INTRAOCULAR LENS STITCHING TO IRIS WITH FULL PRESERVATION OF ITS FUNCTIONS: MICRORECONSTRUCTIVE TECHNIQUES

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Today, implantation of an intraocular lens (IOL) into the capsular bag is the standard approach to surgical treatment of cataracts and aphakia of various origins. However, there are several reasons and conditions that disallow this operation or increase the risk of instability of the implanted lens, such reasons and conditions including weakness of the lens ligaments; degradation of Zinn's zonule, including dislocation of the IOL–capsular bag complex post-surgery; damage to or removal of capsular bag during surgery; lack of capsular bag or its destruction during implantation in aphakia cases. To date, problems associated with fixation and centralization of IOL in non-standard cases involving weak or inexistent capsular support remain unresolved. This study aimed to develop techniques allowing to stitch IOL to the iris without compromising its functions in various situations when it is unfeasible or impossible to fix and center lens in the capsular bag. The patients (n = 12; 12 eyes), depending on the clinical situation, were divided into groups: group 1 — dislocations of the IOL–capsular bag complex (6 eyes); group 2 — complete lack of capsular support (3 eyes); group 3 — weakness of capsular support (3 eyes). A special stitching technique was developed for each of these situations. The results of the treatment were good from clinical and functional perspectives: the IOL was fixed securely and centered properly, and the iris's performance and cosmetic aspects were not compromised.

Keywords: lack or weakness of capsular support, IOL dislocation, destruction of lens ligaments, aphakia, avitria

Compliance with ethical standards: the study was approved (Minutes #239 of April 15, 2024), and the patients voluntarily consented to surgical treatment and processing of personal data.

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МИКРОРЕКОНСТРУКТИВНЫЕ ТЕХНОЛОГИИ ПОДШИВАНИЯ ИНТРАОКУЛЯРНОЙ ЛИНЗЫ К РАДУЖКЕ С ПОЛНЫМ СОХРАНЕНИЕМ ЕЕ ФУНКЦИЙ

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Имплантация интраокулярной линзы (ИОЛ) в капсульный мешок на сегодняшний день признана стандартом в хирургическом лечении пациентов с катарактой и афакией различного генеза. Несмотря на это существует ряд причин и состояний, при которых имплантация линзы в капсульную сумку не представляется возможной или связана с высоким риском ее нестабильной фиксации: несостоятельность связочного аппарата хрусталика, разрушение цинновых связок, в том числе дислокация комплекса «ИОЛ — капсульный мешок» в послеоперационном периоде; повреждение или удаление капсульного мешка во время операции, а также его отсутствие или разрушение при имплантации на афакичных глазах. На сегодняшний день проблемы фиксации и центрации ИОЛ в случаях нестандартных ситуаций, связанных с несостоятельностью или отсутствием «капсульной поддержки», остаются нерешенными. Целью исследования было разработать технологии подшивания ИОЛ к радужке с полным сохранением ее функций, при различных ситуациях несостоятельности или отсутствии возможности фиксации и центрации линзы в капсульном мешке. Пациенты (n = 12; 12 глаз) в зависимости от клинической ситуации были разделены на группы: группа 1 — дислокации комплекса «ИОЛ — капсульный мешок» (6 глаз); группа 2 — полное отсутствие «капсульной поддержки» (3 глаза); группа 3 — несостоятельность «капсульной поддержки» (3 глаза). Для каждой ситуации из этих трех групп была разработана отдельная технология подшивания. В результате проведенного лечения получены высокие клинико-функциональные результаты за счет надежной фиксации и высококачественной центрации ИОЛ, а также полного сохранения объема функций и косметических свойств радужки.

Ключевые слова: несостоятельность или отсутствие капсульной поддержки, дислокация ИОЛ, разрушение связочного аппарата хрусталика, афакия, авитрия

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Implantation of a posterior chamber intraocular lens (IOL) into the capsular bag is the standard approach to surgical treatment of cataracts and aphakia of various origins [1]. However, there are several reasons and conditions making this operation unfeasible or impossible. These reasons and conditions increase the risk of subsequent instability of the lens and include post-surgery weakness of capsular ligaments in cataract cases, aphakias involving a lacking or destroyed capsular bag, eye trauma of various origins, lens subluxations/dislocations, and a number of congenital diseases [2–5].

The weakness of lens ligaments can be congenital (Marfan syndrome, Weill-Marchesani syndrome, homocystinuria, dominant spherophakia, etc.) [6, 7] and acquired (consequences of trauma, glaucoma, pseudoexfoliative syndrome, high-grade myopia, etc.) [8–11]. According to various authors, 15–20% of cataract patients suffer from this condition, and 20% more have it in a latent form that is not always possible to detect before the surgery [2, 12, 13]. Defects of the zonule of Zinn's fibers discovered during the operation often force the surgeon to change the tactics and urgently decide upon an appropriate IOL that can be fixed in place adequately in the given situation [14–16].

Lack of complications with the lens suspensory ligaments occurring during cataract surgery does not exclude their

development afterwards [2, 17]. Dislocations of the IOL-capsular bag complex are some of the gravest complications in the late postoperative period; occurring in 0.2–2.8% of cases at various points of time post-surgery, they usually have an unfavorable prognosis [18–21]. The anatomical and topographic position of the said complex can become incorrect because of the weakness of suspensory ligaments or capsular bag, or fibrosis of the latter [22]. The main reasons behind such weakness are the pseudoexfoliation syndrome, high-grade axial myopia, various eyeball injuries, earlier vitreoretinal intervention, retinitis pigmentosa, diabetes mellitus, and various connective tissue diseases [15, 23–25]. Currently, there is no consensus on the optimal method of treating IOL dislocation in these situations, with the two discernible approaches involving repositioning of the dislocated IOL or its replacement with its subsequent attachment to the sclera or iris [22].

The displacement of the IOL–capsular bag complex relative to the optical axis not only worsens the visual functions of the operated eye but also causes severe complications, including ocular hypertension, secondary glaucoma, corneal dystrophy, indolent iridocyclitis [26]. In case the IOL moves to the posterior segment of the eye, the complications are developing there: recurrent vitrious hemorrage, destruction of the vitreous body with subsequent pathological adhesion and traction, epiretinal fibrosis, and retinal detachment [27, 28]. All of these complications are predictable and require prevention.

Aphakia against the background of complete or partial lack of capsular support is a difficult problem for ophthalmic surgeons. The choice of the optimal method of IOL implantation in such cases remains a debated matter.

