised fragment of the anterior capsule with tweezers. Pneumodissection and, if necessary, hydrodissection were performed. Using the ultrasonic tip of the Centurion Vision System phacosystem (Alcon) and an operating chopper-manipulator, fragmented lens sectors were removed bimanually.

Patients of the main group underwent hydrodynamic trabeculocleaning as part of the PE stage. The irrigation–aspiration tips of the Centurion Vision System phacosystem with two external holes with a diameter of 0.3 mm were used, with the vacuum in the system of 500 mm Hg and an aspiration flow of 30 cm^3/min. Under intraoperative goniolens, a balanced saline solution was supplied along the perimeter of the anterior chamber angle (360°), and debris (pseudoexfoliative material and pigment granules) was washed out (Fig. 1). Manipulation was performed after aspiration of the lens masses and before IOL implantation. Moreover, the position of the tips within the anterior chamber was monitored, and it was necessary to pass the irrigation and aspiration tips close to each other and from the trabecula, without touching the trabecula and the iris root to avoid traumatizing the tissue. The irrigation supply created a hydrodynamic impact, releasing the debris from the angle of the anterior chamber and trabecular fissures, and the aspiration part of the system immediately collected it.

In this study, one of the tasks was the maximum possible cleansing of the trabecular meshwork from trabecular debris, including pigment granules and pseudoexfoliative material. This was visually manifested by a depletion of the color of the structures evaluated; however, methods for controlling the removal of trabecular debris are required. For this purpose, a method was developed for the intraoperative staining of the pseudoexfoliative material to remove it as completely as possible during trabeculocleaning, as well as a method for colorimetric analysis of stained structures. For this purpose, trypan blue dye was injected intraoperatively intracamerally before and after phacoemulsification, monitored with an intraoperative goniolens, and staining of structures was assessed using colorimetric analysis of photoregistration data. Colorimetric analysis indicators R, G, and B were evaluated on a scale ranging from 0 (dark) to 255 (light), changes in the degree of staining of the anterior chamber angle structures were calculated, and their values were compared using the Paint graphics editor.

The inflammatory response after phacosurgery was assessed according to the Fedorov–Egorova classification. For statistical analysis, the inflammatory reaction was scored, where 0 points indicated no reaction, 1 point meant degree 1 inflammatory reaction, and 2 points indicated degree 2 inflammatory reaction.

The efficiency of the procedures was evaluated by achieving an IOP-lowering effect and stabilization of visual functions. When analyzing the hypotensive effect of the procedure, the indicators of true intraocular pressure, individually tolerated (tolerant) intraocular pressure ($P_{0\ tl}$), intolerance index ($I_{int} = P_0 – P_{0\ tl}$), and coefficient of aqueous humor outflow facility were considered. IOP-lowering therapy was also considered, namely, the number of instilled drugs before and after procedures and the ratio of the number of cases of combined therapy or monotherapy. To assess the functional state of the optic nerve, morphometric indicators obtained by performing optical coherence tomography and indicators of static automatic perimetry were taken into account.

a *b*

Fig. 1. Trabeculocleaning under the goniolens control: *a* – intraoperative goniolens; *b* – control of trabeculocleaning

Рис. 1. Трабекулоклининг под контролем гониолинзы: *a* — интраоперационная гониолинза; *b* — контроль трабекулоклининга

In the assessment of the safety of procedure stages, the density of endothelial cells was evaluated. The follow-up period for patients was up to 2 years after treatment. The parametric data obtained following clinical and functional studies were processed by variation statistics using the computer program Statistica 10.0 (StatSoft, Inc.). To assess the significance of the difference between the mean values ($M \pm \sigma$), Student's confidence coefficient (t) was calculated, and with a value of ⩾2.0 and significance of difference (p) less than 0.05 ($p < 0.05$).

