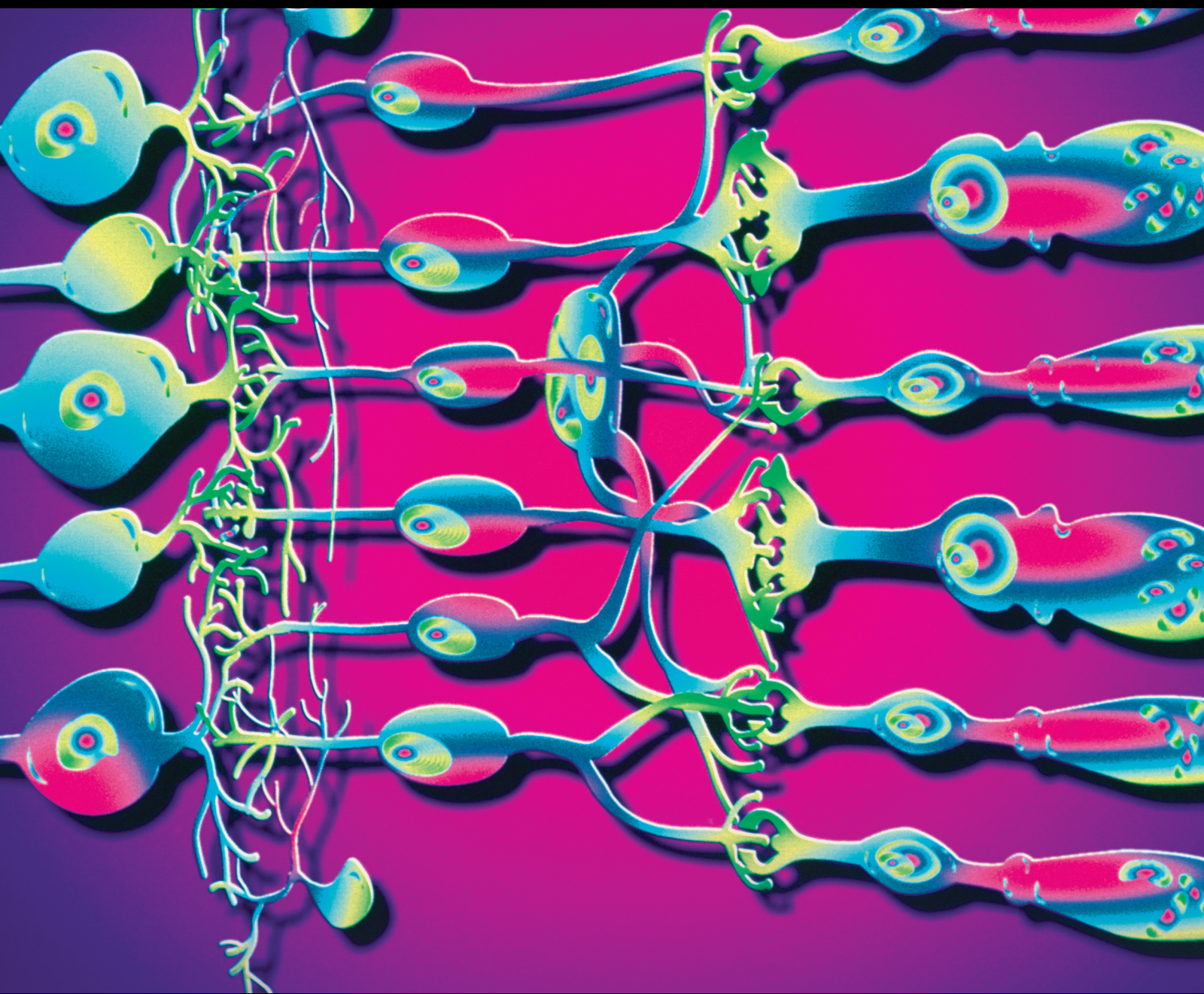
Journal of Ophthalmology

Visual Rehabilitation in Combined Surgical Procedures: Bridging Two Eye Poles for Better Vision

Guest Editors: M. J. Koss, C. Y. Choi, R. R. Krueger, M. Maia, and H. B. Fam



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Editorial Board

Contents

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Editorial

Visual Rehabilitation in Combined Surgical Procedures: Bridging Two Eye Poles for Better Vision

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The starting idea of this special issue was to link innovative anterior to posterior ocular surgical procedures in an era of highly dynamic innovations in both segments of the eye. Every one of the editors had his own perception of what this might implicate and it turns out that all the submitting colleagues had scientific clinical and preclinical projects long before in place and were willing to share their outcomes with us. T. Tandogan et al., for example, illustrated to us the simple challenge of phacoemulsification after vitrectomy as a result of the altered intraocular fluid dynamics, a simple basic paper not only for the beginner, but also for every surgeon *before* he/she starts to perform combined procedures.

There is an intriguing argument for combined procedures—they abandon the need for a second operation! But this argument needs to be weighed with aspects like clinical feasibility, safety, and outcomes. The main promise, for instance, of 27-gauge vitrectomy is as follows: "the smaller you get, the lower is your wound, hence less postoperative complication rates." Eagerly testing new techniques, each surgeon might then experience intraoperatively longer surgical maneuver times (depending on different manufacturers of course). We are thus glad about the manuscript on fluidics of the two-dimensional cutting (TDC) vitrectome by M. Pavlidis, who demonstrates to us how the cutter design makes all the difference for an effective 27-gauge vitrectomy.

All the contributing authors strived for better care by bridging clinical benchmarks like complication rates in minimal invasive small incision cataract and 23/25/27-gauge vitrectomies. F. Höhn et al. and R. M. Navarro et al. could nicely demonstrate both high safety measures and effective outcomes, in single-session phacovitrectomy procedures. The positive impact on visual acuity and quality of vision in patients with symptomatic floaters, who were implanted with a multifocal intraocular lens, will definitely be investigated by others with the introduction of newer multifocal IOLs in the future.

Others, like T. Bertelmann et al., could confirm higher safety of complicated cataract surgery in conjunction with retinal cryocoagulation in a rather large retrospective single-center clinical series. S. Deuchler et al. on the other hand could link complicated PVR retina surgeries with oil tamponades to the timing of a cataract surgery, while K. Nowomiejska et al. could demonstrate good retinal attachment with low corneal graft survival in severe trauma cases and combined vitrectomy, TKP, and corneal transplant surgery.

This special issue touches on many important clinical aspects of combined ocular procedures. We invite the designated readers to share our experiences with them.

Acknowledgments

We want to thank the contributing authors for their work.

M. J. Koss
C. Y. Choi
R. R. Krueger
M. Maia
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Research Article

Impact of Indocyanine Green Concentration, Exposure Time, and Degree of Dissolution in Creating Toxic Anterior Segment Syndrome: Evaluation in a Rabbit Model

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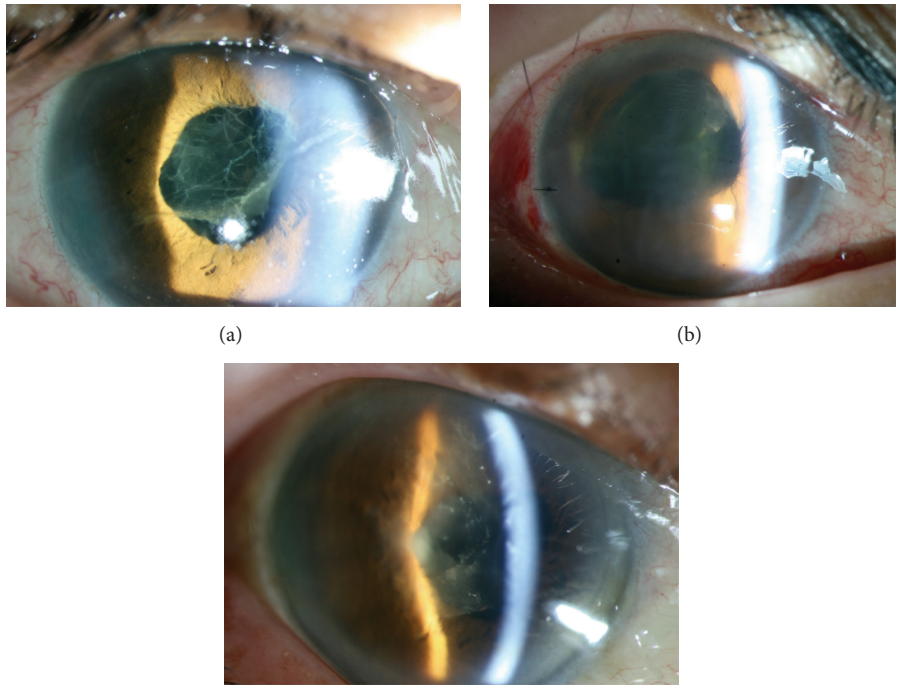
Purpose. To investigate the role of indocyanine green (ICG) dye as a causative material of toxic anterior segment syndrome (TASS) in an experimental rabbit model. *Method*. Eight eyes of four rabbits were allocated to this study. Capsular staining was performed using ICG dye, after which the anterior chamber was irrigated with a balanced salt solution. The effects of different concentrations (control, 0.25, 0.5, and 1.0%), exposure times (10 and 60 seconds), and the degree of dissolution (differently vortexed) were investigated. The analysis involved anterior segment photography, ultrasound pachymetry, prostaglandin assay (PGE_2 Parameter Assay, R&D systems, Inc.), and scanning electron microscopy of each iris. *Result*. There was no reaction in the control eye. A higher aqueous level of PGE_2 and more severe inflammatory reaction were observed in cases of eyes with higher concentration, longer exposure time, and poorly dissolved dye. Additionally, scanning electron microscopy revealed larger and coarser ICG particles. *Conclusion*. TASS occurrence may be associated with the concentration, exposure time, and degree of dissolution of ICG dye during cataract surgery.

1. Introduction

Toxic anterior segment syndrome (TASS), an acute, noninfectious inflammation of the anterior segment of the eye, is a complication of anterior segment eye surgery, such as cataract extraction surgery. Various contaminants, usually from surgical equipment or supplies, have been implicated as causes of TASS [1]. Since 2000, there have been several reports of varying degrees of anterior segment damage from toxic substances after cataract surgery; some of these events had the appearance of an outbreak [2–6]. This led to the formation of the TASS task force, and the American Society of Cataract and Refractive Surgery (ASCRS) task force team reported 367 cases of TASS with multiple potential causative factors in 2010 [7].

TASS typically develops within 24 hours after surgery and is characterized by corneal edema and cellular reaction in the anterior chamber of the eye. Although most cases of TASS can be treated successfully with topical steroids, topical nonsteroidal anti-inflammatory agents, or both, the inflammatory response associated with TASS can cause serious damage to intraocular tissues, resulting in vision loss [8, 9].

From October 2008 to November 2008, the Kangbuk Samsung Hospital Ophthalmology Surgical Center observed several patients who developed TASS after cataract surgery and who had been exposed to indocyanine green (ICG) dye for anterior capsular staining because of the presence of a mature senile cataract (Figure 1). The Ophthalmology Surgical Center had recently changed the dye for capsular staining from trypan blue to ICG. Trypan blue (Vision blue,



(a) (b) (c)

Figure 1: Corneal edema, severe inflammation, and fibrous membrane formation in the anterior chamber ((a) Patient 1, (b) Patient 2, and (c) Patient 3).

DORC International, Zuidland, Netherlands) is commercially available and can be injected as it is, requiring no dilution. In contrast, dry ICG powder has to be mixed with diluents before administration. We suspected that ICG dye was the causative factor of the TASS cases described above. We therefore conducted this study to investigate whether ICG dye is a causative agent of intraocular inflammation in an experimental rabbit model.

2. Materials and Methods

This experimental study was approved by and conducted in compliance with IACUC protocol number 10-016-D1-N, 2010.12.16. It involved eight eyes of four male 2.5-month-old New Zealand white rabbits that weighed 2.5–3.0 kg. This was a preliminary study to evaluate the role of ICG with regard to postoperative inflammation, where we aimed to use as few rabbits as possible to evaluate the potential impact of ICG. Using the given study design and sample size, our aim was not to prove the effect statistically but rather to provide proof of principle.

ICG dye was used for anterior capsular staining in these rabbits, and the three physical variables of concentration, exposure time, and degree of dissolution were tested. There are several previous studies dealing with the safety and efficacy of ICG dye for capsular staining in cataract surgery [10, 11]. All animals were healthy and free of clinically detectable ocular disease. All the procedures involving animals were conducted in accordance with the Association for Research in Vision and Ophthalmology Resolution on the Use of Animals in Research. The experimental protocol was approved by the Institutional Animal Care and Use Committee of Kangbuk Samsung Hospital, Seoul, Korea. This work was supported by the Medical Research Funds from Kangbuk Samsung Hospital.

2.1. Preparation of Dye. The ICG dye was prepared by dissolving the commercially available product in aseptic distilled water (Diagnogreen, Daiichi Pharmaceutical, Tokyo, Japan). The control solution did not contain any ICG. According to previous studies [10, 11] the minimal optimum concentration for enhancement of anterior capsule visibility for capsulorhexis is 0.25% of ICG. Another experimental rabbit study confirms this concentration of 0.25% [12].

In this study, three concentrations of ICG (0.25%, 0.50%, and 1.00%) were prepared by dissolving ICG powder in 1.0 mL distilled water (provided with the ICG powder), and then these distilled-water solutions were diluted with 4.0 mL balanced salt solution (BSS, Alcon, Fort Worth, USA) to the final concentration of 0.5% ICG solution. To achieve concentrations of 0.25 and 1.0% ICG solutions, 1.0 mL distilled water with 9.0 mL BSS and 0.5 mL distilled water with 2.0 mL BSS were mixed, respectively, with 25 mg ICG granules. The calculated osmolarity values for each solution were 277.73, 250.45, and 250.5 mOsm (0.25%, 0.50%, and 1.0%), respectively. The pH measurements (Istek's Desktop pH meter, model 730P) of each solution at 37°C were 7.36 ± 0.05, 7.48 ± 0.05, and 7.44 ± 0.06 (0.25%, 0.5%, and

1.0%), respectively. To prepare these solutions, we used the approved clean bench with HEPA Filter and laminar flow system (Kastech, KT44-21C) in a facility dedicated solely to animal studies in Kangbuk Samsung Hospital Animal Study Laboratory. A vortex mixer (KMC-1300V, Vision Scientific, Seoul, Korea) was used to standardize dissolution, and the powder was dissolved for three minutes. This device allowed for more homogeneous dissemination of the granules and helped to avoid their accumulation in higher concentrations on different parts of the iris surface. This particular mixer device was utilized because it provided more consistent results than manual shaking, and it was a common device for mixing solutions.

2.2. Surgical Technique. General anesthesia was induced by intramuscular injection of zolazepam tiletamine (10 mg/kg; Zoletil, Virbac, Carros, France) and xylazine hydrochloride (0.5 mg/kg; Rompun, Bayer Healthcare, Seoul, Korea), supplemented with topical anesthetic (Alcaine, Alcon-Couvreur NV, Puurs, Belgium). A wire lid speculum was inserted to separate the eyelids. Two clear corneal incisions were made using a 1.0 mm diamond blade. One incision was used for the injection of the ICG solution and BSS for capsular staining or anterior chamber irrigation, respectively. The second incision served as the exit point for the irrigation solution. After a clear corneal incision was performed, air was injected into the anterior chamber to displace the aqueous humor. Then, with a 26-gauge cannula, 0.1 mL ICG solution was instilled onto the anterior capsule for the scheduled time, and the anterior chamber was washed with BSS. The time of exposure to ICG was 10 seconds or 60 seconds.

2.3. Description of Rabbits

Rabbit Number One (ICG presence or absence) is described as follows:

Right eye: 0.50% ICG dye prepared by vortexing for three minutes was administered for an exposure time of 60 seconds.

Left eye (control): a mixture of distilled water and BSS without ICG was administered.

Rabbit Number Two (difference in exposure time) is described as follows:

Right eye: 0.50% ICG dye vortexed for three minutes was administered for 60 seconds.