Anterior chamber IOLs fixed in the corner of that chamber or attached to the iris are easy to implant, but the side effects and complications associated with them include optical aberrations, aniseikonia, visible shine from the edges of the lens, limited pupil mobility, development of chronic uveitis and glaucoma, and a high risk of loss of endothelial cells followed by bullous keratopathy [8, 29].

Scleral fixation of the IOL enables restoration of the iridolenticular diaphragm to an almost natural state, and the lens does not contact the endothelium of the cornea and structures of the anterior segment of the eye, which reduces the risk of corneal dystrophy, glaucoma, and chronic inflammation. Despite the benefits, transcleral stitching is a technically more complex method because it disallows visual control and, accordingly, prevents factoring in the individual anatomical and topographic features of the eye in the IOL fixation zone. This yields an unpredictable variability in position (tilt) and mobility (rotation) of the IOL relative to the optical axis, which affects the quality of vision and commonly causes complications, such as eruption and biodestruction of the fixing elements, vitrious hemorrage, retinal detachment, endophthalmitis [30].

For an eye surgeon, stitching IOLs with supporting elements to the iris is the most frequently practiced and familiar manipulation, which is performed given the tissue of the iris is unchanged (due to injuries, uveitis, aniridia, dystrophy, etc.). The key advantages of this technique are better visualization of the process, possibility to stitch through small self-sealing incisions, alignment of the IOL and iris planes (prevents tilt and rotation of the lens, thus improving the quality of vision), a lower degree of biodegradation of suture material, and the applicability of various elastic IOLs. Among the most common complications associated with this method are hyphema, iridodialysis, iris injury, pupil shape deformation, iris function impairment [31, 32].

Thus, the problems of fixation and centering of IOL in non-standard situations involving weakness or lack of capsular support, which can be discovered during surgery or occur in the postoperative period, remain unresolved. Today, the urgent task is to develop affordable, safe, reliable, function-preserving techniques of IOL fixation and centering for cases complicated by weakness of the suspensory ligaments of the lens, including dislocations of the IOL–capsular bag complex in the postoperative period, and damage or removal of the capsular bag during cataract surgery and implantation on aphakic eyes (including cases of associated destruction of the anterior hyaloid membrane with partial or complete loss of the vitreous body).

This study aimed to develop microreconstructive techniques allowing to stitch IOL to the iris without compromising its functions in various situations when it is unfeasible or impossible to fix and center the lens relying on capsular support.

METHODS

The study included 12 patients (12 eyes) aged 53–85 years (mean age — 67.4 ± 11.7 years) who have undergone surgery at the Research Center for Ophthalmology of Pirogov Russian National Research Medical University.

The inclusion criteria were: dislocation of the IOL–capsular bag complex; complete lack of capsular support (no capsular bag, destroyed anterior hyaloid membrane, partially or completely lost vitreous body); capsular support weakness (partially compromised suspensory ligaments and/or capsular bag).

The exclusion criteria were: corneal dystrophy and opacities hindering visualization of the anterior segment of the eye; iris dystrophy; congenital and acquired iris defects; glaucoma (primary open-angle glaucoma, closed-angle glaucoma, secondary glaucoma); diabetic retinopathy; dystrophic diseases of the fundus (central chorioretinal retinal dystrophy, age-related macular dystrophy, dry and wet); occlusion of retinal vessels, acute inflammatory diseases of the eyeball; intraocular tumors.

We haven't registered a significant concomitant somatic pathology that could affect the results of the assessment of the functional state of the visual system.

All patients underwent a comprehensive ophthalmological examination, including: visometry to establish uncorrected visual acuity (UCVA) and best corrected visual acuity (BCVA); pneumotonometry (CT-80 Topcon, Japan), biomicroscopy (Carl Zeiss SL 120, Germany), ophthalmoscopy with a MaxField non-contact lens (Ocular Inc., USA), and special tests like eye and orbit ultrasound (Quantel Compact Touch AB, France), pupillography with a corneal topographer (C.S.O Sirius, Italy).

The results were processed using standard Microsoft Office Excel descriptive statistics tools. The data are given as $M \pm \sigma$, where M is the arithmetic mean, and σ is the standard deviation.

The patients were divided into the following groups: group 1 — dislocation of the IOL–capsular bag complex (6 eyes); group 2 — complete lack of capsular support (3 eyes); group 3 — weakness of capsular support (3 eyes).

IOL–capsular bag complex dislocation was diagnosed when there was a rupture and stretching of the suspensory ligaments of the lens post-surgery as remote complications. The complex moves in a plane parallel to the plane of the iris and can also move in the plane of the optical axis (to determine this, the patient is examined in supine position).

Complete lack of capsular support was diagnosed when there was no capsular bag, the anterior hyaloid membrane was disrupted, vitreous body partially or completely corrupted.

Capsular support weakness was diagnosed when the ligaments and/or the capsular bag were compromised to a