RESULTS AND DISCUSSION

The initial values of the true intraocular pressure in the main and control groups were 23.6 ± 3.2 and 22.3 ± 3.6 mm Hg and those of individually tolerated pressures were 16.6 ± 1.5 and 16.5 ± 2.8 mm Hg, respectively. The average number of instillations was 3.4 ± 0.82 and 3.5 ± 0.89 drops per day in the main and control groups, respectively. In the main group, 71.2% of the patients received a combined IOP-lowering therapy and 28.8% received monotherapy, and in the control group, the rates were 73.7% and 26.3%, respectively.

The clinical and functional indicators of the control group for the follow-up period are presented in Table 1. In the control group (76 patients, 76 eyes), the IOP-lowering effect of SLT was 21%, and the decrease in the true intraocular pressure from the baseline was 35.9% ($p < 0.05$). The value of the C coefficient increased by 30.7% ($p < 0.05$).

The clinical and functional indicators of the main group for the follow-up period are presented in Table 2. In the main group (111 patients, 111 eyes), the true intraocular pressure decreased by 21.3% from the preoperative $P0$ values and by 39% from the initial IOP values ($p < 0.05$). Moreover, a significant improvement was noted in the index of aqueous humor outflow facility by 33.3%, from 0.12 to 0.16 mm^3/(mm Hg • min) ($p < 0.05$).

The shortest time of ultrasound action during cataract surgery was noted in the main group (Tables 3 and 4), both at low- (acoustic density <34 dB) and high-density cataracts (>34 dB); this was associated with additional femtolaser assistance in the main group ($p < 0.001$).

The indicator of the total equivalent power of ultrasound was also significantly lower in the main group ($p < 0.001$). The amount of balanced saline solution consumed during PE in the main group was also significantly less than that in the control group ($p < 0.001$).

In addition, dynamic trabeculocleaning does not imply long-term additional use of fluid. Debris aspiration was performed simultaneously to the standard aspiration–irrigation, and the differences in time were insignificant.

The energy indicators at the stages of cataract surgery influenced the incidence of postoperative inflammatory reactions. The rates of corneal reactions in the main and control groups were 17% and 24%, respectively.

In the FSLAPE group, the complication rate was lower than in the control group. This is noticeable in cases of high-density cataracts (>34 dB), as there was a significantly lower ($p < 0.001$) number of postoperative reactions in the main group (0.23 ± 0.09) than in the control group (0.66 ± 0.14 points).

The comparison of trabecular pigmentation before and after SLT showed a significant decrease in pigmentation according to the colorimetric analysis in the control and main groups (Tables 5 and 6).

A significant decrease in trabecular pigmentation after trabeculocleaning should be noted. Thus, after complex treatment (SLT and trabeculocleaning) in the main group, the trabecular meshwork was significantly lighter in contrast to that in the control group ($p < 0.05$) (Table 7).

Therefore, after 2 years, the most pronounced IOP-lowering effect and the best value of the aqueous humor outflow facility were noted in the main group (Table 8).

The best results after 2 years of follow-up were noted in the main group, where $P0$ decreased by 35.2% ($t = 23.0$; $p < 0.001$) from the initial value (from 23.6 ± 3.2 to 15.3 ± 2.1 mm Hg), and the coefficient of the aqueous humor outflow facility improved by 50% (from 0.12 ± 0.03 to 0.18 ± 0.05 mm^3/(mm Hg • min) ($t = 14.3$; $p < 0.001$).

After 2 years of follow-up in the main group, the mean IOP $P0$ (15.3 ± 2.1 mm Hg) was below the tolerance value (16.6 ± 1.5 mm Hg), and the mean value of the intolerance index (I_{int}) was significantly ($t = 6.8$; $p < 0.001$) lower (–1.2 ± 0.8 mm Hg) than that in the control group (0.2 ± 1.1 mm Hg).

Therefore, the abolition of IOP-lowering drugs became possible in the main group in 30 patients (30 eyes, 27%) and only in 5.3% of cases (4 eyes) in the control group. The average number of instillations in the main group after 2 years was significantly lower (1.96 ± 1.1 drops per day) than that in the control group (2.7 ± 1.19 drops per day) ($p < 0.05$).