Left eye: 0.50% ICG dye vortexed for three minutes was administered for 10 seconds.

Rabbit Number Three (difference in degree of dissolution) is described as follows:

Right eye: 0.50% ICG dye vortexed for three minutes was administered for 60 seconds.

Left eye: 0.50% ICG dye vortexed for 30 seconds was administered for 60 seconds.

Rabbit Number Four (difference in ICG concentration) is described as follows:

Right eye: 0.25% ICG dye vortexed for three minutes was administered for 60 seconds.

Left eye: 1.00% ICG dye vortexed for three minutes was administered for 60 seconds.

2.4. Evaluation. Anterior segment photography, prostaglandin E_2 (PGE_2) competitive enzyme-linked immunosorbent assays (ELISA), and scanning electron microscopy were used to evaluate the eyes. Inflammatory reactions such as corneal edema, fibrin formation, and conjunctival injection were measured in the anterior segment with photography using slit lamp biomicroscopy (BX 900, Haag-Streit International, Koeniz, Switzerland) preoperatively and at 30 minutes, 12 hours, and 24 hours postoperatively. Within the cyclooxygenase cascade, PGE_2 plays a major part in mediating the classical signs of inflammation and pain. Aqueous PGE_2 levels can therefore serve as an indicator of the relative level of inflammation [13]. Twenty-four hours after the experiment, aqueous PGE_2 concentrations were determined using a commercially available ELISA kit (PGE_2 Parameter Assay, R&D Systems, Minneapolis, MN, USA). The minimum PGE_2 quantification limit was 19.6 pg/mL, and the coefficient of variation was less than 11% within the calibration range (90–6000 pg/mL). Finally, eight rabbit iris specimens were excised for iris surface assessment using scanning electron microscopy (S-2380N, Hitachi, Tokyo, Japan).

3. Results

3.1. Anterior Segment Inflammation by Anterior Segment Photography. "Fibrous membrane" [14] formation in the anterior chamber was observed immediately after applying ICG to the right eye of Rabbit Number One. The fibrous membrane was more pronounced at 12 hours after the experiment and then disappeared within 24 hours (Figure 2(a)). The control eye (left eye) was clear at all times (Figure 2(b)). Fibrous membrane formation was more prominent in the right eye of Rabbit Number Two, which was exposed to ICG for a longer time than left eye with shorter exposure time (Figure 3). In the early period after the experiment, the left eye, into which ICG had been injected, which was dissolved for only a short period of time (30 seconds), was more inflamed than the right eye, which was treated with a more dissolved solution of ICG. However, after 24 hours, the anterior chambers of both eyes were clear (Figure 4). A very severe inflammatory reaction for up to 24 hours was observed in the eye to which 1.00% ICG had been applied. There were no inflammatory reactions in the eye treated with 0.25% ICG (Figure 5).

3.2. Quantification of Aqueous Prostaglandin E_2 Level. The results of prostaglandin E_2 ELISA analysis correlated well with those of anterior segment photography. The rabbit eyes exposed to ICG for a longer period of time (60 seconds), ICG dissolved for only a short time (30 seconds), or ICG with a high concentration (1.00%) resulted in high PGE_2 levels.

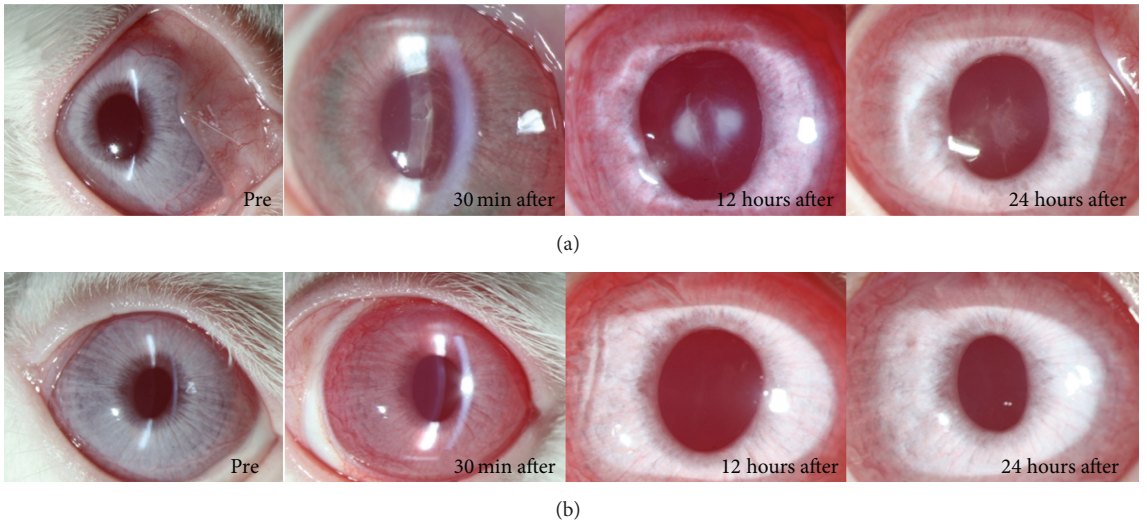


Figure 2: Fibrous membrane in the anterior chamber was observed immediately after applying ICG to the right eye of Rabbit Number One (a). It was more pronounced at 12 hours after the injection and then disappeared within 24 hours. The control eye was clear at all times (b).

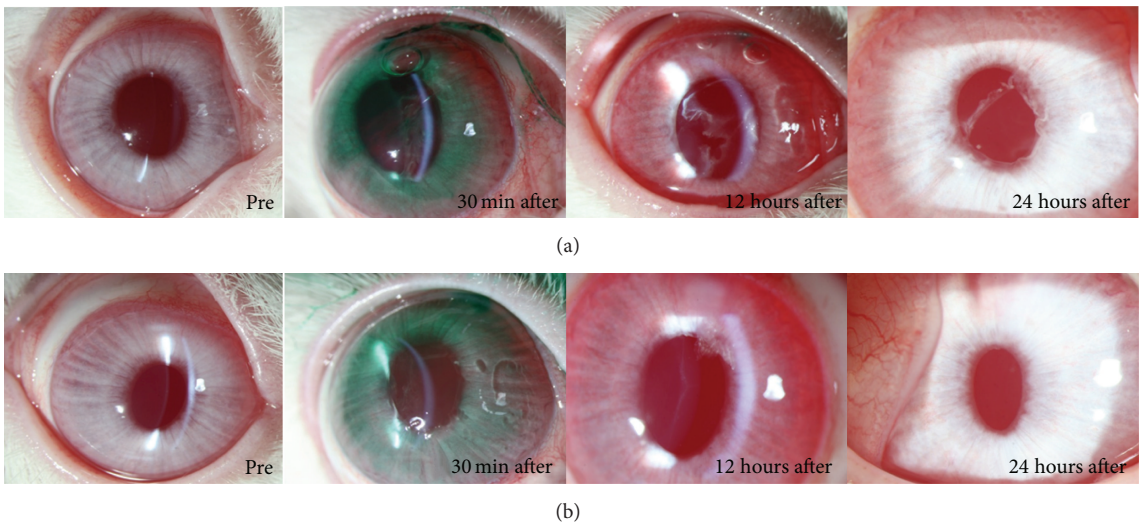


Figure 3: Compared to the ICG exposure time, fibrous membrane formation was more prominent in the right eye (a) of Rabbit Number Two that was exposed to ICG for a longer time than left eye (b).

The most significant difference was observed between eyes treated with different concentrations of ICG (Figure 6).

3.3. Assessment of Residual ICG Dye by Scanning Electron Microscopy. Residual ICG particles on the iris surface were observed using scanning electron microscopy. ICG granules were identified based on their presence and morphology compared to the control image. As there could not physiologically be electron dense round particles on the iris, these particles were characterized as ICG granules. Furthermore, the ICG granules were also completely different in size and shape when compared with inflammatory cells, fibers, and muscular structures. There were many ICG granules on the iris of the right eye of Rabbit Number One, ranging in size from 1 to 5 μm. No similar granules were observed in the control eye (Figure 7). The right eye of Rabbit Number Two, which was exposed to ICG for 60 seconds, had slightly more granules than the left eye (Figure 8). The left eye of Rabbit Number Three treated with ICG dissolved for only 30 seconds had larger white granules compared to those in the right eye of the same rabbit treated with ICG dissolved for three minutes (Figure 9). The large sizes of these granules on the left eye may be related to incomplete dissolution caused by shorter mixing time. There were numerous granules in the left eye of Rabbit Number Four, which was treated with 1.00% ICG. In contrast, very few remnant ICG particles were observed in the right eye of this rabbit, which was treated with 0.25% ICG (Figure 10).

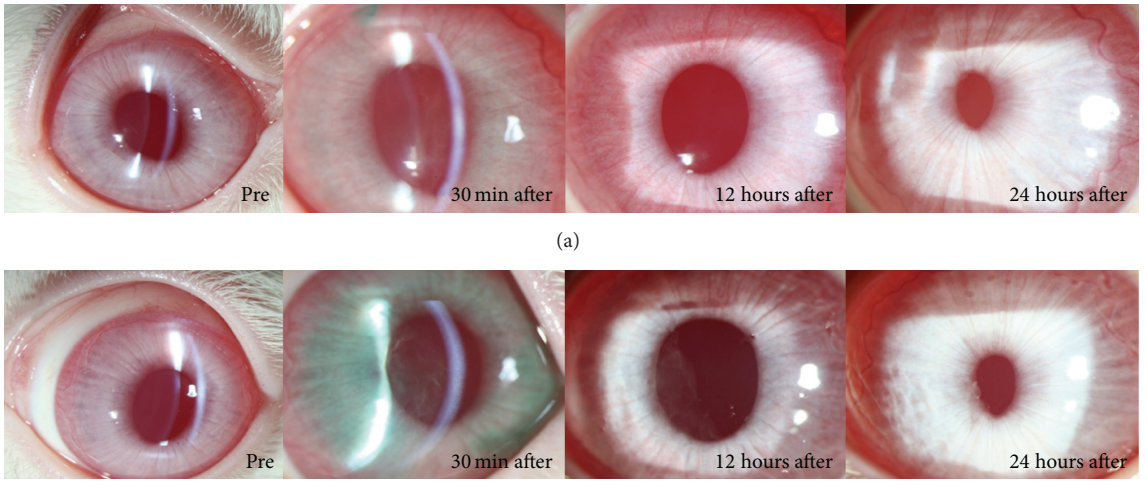


Figure 4: The right eye injected with ICG, dissolved for 3 minutes (a), and the left eye injected with ICG, dissolved for only 30 seconds (b). After 24 hours, the anterior chambers of both eyes were clear.

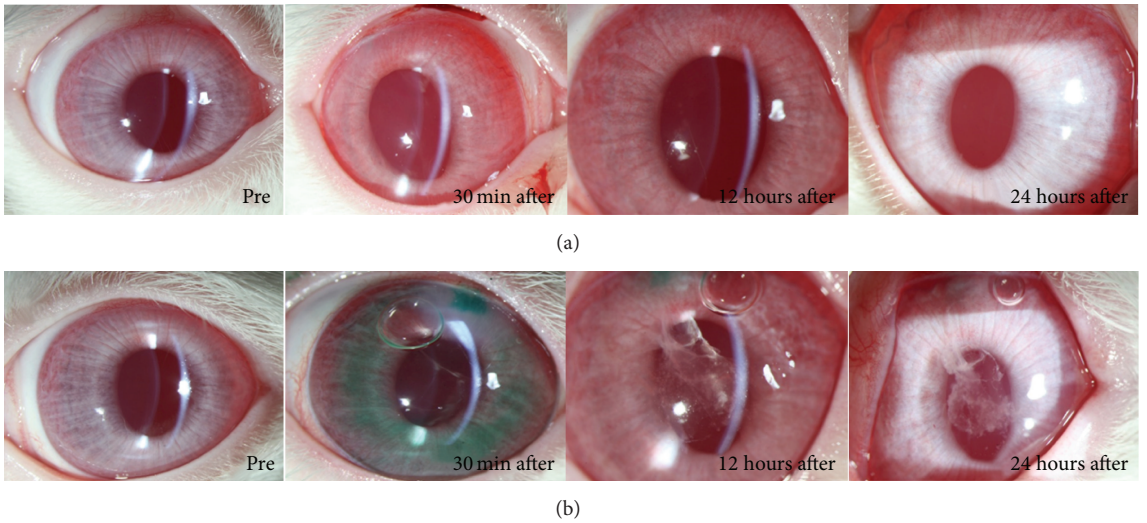


Figure 5: A very severe inflammation for up to 24 hours was observed in the eye to which 1.00% ICG had been applied (b). There was no inflammation in the eye treated with 0.25% ICG (a).

4. Discussion

There are several factors influencing anterior chamber inflammation during cataract surgery, such as insufficient mydriasis, elongated surgery time, excessive use of ultrasonic energy during phacoemulsification, iris incarceration into the corneal incisions, iris damage through phaconeedle, and irritating or toxic foreign materials. In this study we isolated and analyzed the role of ICG as a factor for inflammation in the anterior chamber.

Our results based on an animal model suggest that residual intraocular indocyanine green (ICG) dye can cause postoperative inflammation in the anterior segment. In this preliminary study to evaluate the role of ICG with regard to postoperative inflammation, the study design and sample size were optimized to harm as few rabbits as possible in order to provide proof of principle rather than prove a statistical effect.

Although toxic anterior segment syndrome was first described by Monson et al. [15] in 1992, its exact pathophysiology still remains unclear. It is known, however, that toxic foreign substances that intra- or postoperatively enter the anterior chamber can cause inflammation.

The common causes of TASS, as described by the ASCRS task force team, include improper cleansing of surgical equipment, use of enzymatic cleaners, an inappropriate detergent concentration, and antibiotics or preservatives for antibiotics that are intraoperatively mixed with an irrigation solution [7]. However, no prior study has reported yet that ICG dye used for anterior capsular staining can cause TASS; trypan blue and ICG are both used as a capsular staining agent [16–21].

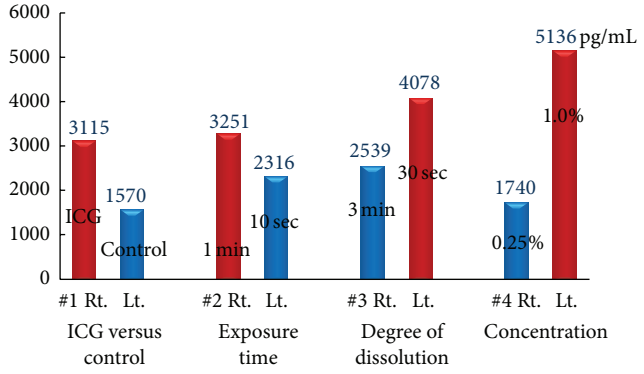


FIGURE 6: The PGE_2 concentrations in aqueous humor. The rabbit eyes exposed to ICG for a longer period of time (60 seconds), ICG dissolved for only a short time (30 seconds), or a high concentration of ICG (1.00%) resulted in high PGE_2 levels.

Trypan blue is commercially available in liquid form, whereas ICG comes in powder form and needs to be dissolved in a solvent before use. In countries such as South Korea where there are legal issues surrounding the intraocular use of trypan blue and/or import difficulties, ICG is used for anterior capsular staining. Generally, a 0.5% ICG solution is used for anterior capsular staining [10]. No standardized guidelines on methods of preparation or use of the solution are available. As such, there is a possibility that the concentration of the prepared ICG solution could be higher than required or that the dye may not be properly dissolved. In addition, if the anterior chamber is exposed to the dye solution for too long after injection of the solution or if the anterior chamber, especially the iris, is insufficiently washed, residual ICG particles may cause inflammation. We therefore performed *in vivo* experiments in rabbits to determine how the factors related to administration of ICG such as time of exposure to ICG, degree of dissolution, and concentration may influence the intraocular inflammatory reaction caused by ICG.