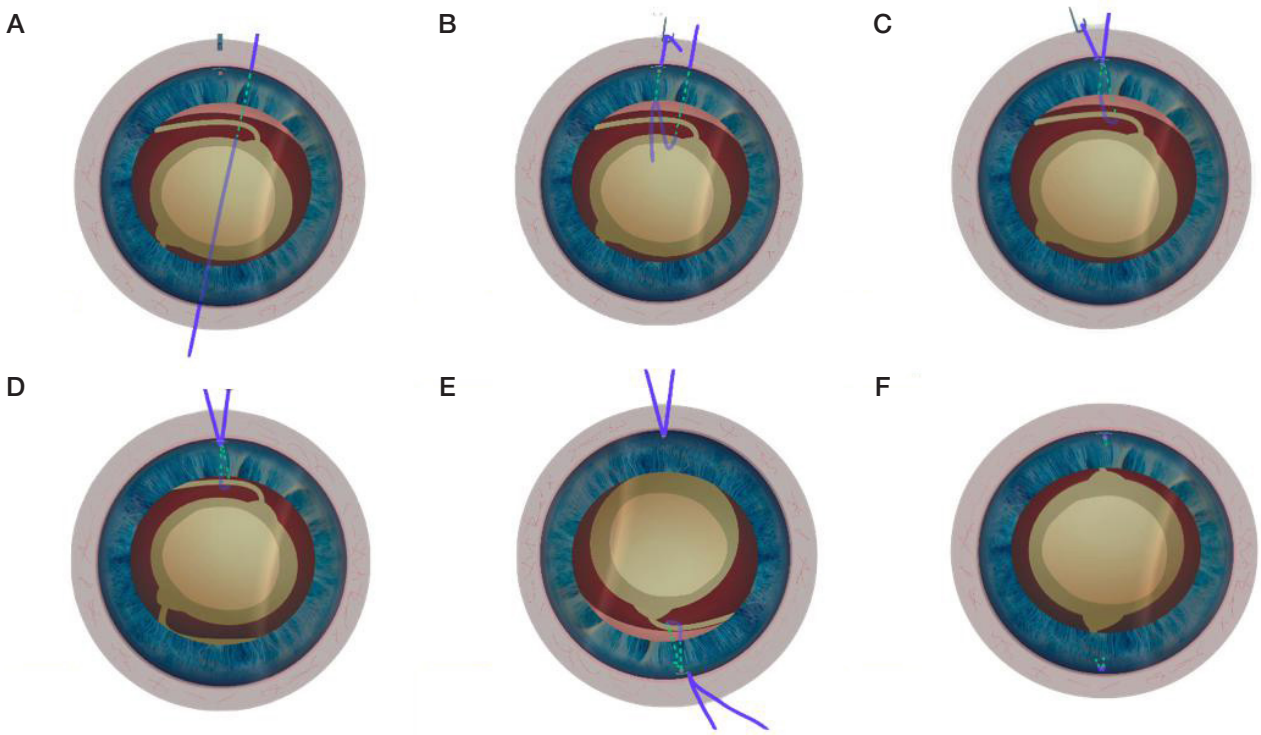

Fig. 1. IOL repositioning and stitching to the iris in cases involving dislocation of the IOL–capsular bag complex. A. Suture made on the top haptic element (*blue line*), needle with a thread passed through the corneal edge of the limb, root of the iris (*dotted line* shows the position of the needle behind the iris and the haptic element), and brought out; paracentesis made 2–3 mm from the needle injection point, microcoloboma made in the iris root in the projection of the paracentesis (highlighted pink). **B.** Output end of the thread brought out by a microhook through microcoloboma and paracentesis. **C.** The input second end of the thread is pulled through the same paracentesis. **D.** The IOL–capsular bag complex is pulled to the point when the base of the opposite haptic element appears. **E.** Similar manipulations performed on the opposite haptic element. **F.** The threads are pulled out, tied, and cut off, the incisions hydrated.

various degree but not fully destroyed; such conditions created a risk of IOL migration into the vitreal cavity during surgery.

The follow-up period was from 6 months to 2 years.

RESULTS

Examination of group 1

The average UCVA was 0.43 ± 0.17, the average BCVA was 0.63 ± 0.19, and the average intraocular pressure (IOP) was 18.1 ± 2.5 mmHg.

Biomicroscopy revealed iridodonesis with a displacement of the IOL–capsular bag complex relative to the plane of the iris, which brought IOL's haptics to different levels of the pupil area. In supine position, the displacement of the complex in the eyeball axis ranged from insignificant to almost vertical. At this stage, it is important to determine the projection of the meridians of location of the bases of IOL's haptics.

In cases involving displacement of the IOL–capsular bag complex, we applied the technique developed by us (patent No. RU 2817077 C1, 09.04.2024. Priority 07.04.2023).

The topography of the displaced complex and the projections of the meridians of haptic elements were additionally registered during surgery. It should be remembered that these parameters can change somewhat as the patient's head is repositioned. Next, with a needle carrying a thread, we punctured the corneal edge of the limb on the meridian of projection of the base of the haptic element visible in the pupil zone, pierced the iris root, moved the needle to the posterior chamber parallel to the iris into the visual zone of the pupil, then punctured the capsule and wound around the rear surface of the base of the visible haptic element in the pupil zone, and moved the needle out to the anterior chamber. Then, the needle was passed over the iris in the direction of the angle of the anterior chamber and brought out, piercing the cornea in the prelimbal zone, and the thread was cut off above the eyeball. A 1.0 mm paracentesis was formed 2–3 mm from the needle injection site in the limb area, and the anterior chamber was filled with viscoelastic. Using a 27G vitreotome, we formed a microcoloboma at the root of the iris in the projection of paracentesis (Fig. 1A). Then, a microhook was introduced through the paracentesis and microcoloboma into the posterior chamber, moved along the iris through the pupil area to the anterior chamber, where we captured the output end of the thread and, reversely, brought it out through the paracentesis (Fig. 1B). After that, the microhook was introduced to the anterior chamber through the same paracentesis above the iris root, by the needle injection point, captured the second end of the thread and brought it out in reverse (Fig. 1C).

Thus, the resulting loop trapped the haptic element of the IOL and a fragment of the iris root 2–3 mm wide. Next, the captured haptic element of the IOL–capsular bag complex was pulled so that the base of the opposite haptic element appeared in the pupil area (Fig. 1D). If this technique fails to bring the opposite haptics from under the iris into the pupil area, visualization can be achieved with the help of iris hooks or mydriatics.

At the next stage, we repeated the routine at the opposite haptic element found on the opposite end of the meridian (Fig. 1E). The needle injection point and microcoloboma were positioned along the respective meridians, symmetrically in the projection of the previously made injection point and microcoloboma. Having completed manipulations on the opposite haptic element of the lens, we tied the threads pulled through the paracenteses and cut them off (Fig. 1F). Viscoelastic was washed out of the anterior chamber, the incisions were sealed by hydration.

Results of the control examination after 2 years: average UCVA — 0.86 ± 0.23, average BCVA — 0.96 ± 0.13, average IOP — 17.6 ± 1.63 mmHg.