In the analysis of the parameters of static automated perimetry (MD and PSD) and OCT of the ONH (S of the excavation and retinal nerve fiber layer thickness) after 2 years, no significant changes from the initial values were detected in the main group ($p > 0.05$), and significantly higher ($p < 0.05$) stabilization of visual functions (97.3% of cases) was noted when compared with the control group (81.6% of cases).

To assess the safety of procedures at all stages of treatment, endothelial cell density was monitored. A significant decrease was recorded by 7.7% in the main group and by 8.6% in the control group ($p > 0.05$).

Thus, the study showed the efficiency and safety of the technology developed for complex energy surgical treatment of POAG in the initial stage and PES-associated cataracts based on the use of modified laser, hydrodynamic, and ultrasound techniques, namely, SLT, FSLAPE with IOL implantation, and hydrodynamic

Table 1. Clinical and functional indicators before and after treatment of the control group, 76 eyes, $M \pm \sigma$

Таблица 1. Клинико-функциональные показатели до и после лечения пациентов в контрольной группе, 76 глаз, $M \pm \sigma$

Parameters	Before SLT	1 month after SLT	After PE				
			After 1 month	After 6 months	After 12 months	After 18 months	After 24 months
Visual acuity	0.28 ± 0.08*	0.29 ± 0.12	0.59 ± 0.25*	0.57 ± 0.22*	0.54 ± 0.21*	0.53 ± 0.2	0.52 ± 0.22
Optic nerve head area, S_{ONH}, mm^2	1.85 ± 0.22	1.87 ± 0.24	1.86 ± 0.22	1.86 ± 0.23	1.85 ± 0.24	1.84 ± 0.25	1.84 ± 0.24
Area of the optic nerve head excavation, S_e, mm^2	0.84 ± 0.21*	0.73 ± 0.19*	0.72 ± 0.19*	0.75 ± 0.18**	0.76 ± 0.2*	0.77 ± 0.17	0.79 ± 0.17
S_e/S_{ONH} ratio	0.45 ± 0.11*	0.39 ± 0.12*	0.39 ± 0.13*	0.4 ± 0.11*	0.44 ± 0.12*	0.42 ± 0.11	0.44 ± 0.12
Retinal nerve fiber layer, μm	76.6 ± 5.2	76.8 ± 5.3	77.3 ± 5.4	76.9 ± 5.0	76.7 ± 5.3	76.6 ± 5.2	76.4 ± 5.3
Mean deviation of the photosensitivity reduction, dB	–5.1 ± 0.4*	–4.6 ± 0.5*	–4.1 ± 0.5*	–4.6 ± 0.5*	–4.7 ± 0.5*	–5.0 ± 0.5	–5.2 ± 0.53*
Pattern standard deviation, dB	4.4 ± 0.45 *	3.3 ± 0.43*	3.9 ± 0.47*	4.1 ± 0.49*	4.2 ± 0.51*	4.4 ± 0.52	4.5 ± 0.5*
Tonometric intraocular pressure, mm Hg	23.2 ± 3.1*	19.3 ± 2.8*	19.5 ± 2.2*	21.6 ± 1.6*	22.1 ± 1.9*	22.6 ± 1.9	22.9 ± 1.8*
P_0, mm Hg	18.1 ± 2.9*	14.3 ± 2.2*	14.8 ± 1.8*	16.4 ± 2.1*	16.9 ± 2.4*	17.1 ± 2.3	17.7 ± 2.4*
Coefficient (C), mm^3/(mm Hg · min)	0.13 ± 0.02*	0.17 ± 0.02*	0.17 ± 0.03*	0.16 ± 0.03*	0.16 ± 0.03*	0.15 ± 0.03	0.14 ± 0.03*
F, mm^3/min	0.9 ± 0.16	0.82 ± 0.14	0.8 ± 0.13	0.83 ± 0.12	0.97 ± 0.12	0.92 ± 0.18	0.83 ± 0.19
Becker coefficient (P_0/C)	133 ± 28.9*	88.7 ± 29.2*	87.3 ± 28.5*	101.8 ± 32*	112.4 ± 34.1*	114.2 ± 31.3	123 ± 33.5
Density of endothelial cells, cells/mm^2	2240 ± 298*	2186 ± 302	2164 ± 263	2172 ± 174	2160 ± 179*	2146 ±177	2153 ± 171