In this study, anterior chamber inflammation was found to be severe, and scanning electron microscopy of the iris surface showed more residual ICG particles when the time of exposure was long (60 seconds) and when the dissolving time was short (30 seconds). The degree of inflammation was much more severe and there were more residual ICG particles on the iris surface when 1.00% ICG was used compared to those when 0.25% ICG was used. The concentration of PGE_2 in the aqueous humor was measured to quantify the degree of anterior chamber inflammation. We found that the higher the degree of anterior chamber inflammation was, the higher the level of PGE_2 was in the aqueous humor.

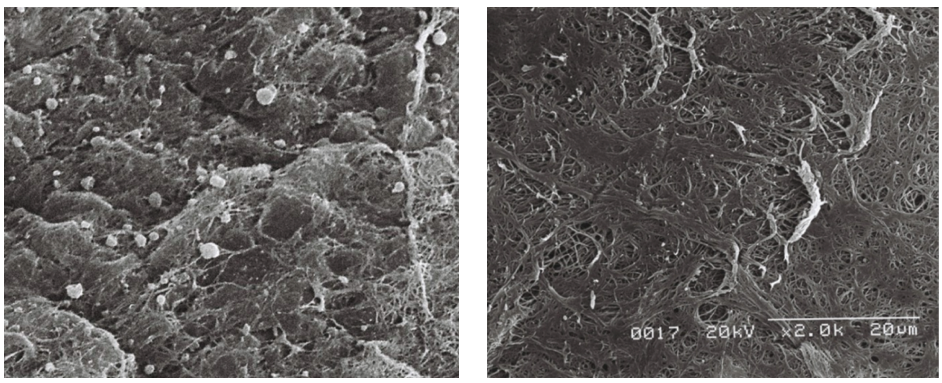
Based on these findings, we hypothesize that insoluble particles that remain in the ICG solution attached to the iris surface or to the anterior chamber angle during anterior capsular staining without being completely washed off can cause inflammation. Thus, if the formation of insoluble ICG particles can be minimized, inflammation caused by residual ICG particles could be reduced. The dissolution time, solution concentration, and solvent type all contribute to the formation of insoluble ICG particles. Generally, a mixed solution of distilled water and BSS is used to prepare ICG dye solution. Nishimura et al. [22] reported that insoluble ICG particles could form when BSS was used to prepare the ICG dye solution.

A preliminary experiment was performed using different ICG concentrations and different ratios of the two solvents [distilled water and BSS], and we observed a difference in the amounts of insoluble particles that were formed using a light microscope. We found that the higher the ICG concentration and the proportion of BSS in the solvent, the greater the proportion of insoluble particles (data not shown). This is likely to be related to the saturability of the solution. Of the substances used, the one which is most similar to aqueous humor in composition is BSS. As BSS contains various ions and molecules, its upper limit of complete dissolution of ICG is 0.5%. If the ratio of distilled water is increased to achieve complete dissolution of ICG, however the pH and osmolality of the ICG dye solution could decrease, which would adversely affect the anterior segment structures. Thus, sufficient time is required to dissolve ICG in a mixed solution containing a higher ratio of BSS to distilled water in order to maintain the regular intraocular environment.

Parikh and Edelhauser [23] experimentally showed that corneal edema with TASS is likely due to direct corneal endothelial toxicity. However, in this study, the postoperative complications related to the iris were more pronounced than corneal decompensation. The concentration and saturability of ICG presumably all play a role in the anterior chamber inflammation. The mesh-like characteristic of the iris structure may function as a reservoir for the remaining particles. Therefore, the postoperative inflammation is more likely related to the iris than to the cornea. Thus, ICG-related anterior chamber inflammation, such as fibrin formation, could occur.

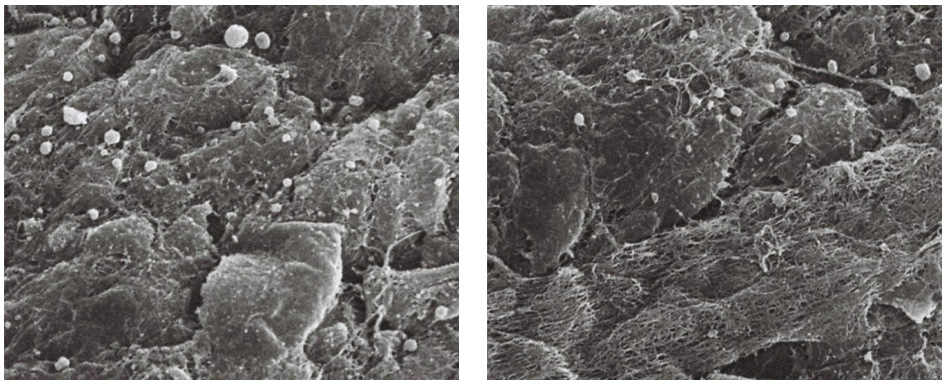
The limitations of this study are as follows: we only used a small number of rabbits; the pupil was undilated when anterior capsular staining was performed, which increased the possibility of ICG particles remaining on the iris surface; the amount of insoluble ICG in the anterior chamber could not be quantitatively measured according to exposure time, dissolution time, or concentration. There might also be differences in the inflammatory reactions of humans and rabbits. The difference in osmolarity values could also affect the inflammatory reactions after exposure of ICG solution in the anterior chamber. Nevertheless, we demonstrated for the first time that ICG can cause intraocular inflammation. In addition, we showed that the concentration of ICG, time of exposure to ICG, and the degree of dissolution of ICG affected the severity of inflammation. Anterior segment photography, scanning electron microscopy, and aqueous PGE_2 ELISA objectively showed that the greater the number of residual intraocular ICG particles was, the greater the severity of inflammation was.

These results show that, in the absence of trypan blue, ICG could also be used with caution as a capsular dye. In this case, special care should be taken to ensure a proper dissolution rate, lower concentration, and thorough cleansing of the ICG from the anterior chamber after staining the anterior capsule



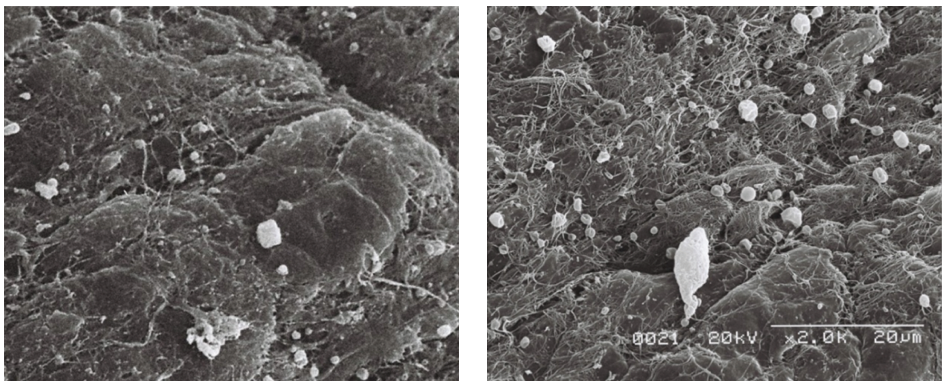
(a) (b)

Figure 7: Residual ICG particles on the iris surface were observed using scanning electron microscopy. There were many ICG granules on the iris of the right eye of Rabbit Number One, ranging in size from 1 to 5 μm (a). However, no similar granules were observed in the control eye (b).



(a) (b)

Figure 8: The right eye of Rabbit Number Two, which was exposed to ICG for 60 seconds, had slightly more granules (a) than the left eye (b).

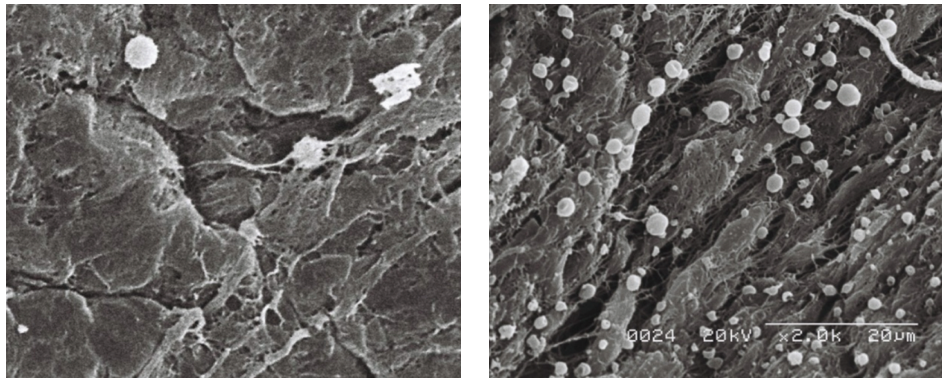


(a) (b)

Figure 9: The left eye of Rabbit Number Three treated with ICG dissolved for only 30 seconds had larger white granules (b) compared with the right eye, which was treated with ICG, that was vortexed for a longer time (a).

of the lens to avoid ICG granules from being captured within the meshwork-like structures of the iris surface which can otherwise cause significant anterior chamber inflammation. Chang et al. [12] suggest that the minimal concentration of ICG dye to show similar visibility with ICG 0.5% is ICG 0.25%. We also suggest a similar conclusion that the lower concentration of ICG dye can be a safer option for cataract surgery in terms of saturability, pH, and osmolarity of ICG.

Further studies are required to investigate other substances that can be related to the occurrence of TASS.



(a) (b)

Figure 10: There were numerous granules in the left eye of Rabbit Number Four, which was treated with 1.00% ICG (b). In contrast, very few remnant ICG particles were observed in the right 0.25% ICG-treated eye of this rabbit (a).

Disclosure

The authors alone are responsible for the content and writing of the paper.

Competing Interests

The authors report no competing interests.

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Research Article

Two-Dimensional Cutting (TDC) Vitrectome: In Vitro Flow Assessment and Prospective Clinical Study Evaluating Core Vitrectomy Efficiency versus Standard Vitrectome

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Purpose. To evaluate comparative aspiration flow performance and also vitrectomy operating time efficiency using a double-cutting open port vitreous cutting system incorporated in a two-dimensional cutting (TDC, DORC International) vitrectome design versus standard vitreous cutter. *Methods*. In vitro investigations compared aspiration flow rates in artificial vitreous humor at varying cutter speeds and vacuum levels using a TDC vitrectome and a standard vitrectome across different aspiration pump systems. A prospective single-centre clinical study evaluated duration of core vitrectomy in 80 patients with macular pucker undergoing 25-gauge or 27-gauge vitrectomy using either a TDC vitrectome at 16,000 cuts per minute (cpm) or standard single-cut vitrectome, combined with a Valve Timing intelligence (VTi) pump system (EVA, DORC International). *Results*. Aspiration flow rates remained constant independent of TDC vitrectome cut rate, while flow rates decreased linearly at higher cutter speeds using a classic single-blade vitrectome. Mean duration of core vitrectomy surgeries using a TDC vitreous cutter system was significantly ($p < 0.001$) shorter than the mean duration of core vitrectomy procedures using a single-cut vitrectome of the same diameter (reduction range, 34%–50%). *Conclusion*. Vitrectomy surgery performed using a TDC vitrectome was faster than core vitrectomy utilizing a standard single-action vitrectome at similar cut speeds.

1. Introduction

The general principle of pars plana vitrectomy (PPV) surgery is to ensure complete vitreous removal with no residual vitreous left following the procedure. A principal goal in PPV is to minimize vitreous traction by removing only the target ocular tissue, without inadvertently drawing unwanted tissue into the vitrectomy probe port or creating distant traction that might cause iatrogenic retinal tears or other complications. The degree of retinal traction created by vitrectomy cutters is influenced by the effect of time of aspiration, distance from the retina, and cutting rate. Retinal traction increases with increasing aspiration vacuum and proximity to the retina and decreases with higher cut rates [1].

Evolution of Vitrectomy Cutter Technology. Developments in vitrectomy probe technology have accelerated in recent years, designed to improve intraoperative surgical control and allow quick core vitrectomy (bulk vitreous removal) and tractionless controlled vitreous shaving. Alterations in geometrical design and size of vitrectomy probe, together with duty cycle, which is the proportion of time the cutter port is open rather than closed relative to a complete opening and closing surgical cutting cycle, and cutting speed provide additional performance capabilities for more efficient and safer surgery.

Aspiration rate produced by smaller-gauge vitreous cutters is proportionally decreased due to a reduced port size and smaller diameter, explained by Poiseuille's law that flow is proportional to the radius of the tube. This necessitates higher infusion and aspiration pressures to remove vitreous when using smaller-gauge vitrectomes. However, enlarging the port diameter of a vitreous cutter to increase flow becomes less effective as the port becomes larger [2]. Oshima et al. confirmed the feasibility of a 27-gauge instrument system for microincisional vitrectomy surgery (MIVS) in a variety

of vitreoretinal procedures, pointing out that such a system might reduce concerns about wound sealing complications in selected cases [3].

The concept of a double-cutting instrument for use in ophthalmic surgery was first patented in 1992 [4]. When vitreous enters the inner aperture, it is cut first in a forward motion and then again during the backward motion. Nearly two decades on, it was suggested that a dual port vitreous cutter system might allow surgeons to perform bulk vitrectomy more efficiently [5]. Rizzo et al. developed a modified vitrectomy probe design with an extra aspiration port in the internal capilair to extend overall duty cycle [6]. The idea involved inclusion of an opening in the internal guillotine pipe or inner vitrectome sleeve. Investigators found that, using modified 23-gauge vitrectomy probes, the time of aspiration remained almost constant irrespective of cutting speed, indicating almost no reduction of flow but, more importantly, that aspiration time was significantly reduced compared with a standard single port cutter.

Two-Dimensional Cutting (TDC) Vitrectome Design. The concept of a double-action surgical cutting probe has only recently been developed and incorporated into modern vitrectomy instrumentation probes that feature 2 cutter openings in the guillotine shaft, thereby performing a vitreous cutting action on both forward and backward stroke of the probe device. The principal advantages of this novel guillotine sleeve design included a doubling of cut rate, increased flow, and potentially decreased retinal traction or force exerted by the probe.

In 2013 the author in cooperation with DORC International developed a newer vitrectome design, introducing a modified vitreous cutter technology called two-dimensional cutting (TDC) vitrectome system, launched in conjunction with the EVA ophthalmic surgical platform, a new aspiration system designed to provide both flow and vacuum control mode vitrectomy for enhanced intraoperative fluidics stability.

The TDC vitrectome comprises a tubular outer part and an axially movable tubular inner part arranged in the outer part [7]. The outer part has a closed distal end and the inner part an open distal end. Both parts have an opening in the tube, allowing continuous aspiration of tissue during a complete cutter cycle movement. The inner tube has been designed with a rectangular aperture for increased and continuous flow functionality. The axial position of the distal cutting edge of the inner part as a function of the circumferential direction initially proceeds towards the proximal end and then back to the distal end again. Figure 1 illustrates core design elements of a TDC vitrectome and a classic single-cut vitrectome.

The TDC vitrectome performs a double-cutting movement during one complete cycle that is twice the rate of the former simple single-cut vitrectome model, effectively cutting vitreous at up to 16,000 cpm. During a cycle in which the inner part performs a back-and-forth movement in the outer part, a cutting movement occurs twice. A first cutting movement occurs by cooperation of the distal end of the inner part with the distal cutting edge of the outer part. The second cutting movement is realized through cooperation of the distal cutting edge of the inner part with the proximal cutting edge of the outer part. The port diameter of this new TDC vitrectome is larger than previous vitrectome designs (for the 23-gauge TDC vitrectome, e.g., the port is positioned 0.22 mm from the distal end and measures 0.41 mm long and 0.45 mm wide), theoretically allowing a greater amount of tissue to be captured per cutting cycle. Owing to the increased cutting and snipping capacity, the surgical intervention can be shortened and, moreover, the traction exerted on the ocular tissue drawn in during the aspiration phase decreases while the suction flow increases.