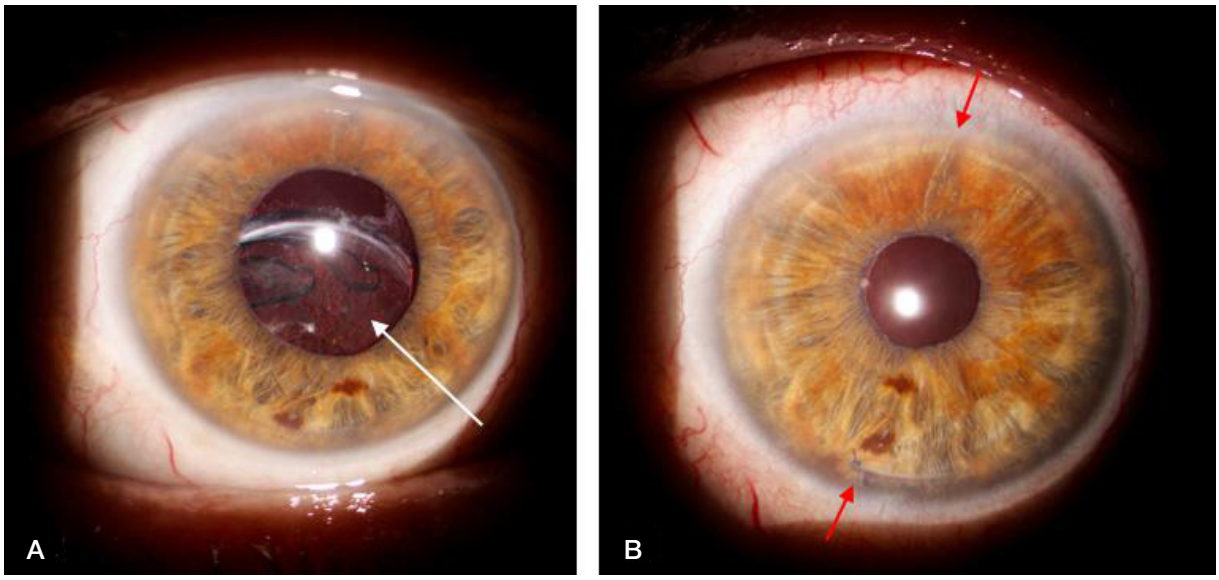

Fig. 2. Anterior segment of the eye with dislocated IOL–capsular bag complex. A. Before surgical treatment (drug-induced mydriasis): dislocation of the IOL (*white arrow*). **B.** After surgical treatment: round pupil, active reaction to light, solid fixing suture knots, IOL fixed and centered as expected from the suggested technique; *red arrows* point to the zones of suture knots and microcolobomas

Pupils of the operated eyes round, active reaction to light, suture knots solid, IOLs fixed and centered as expected from the suggested technique (Fig. 2A, B). Comparison to the fellow eye: similar size and shape of pupils, direct and coordinated reactions to light preserved in full.

Pupillography was performed at various times post-surgery on both the operated and the fellow eye. The diameter of the pupil was measured in scotopic (0.04 lux), mesopic (4 lux) and photopic (50 lux) conditions. Results of the control examination after 2 years: average pupil diameter in scotopic conditions — 4.45 ± 0.71 mm, in mesopic conditions — 4.27 ± 0.68 mm, in photopic conditions — 3.97 ± 0.59 mm. Pupillography of the fellow eye: average pupil diameter in scotopic conditions — 4.3 ± 0.83 mm, in mesopic conditions — 4.07 ± 0.76 mm, in photopic conditions — 3.81 ± 0.76 mm.

Examination of group 2

The average UCVA was 0.04 ± 0.01, the average BCVA was 0.28 ± 0.2, and the average IOP was 17.0 ± 2.64 mmHg.

Two cases involved postoperative aphakia with missing capsular bag and corrupted anterior hyaloid membrane, partial loss of the anterior parts of the vitreous body; one case had aphakia with missing capsular bag, avitria.

To implant the IOL with lacking capsular support, we applied the technique developed by us (patent application No. 2024116758 of 18.06.2024).

In the 12-hour zone, we made two parallel paracentesis (temporal and nasal) on the limb, 2–3 mm away from each other, perpendicular to the limb. Symmetrically, two similar paracentesis were made in the projection of these meridians in the 6-hour zone. The anterior chamber was filled with viscoelastic. Using a 27 G vitreotome, we made temporal and nasal microcolobomas in the projection of each paracentesis, 12-hour and 6-hour zones of the iris root (Fig. 3A). Depending on the conditions, paracenteses and microcolobomas can be made in other zones.

Outside the eye, we tied one fixing thread sequentially to the top and bottom haptic elements of the IOL (Fig. 3B). After that, the IOL with tied fixing threads on the top and bottom haptic elements was inserted into the injector and implanted into the anterior chamber through a pre-made corneal tunnel. Thus, the IOL was positioned in the anterior chamber and anchored by the ends of the threads passing through the corneal tunnel and tied to the haptic outside the eye. Alternatively, the ends of the lower fixing thread can be pulled by a microhook into the lower paracentesis, and the IOL will be suspended by the ends of the upper fixing thread in the tunnel, those of the lower thread — in one of the lower paracenteses, so the lens could already be tucked through the pupil area behind the iris.

Then, in the 12-hour zone, we introduced a microhook through the temporal paracentesis and microcoloboma, moved it through the posterior chamber parallel to the iris, reached the anterior chamber through the pupil, captured the output end of the thread fixing to the top haptic element there, and pulled it out reversely through the paracentesis (Fig. 3C). After that, in a similar way, the inner end of the top haptic element's fixing thread was pulled outside through nasal microcoloboma and paracentesis. Next, we put a microhook through the temporal paracentesis into the corner of the anterior chamber above the nasal microcoloboma, captured the second inner end of the fixing thread and pulled it out through the temporal paracentesis. In the 6-hour zone, similar manipulations were performed with the thread fixing IOL's bottom haptic element (Fig. 3D).

The next step involved positioning the IOL through the pupil area behind the iris, pulling the ends of the haptics' fixing threads and knotting them (Fig. 3E). The remaining ends were cut off in the anterior chamber, the viscoelastic washed out, and the incisions sealed by hydration (Fig. 3F).

Thus, the IOL is constantly held inside the eye by fixing threads trapping haptic elements, and cannot independently move behind the iris and sink to the fundus. This means that during implantation, the surgeon can freely and safely manipulate the IOL inside the eye expecting no unplanned movements therefrom.

Alternatively, when avitria is complete, the vitreal cavity can be tamponed with a perfluorocarbon liquid (PFCL), and all of the above manipulations performed such conditions, with PFCL replaced at the end of the operation.

Results of the control examination after 1 year: average UCVA — 0.53 ± 0.15, average BCVA — 0.66 ± 0.05, average IOP — 18 ± 4.9 mmHg.