* The difference between the mean values before and after SLT is significant ($p < 0.05$).
Note. SLT, selective laser trabeculoplasty; PE, phacoemulsification.

Table 2. Average values of clinical and functional parameters of the main group before and after combined treatment, 111 eyes, $M \pm \sigma$

Таблица 2. Средние значения клинико-функциональных показателей пациентов в основной группе до и после комбинированного лечения, 111 глаз, $M \pm \sigma$

Parameters	Before SLT, on antihypertensive therapy	1 month after SLT	After FSLAPE and TC with IOL implantation				
			After 1 month	After 6 months	After 12 months	After 18 months	After 24 months
Visual acuity	0.3 ± 0.1*	0.32 ± 0.11	0.67 ± 0.2*	0.7 ± 0.11*	0.72 ± 0.12*	0.73 ± 0.11	0.7 ± 0.11
Optic nerve head area, S_{ONH}, mm^2	1.88 ± 0.24	1.86 ± 0.26	1.84 ± 0.23	1.85 ± 0.22	1.86 ± 0.24	1.85 ± 0.24	1.86 ± 0.24
Area of the optic nerve head excavation, S_e, mm^2	0.87 ± 0.2*	0.75 ± 0.18*	0.73 ± 0.17*	0.74 ± 0.16*	0.74 ± 0.18*	0.73 ± 0.17	0.73 ± 0.17
S_e/S_{ONH} ratio	0.46 ± 0.1*	0.4 ± 0.11*	0.38 ± 0.09*	0.39 ± 0.12*	0.4 ± 0.11*	0.39 ± 0.12	0.39 ± 0.11
Retinal nerve fiber layer, μm	77.9 ± 4.9	78.2 ± 5.1	78.3 ± 5.2	78.2 ± 5.0	78.2 ± 5.1	78.3 ± 5.0	78.1 ± 5.2
Mean deviation of the photosensitivity reduction, dB	–5.3 ± 0.4*	–4.7 ± 0.4*	–4.8 ± 0.42*	–4.7 ± 0.41*	–4.9 ± 0.43*	–4.8 ± 0.42	–5.1 ± 0.44
Pattern standard deviation, dB	4.6 ± 0.4*	3.5 ± 0.5*	3.3 ± 0.52	3.4 ± 0.5	3.5 ± 0.51	3.4 ± 0.52	3.6 ± 0.5
Tonometric intraocular pressure, mm Hg	23.5 ± 1.9*	19.0 ± 1.8*	18.2 ± 1.8*	18.9 ± 1.6*	19.8 ± 1.9*	19.9 ± 1.8	20.3 ± 1.7
P_0, mm Hg	18.3 ± 1.5*	14.4 ± 1.8*	13.3 ± 2.3*	14.6 ± 2.1*	14.9 ± 2.17*	15.1 ± 2.2	15.3 ± 2.1
Coefficient (C), mm^3/(mm Hg · min)	0.12 ± 0.03*	0.16 ± 0.03*	0.2 ± 0.04*	0.19 ± 0.04*	0.19 ± 0.04*	0.19 ± 0.04	0.18 ± 0.05
F, mm^3/min	0.97 ± 0.24*	0.7 ± 0.22*	0.8 ± 0.22*	0.75 ± 0.2*	0.77 ± 0.2*	0.76 ± 0.2	0.8 ± 0.23
Becker coefficient (P_0/C)	146 ± 26.8*	88.2 ± 24*	73.2 ± 25*	76.4 ± 22*	77.4 ± 24*	78.2 ± 22.5	82.4 ± 24.1
Density of endothelial cells, cells/mm^2	2178 ± 284	2160 ± 288	2014 ± 263	2012 ± 174	2010 ± 179	2011 ± 178	2013 ± 175

