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THE EFFECT OF PRESET INTRAOPERATIVE INTRAOCULAR PRESSURE DURING PHACOEMULSIFICATION ON THE BLOOD FLOW VELOCITY IN THE CENTRAL RETINAL ARTERY

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✧ ***Aim.*** To evaluate the effect of preset elevated intraocular pressure (IOP) level during phacoemulsification on central retina artery and central retinal vein hemodynamics and to determine possible compensatory mechanisms of the ocular blood flow autoregulation in response to intraoperational IOP jump. ***Methods.*** This prospective study included 23 cataract patients without concomitant ocular vascular conditions (15 women and 8 men) aged from 62 to 83 years. The mean age was 72.5 ± 5.7 years. In all patients, an intraoperational color duplex scanning in the regimens of color Doppler imaging and pulsed wave velocity imaging using ultrasound scanner Logiq S8 (GE). The blood flow was estimated in retrobulbar vessels: central retinal artery, central retinal vein with maximal systolic velocity, end-diastolic velocity of the blood flow, and resistance index (RI). The investigation was performed under IOP control, which was measured using Icare Pro tonometer, and under blood pressure control using patient monitoring system Draeger Vista 120. In the operating room, ocular blood flow was examined three times: immediately before surgery, straight after the surgical incision sealing at preset intraoperational IOP level, and after IOP normalization and repeated sealing of the corneal tunnel. ***Results.*** Under preset intraoperational IOP maintenance on 58.01 ± 8.10 mm Hg level, there was a clinically significant ($p < 0.05$) decrease of blood flow velocity in the central retinal artery. In 30.4% of cases, the blood flow velocity in the central retinal artery during diastolic phase was not registered. The flow velocity in central retinal vein did not change significantly, and did not depend on IOP level ($p < 0.05$). ***Conclusions.*** At the 55–60 mm Hg IOP level, in humans, compensatory blood flow autoregulation mechanisms in response to intraoperational IOP jumps are absent, up to complete blood flow stop in the central retinal artery at the diastolic phase, and this could be a risk factor for retinal ischemia.

✧ ***Keywords:*** cataract; phacoemulsification; intraocular pressure; central retinal artery; ischemia.

ВЛИЯНИЕ ЗАДАННОГО ИНТРАОПЕРАЦИОННОГО ОФТАЛЬМОТОНУСА ПРИ ФАКОЭМУЛЬСИФИКАЦИИ НА СКОРОСТЬ КРОВОТОКА В ЦЕНТРАЛЬНОЙ АРТЕРИИ СЕТЧАТКИ

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✧ ***Цель исследования*** состояла в оценке влияния заданного повышенного уровня внутриглазного давления (ВГД) во время факоэмульсификации катаракты на состояние кровотока в центральной артерии и центральной вене сетчатки и определении возможных компенсаторных механизмов ауторегуляции глазного кровотока в ответ на резкое интраоперационное повышение уровня ВГД. ***Материалы и методы.*** Проспективное исследование включало 23 пациента с катарактой, у которых отсутствовала сопутствующая глазная сосудистая патология (15 женщин и 8 мужчин) в возрасте от 62 до 83 лет. Средний возраст составил 72,5 ± 5,7 года. Всем пациентам проводили интраоперационное цветовое дуплексное сканирование в режимах цветового доплеровского картирования и импульсной доплерографии с помощью ультразвукового сканера Logiq S8 (GE). Определяли кровоток в ретробульбарных сосудах: центральной артерии сетчатки, центральной вене сетчатки с регистрацией максимальной систолической скорости, конечной диастолической скорости кровотока и индекса резистентности (RI). Исследование проводили под контролем уровня ВГД, которое измеряли с помощью тонометра Icare Pro, и под контролем артериального давления с использованием систем мониторинга пациента Draeger Vista 120. В условиях операционной исследовали глазной кровоток трёхкратно: непосредственно перед операцией, сразу после герметизации операционного доступа на заданном интраоперационном уровне ВГД и после нормализации офтальмотонуса и повторной герметизации роговичного тоннеля. ***Результаты.*** При поддержании интраоперационно внутриглазного давления на уровне 58,01 ± 8,10 мм рт. ст. наблюдалось клинически значимое ($p < 0,05$) снижение скорости кровотока в центральной артерии сетчатки. В 30,4 % случаев скорость кровотока в центральной артерии сетчатки в диастолическую фазу не регистрировалась. Скорость кровотока в центральной вене сетчатки менялась незначительно и не зависела от уровня ВГД ($p > 0,05$). ***Выводы.*** На уровне ВГД 55–60 мм рт. ст. у человека отсутствуют компенсаторные механизмы ауторегуляции кровотока в ответ на резкое повышение интраоперационного ВГД, вплоть до полного прекращения кровотока в центральной артерии сетчатки в диастолическую фазу, что может являться фактором риска ишемии сетчатки.