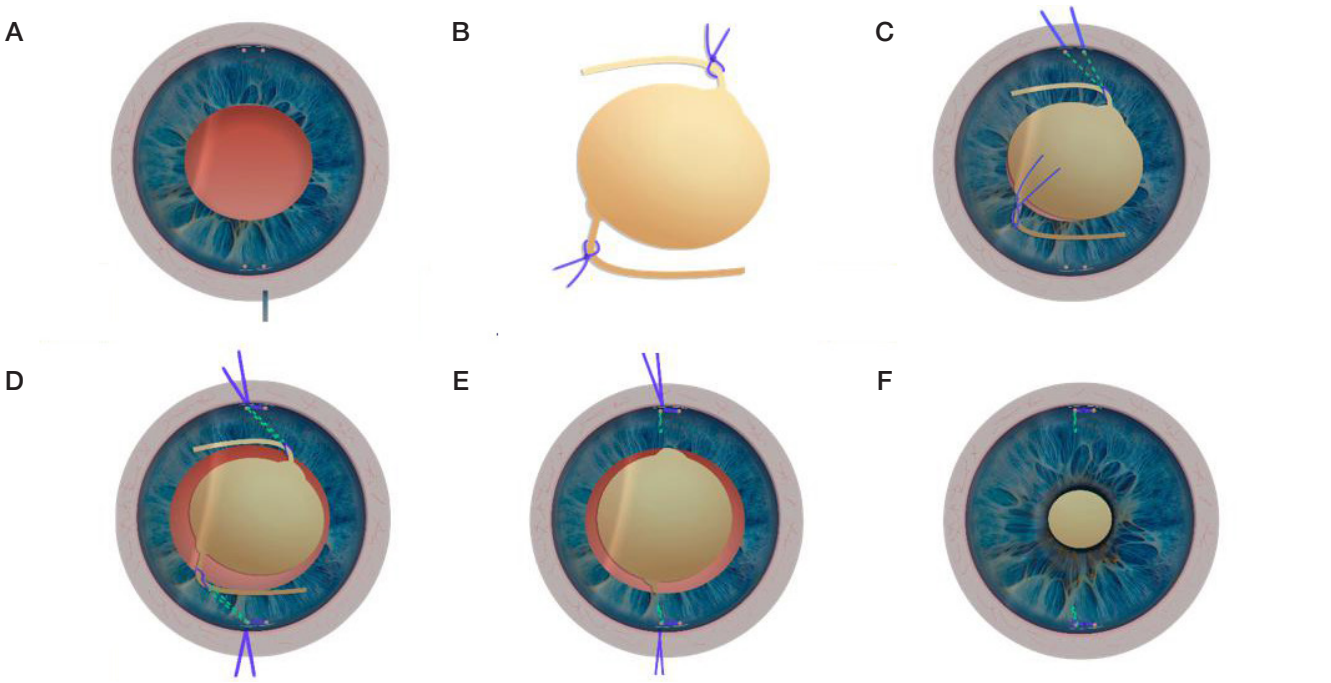

Fig. 3. IOL implantation in the absence of capsular support. A. Two paracenteses (temporal and nasal) made in the limb, 2–3 mm from each other, with similar paracenteses made at the opposite ends of the same meridians in symmetrical positions; next, microcolobomas made in the projection of each paracentesis (highlighted pink). **B.** Top and bottom haptic elements with fixing threads (blue color) tied to them, outside the eye. **C.** IOL with sutures implanted into the anterior chamber, the ends of the thread fixing top haptic element pulled through the respective microcoloboma and paracentesis (temporal and nasal). **D.** Similar manipulations done on the bottom haptic element (opposite): with the help of a microhook, both ends of the fixing threads pulled through the upper and lower temporal paracenteses. **E.** The IOL is positioned behind the iris, the ends of the fixing threads are pulled and knotted. **F.** The ends of the threads are cut off, viscoelastic washed, incisions hydrated

Pupils of the operated eyes round, active reaction to light, suture knots solid, IOLs fixed and centered as expected from the suggested technique (Fig. 4A, B). Comparison to the fellow eye: similar size and shape of pupils, direct and coordinated reactions to light preserved in full.

Pupillography results: average pupil diameter in scotopic conditions — 4.39 ± 1.02 mm, in mesopic conditions — 3.98 ± 0.97 mm, in photopic conditions — 3.53 ± 1.04 mm.

Pupillography of the fellow eye: average pupil diameter in scotopic conditions — 5.03 ± 0.7 mm, in mesopic conditions — 4.89 ± 0.73 mm, in photopic conditions — 4.61 ± 0.62 mm.

Examination of group 3

The average UCVA — 0.35 ± 0.27, average BCVA — 0.51 ± 0.43, average IOP — 13.6 ± 1.52 mmHg. In two cases, we registered total corruption of the ligaments and the lens capsule (top segments), aggravated by damaged anterior hyaloid membrane and partial loss of the vitreous body; in one case, there was no lens capsule with the preserved anterior hyaloid membrane of the vitreous body.

To implant the IOL with weak lacking capsular support in the background, we applied the technique developed by us (patent application No. 2809441 of 11.12.2023. Priority 07.04.2023). Essentially, this technique combines the two described above.

In the 12-hour zone of the limb, we made two parallel paracenteses, temporal and nasal, 2–3 mm apart, perpendicular to the limb (it is desirable, but not mandatory, to select the zone on the meridian opposite the best preserved remaining parts of the capsular support, which can act as additional suspension for the implanted IOL). The anterior chamber was filled with viscoelastic. Using a 27G vitreotome, we made temporal and