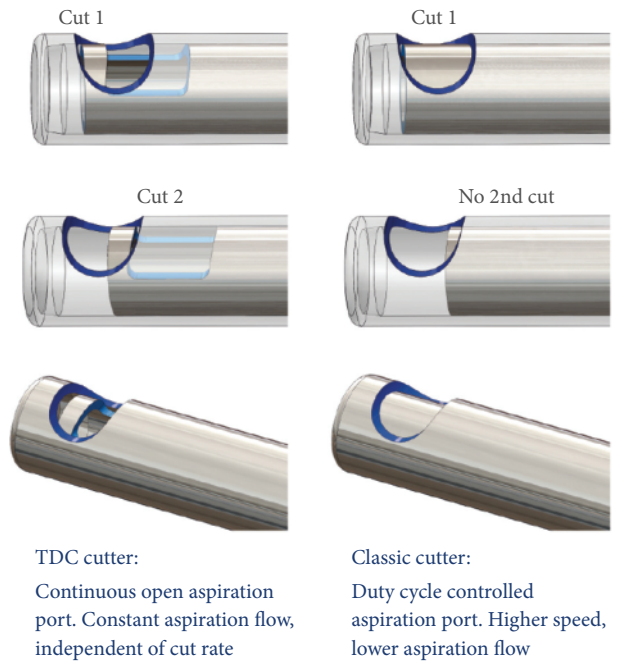

Figure 1: TDC vitrectome design and classic single-cut vitrectome.

We report below the methodologies and findings from in vitro comparisons of aspiration flow dynamics utilizing TDC and standard vitrectomes connected to different surgical platforms, together with methods and results of a prospective surgical case series study evaluating duration of core vitrectomy procedures and therefore comparative flow efficiency performance, using a TDC vitrectome system versus standard vitreous cutter system.

2. Methods

2.1. In Vitro Aspiration Flow Rate Tests. In vitro evaluations were undertaken to assess volumetric aspiration flow rates (the main outcome measure) of a two-dimensional cutting vitrectome compared with a standard vitrectome of the same gauge. Vitreous cutters, sizes 25-gauge and 27-gauge for both standard blade and TDC vitrectomes, were connected to a DORC EVA ophthalmic surgical unit, and test measurements were obtained for varying vacuum levels and at different cutter speeds up to 8,000 cpm. A standard blade vitrectome of both gauges was also evaluated for aspiration flow rate

at varying cut rates when connected to an Associate 6000 machine. The Associate system integrates a peristaltic and Venturi pump system, while the EVA phaco/vitrectomy system incorporates a VacuFlow Valve Timing intelligence (VTi) fluidics control system, which provides instantaneous flow or vacuum mode aspiration.

A cut rate and a vacuum level were set on a EVA machine according to the following range of tested settings: cut rate of 0 cpm, 1,000 cpm, 2,000 cpm, 3,000 cpm, 4,000 cpm, 5,000 cpm, 6,000 cpm, 7,000 cpm, and 8,000 cpm; and a vacuum level of 350 to 550 mmHg. The highest vacuum limit was set to 550 mmHg due to the stability of the vacuum til 550 mmHg. Above 550 mmHg every pump system delivers fluctuating vacuum parameters, which are not appropriate for exact evaluations.

Before each test, a priming procedure was performed to ensure that the aspiration tubing of the cutter was completely filled with water and that the cutter was positioned with its tip into a cup filled with fluid. The cup was placed on a high precision balance (0.01 g) which was connected to a computer. After activation of the vitreous cutter, a small time was allowed for attainment of a constant vacuum level in the aspiration tubing. When the vacuum level was constant, the weight reduction of the fluid in the cup was measured and the aspiration flow calculated by dividing the weight reduction by the time elapsed.

Initially, these tests were performed with water. The same tests were then performed using artificial vitreous humor as aspirating fluid. The artificial vitreous, consisting of a mixture of deionized water, agar, and hyaluronic acid sodium salt, was produced according to a protocol published by Kummer et al. [8] and used as a suitable dummy tissue to represent human vitreous humor for these in vitro experiments. For all tests performed, a density of 1.0 kg/L was used to covert the measured mass flow to a volume flow. Using artificial vitreous, 3 trials of 30 seconds' duration were performed. Per gauge size (and type) at least 2 vitreous cutters were tested. The average aspiration flow was calculated by averaging the measurement results of the different trials and the different vitreous cutters of the same type and gauge.

2.2. In Vivo Comparative Efficiency Performance. We evaluated overall vitrectomy cutting time (in seconds) required to remove core vitreous in 80 patients diagnosed with macular pucker as part of a comparative evaluation of flow and operating duration using a TDC vitrectome and former standard single-cut vitrectome design (25-gauge and 27-gauge systems, DORC) during core vitrectomy procedures.

Caucasian subjects aged over 50 years, diagnosed with macular pucker, refraction of +2 to −2 diopters, no previous intraocular surgery, and having a detached posterior vitreous were recruited. Inclusion criteria were chosen to ensure adherence to a similarity principle, with similar vitreous liquefaction, similar case duration and difficulty, similar vitreous volume, and similar overall ocular conditions having had no prior ocular surgical intervention. Patients with a diagnosis at baseline of glaucoma, asteroid hyalosis, acute or chronic uveitis, or trauma were excluded. A total of 80 patients were enrolled, with equal numbers, or 20 eyes, randomly allocated to one of four surgical treatment groups: 25-gauge standard vitreous cutter PPV, 25-gauge TDC vitreous cutter PPV, 27-gauge standard vitreous cutter PPV, and 27-gauge TDC vitreous cutter PPV; all procedures performed using the EVA surgical system.

Core vitreous volume was defined intraoperatively as the central area of the vitreous that could be visualized via a 90-diopter (D) PPV lens using the EIBOS I (Haag-Streit) viewing system. During central vitrectomy in the visible area of the 90 D lens, the eye was left stable so as to standardize the viewing field of vitreous removal and to allow for more precise evaluation. The field of the 90 D EIBOS lens remains constant and independent of distance to the eye. Using the EVA vitrectomy surgery machine with identical configuration settings and machine parameters for core vitrectomy mode, aspiration power was set at a maximum 680 mmHg, while vitrectome cutting speed used throughout the vitrectomy procedure was as high as 8,000 cuts per minute, equivalent to 16,000 cpm, using a TDC vitrectome.

All vitrectomized subjects were adequately informed prior to surgery about standard PPV for epiretinal membrane and core vitrectomy measurements and signed a consent form. Time measurement of core vitrectomy duration was made by a secondary person without a need to change standard vitrectomy procedures of PPV for epiretinal membrane removal. The study adhered to the tenets of the Declaration of Helsinki, and local regulatory requirements were fulfilled. Time and flow data were analyzed using linear least squares regression analyses and two-tailed t-tests. Performance of the new generation 25-gauge and 27-gauge TDC vitrectomes was analyzed relative to the current generation or standard 25-gauge and 27-gauge cutter. Statistical significance (p value) of comparison between PPV durations performed using standard and TDC vitreous cutters was set at 0.001.

3. Results

3.1. In Vitro Assessment of Aspiration Flow Rates. For in vitro investigations conducted in artificial vitreous, as the cutting rate increased from 0 to 8,000 cpm using a TDC vitrectome connected to EVA surgical aspiration system, aspiration flow rate remained constant, while aspiration flow rate steadily decreased at higher cut speeds with a standard vitrectome connected to the EVA or Associate surgical systems. Figures 2 and 3 show illustrative aspiration curve analyses obtained from comparative test evaluation measurements using a 25-gauge and 27-gauge TDC vitreous cutter and a classic 25-gauge and 27-gauge cutter in combination with the EVA machine and Associate platform at varying cutting rates, measured at a vacuum setting of 350 to 550 mmHg.

Table 1 includes measured aspiration flow rates obtained with the TDC and standard single-cut vitrectomes (25-gauge and 27-gauge) combined with EVA for varying vacuum levels and at cut speeds up to 8,000 cpm, confirming continuous high aspiration flow rates using a TDC vitrectome that are maintained constant at cut rates from 0 cpm to 8,000 cpm.

Table 1: Comparison of aspiration flow rates (mL/min) using TDC and standard single-cut vitrectomes connected to the EVA surgical system at varying cut rates and different vacuum pressures, in vitro tests performed using artificial vitreous humor as the aspirating fluid.

Cut rate (cpm)	0	2,000	4,000	5,000	6,000	7,000	8,000
25G TDC vitrectome flow rate (mL/min)							
350 mmHg	1.8	1.8	1.8	1.9	1.9	2.0	1.9
550 mmHg	3.2	3.3	3.2	3.3	3.3	3.3	3.3
Max mmHg	4.3	4.3	4.2	4.3	4.2	4.2	4.2
25G standard vitrectome flow rate (mL/min)							
350 mmHg	1.8	1.3	1.3	1.1	1.0	0.9	0.7
550 mmHg	3.1	2.2	2.2	1.8	1.6	1.6	1.1
Max mmHg	3.9	2.8	2.7	2.3	2.0	1.9	1.3
27G TDC vitrectome flow rate (mL/min)							
350 mmHg	0.9	0.8	0.9	0.9	0.9	0.9	0.9
550 mmHg	1.6	1.6	1.6	1.6	1.6	1.6	1.6
Max mmHg	1.9	2.0	2.0	2.1	2.1	2.1	2.0
27G standard vitrectome flow rate (mL/min)							
350 mmHg	0.8	0.6	0.7	0.6	0.5	0.5	0.4
550 mmHg	1.5	1.1	1.1	0.9	0.8	0.8	0.6
Max mmHg	1.9	1.4	1.4	1.2	1.0	1.0	0.7

TDC: two-dimensional cutting; cpm: cuts per minute; mmHg: millimeters of mercury.

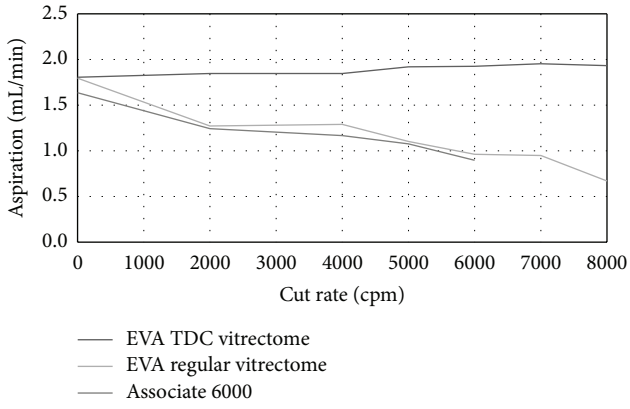

Figure 2: Aspiration flow rates of 25G TDC and standard vitrectomes @ 350–550 mmHg.

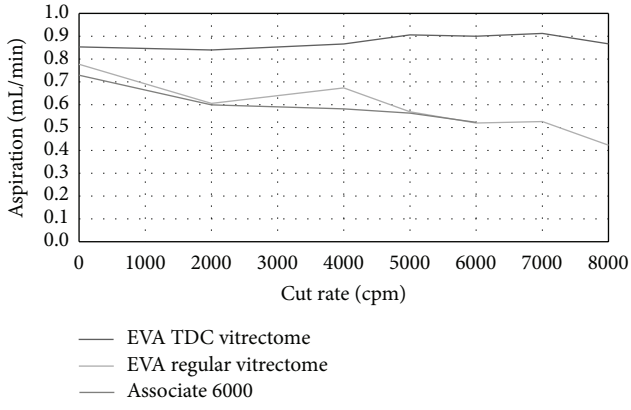

Figure 3: Aspiration flow rates of 27G TDC and standard vitrectomes @ 350–550 mmHg.

At a vacuum set at 350 mmHg, average aspiration flow rate measured using a 25-gauge TDC vitrectome in combination with the EVA surgical system ranged from 1.8 mL/min to 2.0 mL/min at cut rates between 0 cpm and 8,000 cpm; for the classic vitrectome connected to the EVA system, the flow rate measurement declined to 0.7 mL/min at 8,000 cpm from a flow rate of 1.3 mL/min at 2,000 cpm. When the classic 25-gauge vitrectome was connected to the Associate 6000 system, aspiration flow rate decreased from 1.6 mL/min at 0 cpm to 0.9 mL/min at 6,000 cpm cut rate, with vacuum set at 350 to 550 mmHg. Aspiration flow rate with a 27-gauge TDC vitrectome in combination with the EVA surgical system at maximum mmHg ranged between 2.0 mL/min and 2.1 mL/min and between 2,000 cpm and 8,000 cpm cut rates, compared with a linear decrease in measured aspiration flow rate at increasing cutter speeds with the 27-gauge classic vitrectome connected to the EVA system.

3.2. In Vivo Evaluations of Surgical Efficiency in Core Vitrectomy. In the comparative case series clinical study, the mean duration of core vitrectomy procedures using 25-gauge and 27-gauge TDC vitreous cutter system was statistically significantly ($p < 0.001$) shorter than the mean operating duration for core PPV performed utilizing a standard single-cut vitrectome of the same gauge.

Table 2 tabulates the mean duration of core vitrectomy procedures for each surgical intervention group assessed. The data show that the mean duration of PPV performed using a 27-gauge TDC vitrectome was 34% shorter (−83.0 seconds) than the mean duration measured for PPV using a standard 27-gauge single-cut vitrectome; similarly, for 25-gauge PPV, the respective reduction in duration of surgery using a TDC

Table 2: Mean duration of core vitrectomy operating time for 27-gauge and 25-gauge surgeries utilizing either a standard single-cut or a TDC vitrectome.

Parameter	25-gauge vitrectomy		27-gauge vitrectomy	
	Standard vitrectome ($n = 20$)	TDC vitrectome ($n = 20$)	Standard vitrectome ($n = 20$)	TDC vitrectome ($n = 20$)
Mean core vitrectomy duration (SD), in seconds	148.19 (25.14)	73.80 (18.61)	242.71 (25.52)	159.71 (29.47)
p value: significance of comparison between core vitrectomy durations performed using a standard and a two-dimensional cutting (TDC) vitrectome (t-test)	$p < 0.001$		$p < 0.001$	

Mean duration of core vitrectomy operating time for 27-gauge and 25-gauge surgeries utilizing either a standard single-cut or a TDC vitrectome is shown above, demonstrating significantly shorter case duration for TDC vitrectomy surgery groups ($n = 80$, 20 eyes assigned, resp., to each surgery group).

vitrectome system compared with a standard vitrectome was 50% (−74.39 seconds).

4. Discussion

In vitro tests demonstrate that a more predictable and consistent flow of vitreous around the instrument probe is achieved using a TDC vitrectome compared with a regular vitrectome system. A TDC vitrectome delivered good overall stability in aspiration flow rate that is independent of cut speed. At a cut rate of 8,000 cpm, equivalent to 16,000 cpm, we postulate that a TDC vitrectome, by cutting the vitreous into smaller bites, may induce less iatrogenic breaks. Moreover, the continuous open port of the TDC vitreous cutter permits greater tissue removal efficiency that is unaffected by cutter velocities, showing the potential of TDC vitrectome technology for faster, less turbulent, and potentially safer smaller-gauge vitrectomy.

The reported comparative evaluation of core vitrectomy duration in 80 patients undergoing surgery for macular pucker (epiretinal membranes) revealed that surgical case time using TDC vitrectome PPV is less than vitrectomy operating time performed using a standard single port cutter of the same gauge. Vitrectomy surgery using a TDC vitrectome resulted in faster core vitrectomy, a finding that was consistent across both 25-gauge and 27-gauge instrumentation surgery groups.

Fluidic stability and control during vitrectomy is essential. Retinal surgeons choose high vitreous cutter rates so as to maximize fluidic stability and reduce unwanted force or traction. Higher cutting rates using a TDC vitrectome in combination with continuous uninterrupted aspiration flow as a result of 2 open cutting ports help to ensure faster complete vitreous removal. If the higher double-cutting rate minimizes unwanted vitreous traction and reduces the risk of iatrogenic retinal damage is object of a safety designed ongoing study. Early 25-gauge vitrectomy systems were marked by reduced fluid flow and longer vitrectomy duration compared with 20-gauge systems [9]. However, the design of new generation dual-opening vitreous cutters effectively overcomes these initial limitations by providing for consistent flow irrespective of the cut rate used during vitrectomy surgery.