✧ ***Ключевые слова:*** катаракта; факоэмульсификация; внутриглазное давление; центральная артерия сетчатки; ишемия.

INTRODUCTION

The implementation of contemporary microinvasive technologies in ophthalmic surgery has resulted in a transition from wide surgical access to small incisions and surgeries in a normotensive eye. Maintaining a balance of irrigation and aspiration flows during surgery is the basic principle in both cataract and vitreoretinal surgery.

The progress in the development of new generations of high-speed aspiration systems makes increasingly stringent demands on maintaining flow balance and stabilizing the anterior and posterior chambers of the eye during surgery. This inevitably leads to an increase in forced irrigation. To maintain the volume of the anterior chamber of the eye and to stabilize it at the time of occlusion breakthrough, when the aspiration flow rises sharply, many surgeons increase the height of the irrigation bottle using gravity systems or increase the flow of irrigation solution under pressure in systems with forced infusion. In systems with active fluidonics, most surgeons increase the specified level of intraocular pressure (IOP) to 55 to 60 mmHg and higher, allowing the flow to be supported automatically based on data from sensors that monitor the IOP level. The system automatically adjusts the balance shift of irrigation and aspiration flows, which not only maintains a given level of intraocular pressure, but also ensures the absence of fluctuation of the anterior chamber and its microcollapses. There is a variety of causes of instability of the anterior chamber, including a sharp increase in aspiration flows at the time of occlusion breakthrough and excessive external filtration to the irrigation block, inconsistency of the incision geometry with the diameter of the surgical instrument, irrigation block, an excess of viscoelastic gel in the anterior chamber, or air bubbles entering the irrigation system.

In order to ensure continuous maintenance of the volume of the anterior chamber, which is only 0.17–0.25 μl [1], the height of the location of the irrigation bottle is increased to 80–110 cm and higher in systems with gravity supply.

The theoretical level of IOP is calculated by the formula [2]:

$$\text{IOP level (mmHg)} = \text{Bottle height (cm)} \times 10/13.6,$$

where 13.6 is the density of mercury, g/cm^3, and the density of water is 1 g/cm^3.

Thus, the IOP level during surgery at a bottle height of 80 cm with irrigation liquid is 58.8 mmHg.

According to Khng et al (2006), the IOP level in real measurement differed from the theoretical one by only 5% to 11% [2]. It is generally accepted that the negative impact of a high level of IOP consists mainly of 2 factors [3]: (1) direct compression damage to tissues under the influence of high pressure [3–5] and (2) tissue ischemia resulting from the compression of blood vessels supplying eye tunics [6–10].

The question of whether there are autoregulation mechanisms in the eye that compensate for a sharp increase in the IOP level during surgery is very relevant. The literature presents only few publications on the effect of an increased IOP level on the occurrence of ischemic reperfusion injury to the retina in an experiment in animals. The results of these *in vivo* studies showed that an increase in IOP to 110–130 mmHg by active administration of saline or air into the anterior chamber resulted in the retinal and choroidal circulation cessation [11–13].