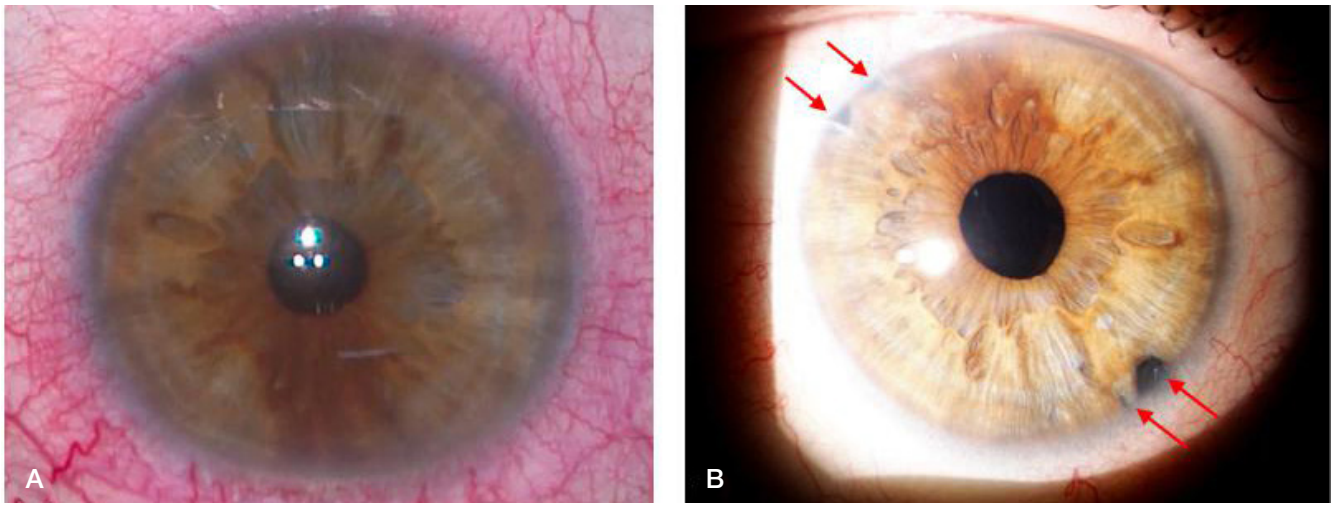

Fig. 4. Anterior segment of the eye with lacking capsular support. A. Before surgery. **B.** After surgery: round pupil, active reaction to light, solid fixing suture knots, IOL fixed and centered as expected from the suggested technique; red arrows point to the zones of suture knots and microcolobomas

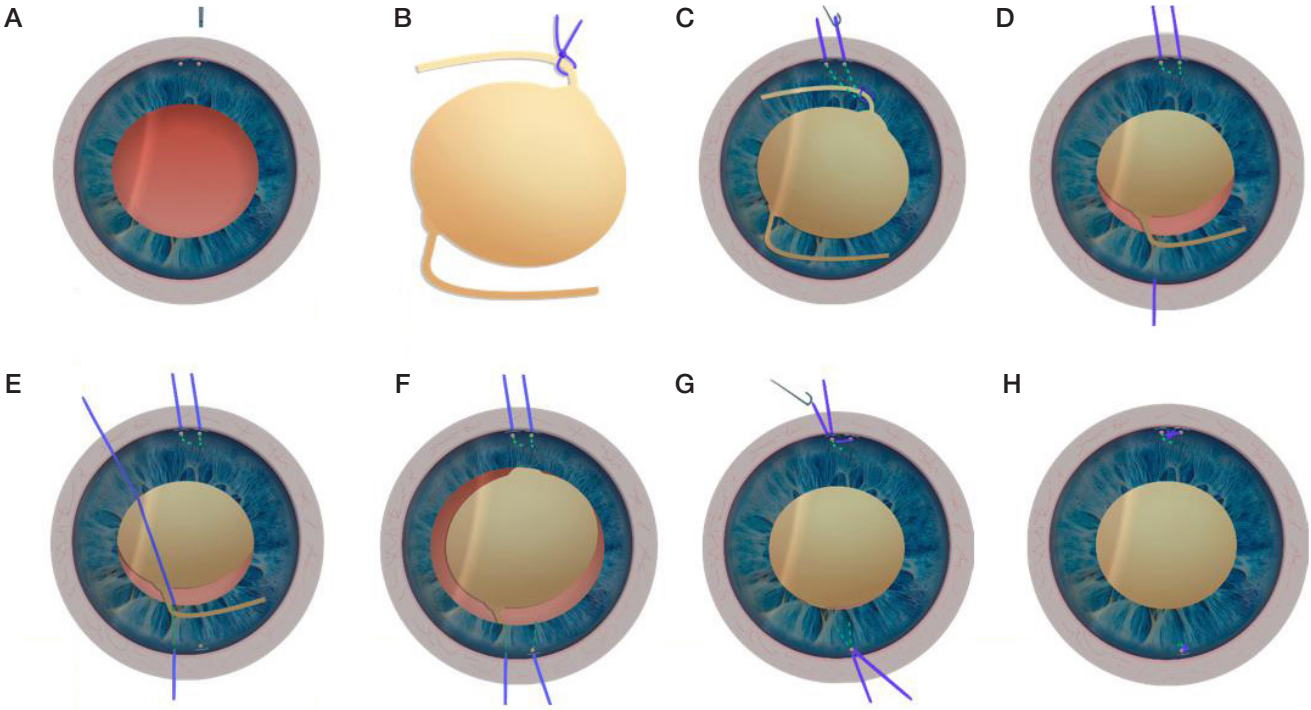

Fig. 5. IOL implantation and attachment to the iris against the background of weak capsular support (diagram). A. Two paracenteses (temporal and nasal) made in the limb, 2–3 mm from each other, then microcolobomas made in the projection of each paracentesis (highlighted pink). **B.** Outside the eye, the fixing thread is tied to the top haptic element (highlighted blue). **C.** The IOL with a suture is implanted into the anterior chamber, inner and outer ends of the thread fixing the lens to the top haptic element pulled out with a microhook through the respective microcoloboma and paracentesis. **D.** Top haptic element positioned behind the iris; the IOL is pulled up by the ends of the threads until the base of the bottom haptic element appears. **E.** Suture made on the bottom haptic element (blue line), needle with a thread passed through the corneal edge of the limb, root of the iris (dotted line shows the position of the needle behind the iris and the haptic element), and brought out; paracentesis made 2–3 mm from the needle injection point, microcoloboma made in the iris root in the projection of the paracentesis (highlighted pink). **F.** Bottom haptic element positioned, output end of the thread pulled out through the microcoloboma and the paracentesis with a microhook. **G.** Both input second ends of the threads pulled to the paracentesis and knotted. **H.** The ends of the threads are cut off, viscoelastic washed, incisions hydrated

nasal microcolobomas, 2–3 mm apart, in the projection of each paracentesis (Fig. 5A). Outside the eye, the fixing thread was tied to the top haptic element (Fig. 5B). The lens with the thread tied to the top haptic element was inserted in the injector and implanted into the anterior chamber through a pre-made corneal tunnel. Thus, the IOL was positioned in the anterior chamber and anchored there by the ends of the thread that passed through the corneal tunnel and was tied to the top haptic element.