* The difference between the mean values before and after SLT is significant ($p < 0.05$).
Note. SLT, selective laser trabeculoplasty; FSLAPE, femtosecond laser-assisted phacoemulsification; TC, trabeculocleaning; IOL, intraocular lens.

Table 3. Intraoperative indices at the FEC stage with acoustic density below 34 dB in groups, *M* ± σ

Таблица 3. Интраоперационные показатели на этапе факоэмульсификации с акустической плотностью ниже 34 дБ в группах, *M* ± σ

Parameters	Main group (SLT + FSLAPE + TC)	Control group (SLT + PE)	Student's ratio (*t*)	*p*
Ultrasound time, s	20.46 ± 6.6	54 ± 6.7	34.6	<0.001
Total equivalent power, %	9.9 ± 1.2	19.7 ± 3.15	26.0	<0.001
Amount of solution, ml	33.5 ± 4.1	78.5 ± 10.9	34.4	<0.001

Note. SLT, selective laser trabeculoplasty; FSLAPE, femtosecond laser-assisted phacoemulsification; TC, trabeculocleaning.

Table 4. Intraoperative indicators at the FEC stage with an acoustic density of over 34 dB in groups, *M* ± σ

Таблица 4. Интраоперационные показатели на этапе факоэмульсификации с акустической плотностью свыше 34 дБ в группах, *M* ± σ

Parameters	Main group (SLT + FSLAPE + TC)	Control group (SLT + PE)	Student's ratio (*t*)	*p*
Ultrasound time, s	66.2 ± 8.1	92.7 ± 3.4	31	<0.001
Total equivalent power, %	20.6 ± 3.2	23.7 ± 2.4	10.2	<0.001
Amount of solution, ml	52.0 ± 12.5	89.7 ± 9.3	23.7	<0.001

Table 5. Average values of indicators of colorimetric analysis of pigmentation of the trabecular meshwork before and after SLT in patients of the control group, *M* ± σ

Таблица 5. Средние значения показателей колориметрического анализа пигментации трабекулярной сети у пациентов контрольной группы, *M* ± σ

Group name	Colorimetric analysis parameters		
	R (red)	G (green)	B (blue)
Before SLT	179.7 ± 61.7	138.6 ± 73.9	100.2 ± 53.9
After SLT	206.9 ± 69.6	166.1 ± 66.1	119.5 ± 55.6
Student's ratio (*t*)	2.4	2.38	2.2
p	<0.05	<0.05	<0.05

Note: Selective laser trabeculoplasty (SLT)

Table 6. Mean values of indicators of colorimetric analysis of pigmentation of the trabecular meshwork before and after SLT in patients of the main group, *M* ± σ

Таблица 6. Средние значения показателей колориметрического анализа пигментации трабекулярной сети у пациентов основной группы, *M* ± σ

Group name	Colorimetric analysis parameters		
	R (red)	G (green)	B (blue)
Before SLT	178.9 ± 88.2	140.7 ± 83	102.8 ± 60.9
After SLT	208 ± 82.9	162.4 ± 76.6	121.2 ± 59.8
Student's ratio (*t*)	2.5	2.0	2.3
p	<0.05	<0.05	<0.05

Note: Selective laser trabeculoplasty (SLT)

Table 7. Mean values of indicators of colorimetric analysis of pigmentation of the trabecular meshwork after trabeculocleaning in patients of the main group, *M* ± σ

Таблица 7. Средние значения показателей колориметрического анализа пигментации трабекулярной сети после трабекулоклининга у пациентов основной группы, *M* ± σ