Several publications present data on pathological changes in the eye tunics in the early period after modeling of retinal ischemia-reperfusion under the influence of high IOP characterized by retinal edema and atrophy of ganglion cells [14]. In the late postischemic period (Day 30), damage mainly to the outer layers of the retina was revealed, which is probably associated with compression and ischemic injury of the choroid and results in its thinning and infiltration with lymphocytes [15]. The authors found an increase in apoptosis factors BAX and BCL-2, as well as an increase in the concentration of monocyte chemoattractant protein (MCP-1) in the retina-choroid complex, indicating a pronounced activation of cell apoptosis and an inflammatory reaction in eye tunics.

G. Chidlow et al (2002) determined a significant decrease in the amplitude of α- and β-waves of the electroretinogram, the level of nitric oxide synthase, and a decrease in the content of specific ganglion cell messenger ribonucleic acid in rats in an experiment when simulating retinal ischemia with an increase in IOP for 45 minutes [16].

Currently, there are several invasive and noninvasive instrumental methods for studying eye hemodynamics, each of them has advantages and disadvantages [20,21]. These methods allow for the determination of deterioration in the ocular hemodynamics in patients with glaucoma and ophthalmic hypertension [22].

Most authors agree that an increase in the IOP level negatively affects the retina photosensitivity and contributes to an increase in the area of excavation of the optic nerve disc in patients with myopic and emmetropic refraction [17–19].

The appearance of color duplex ultrasonography in clinical practice has allowed for visualization of the orbital vessels supplying the retina and optic nerve to determine the quantitative parameters of blood flow [23]. Thus, in the 1999 study by Joos and Steinwand using color duplex ultrasonography, it was revealed that a decrease in the maximum systolic and final diastolic blood flow velocity and an increase in vasoresistance in the posterior short ciliary arteries correlates directly with an increase in the IOP level in healthy individuals with its gradual increase from 25 to 50 mmHg [24].

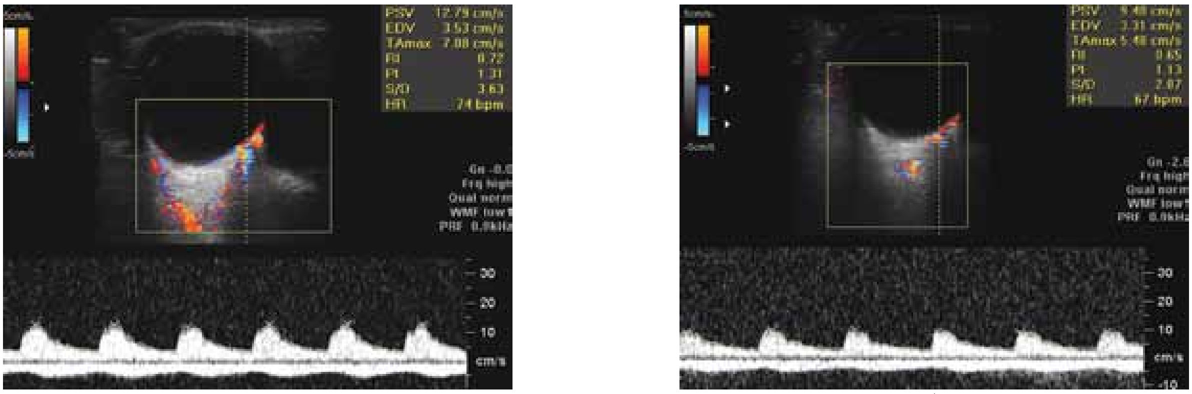
The literature presents only few publications on the effect of a high IOP level depending on the type of aspiration system. There are reports on direct time dependence for apoptosis of retinal ganglion cells and changes in the permeability of the blood-brain barrier [25] and decreased visual acuity according to electroencephalography in the experiment [18]. Increased IOP leads to more frequent corneal edema and more pronounced inflammatory phenomena [26], and also increases the incidence of macular edema in the postoperative period [27].