Then, we introduced a microhook through the temporal paracentesis and microcoloboma, moved it through the posterior chamber parallel to the iris, reached the anterior chamber through the pupil, captured the output end of the thread fixing to the top haptic element there, and pulled it out in reverse order. After that, in a similar way, the inner end of the top haptic element's fixing thread was pulled outside through nasal microcoloboma and paracentesis (Fig. 5C). Having positioned the top haptic element behind the iris, we pulled both ends of the fixing thread and thus moved the optical part of the IOL behind the plane of the iris until the base of the bottom haptic element appeared in the pupil area, with the bottom haptic element remaining in the anterior chamber (Fig. 5D).

The next step involved manipulations from the first technique performed on the bottom haptic element. We injected the needle into the cornea and made microcolobomas at the opposite ends of the respective meridians, symmetrically in the projection of the previously made microcolobomas.

The needle was introduced into the cornea at the limb, then pierced the root of the iris, moved to the posterior chamber parallel to the iris, and brought into the pupil area, wound around the posterior surface of the base of the haptic element visible in the pupillary zone, and pulled out into the anterior chamber. The needle was passed over the iris in the direction of the angle of the anterior chamber and brought out, piercing the cornea; next, the thread was cut off above the eyeball (Fig. 5E). Further, 2–3 mm from the needle injection point, we made a paracentesis in the limb zone, and using a 27G vitreotome created a microcoloboma in the root of the iris, then positioned the bottom haptic element behind the iris, and pushed a microhook through the paracentesis and the microcoloboma behind the iris and into the posterior chamber, parallel to the iris, through the pupil zone, and into the anterior chamber, over the IOL, to capture the output end of the thread there, after which the microhook with the thread was brought out through the paracentesis in reverse order. Next, the microhook was introduced to the anterior chamber through the paracentesis, moved above the iris root by the needle injection point, captured the second end of the thread and brought it out reversely (Fig.5F). Thus, the resulting loop trapped the bottom haptic element of the IOL. Once through with manipulations on the bottom haptic element, we pulled both ends of the thread fixing the top haptic element through a single paracentesis (Fig. 5G). The ends of the threads were tied and cut off, viscoelastic washed out of the anterior chamber, incisions sealed by hydration (Fig. 5H).

Results of the control examination after 6 months: average UCVA — 0.8 ± 0.17, average BCVA — 0.9 ± 0.17, average IOP — 13.3 ± 2.5 mmHg.

Pupils of the operated eyes round, active reaction to light, suture knots solid, IOLs fixed and centered as expected from the suggested technique. Comparison to the fellow eye: similar size and shape of pupils, direct and coordinated reactions to light preserved in full.

Pupillography results: average pupil diameter in scotopic conditions — 4.37 ± 0.29 mm, in mesopic conditions — 3.54 ± 0.58 mm, in photopic conditions — 3.09 ± 0.3 mm.

Pupillography of the fellow eye: average pupil diameter in scotopic conditions — 4.53 ± 0.44 mm, in mesopic conditions — 3.95 ± 0.61 mm, in photopic conditions — 3.45 ± 0.39 mm.

DISCUSSION

The problem of postoperative dislocation of the IOL–capsular bag complex in ophthalmic surgery retains its relevancy. An analysis of literature shows that today, there are no effective solutions thereto. There are two approaches to remedying this complication, one involving stitching the dislocated IOL to the membranes of the eyeball (iris or sclera), another suggesting replacement of the IOL with a lens attached differently; both approaches have several significant drawbacks [33]. Suturing to the iris offers the lowest risk of complications during and after surgery, that of repeated dislocations, and also allows positioning the IOL more centrally and stable relative to the optical axis of the eye.

Several authors have proposed various original methods of repositioning and stitching the IOL–capsular bag complex to the iris [1, 17, 21, 28, 34, 35]. The drawbacks of these methods include: lack of visualization during manipulations on haptic elements; putting fixing sutures in the most mobile areas of the iris stroma, which disrupts its diaphragmatic function and creates cosmetic defects associated with the shape, size and synchronicity of the pupils. Moreover, the suture area is constantly pulled by the antagonist muscles (sphincter and dilator of the pupil), which undermines strength, reliability, and durability of the fixing sutures in the long-term. Such methods of stitching jeopardize topographically accurate and symmetrical application of sutures fixing IOL to the opposite haptic elements while involving a similar, precisely measured volume of the iris tissue.

The microsurgery technique of stitching the IOL–capsular bag complex to the iris described in this paper, has a number of significant advantages over the said methods. Firstly, all manipulations that involve IOL haptics capturing and stitching to carried out under full visual microscopic control in the area of the pupil or anterior chamber, ensuring the process is accurate and atraumatic. The use of the iris root microcolobomas in the projection of the limb at opposite ends of the same meridian ensures topographically accurate and symmetrical application of fixing sutures to the IOL's opposite haptics, with the sutures placed on the said elements and involving a precisely measures volume of the iris root tissue (2–3 mm) at a planned location. This makes the centering of IOL accurate, even for toric and multifocal models.

The location of the fixing suture knots in the projection of the limb, where the iris root tissue, only 2–3 mm of which is used, is not essential functionally, leaves the structure of the iris virtually unchanged, and does not disrupt operation of its muscles, thus allowing to fully retain functions and cosmetic properties of the iris and the pupil. Moreover, the involved iris root tissue is exposed to minimal dynamic forces, which ensures reliability, strength, and durability of fixing sutures.

A positive feature of this technique is the possibility of repeated and additional manipulations aimed at achieving the set goals.

When removing cataracts, surgeons occasionally encounter weak of lacking capsular support. The most common cause of such weakness is the poor condition of the suspensory ligaments of the lens. The most popular solution in such cases is implantation of a capsule ring, which enables intraoperative stabilization of the capsular bag and IOL implantation. However, some authors note that the effectiveness of this technique is low [33, 36]. Often, patients that underwent such manipulations develop the IOL–capsular bag complex dislocation post-surgery. In addition to the problems with ligaments, some of them also suffer breaches of integrity of the lens capsule during surgery, sometimes ending in the complete loss thereof. Patients with aphakias of various origins (postoperative, traumatic, etc.) form a separate group among those having problems with capsular support. For most of them, it is necessary to anchor the IOL during primary and delayed surgical interventions [37].

Back in the 1950s and 1960s, seamless fixation of IOLs to the iris became a topic of interest, when two ophthalmologists proposed similar techniques: E. Epstein with the "Maltese cross" or "cufflinks", and C.D. Binkhorst with the iris-clips lens [31, 38, 39].