Group name	Colorimetric analysis parameters		
	R (red)	G (green)	B (blue)
Before trabeculocleaning	199 ± 7.9	152.8 ± 7.1	115.8 ± 7.7
After trabeculocleaning	222.9 ± 7.8	181.9 ± 8.6	140.2 ± 8.1
Student's ratio (*t*)	2.1	2.6	2.18
p	<0.05	<0.05	<0.05

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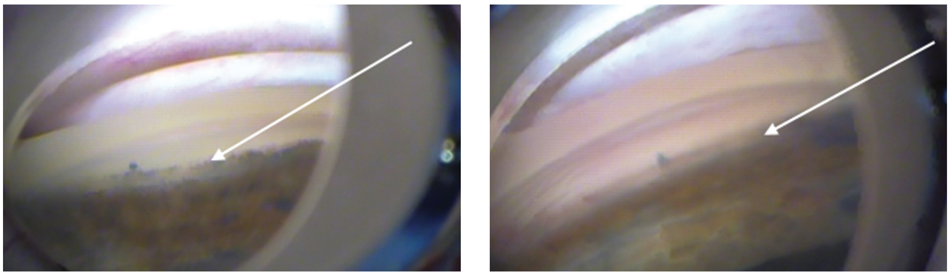
Table 8. Tonographic parameters before and 2 years after treatment, $M \pm \sigma$

Таблица 8. Тонографические показатели до и через 2 года после лечения, $M \pm \sigma$

Groups	Intraocular pressure (P_0)			Coefficient (C)		
	Before treatment	After treatment	Δ, %	Before treatment	After treatment	Δ, %
Main group (SLT + FSLAPE + TC)	23.6 ± 3.2	15.3 ± 2.1	35.2	0.12 ± 0.03	0.18 ± 0.05	50
Control group (SLT + PE)	22.3 ± 3.6	17.6 ± 2.4	21.8	0.13 ± 0.02	0.14 ± 0.03	7.7

Note. SLT, selective laser trabeculoplasty; FSLAPE, femtosecond laser-assisted phacoemulsification; TC, trabeculocleaning.



a *b*

Fig. 2. Fragment of a gonioscopic image in patient K., 65 years old, under conditions of intraoperative staining: *a* – before trabeculocleaning (the arrow points at stained pseudoexfoliative material on the trabeculum); *b* – after trabeculocleaning (the arrow points at the state of the tradculum)

Рис. 2. Фрагмент гониоскопической картины у пациента К., 65 лет, в условиях интраоперационного окрашивания: *a* — до трабекулоклинига (стрелка указывает на окрашенный псевдоэксфолиативный материал на трабекуле); *b* — после трабекулоклининга (стрелка указывает на состояние трабекулы)

trabeculocleaning, which enables achieving an IOP-lowering effect in 35.2% ($t = 23.0$; $p < 0.001$) of the initial values of the true intraocular pressure, individual level of intraocular pressure without the use of IOP-lowering drugs in 27% of cases, and stabilization of visual functions and morphometric parameters of the optic nerve disk during 2 years of follow-up in 97.3% of cases, in contrast to the SLT technique followed by PE (21.2%, 5.3%, and 81.6%, respectively).

CONCLUSION

Femtosecond laser-assisted cataract surgery, including hydrodynamic trabeculocleaning, employed as part of the complex treatment of patients with cataract associated with POAG in the initial stage and PES, helps to minimize the trauma of the procedure, to reduce the intraocular pressure to an individual level, and to stabilize visual functions in 97.3% of cases.

ADDITIONAL INFORMATION

Author contributions. All authors confirm that their authorship complies with the ICMJE criteria. All authors have made a significant contribution to the development of the concept, research and preparation of the article, read and approved the final version before its publication. B.G. Jashi collected and processed the material, performed statistical processing, prepared the illustrations, created the concept and design of the study, collected the material, and wrote the text of the article. S.V. Balalin performed statistical processing and edited the text.

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