In clinical practice, the question of the effect of increased IOP on the hemodynamic state of the retina and optic nerve in a relatively tight eye remains poorly understood. This study aims to assess the effect of increased IOP during phacoemulsification on the state of blood flow in the central retinal artery and central retinal vein and to identify possible compensatory mechanisms of ocular blood flow autoregulation in response to a steep intraoperative increase in IOP.

PATIENTS AND METHODS

Twenty-three patients (15 women, 8 men) ranging in age from 62 to 83 years were examined. The average patient age was 72.5 ± 5.7 years. The criterion for inclusion in the study was the presence in patients of cataract of varying density degree in the absence of other ocular pathology. The exclusion criteria were previous surgical interventions on the eye; history of vascular, inflammatory, or dystrophic diseases of the eye; high degree of refractive error; hemodynamically significant stenosis of the internal carotid artery; diabetes mellitus; or uncompensated arterial hypertension. The control group consisted of 40 individuals of the same age group without cardiovascular disease or diabetes.

Before surgery, a standard ophthalmological examination was performed on all patients, including visual acuity testing, optical or ultrasound biometry, keratometry, and tonometry. The IOP level was measured using a special Icare Pro tonometer (Icare Finland, Oy, Finland). Immediately before surgery,



a *b*

Fig. 1. The Doppler spectral analysis of blood flow velocities in the central retinal artery: *a* – before cataract surgery (V_{syst} = 12.3 cm/s, V_{diast} = 4.1 cm/s); *b* – immediately following cataract surgery (V_{syst} = 9.4 cm/s, V_{diast} = 3.3 cm/s)

Рис. 1. Доплеровский спектр кровотока в центральной артерии и центральной вене сетчатки: *a* — непосредственно перед операцией (V_{syst} = 12,3 см/с, V_{diast} = 4,1 см/с); *b* — сразу после операции (V_{syst} = 9,4 см/с, V_{diast} = 3,3 см/с)

blood pressure was measured using a standard noninvasive method on the left brachial artery using the Draeger Vista 120 patient monitoring system (Draeger Medical GmbH, Luebeck, Germany).

All patients underwent intraoperative color duplex scanning in the modes of color Doppler mapping and pulsed Doppler sonography using a Logiq S8 ultrasound scanner (GE, Waukesha, WI).

In the operating room, the ocular blood flow was studied 3 times: immediately before surgery, immediately after sealing the operative access at a given intraoperative level of IOP (Fig. 1, *a* and *b*), and after normalization of the IOP and resealing of the corneal tunnel (Fig. 2). The interval between the second and third measurements averaged 3.48 ± 0.36 hours. Blood flow was determined in retrobulbar vessels, namely the central retinal artery (CRA) and the central retinal vein (CRV), with registration of the maximum systolic blood flow velocity (V_{syst}), final diastolic blood flow velocity (V_{diast}), and resistance index (RI).

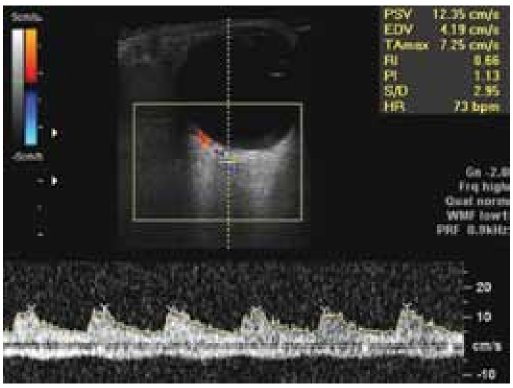


Fig. 2. The Doppler spectral analysis of blood flow velocities in the central retinal artery after normalization of intraocular pressure (V_{syst} = 12.7 cm/s, V_{diast} = 3.5 cm/s)

Рис. 2. Доплеровский спектр кровотока в центральной артерии сетчатки и центральной вене сетчатки после нормализации офтальмотонуса (V_{syst} = 12,7 см/с, V_{diast} = 3,5 см/с)