Findings from this small comparative case series assessment are supportive of the efficiency of TDC vitrectome technology and of faster cut speeds for vitrectomy surgery. Results suggest significantly decreased operating time for core vitrectomy. The author's experience performing microincisional vitrectomy with small-gauge instruments suggests that the approach is particularly well suited for microsurgical maneuvers that may be required for proliferative diabetic retinopathy, vitreomacular traction, macular hole closure, and high myopia cases. Evaluations reported herein are nonetheless limited by small research scale and by the fact that the same surgeon performed all vitrectomies in this single-centre clinical assessment. There is undoubtedly a surgical learning curve involved in mastering the technique of using small-gauge vitrectomy instruments, typically involving the first 20 or so cases. Future follow-up studies might usefully evaluate postoperative visual, anatomic, and safety outcomes.

Survey trends illustrate growing utilization of sutureless microincision vitrectomy in everyday retina practice [10]. Advocates of microincisional vitrectomy instrumentation highlight surgical advantages compared with conventional 20-gauge surgery in addition to sutureless vitrectomy capability, namely, reduced operating time, greater precision in performing delicate maneuvers, less tissue manipulation, and reduced postoperative inflammation and rapid visual recovery [11, 12]. A report by the American Academy of Ophthalmology in 2010 noted that, compared with 20-gauge vitrectomy, small-gauge vitrectomy is associated with significantly lower levels of patient discomfort and ocular inflammation, with faster improvement in visual acuity, and an acceptably low incidence of adverse events comparable to those observed for 20-gauge vitrectomy [13].

Overall, vitrectomy case duration using a TDC vitrectome in combination with the EVA surgical machine was shorter than vitrectomy operating time using a standard or classic single-cut vitrectome in patients undergoing vitrectomy for epiretinal membranes. Faster operating times offer the potential of reduced costs as well quicker postoperative rehabilitation [14]. Reported findings suggest that a TDC

vitrectomy probe provides greater operating efficiency than conventional vitreous cutter instrumentation during sutureless small-gauge vitrectomy.

Additional Points

Experimental assessments show maintenance of constant high aspiration flow independent of cutter speed using a two-dimensional cutting (TDC) vitrectome for vitreous removal. A prospective single-centre clinical study assessed duration of core vitrectomy procedure using a TDC vitrectome versus a standard single-cut guillotine vitrectome; the results reveal shorter operating times using a double-cutting TDC vitrectomy probe.

Competing Interests

Mitrofanis Pavlidis is a consultant to DORC International and declares a proprietary financial interest as codeveloper in collaboration with DORC of the TDC vitreous cutter.

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Research Article

In Vivo Imaging of Intraocular Fluidics in Vitrectomized Swine Eyes Using a Digital Fluoroscopy System

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Purpose. To describe the characteristics of intraocular fluidics during cataract surgery in swine eyes with prior vitrectomy. *Methods*. We prepared three groups of enucleated swine eyes (nonvitrectomized, core, and totally vitrectomized). Irrigation and aspiration were performed (2.7 mm conventional sleeved phacosystem) using a balanced saline solution mixed with a water-soluble radiopaque contrast medium at 1 : 1 ratio. We imaged the eyes using a digital fluoroscopy system (DFS) during phacoemulsification and compared the characteristics of the intraocular fluid dynamics between the groups. *Results*. The anterior chamber depth (ACD) after the commencement of irrigation differed between groups (2.25 ± 0.06 mm; 2.33 ± 0.06 mm; 3.17 ± 0.11 mm), as well as the height of the fluid flowing from the anterior chamber into the posterior cavity that was identified by lifting up the iris to correct the infusion deviation syndrome (0.00 ± 0.00 mm; 0.41 ± 0.04 mm; 2.19 ± 0.35 mm). *Conclusions*. DFS demonstrated differences in fluid dynamics during phacoemulsification in swine eyes with or without prior vitrectomy. In completely vitrectomized eyes, the large ACD, which developed during phacoemulsification, could be reduced by lifting the iris and allowing the fluid to shift to the posterior cavity. Recognizing the differences in fluidics of vitrectomized eyes as compared to those of the nonvitrectomized eyes may reduce the frequency of intraoperative complications.

1. Introduction

With progressive refinements in vitreoretinal surgical techniques, an increasing number of posterior segment disorders are being successfully managed with pars plana vitrectomy. However, cataract formation is a frequent complication after vitrectomy, occurring in up to 80% of cases. Well-known potential complications that may arise from cataract surgery after vitrectomy include poor pupil dilation, posterior synechiae, zonular damage, posterior capsular tears, increased mobility of the iris-lens diaphragm, and altered intraocular fluid dynamics as a result of the absence of the anterior hyaloid surface [1]. Upon first entry of the phacotip into the anterior chamber, characteristically, the iris-lens diaphragm bows posteriorly as soon as irrigation begins, causing the anterior chamber to deepen excessively and the pupil to dilate widely. In 2003, Ahfat et al. described this phenomenon as infusion deviation syndrome (IDS): the initial deepening of the anterior chamber followed by a sudden and unpredictable shallowing [2]. The most important feature of these eyes is the lack of vitreous support. A phakic, vitrectomized eye has a posterior segment filled with fluid that lacks the properties of a gel due to the absence of collagen and hyaluronic acid [3].

Among studies on intraocular fluid dynamics, one particular study used a model that evaluated the fluidics of the anterior chamber using microparticles. The anterior flow

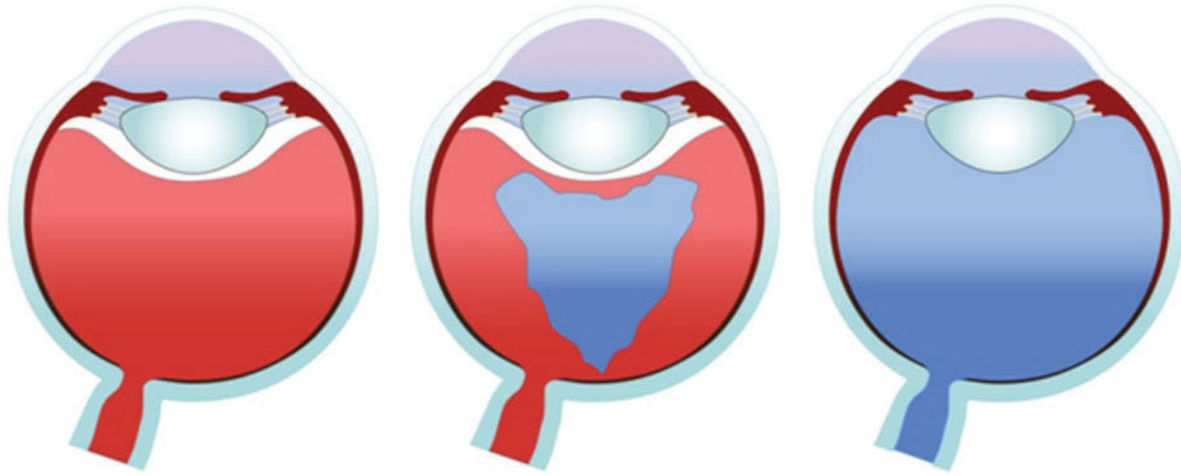

Figure 1: (a) Nonvitrectomized, (b) core vitrectomized, and (c) totally vitrectomized swine eyes.

could be documented with the help of a camera and a computer that monitored the flow of the microparticles [4].

Fluoroscopy is an imaging technique commonly used by physicians to obtain real-time images of the internal structures of a patient through the use of a fluoroscope such as for dynamic digital cardiovascular imaging applications.

Modern fluoroscopes couple the screen to an X-ray image intensifier and charge-coupled device (CCD) video camera, allowing the images to be recorded and played on a monitor.

The purpose of this study was to investigate the exact mechanism of IDS using a digital fluoroscopy system (DFS) in real time. We also sought to compare the changes in the iris, lens, and anterior hyaloid surface according to the degree of vitrectomy and to compare the intraocular fluid dynamics according to these changes.

Table 1: Physical properties of iodixanol (Visipaque).

Formula	$C_{35}H_{44}I_6N_6O_{15}$
Molecular mass	1550.191
Concentration of iodine (mgI/mL)	320
Osmolality (mOsmol/kg water)	290
Viscosity (cP)	
20°C	26.6
37°C	11.8
Density (g/mL)	
20°C	1.369
37°C	1.356
Protein binding	Negligible
Metabolism	Excreted unchanged
Half-life	2.1 hours
Excretion	Renal

2. Methods

This study was performed on enucleated eyes of pigs which were 5–8 months old having an axial length of around 24 mm. They were all studied within six hours after enucleation. Nine swine eyes were divided into three groups of three eyes each to compare the intraocular fluid dynamics according to the degree of vitrectomy. Groups 1, 2, and 3 were classified as normal swine eyes that did not undergo vitrectomy (Figure 1(a)), those that underwent core vitrectomy (Figure 1(b)), and those that underwent total vitrectomy (Figure 1(c)), respectively. The eyes of Groups 2 and 3 underwent a pars plana, 23-gauge, 3-port vitrectomy in the usual manner.

Images were taken using iodixanol (Visipaque, GE Healthcare, 320 mg-I/mL, osmolality 290 mOsm/kg water), which is a nonionic, isoosmolar contrast medium (Table 1). The contrast medium was mixed with a balanced saline solution (BSS) in a 1 : 1 ratio and then heated up to 37°C just before the experiment [5].

In each swine eye, the anterior chamber was irrigated with contrast medium mixed with BSS through a clear corneal incision (2.75 mm), using the Infiniti Phaco System (Alcon Laboratories), with the same parameters (aspiration flow rate: 30 mL/min, bottle height: 76 cm) for each procedure. We used a 30-degree phacotip with a 0.9 mm outer diameter.

In each group, the initial change of the anterior chamber depth (ACD) after irrigation with contrast medium was observed. If present, the degree of IDS was measured and the iris was lifted with a second instrument for 10 seconds. We observed the flow of irrigation fluid from the anterior chamber to the posterior cavity and recorded the amount of contrast medium in the posterior cavity.

The flow of the contrast medium in the eyes was filmed during phacoemulsification using the DFS (AXIOM Artis dFC, Siemens, USA) at a speed of 30 frames per second. The whole imaging system enables a very high resolution of 184 μm pixel pitch (956 × 954 pixels for a 9.76-inch diagonal). We compared the changes of the ACD and the amount of contrast medium in the posterior cavity before

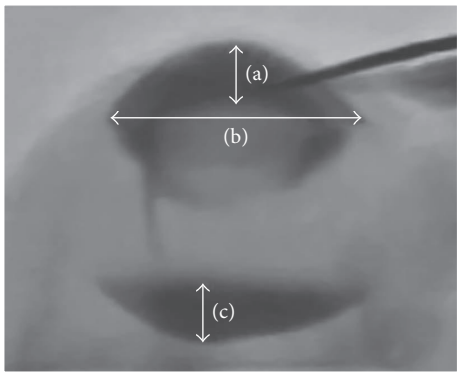

Figure 2: Fluoroscopic image of a swine eye: (a) anterior chamber depth, (b) angle-to-angle length, and (c) height of the contrast medium in the posterior cavity.

and after lifting the iris with a second instrument using still images taken from the real-time DFS. In this study, ACD was measured as the distance from the posterior corneal surface to the anterior lens surface, and the height of the contrast medium in the posterior cavity was measured as the distance from the anterior surface of the contrast medium to the anterior retinal surface (Figure 2). To compensate for the variation in image size, the angle-to-angle length of each eye was standardized to 10.0 mm. In each eye, the ACD and height of the contrast medium in the posterior cavity were also normalized using the same conversion ratio of angle-angle-length, and we compared the ACD and height of the contrast medium in the posterior cavity. Comparisons were made using the paired t-test. A P value of < 0.05 was considered to be statistically significant.

3. Results

In the nonvitrectomized eyes (Figure 3(a)), the iris-lens diaphragm did not bow posteriorly after irrigation began (mean ACD: 2.25 ± 0.06 mm). When the iris was lifted with the second instrument (mean ACD: 2.22 ± 0.05 mm), irrigation fluid did not pass into the posterior cavity (Figure 3(b)). In the core vitrectomized eye (Figure 3(c)), limited posterior bowing of the iris-lens diaphragm occurred (mean ACD: 2.33 ± 0.06 mm). After lifting the iris with the second instrument (mean ACD: 2.28 ± 0.07 mm), a small amount of irrigation fluid passed into the posterior cavity (mean height of the contrast medium in the posterior cavity: 0.41 ± 0.04 mm, (Figure 3(d))). We could also observe the narrow space between the posterior lens capsule and the relatively intact anterior hyaloid surface, and, in some areas, the real-time fluid shifts from the anterior chamber to the posterior cavity with the DFS. However, in the totally vitrectomized eyes, the iris-lens diaphragm bowed markedly as soon as the irrigation began (mean ACD: 3.17 ± 0.11 mm) (Figure 3(e)). When the iris was lifted with the second instrument, a large amount of fluid passed into the posterior cavity (mean height of the contrast medium in the posterior cavity: 2.19 ± 0.35 mm), and then the ACD was normalized (Figure 3(f), mean ACD: 2.32 ± 0.03 mm). Figure 3 shows the different chamber depths before the iris was lifted and amounts of dye that passed from the anterior chamber into the posterior cavity after lifting the iris.

After irrigation commenced, the mean ACD of the core vitrectomized eyes was not significantly deeper than that of the nonvitrectomized eyes ($P = 0.135$). However, the mean ACD of the totally vitrectomized eyes was significantly deeper than that of nonvitrectomized eyes ($P < 0.001$, (Figure 4)). In the case of the nonvitrectomized eyes, the change in the mean ACD after lifting the iris was not significant ($P = 0.094$). However, in the core vitrectomized eyes, the change in the mean ACD was significant ($P = 0.023$), as well as in the totally vitrectomized eyes ($P = 0.009$ (Figure 5)). The mean height of the contrast medium in the posterior cavity of the totally vitrectomized eyes was significantly greater than that of the core vitrectomized eyes ($P = 0.001$). There was no contrast medium in the posterior cavity of the nonvitrectomized eyes (Figure 6).

4. Discussion

Infusion deviation syndrome (IDS) is caused by a lack of vitreous support and posterior bowing of the iris-lens diaphragm. IDS can result in the blockage of fluid passage from the anterior chamber to the vitreous cavity, causing significant pressure differences between the anterior and posterior compartments [3]. This phenomenon results from a loss of anterior chamber and vitreous volume, causing the anterior chamber and liquified vitreous to leak after the initial incision is made. In all cases of IDS, lifting the iris or preinjection of viscoelastics before commencing the irrigation helps to prevent strong fluctuations of anterior chamber depth, iris-capsular bag diaphragm, and problems which may be caused by it. Patients may experience pain during surgery caused by IDS, which can trigger unexpected abrupt agitation and unwanted movements of patient. This can increase the risk of complications during the surgery. It is therefore very important for surgeons to be aware of the IDS and proper management of it intraoperatively.

In this study, posterior bowing of the iris-lens diaphragm was not observed in nonvitrectomized eyes when irrigation was initiated, and posterior bowing was only slightly evident in the core vitrectomized eyes. However, in the totally vitrectomized eyes, the iris-lens diaphragm was significantly displaced posteriorly, and the anterior chamber was significantly deepened. Eyes that have undergone meticulous vitrectomy are at a higher risk for this syndrome.

IDS can also occur in axial myopia, because of their zonular laxity. The combination of these anatomic factors allow the iris and capsular bag to move posteriorly with the introduction of pressurized fluid into the anterior chamber [6]. To stabilize the anterior chamber, a second instrument was used to lift the iris for a few seconds, allowing fluid to pass from the anterior chamber to the vitreous cavity, resulting in pressure equilibration.