Later, in 1968, S.N. Fedorov and V.D. Zakharov created the Sputnik iris-clip lens, which was the base model in clinical practice for several years. However, this type of fixation could entail a severe complication: dislocation of the IOL into the anterior chamber or into the vitreal cavity, triggered by any planned or unplanned pupil dilation, further aggravated by restriction of the diaphragmatic function of the iris [8, 40].

In 1970, J. Worst proposed an IOL model called "medallion," which had to be stitched to the iris beyond the equatorial zone of the lens, and in 1973, he developed a lens model with seamless attachment to the iris, the "claw lens." This method implied pinching the iris stroma at two points at the distal ends of the IOL, for which slits were made in the haptic part of the lens. The key points of the operation are the use of myotics to maximize pupil constriction and iris expansion, use of viscoelastics to minimize injury to the corneal endothelium, and use of a second instrument to hold the IOL during fixation [8, 41]. However, attaching the IOL to the functionally active zone of the iris stroma violated its functioning.

Most of the works covering stitching of IOLs to the iris describe the process of suturing the haptic elements of the lens to the mid-peripheral zone of the stroma of the iris using the M.A. McCannel method and Siepser knots (dead loop knots). The drawbacks of this technique include iris function impairment, as well as a high risk of iris atrophy, pigment dispersion, uveitis, and cystic macular edema [8, 42].

Some authors have demonstrated various ways of stitching the IOL to the iris when the capsular support is weak of absent [40, 43 , 44]. The main disadvantage of the proposed techniques is still the risk of unplanned IOL luxation into the vitreal cavity during surgery, with all the consequences and complications that follow. Technical drawbacks of the suggested methods: suturing in functionally active areas of the iris stroma, which leads to pupil deformation (violation of diaphragmatic and cosmetic functions); lack of complete visual control over the manipulations of capturing and stitching IOL haptics; difficulties with achievement of a topographically correct and symmetrical positions of the seams on opposing haptic elements; increased risk of unpredictable traumatism of the structures of the anterior segment of the eye given the extremely limited room for a maneuver available to the ophthalmic surgeon.

The technique of IOL implantation suggested in this paper, that which was developed for the cases of lacking capsular support, has a number of significant advantages over the mentioned methods.

In addition to the advantages described above (first technique), which are also useful in the context of similar microsurgical techniques and manipulations, application of fixing threads on both haptic elements of the IOL outside the eye with subsequent implantation ensures a fully controlled position thereof throughout the operation enabled by the threads pulled out. The suggested technique solves the key problem: it allows

full control over the IOL position inside the eye during surgery, eliminating the risks of lens luxation to the fundus. Thus, the surgeon feels confident and fully controls the process, and also can do additional reconstructive manipulations in the eye if necessary. Performing most steps in the anterior chamber means full visual control over the work with seams and reliable pulling of the threads' ends into the planned zones of knots.

The use of microhooks and microcolobomas to capture and pull out fixing threads' ends makes the process completely controllable, predictable, and atraumatic, ensuing accurate localization of the knots and precise capturing of the volume of the iris root tissue (2–3 mm) needed for the purpose. The symmetrical, precise topographic positioning of the fixing suture knots in the projection of the limb at opposite ends of the same meridian ensures high-quality fixation and centering of the IOL, and the iris retains its functions and anatomical and cosmetic properties in full.

The technique presented in this paper addresses cases of weak capsular support (partial corruption of the suspensory ligaments and/or capsular bag). Essentially, it is a combination of the first two techniques, with the first stage involving a set of manipulations from the second technique, and the second stage employing manipulations from the first technique, the former performed on one haptic element, the latter on the opposite one. Thus, the advantages of both techniques are realized. This combined technique is a preferred approach in cases when some parts of capsular support remain and can be used for IOL suspension during implantation. The technique is a safe method for doubtful situations when there is a risk of the IOL dropping into the vitreal cavity during surgery. Application of a fixing suture outside the eye to one of the haptic elements, followed by pulling its ends into the paracentesis, ensures controlled behavior of the IOL inside the eye throughout the operation and does not allow the lens to luxate onto the fundus.

With these techniques, the entire set of manipulations, which is carried out through self-sealing micro-punctures and micro-incisions with use of viscoelastics, creates conditions for anatomical and topographic stability of the structures and microspaces of the eye during surgery, thus enabling a more accurate, controlled, atraumatic work inside the eye at the micro level.

Thus, the developed and proposed set of micro-constructive techniques makes it possible to effectively stitch IOL to the iris while preserving of its functions; the techniques are applicable in various situations when the suspensory ligaments are weak, or it is impossible to anchor and enter the lens relying on the capsular support.

CONCLUSIONS

The developed micro-constructive techniques allow: 1. Transferring the basic manipulations of suturing to the haptic elements of the IOL to the visible zone of the pupil and anterior chamber, where the work is done under full microscopic control, which significantly improves the accuracy, controllability, safety of the process, and makes it atraumatic. 2. Making microcolobomas at the iris root in the projection of limbal paracentesis and to pass through them, using a microhook, the end of the thread capturing the haptic element, so the resulting loop embraces the haptic element of the IOL and a precisely measures volume (2–3 mm) of the iris root tissue. The precise topographic execution of this manipulation translates into symmetrical arrangement of fixing knots on the IOL's opposite haptic elements on one meridian, which means high-quality centering, including for toric and multifocal models. 3. Applying topographically oriented, precise fixing sutures in the projection of the limb, localized in the zone of the most functionally inert iris root tissue, and, as a result, ensure full preservation of the volume of functions and cosmetic properties of the iris and the pupil. Moreover, the involved iris root tissue is exposed to minimal dynamic forces, which ensures reliability, strength, and durability of fixing sutures. 4. Applying fixing threads to the haptic elements of the IOL outside the eye with subsequent implantation, in case of failure or absence of capsular support, which enables full control over the behavior of the IOL inside the eye throughout the operation, eliminating the risks of lens luxation into the vitreal cavity and empowering the surgeon with confidence. 5. Performing all manipulations through self-sealing micro-punctures and micro-incisions, using viscoelastics that create conditions for anatomical and topographic stability of structures and microspaces inside the eye throughout the operation and ensure improved microsurgical reconstruction. This opens up a new direction in ophthalmic surgery, enabling assembling of collapsible structures inside the eye from various micro-components (microconstruction), and, above all, the assembling and installation of the IOL from separate microelements.

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