All patients (23 eyes) underwent phacoemulsification with intraocular lens implantation. Surgical procedures were performed under the same conditions, with topical instillation anesthesia and 2.2 mm wide corneal access with 2 additional 1.2 mm wide paracentesis. For phacoemulsification, the Centurion Vision System (Alcon, Fort Worth, TX) was used with the parameters of the level of the preset predetermined IOP level of 60 mmHg, vacuum of 650 mmHg, aspiration rate of 27 cm^3/min, and 100% torsional ultrasound. The lens nucleus was removed using the quick chop technique, and cortical masses were aspirated using a bimanual irrigation and aspiration system. A flexible intraocular lens made of hydrophobic acrylic was implanted into the lens capsule, with thorough washing of the viscoelastic gel. Sealing of the eye was performed by hydration of the corneal stroma with irrigation solution (balanced salt solution). There were no complications during any of the surgeries. The average surgery time was 6.56 ± 1.19 hours.

Statistical analysis was performed using Microsoft Excel (Microsoft Corp, Redmond, WA) and SPSS 25.0 (IBM Corp., Armonk, NY). Analysis of the statistical correlation between parameters was performed using the method of multivariate analysis of variance for coherent samples. Differences between the mean values were considered significant at $P < 0.05$.

RESULTS

The IOP level in the preoperative period was within the range of 12.1 to 24.1 mmHg. Blood pressure was 102 to 217 mmHg in systole and 54 to –94 mmHg in diastole, respectively. Table 1 presents data on changes in the level of IOP and blood pressure immediately before each color duplex ultrasonography.

Analysis of the results of ocular hemodynamic study showed that before surgery, the maximum systolic blood flow velocity in the CRA ranged from 7.2 to 21.6 cm/s (Figs. 3 and 4) and from 3.8 to 5.7 cm/s in the final diastolic blood flow velocity (Table 2, Fig. 5). Immediately after surgery, at a given IOP level of 58.01 ± 8.10 mmHg in the CRA, a statistically significant decrease in the final diastolic blood flow velocity was noted with an increase in RI ($P < 0.05$) (Fig. 5). In 7 of the 23 patients (30.4%), V_{diast} in CRA was not registered (Fig. 5). After normalization of the IOP, restoration of hemodynamic parameters in the CRA to the initial level was noted in all patients ($P > 0.05$) (Fig. 5). According to the data obtained during the study, the blood flow velocity in CRV did not change significantly, did not statistically differ from the initial measurement, and did not depend on the level of intraocular pressure ($P > 0.05$) (Fig. 3).

DISCUSSION

This study confirmed the negative effect of a high level of ocular pressure (58.01 ± 8.10) on the blood flow velocity in the central retinal artery during surgical procedure, which continues and expands the findings of Joos and Steinwand (1999), who studied the effect of a phased increase in IOP on eye hemodynamics.

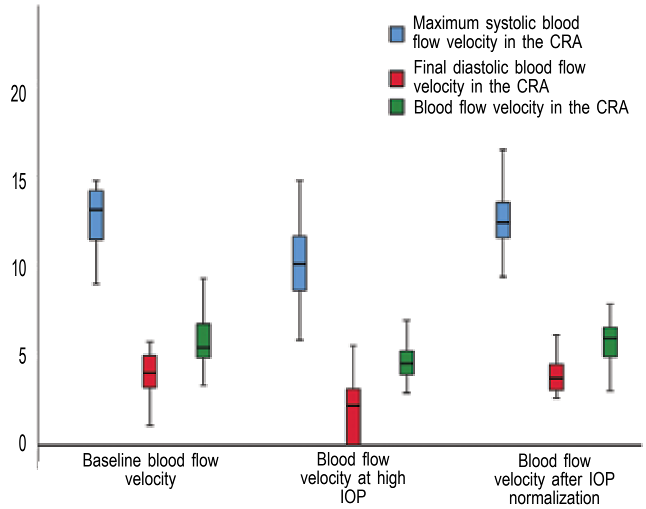


Fig. 3. Peak systolic velocity and end-diastolic velocity of blood flow in the central retinal artery with varying levels of intraocular pressure