In our study, movement of the irrigation fluid of the anterior chamber into the posterior cavity by lifting the iris

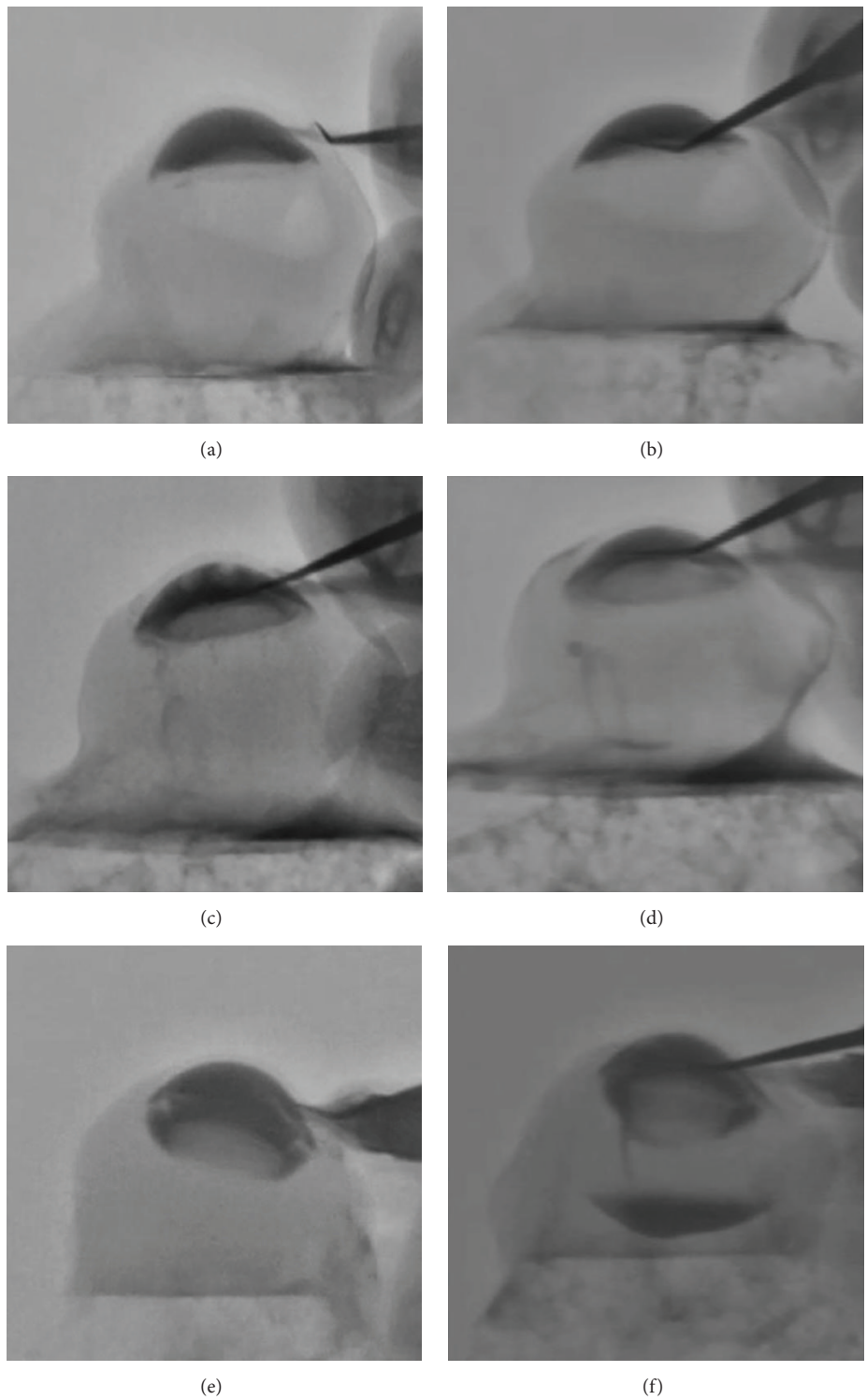

Figure 3: Fluoroscopic images of a swine eye (a, c, e) before lifting the iris and (b, d, f) after lifting the iris; (a, b) nonvitrectomized, (c, d) core vitrectomized, and (e, f) totally vitrectomized swine eyes.

worked to stabilize the anterior chamber. This procedure is a safe option for stabilizing the anterior chamber. Once satisfactory anterior chamber depth is achieved, the lens can be removed in the usual manner without difficulty [7]. Another management option is to reduce the height of the infusion bottle and to add a second infusion line to shallow the anterior chamber by decreasing the infusion pressure. Although this may bring anterior chamber depth back to

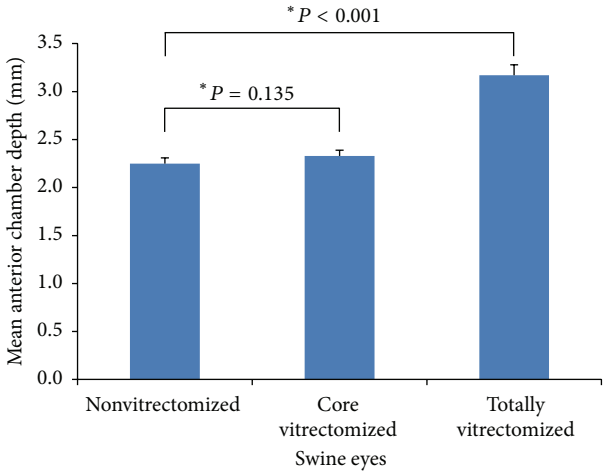

Figure 4: Mean anterior chamber depth after commencement of irrigation.

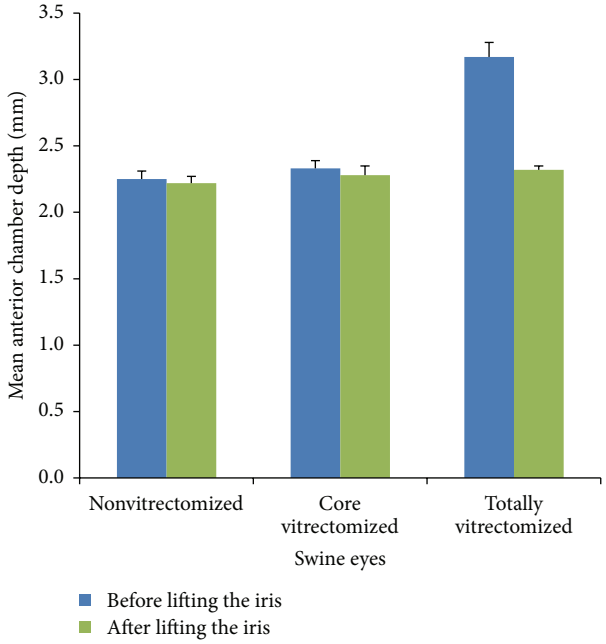

Figure 5: Change of mean anterior chamber depth before and after lifting the iris. In the nonvitrectomized eyes, the mean change of the ACD was not significant ($P = 0.094$). However, in the core vitrectomized and totally vitrectomized swine eyes, the mean changes of the ACD were significant ($P = 0.023$, $P = 0.009$, resp.).

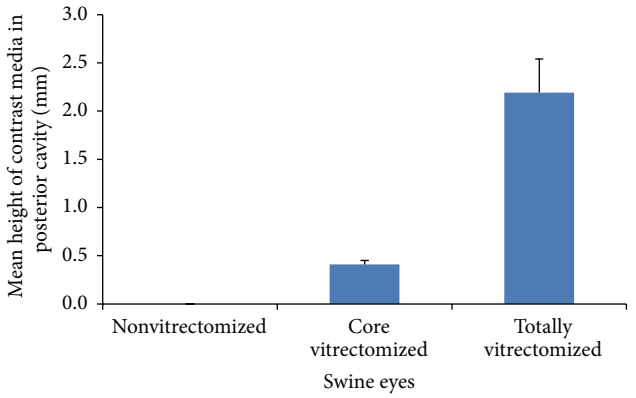

Figure 6: Mean height of the contrast medium in the posterior cavity of the eyes according to group. The mean height of the contrast medium in the posterior cavity in the totally vitrectomized eyes was significantly greater than that of the core vitrectomized eyes ($P = 0.001$). However, there was no flow of contrast medium into the posterior cavity in the nonvitrectomized eyes.

normal, it requires a significant amount of time, an additional incision, and supplementary tubing. Careful determination of bottle height is necessary because improper inflow-outflow management will subject the eye to more chamber volatility and increase the risk of posterior capsule rupture [6].

Using the Miyake-Apple technique, one can observe the lens and adjacent structures after cutting the posterior half of an eye and placing it on a transparent slide [8]. The posterior cavity can be observed by dissecting a part of the posterior chamber or by using an endoscope. However, cutting a part of the posterior cavity can cause a deterioration of the posterior structure as well as the flow of fluid. In addition, an endoscopic camera is not appropriate to study fluid dynamics as it only views a part of the posterior cavity and has low resolution.

Imaging systems such as computed tomography (CT) or magnetic resonance imaging (MRI) can be used to observe fluid flow without disturbing the intact structure. However, it is difficult to observe the dynamic flow of fluid with CT or MRI as these modalities typically only acquire images at a specific moment in time, as opposed to acquiring them over a period of time. While microparticles can be used to study anterior chamber fluid dynamics, they cannot be used in the studies of intraocular fluid dynamics between anterior and posterior chamber.

Diagnostic and interventional radiology have a continuing requirement for dose-efficient X-ray-based imaging techniques to visualize moving anatomic structures, organs, and/or clinical items of interest. Such imaging techniques are commonly associated with contrast medium-aided examinations of the gastrointestinal tract, cardiovascular system, and various other soft tissue organs and structures. One of the advantages of DFS is that it affords the possibility to observe the shape of a structure and the movement of contrast medium while maintaining the intact internal structure [9]. Due to the high resolution of the DFS used in this study, clear images were obtained with diluted contrast medium. Moreover, movement of the iris and lens was observed against the background of the contrast medium, the movement of the contrast medium was identified in real time, and a 30-frame-per-second video clip was successfully obtained.

In this study, we could observe the different changes in anterior chamber depth and the amount of contrast medium that had passed through the posterior cavity in real-time DFS. This is the first time that DFS has been applied in this way in ophthalmology.

The resolution of this imaging technology can be a limitation, although in this study it offered no challenges to identifying the fluid passage and accumulation in the posterior cavity. Moreover, this DFS method can be used to visualize the experimental outcomes of pharmacologic vitreolysis in vivo [5].

Using ultrasound images to observe the vitreous status in vivo, there is an impedance of the crystalline lens on image quality, especially the area directly behind the crystalline lens. But the crystalline lens did not affect the resolution of DFS in the experimental model and afforded the advantage of examining the reaction process in real time [5].

Iodixanol is the only contrast medium formulated with sodium and calcium in a ratio equivalent to that of blood. Iodixanol, a water-soluble contrast medium, is used in coronary angiography with DFS [10]. While iodixanol is well tolerated by the vascular endothelium and has a wide margin of safety, some studies have reported morphologic changes of endothelial cells and vasoreactivity [11–13]. However, to date there have been no studies regarding the toxicity of contrast medium on the human eye. If a study were to be conducted investigating the toxicity of iodixanol on the human eye, the DFS could be applied to study the phacodynamics in the eye.

In conclusion, in this study we could successfully observe real-time images of anterior and posterior cavity using DFS, demonstrating differences in fluid dynamics during phacoemulsification in eyes with or without prior vitrectomy. In the completely vitrectomized eyes, the significantly deep anterior chamber which developed during phacoemulsification could be normalized by allowing the fluid shift to the posterior cavity. Using the digital fluoroscopy system we could successfully identify intraocular fluidics between anterior chamber and posterior cavity. In the group of vitrectomized eyes, a significantly large amount of fluid flowed to the posterior cavity which then led to a normalized anterior chamber depth. Recognizing the differences in the fluidics of the vitrectomized eye as compared to those of the nonvitrectomized eyes may reduce the frequency of intraoperative complications. This study on vitrectomized swine eyes suggests that DFS represents a favorable experimental method to study the intraocular fluid dynamics in vivo.

Disclosure

The authors alone are responsible for the content and writing of the paper.

Competing Interests

The authors report no competing interests and they do not have financial or proprietary interests in any of the materials mentioned.

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Clinical Study

A Comparison of Clinical Outcomes of Dislocated Intraocular Lens Fixation between In Situ Refixation and Conventional Exchange Technique Combined with Vitrectomy

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Purpose. To evaluate surgical efficacy of in situ refixation technique for dislocated posterior chamber intraocular lens (PCIOL). *Methods*. This was a single-center retrospective case series. 34 patients (34 eyes) who underwent sclera fixation for dislocated IOLs combined with vitrectomy were studied. Of 34 eyes, 17 eyes underwent IOL exchange and the other 17 eyes underwent in situ refixation. *Results*. Mean follow-up period was 6 months. Mean logMAR best corrected visual acuity (BCVA) was not significantly different between the groups 6 months after surgery (0.10 ± 0.03 in the IOL exchange group and 0.10 ± 0.05 in the refixation group; $p = 0.065$). Surgically induced astigmatism (SIA) was significantly lower in the refixation group (0.79 ± 0.41) than in the IOL exchange group (1.29 ± 0.46) ($p = 0.004$) at 3 months, which persisted to 6 months (1.13 ± 0.18 in the IOL exchange group and 0.74 ± 0.11 in the refixation group; $p = 0.006$). Postoperative complications occurred in 3 eyes in the IOL exchange group (17.6%) and 2 eyes in the refixation group (11.8%). However, all of the patients were well managed without additional surgery. *Conclusion*. The in situ refixation technique should be preferentially considered if surgery is indicated since it seemed to produce a sustained less SIA compared to IOL exchange.

1. Introduction

Dislocation of the intraocular lens (IOL) after cataract surgery has been reported to occur in 0.2% to 1.8% of the patients [1, 2]. This uncommon ocular complication is important because it leads to serious visual disturbance that may need complicated surgical correction. IOL dislocation during the early postoperative period occurs because of inadequate capsular bag or ciliary sulcus support, whereas optic or haptic induced capsular damage can lead to IOL dislocation at a later stage [3, 4]. A variety of techniques for managing dislocated IOLs have been reported which can generally be classified into open- and closed-eye procedures [5–12]. Extraction of the dislocated IOL in the open eye method involves removal of a dislocated IOL through a large corneal incision followed by exchanging with a new secondary IOL. It accompanies the risk of vitreous prolapse, ocular collapse, intraocular hemorrhage, and induction of large amounts of astigmatism. Repositioning of the dislocated IOL using a closed-eye method is a desirable alternative [11]; however, it entails disadvantages such as surgical difficulty and multiple instrument passages. During surgical intervention, an important consideration is whether to remove, exchange, or reposition the dislocated IOL. The decision to undertake exchange or refixation of a dislocated IOL is usually made based on the clinical features of an individual case. If dislocated IOL is not adequate for reposition, it may be removed and exchanged. However, when there is no contraindication to reposition and sclera fixation of dislocated original IOL, the patient may receive a sclerally sutured IOL. Several previous studies have already identified improved best corrected visual acuity (BCVA) after sclerally fixated sutured posterior chamber intraocular lens (PCIOL) in patients with dislocated IOLs [1, 4, 12]. However, postoperative outcomes may differ according to the surgical techniques.

The aim of this study was first to introduce in situ refixation technique, which is a novel repositioning technique

using a bilimbal small incision to manage posteriorly dislocated IOL, and then to evaluate its surgical efficacy in a retrospective comparative study.

2. Materials and Methods

2.1. Subjects. The study protocol was approved by the Institutional Review Board of the Kyungpook National University School of Medicine. A retrospective review was conducted on the medical records of 34 eyes of 34 patients with dislocated IOLs who underwent IOL exchange or in situ refixation combined with vitrectomy between January 2010 and May 2015. All surgeries were performed by one surgeon (H. K. Kim) at Kyungpook National University Hospital, Daegu, Republic of Korea. Patients aging 18 or older, who have suffered dislocated IOL without ample capsular support and so have to undergo scleral fixation surgery of dislocated IOL, were included. The exclusion criteria were as follows: (1) history of underlying corneal disease (e.g., corneal laceration, bullous keratopathy, or Fuchs' dystrophy); (2) glaucoma; (3) history of optic neuritis; (4) state of aphakia; (5) history of previous IOL dislocation; and (6) follow-up duration less than 6 months.