Рис. 3. Максимальная систолическая и конечная диастолическая скорость кровотока в центральной артерии и вене сетчатки при различном уровне внутриглазного давления (ВГД). ЦАС — центральная артерия сетчатки, ЦВС — центральная вена сетчатки

Our study revealed that an increase in IOP during phacoemulsification significantly reduces the blood flow velocity in the central retinal artery up to the lack of registration of diastolic blood flow in the CRA, regardless of the initial blood pressure. Complete cessation of diastolic blood flow in the CRA was recorded in 7 of the 23 patients (30.4%), which corresponds to the data reported in previous experimental studies on animals and *in vivo*.

Indices of the final diastolic blood flow velocity in the CRA were not determined when the IOP reached a certain threshold level, within 55 to 60 mmHg and higher, which was not noted in previous studies with

Table 1 / Таблица 1

Mean indices of intraocular pressure and blood pressure in patients before and after cataract surgery
Средние показатели уровня внутриглазного давления и артериального давления у пациентов до и после факоэмульсификации катаракты

Blood flow indices	Index registration terms		
	Before surgery (n = 23)	Immediately after sealing (n = 23)	After IOP normalization (n = 23)
Intraocular pressure, mmHg	18.510 ± 2.90	58.01 ± 8.10	22.75 ± 2.90
Systolic blood pressure, mmHg	156.57 ± 23.27	162.30 ± 21.5	140.05 ± 16.557
Diastolic blood pressure, mmHg	75.13 ± 10.03	78.87 ± 14.32	73.68 ± 11.934

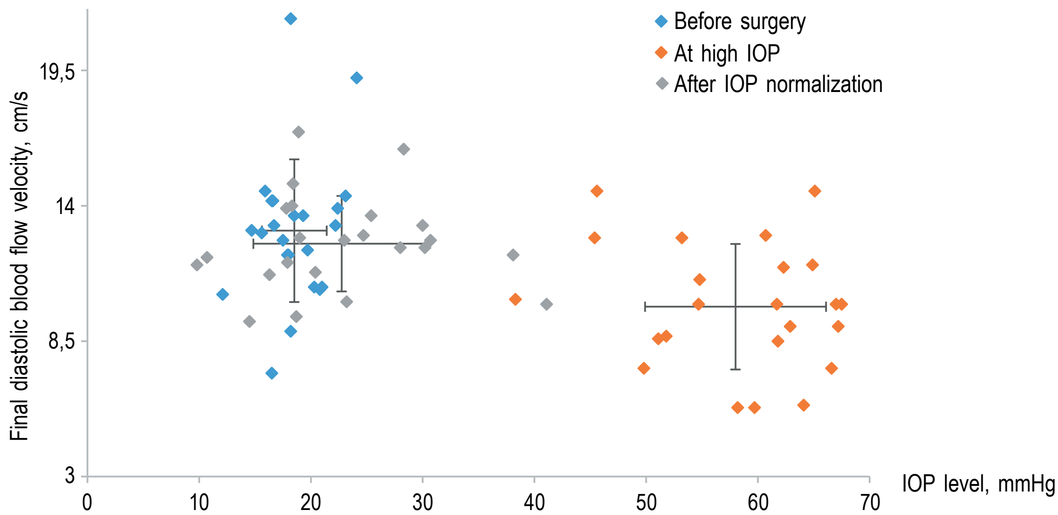


Fig. 4. The effect of intraocular pressure on the peak systolic velocity of blood flow in the central retinal artery

Рис. 4. Влияние уровня внутриглазного давления на максимальную систолическую скорость кровотока в центральной артерии сетчатки