The 34 patients in the study were divided into two groups based on the surgical techniques for managing dislocated IOLs: the IOL exchange group and the in situ refixation group. The patients in the IOL exchange group underwent removal of dislocated IOL and concurrent secondary IOL implantation with scleral fixation. The patients in the in situ refixation group underwent repositioning of the dislocated IOL using a bilimbal small incision with double haptic scleral fixation. The surgical technique was chosen with the following considerations: IOL design, kinds of optic material, presence of deformation of the IOL, and necessity of refractive change. Patients with dislocated IOL, which was 3-piece design without any deformation, were chosen for in situ refixation technique. Patients, who had late haptic or single piece designed IOL, any deformation or breakdown of IOL, and the needs for refractive correction, were undergone with IOL exchange technique.

2.2. Surgical Technique. All patients underwent vitrectomy for anteriorly prolapsed vitreous before the scleral fixation of IOL under general anesthesia. Pars plana approach or anterior two-port vitrectomy were performed. Vitrectomy techniques were chosen at the surgeon's discretion according to the states of dislocated IOLs and vitreoretinal pathology. Pars plana approach was performed in cases with complete IOL dislocation into the vitreous cavity or dislocation posteriorly with one haptics adherent to the vitreous base. A 23-gauge standard three-port vitrectomy was setup to remove the vitreous and free the dislocated IOL from vitreous adhesions. Following placement of the infusion cannula, two sclerotomies were placed through the pars plana. In each cases of PPV, the surgeon attempted a complete vitrectomy that extended to the periphery to remove as much vitreous as possible, because the residual vitreous might induce IOL kinking and vitreoretinal traction afterward. After core vitrectomy, the peripheral retina was carefully examined with sclera indentation to remove the vitreous gel and find any retinal break. Two 23-gauge peeling forceps were introduced into the vitreous cavity through the two previously positioned port sites to grasp and raise the dislocated IOL up to the back of the iris plane so the IOL could be clearly visualized. After PPV, sclerotomy sites were carefully checked for any vitreous incarceration. In contrast, when prolapsed vitreous was present in the anterior chamber, AV was performed with introducing a bimanual port through a corneal incision site to remove and prevent traction on vitreous strands.

After vitrectomy, an IOL was sclerally fixated with the two different surgical methods: conventional IOL exchange or IOL refixation. A conjunctival incision was created and two-half thickness triangular scleral flaps with 180° apart were performed. In the IOL exchange group, a slit knife was used to make an approximately 6.0 mm superior corneal incision. In contrast, 1.5 mm sized two limbal incisions on opposite sides of direction were made in the IOL refixation group (Figure 1(a)). We named this novel approach as the in situ refixation technique. The dislocated IOL is visualized at the back of the iris plane after being floated from the vitreous cavity through vitrectomy procedure. The anterior chamber was maintained using an ophthalmic viscosurgical device (OVD) (sodium hyaluronate 1.65%, chondroitin sulfate 4% [DiscoVisc]) during scleral fixation. A 10-0 polypropylene (PROLENE) suture was inserted with a curved needle under the scleral flap about 1.5–2.0 mm posterior to the limbus and it was pulled out to the opposite sclera flap (Figure 1(b)). In the IOL refixation group, the suture thread was hooked out of the eye through limbal incision site and cut in two pieces. Each haptics was externalized through one of the limbal incision sites, and the cut suture threads were tied to each haptics (Figures 1(c) and 1(d)). Once the suture was tied and tensed to the haptics, it was reinserted intraocularly. After tightening sutured haptics, centration of the lens was carefully checked and the sutures were tied under the scleral flaps. A stromal hydration was performed at both edges of the two limbal incision sites instead of suture to help seal it. In the IOL exchange group, a conventional IOL exchange technique was applied to scleral fixation of the IOL. When we used IOL cutter or refolding technique for the removal of dislocated IOL, we made 3.5 mm superior limbal incision. In cases of rigid optic material, such as poly(methyl methacrylate) (PMMA), 6 mm sized superior scleral tunnel incision was used. The dislocated original IOL was grasped with an intraocular forceps and carefully extracted through superior incision. After the dislocated IOL was removed, a retrieved suture was pulled out through the same site with H-hook and cut. In all patients in the IOL exchange group, a new secondary IOL was chosen as Model MN60AC (Alcon Laboratories, Inc.), which is a foldable 3-piece acrylic IOL. Knots were buried under the scleral flaps. The corneal incision site was sutured using 10-0 ETHILON and conjunctival suture was made with 8-0 vicryl.

2.3. Main Outcome Measures. All patients underwent a comprehensive ophthalmological examination on their scheduled

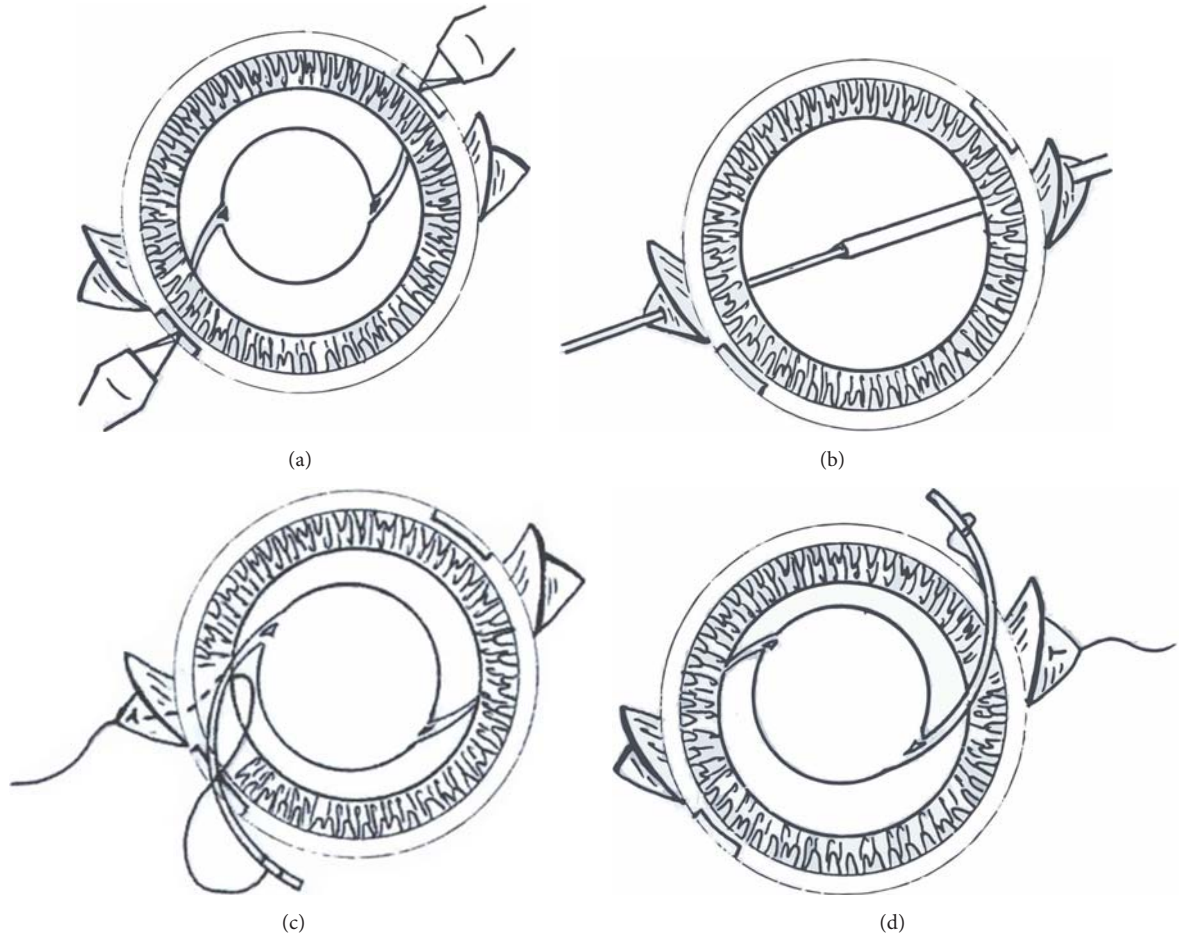

Figure 1: Drawing images of in situ refixation technique. (a) Bilimbal incision was made on the nearest axis of the dislocated haptics. (b) The suture needle was inserted under the two triangular partial thickness sclera flaps. (c) One haptics was externalized through the limbal incision and one of the cut suture thread ends was tied to the haptics. (d) The other haptics was tied with the same procedure to that in (c).

follow-up date. The following parameters were included before and after surgery: age, gender, BCVA, intraocular pressure (IOP), endothelial cell density, and spherical equivalent as determined by biometry using an autorefractometer (Topcon, KR-8800, autokeratorefractometer, Tokyo, Japan) and IOL master (Carl Zeiss Meditec, Jena, Germany). Surgically induced astigmatism (SIA) and surgical complications were also assessed. Potential postoperative complications included marked IOP elevation higher than 25 mmHg, corneal decompensation, IOL redislocation or capture, suture knot exposure, cystoids macular edema (CME), vitreous hemorrhage, retinal break or detachment, and endophthalmitis. Visual acuities were measured with Snellen's chart, and values were converted to the logarithm of the minimum angle of resolution (logMAR). SIA was calculated by the astigmatic vector analysis [13, 14]. Corneal endothelial cell density (cells/mm^2) was inspected in central corneal endothelial cells with a noncontact specular microscope (Topcon Corp., SP-3000P, Japan), and analyzed by manual check of the automatic analysis software before the operation and 3 months after the operation. Macular optical coherence tomography (OCT) (Carl Zeiss Meditec, Dublin, CA) was performed in the case of the presence of metamorphopsia or reduced BCVA during the follow-up. All patients in this study underwent PPV or AV before the sclera fixation of IOL. Undergoing PPV may influence the surgical outcomes and induce the difference among patients so the subjects were also classified into two groups according to the surgical option of vitreous management. The PPV group included patients with sclera fixation of IOL who underwent full vitrectomy, and the AV group comprised patients with sclera fixation of IOL who underwent AV only.

Statistical analysis was performed using SPSS software version 18.0 (SPSS, Inc., Chicago, IL, USA). The relationship between the IOL exchange and IOL refixation groups was compared using Student's t-test. Preoperative and postoperative parameters were compared using paired t-test. The distributions for variables were expressed as mean ± standard deviation. Statistical significance was defined as p value < 0.05 for all tests.

Table 1: Demographic characteristics of patients with IOL exchange and IOL refixation groups.

	IOL exchange	IOL refixation
Number of patients (eyes)	17 (17)	17 (17)
Age (years)	56.92 ± 11.36	63.65 ± 9.93
Gender (male/female)	12/5	17/0
Right/left	7/10	9/8
Axial length (mm)	24.20 ± 1.43	24.29 ± 1.84

Table 2: Presumed causes of IOL dislocation.

	IOL exchange	IOL refixation
Eye trauma	2 (12%)	2 (12%)
Pseudoexfoliation syndrome	2 (12%)	1 (6%)
Nd:YAG capsulotomy	2 (12%)	1 (6%)
Inadequate capsular/zonular support	2 (12%)	2 (12%)
Unknown	9 (52%)	11 (64%)

3. Results

3.1. Patients Demographics. In total, 34 eyes of 34 patients were included in this study. The subjects included 29 men and 5 women, ranging in the age from 40 to 79 years. The mean postoperative follow-up was 8.3 months (range: 6–12 months). Of 34 eyes, 17 eyes (50%) were assigned to the IOL exchange group and 17 eyes (50%) were assigned to the IOL refixation group. Table 1 summarized the demographic characteristics of the patients. There was no significant difference in terms of preoperative age, axial length, and postoperative follow-up duration between the two groups. The cause of IOL dislocation seemed to be eye trauma in four eyes, pseudoexfoliation syndrome in three eyes, inadequate capsular support after neodymium:yttrium-aluminum-garnet (Nd:YAG) capsulotomy in three eyes, inadequate capsular or zonular support in the absence of Nd:YAG capsulotomy in four eyes, and unknown cause in 20 eyes. These data are shown in Table 2. The preoperative underlying ocular diseases in the IOL exchange group were previous rhegmatogenous retinal detachment in 3 eyes (2 eyes underwent PPV and 1 eye underwent segmental scleral buckle procedure) and diabetic retinopathy in 2 eyes. The IOL refixation group included 1 vitrectomized eye owing to previous retinal detachment, 1 eye with diabetic retinopathy, and 1 eye with previous branch retinal vein occlusion history.

3.2. Visual Outcomes. Visual outcomes and SIA are presented in Table 3. Mean BCVA (logMAR) significantly improved from 0.35 ± 0.24 preoperatively to 0.11 ± 0.08 postoperatively at 3 months in the IOL exchange group and from 0.31 ± 0.20 preoperatively to 0.10 ± 0.08 postoperatively in the IOL refixation group ($p < 0.001$, for both groups). However, both preoperative and postoperative visual results were similar between the eyes that underwent IOL exchange and the eyes that underwent IOL refixation ($p = 0.613$ and $p = 0.790$, resp.). No statistically significant difference was found between BCVA at 3 months and BCVA at 6 months (0.10 ± 0.03) ($p = 0.096$) in IOL exchange group and IOL refixation group (0.10 ± 0.05) ($p = 0.065$). Notably, the IOL refixation group exhibited significantly less SIA (0.79 ± 0.41) compared to the IOL exchange group (1.29±0.46) 3 months after surgery ($p = 0.004$). This significant difference in SIA persisted to 6 months (1.13±0.18 in the IOL exchange group and 0.74±0.11 in the refixation group; $p = 0.006$).

Table 3: Visual outcomes and SIA after scleral fixation of IOL.

	IOL exchange	IOL refixation	p
Preoperative BCVA, logMAR	0.35 ± 0.24	0.31 ± 0.20	0.613
Postoperative 3-month BCVA, logMAR	0.11 ± 0.08	0.10 ± 0.08	0.790
SIA at 3 months	1.29 ± 0.46	0.79 ± 0.41	0.004
SIA at 6 months	1.13 ± 0.18	0.74 ± 0.11	0.006

SIA: surgically induced astigmatism; IOL: intraocular lens; BCVA: best corrected visual acuity.

In the IOL exchange group, the mean spherical equivalent (diopter) changed from 2.34 ± 6.84 to −0.73 ± 1.29 ($p = 0.083$), while, in the IOL refixation group, the parameter significantly improved from 2.80 ± 5.97 to −1.18 ± 0.96 ($p = 0.02$). The preoperative and postoperative mean spherical equivalents were similar between the two groups ($p = 0.842$ and $p = 0.271$, resp.).

We also analyzed visual outcomes of the two groups classified according to the surgical method of vitreous management: PPV or AV. Mean preoperative BCVA (logMAR) were 0.42 ± 0.63 in PPV group and 0.33 ± 0.30 in AV group ($p = 0.56$). Mean postoperative BCVA (logMAR) were also similar between the PPV group (0.21±0.21) and the AV group (0.10 ± 0.14) ($p = 0.08$).

3.3. Safety Outcomes. Both groups showed a significant decrease in postoperative endothelial cell density compared to the density before surgery ($p = 0.003$ in the IOL exchange group and $p = 0.015$ in the IOL refixation group, resp.). However, no significant between-group difference was found before surgery ($p = 0.232$) and at 6 months after surgery ($p = 0.612$) (Table 4). IOP elevation over 25 mmHg occurred in 2 out of 34 eyes (5.9%) from the first day after surgery. Elevated IOP was well controlled with antiglaucoma topical medication, and IOP was maintained within the normal range at the final visit time. Furthermore, the two groups showed reduction of IOP from 17.1 ± 4.7 preoperatively to 16.5 ± 2.8 postoperatively in the IOL exchange group and from 16.0 ± 3.3 preoperatively to 14.8 ± 3.0 postoperatively in the IOL refixation group. The between-group difference was not statistically significant before surgery ($p = 0.747$) and after surgery ($p = 0.230$). In addition, the IOP reduction was not significantly different between the two groups ($p = 0.421$ and $p = 0.163$, resp.) (Table 5). Intraoperative complications were not observed in either group. Postoperative complications developed in 3 eyes (retinal break, transient vitreous hemorrhage, IOP elevation) that underwent IOL exchange and 2 eyes (pupillary optic capture of IOL, IOP elevation) that

Table 4: Comparison of endothelial cell density between the IOL exchange and IOL refixation group before and after surgery.