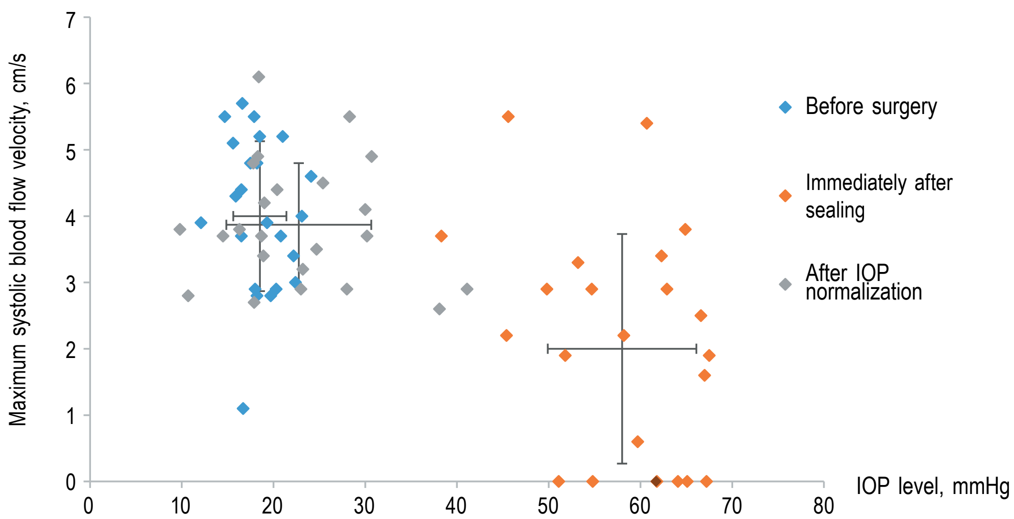


Fig. 5. The effect of intraocular pressure on the end systolic blood flow in the central retinal artery

Рис. 5. Влияние уровня внутриглазного давления на конечную диастолическую скорость кровотока в центральной артерии сетчатки

Table 2 / Таблица 2

Mean hemodynamic parameters in the ocular vessels in patients before and after cataract surgery at various levels of intraocular pressure

Средние показатели гемодинамики в сосудах глаза у пациентов до и после факоэмульсификации катаракты при различном уровне внутриглазного давления

Blood flow indices	Index registration terms			Control (n = 40)
	Before surgery (n = 23)	Immediately after sealing (n = 23)	After IOP normalization (n = 23)	
Central retinal artery, V_{syst}, cm/s	12.55 ± 2.54	10.09 ± 2.07	12.07 ± 1.71	12.03 ± 0.58
V_{diast}, cm/s	3.87 ± 1.18	2.18 ± 1.83*,**	3.67 ± 0.85	3.53 ± 0.19
RI	0.68 ± 0.10	0.79 ± 0.16*,**	0.69 ± 0.5	0.74 ± 0.01
Central retinal vein, V_{syst}, cm/s	5.81 ± 1.51	4.93 ± 1.26**	5.65 ± 1.26	6.48 ± 0.22

*P < 0.05, significance relative to indices before surgery.
**P < 0.05, significance relative to indices of a healthy eye.
V_{syst}, maximum systolic blood flow velocity; V_{diast}, final diastolic blood flow velocity; RI, resistance index.

lower IOP parameters reaching 45 to 50 mmHg. During the study, immediately after the normalization of IOP, the blood flow rate was restored in full.

Our results raise new questions regarding the optimal safe level of IOP during surgical procedures that does not lead to circulatory disorders in the ocular vessels. Assessment of the medium- and long-term effects of hemodynamic changes on the state and functional activity of the retina requires further research.

CONCLUSIONS

Parameters used by surgeons for phacoemulsification, which maintain the level of IOP within 55 to 60 mm Hg and higher, can negatively affect the blood supply to the retina during the entire duration of the surgery. Complete stopping of blood flow in the diastolic phase at an intraocular pressure level of 58.01 ± 8.10 occurs in one-third of patients (30.4% of clinical cases). Changes in blood flow velocity in the CRV were clinically insignificant ($P > 0.05$) and did not depend on fluctuations in IOP. The lack of compensatory mechanisms for autoregulation of ocular blood flow in response to a steep increase in the intraoperative level of IOP can be a risk factor for retinal ischemia.

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