	IOL exchange	IOL refixation	p
Before operation	2070.4 ± 458.8	1778.5 ± 775.6	0.232
Postoperative 6 months	1805.9 ± 426.5	1689.6 ± 685.7	0.612
p	0.003	0.015	

IOL: intraocular lens.

Table 5: Comparison of IOP between the IOL exchange and IOL refixation group before and after surgery.

	IOL exchange	IOL refixation	p
Before operation	17.1 ± 4.7	16.0 ± 3.3	0.747
Postoperative 6 months	16.5 ± 2.8	14.8 ± 3.0	0.230
p	0.421	0.163	

IOP: intraocular pressure; IOL: intraocular lens.

underwent IOL refixation. One retinal break case was treated with laser photocoagulation and had no further complication. One case of vitreous hemorrhage developed in the IOL exchange group, but it was transient and resolved at the final visit without needing additional vitreous surgery. Pupillary optic capture of IOL developed in one eye that underwent IOL refixation. After pupil dilatation, the patient remained in a supine position and optic capture resolved spontaneously. The patient did not need any further procedure. Other postoperative complications, such as redislocation of IOL, CME, retinal detachment, hypotony, secondary glaucoma, and infective endophthalmitis, were not observed.

4. Discussion

In our retrospective study, the results showed that the in situ refixation technique had less SIA than IOL exchange at 3 months and it persisted at 6-month postoperative follow-up time. The IOL exchange method requires a larger corneal incision to remove dislocated IOL, but the in situ refixation technique minimized the cornea incision size.

Therapeutic options were typically decided based on the clinical features of individual cases. A variety of methods for managing dislocated IOL have been reported, including observation, IOL exchange, and IOL refixation [5–11]. Several comparative clinical studies have been reported, but relatively few studies have considered postoperative outcomes, particularly in terms of SIA after IOL scleral fixation surgery. Theoretically, IOL refixation is the optimal surgical option because it is less traumatic than extracting the dislocated IOL and it provides structural stability [8]. In the IOL exchange technique, extraction of the dislocated IOL with an open-system method carries the risk of ocular structural damage, vitreous prolapse, hypotony, and corneal astigmatism induced by a large corneal wound [11]. Therefore, IOL refixation using a closed-eye method is a more preferred surgical technique if it can be performed with intact haptics [6]. Oh et al. [15] reported that there was no significant difference in SIA between IOL exchange and IOL refixation groups despite the considerable SIA by corneal incision performed during surgery in the IOL exchange group. However, our study showed significantly less SIA in the IOL refixation group at postoperative 6 months. Bilimbal incision for haptic externalization might have an impact on lowering SIA when compared to the sutureless IOL fixation method of the previous study [15].

Notably, the most common postoperative complication was a significant decrease in endothelial cell density in both the IOL exchange and the IOL refixation groups. Wang et al. [16] reported that corneal endothelial cell density decreased remarkably after IOL exchange or refixation surgery without a significant difference in the decrease between the two groups. We initially predicted that the IOL refixation group would have less decrease in endothelial cell density than the IOL exchange group because the smaller incision would cause less trauma to the corneal endothelium. However, all patients in the two groups underwent scleral fixation and the loss of endothelial cell density might be attributable to this increased surgical manipulation. Similar to the previous studies, our results showed significantly decreased endothelial cell density in both groups, but there was no statistically significant difference between the two groups.

There was 1 case of IOP elevation in each group during the follow-up period. Increased IOP occurred in 5.9% of the patients who underwent IOL exchange and IOL refixation, respectively, which is a relatively lower incidence compared to the previous studies [9, 17]. Although we excluded patients with preexisting glaucoma in this study, the reason for a lower incidence of IOP elevation remains to be explained. IOP increase in two patients was well managed with IOP-lowering medication within 1 month after surgery, so IOP elevation may not affect the final functional outcome in the long term. During the follow-up time, both groups showed slight decrease of mean IOP at final visit compared to preoperative values. There was no patient who presented hypotony or sclerotomy site leakage. Although the magnitude of IOP reduction was not statistically significant either IOL exchange or IOL refixation group, the reason for IOP lowering effect after surgery should be further studied for a longer period. The IOL refixation group had 1 case of pupillary optic capture of IOL, and it was spontaneously resolved with pupil dilatation and position change. Moreover, 1 case of postoperative retinal break and transient vitreous hemorrhage occurred in the IOL exchange group. Sclerally fixated IOL implantation in the posterior capsule carries the risk of vitreous hemorrhage and retinal breaks with consequent retinal detachment [5]. In spite of these postoperative vitreoretinal complications, several studies have reported acceptable safety for the procedure [18]. In our study, retinal break was readily treated with laser photocoagulation. Vitreous hemorrhage was resolved with conservative treatment and did not require additional retinal surgery. Bellamy has reported that 22% of eyes that underwent PPV with IOL removal and exchange to open loop anterior chamber IOL presented CME [19]. In this study, no patient presented CME during follow-up period. Minimal incision and careful manipulating IOL while extracting it through incision site, especially avoiding contact with uvea, might induce this result. Suture-related complications, such as knot exposure, suture degradation or breakage, and IOL

decentration or tilting were not found in either the IOL exchange or the refixation group. A significantly improved final mean BCVA was achieved in both groups, but the between-group difference was not statistically significant.

Surgical techniques should be selected based on the ophthalmological features of individual patients with regard to the status of the dislocated IOL, adequate capsular support, and concurrent ocular complications. In this study, the most important factor for consideration was the status of the dislocated IOL, such as damaged or highly flexible haptics that were unsuitable for adequate suture support and the size and material of optics. The postoperative results showed that the IOL refixation group had a lower magnitude of SIA than the IOL exchange group. Although IOL exchange technique has the advantage of being useful no matter the type of IOL and degree of dislocation, it necessarily leads to a large corneal incision and SIA [20]. Removal of the dislocated IOL through a large corneal incision site is also accompanied by the possibility of vitreous prolapse, cornea endothelium and iris damage, hypotony, and retinal damage, such as retinal break or retinal detachment [21, 22]. In contrast, IOL refixation has the advantage of leading to relatively less SIA than IOL exchange, owing to the small incision size maintaining structural stability. However, this surgical technique has limited indication because it can only be conducted in case of intact haptics with adequate suture support. This technique has disadvantage for the difficulty in manipulating the haptics while extracting it through bilimbal incision site. IOL refixation includes scleral sutured PCIOL procedure so it also has comparable potential complication like other sclera refixation, such as IOL redislocation or capture, suture breakage or suture knot exposure, vitreous hemorrhage, and CME. Smiddy et al. [8, 23] previously reported that refixation of dislocated IOL into the ciliary sulcus using residual capsule for support is the most commonly used surgical technique. This nonsuturing technique is the least traumatic to the ocular structure compared to fixating the IOL into the sclera by suture because it avoids excessive surgical manipulation. However, it can be performed for selected patients who have adequate residual peripheral capsular support. In patients with a lack of suitable capsular support, scleral suture fixation of an IOL is a good alternative surgical option [24]. Numerous methods are currently used for transscleral fixation of IOLs and each technique has its advantages and drawbacks. Hoffman et al. [25] reported modified sclera fixation technique using a sclera pocket through a clear corneal incision which avoids the need for conjunctival dissection or sclera cautery. Scharioth et al. [26] reported sutureless intrascleral PCIOL fixation technique using a limbus-parallel tunnel of 50% sclera thickness starting from the ciliary sulcus sclerotomies without the need for suturing procedures. Previously reported studies have disadvantages for potential complications of suture erosion, suture-knot exposure, and recurrent dislocation. Despite a variety of surgical techniques for managing dislocated IOLs, a definitive surgical technique for dislocated IOL rescue has not yet been suggested. The surgical option is generally decided based on a surgeon's best judgment given an individual patient's characteristics, and it usually provides significantly improved visual acuity without serious irreparable postoperative complications.

In this study, we also reorganized the patients into two groups according to the surgical method of vitreous management as PPV group and AV group. A previous study [10] reported similar degree of visual improvement in patients who underwent sclera fixation of PCIOL with PPV or AV. This study represents comparable visual outcomes between two groups which is consistent with previous study.

Limitations of this study include analyses from retrospective design and small number of cases (34 eyes) with relatively short follow-up periods (6 months). This study includes lack of measurements with evaluating astigmatism using corneal topography or Scheimpflug imaging. Furthermore, we did not consider the effect of PPV except for preoperative and postoperative BCVA. Previous studies have reported that the performance of a combined PPV has an impact on a more complicated condition [27]. Future studies with larger scales in patients and longer follow-up with evaluating SIA from various methods are highly recommended to confirm true statistical significant difference.

In conclusion, in situ IOL refixation is a beneficial surgical technique in IOL dislocation, producing less SIA compared to IOL exchange with scleral fixation. The two groups had similar results for BCVA, IOP, endothelial cell density, and postoperative complications, with no significant difference at the final follow-up visit. Therefore, IOL refixation technique can be the preferred surgical option because it provides early visual rehabilitation in patient with a dislocated IOL but no damage in haptics. In situ IOL refixation for managing IOL dislocation can produce significantly increased BCVA with less SIA than IOL exchange.

Competing Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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Research Article

Dealings between Cataract and Retinal Reattachment Surgery in PVR

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Introduction. To evaluate the impact of the eye lens status and oil side effects on the outcome of vitreoretinal surgery in retinal detachment with proliferative vitreoretinopathy (PVR) and a temporary silicone oil tamponade (SOT). *Methods*. 101 eyes were analyzed retrospectively and 103 eyes prospectively in regard to their retinal reattachment success rate and key factors for the outcome. Subgroup analysis of 27 eyes with Scheimpflug lens photography (SLP) before and after retinal reattachment service with SOT was performed. For SLP (65% phakic eyes) a Pentacam densitometry reference body with 3 mm diameter was chosen and 3 segments (anterior/mid/posterior) were evaluated separately after a quality check. *Results*. The retinal reattachment rate was highest in the prospective pseudophakic group ($p = 0.039$). Lens transparency loss occurred earlier in middle aged patients than in younger patients. Besides the nucleus, layers posterior and anterior to it showed specific transparency changes. The emulsification rate was higher when eyes had been operated on in the anterior chamber before retinal reattachment service. *Conclusions*. Retinal reattachment surgery seems to benefit from preoperative cataract removal. We found significant lens changes in the nucleus as well as in the layers anterior and posterior to it. This corresponds to the histology of the lens epithelium published before.

1. Introduction

In retinal detachment surgery considerations for the optimal surgical procedure include vitreous substitutes as well as lens aspects: gases or silicone oils are important tools in vitreoretinal surgery because they have the ability to displace aqueous humor from the retinal surface while maintaining the adhesion between retina and retinal pigment epithelium. At the same time, the increase of oxygen concentration after removal of a significant portion of vitreous accelerates lens transparency losses. Several questions are raised upon this complex chapter in ophthalmology: Should younger patients be operated on externally, for example, using buckling technology to seal a retinal hole [1–4]? Is the pneumatic retinopexy procedure justified in spite of a lower primary success rate, because there is a significantly lower rate of lens transparency loss [5]? What kind of impact does pars plana vitrectomy have on the aging process of the patients lens and what is the best choice between different gases and silicone oils [6–9]?

Do lenses primarily have to be removed once there is pathology associated with a retinal detachment, for example, an anterior hyaloid fibrovascular proliferation process, which handicaps the surgeon in removing membranes in the outermost periphery of the vitreous cavity?

It is probably too much simplified but still justified to summarize the current attitude of many specialists in the community: they prefer to save the lens in younger patients, especially where a clearly defined single hole or a group of holes easily accessible with an external buckle could encourage us to stay outside the vitreous or choose a pneumatic retinopexy strategy to seal single breaks in the upper part of the eye. However, when condensed vitreous

is obviously pulling up the retina in many places especially when mixed up with blood and pigment cells and when holes cannot be clearly defined or excluded, this should lead us to immediate intraocular intervention with careful pars plana vitrectomy as complete as possible often combined with or following cataract surgery.

The complexity of the pathology will drive our decision on how to substitute the vitreous with either a special physiologic formula of water (e.g., balanced salt solution), air, several expanding gases, or even several silicone oils.

Because oils can be used as a temporary, prolonged, or even permanent tamponade, it seems to be suitable especially for the management of complicated retinal detachment due to PVR or viral retinitis, giant retinal tears, trauma, and severe proliferative diabetic retinopathy [10, 11], retinal detachment due to a macular hole in highly myopic eye [12, 13], chronic and persistent macular holes, colobomatous retinal detachment [14], and chronic uveitis with hypotony [15]. In all these cases we are still seeking for more knowledge about the best timing for cataract surgery since lenses might be a helpful diaphragm between posterior and anterior chambers, an obstacle for adequate observation, or "just in the way," hindering the surgeon to complete the PPV if needed.

2. Material and Methods

2.1. Study Population. In an extensive retrospective and prospective study set-up ($n = 204$ completed data sets) we analyzed eyes suffering from a retinal detachment with P(D)VR in regard to their retinal reattachment success rate and key factors for the outcome. The main goal was to lower the retinal redetachment rate. Other goals included gathering information about the lens status and its role in the outcome of retinal reattachment service and analyzing whether and how silicone oil emulsification over a 4-month fill according to the algorithm [16–18] of our standard operation procedure (SOP) affected the outcome.

The study was approved by the ethical review committee of the University of Frankfurt/M (IRB decision number E 190/11, transaction number 403/11). The ethical review committee also approved the written participant consent, which was provided by all participants.

This study was conducted in accordance with the Tenets of the Declaration of Helsinki. Patients' records were pseudonymized and deidentified prior to statistical analysis.

2.2. Changes in Lens Density. Retrospectively, 28.71% of the patients were pseudophakic from the beginning, cataract surgery was provided simultaneously with the oil fill in 7.92% or with the oil removal in 34.65%, and in 23.76% of eyes cataract surgery was provided later on.

Prospectively, 39.81% of pseudophakic patients were included, 2.91% of the patients were operated on simultaneously with the oil fill and 39.81% with the oil removal. 14.56% of the patients stayed phakic. The primary phakic patients received Scheimpflug lens photography (SLP) before and after retinal reattachment service with SOT.

To measure changes of lens densities (densitometry) prospectively we used the Pentacam HR Scheimpflug anterior segment imaging system (Oculus Optikgeräte GmbH) Version 1.20b67 [19–21]. It is a noninvasive device; no contact with the eye is necessary. When we measured lenses with a Scheimpflug camera, our measurements followed a geometric principle based on the "non-parallel-to-each-other" orientation of lens and image planes. In the consequence, targets in different distances to a camera will all be captured in focus and distortion-free which plays an important role in ophthalmology for selective measurement especially on the cornea and on the lens. The eyes had to be dilated at least 5 mm to stay in the study group. Primarily, we had 62 phakic patients, who were included in the prospective part of the retinal detachment study. Before the statistical analysis we checked the data for plausibility: quality and completeness of data sets (pre- and postoperative examinations). For quality check only pictures that met the quality specification of the Pentacam imaging system (e.g., no blinking or hazy cornea) were included for analysis. After the quality checks, 27 eyes stayed in the final analysis. The reference body was centered to the corneal apex with a diameter of 3 mm to analyze the lens densitometry average value with a 3D model for the whole lens as well as for the 3 lens segments (anterior/mid/posterior) separately as explained below.

To detect potentially age-related lens changes, we grouped the eyes into group 1 (1940s, 66–75 years old), group 2 (1950s, 56–65 years old), group 3 (1960s, 46–55 years old), and group 4 (≥1970s, 25–45 years old).

If the patient got examined several times a day, we always used the same scheme: we took the first measurement for analysis. Only if this measurement did not meet the quality specifications would we take the following one.

To calculate the reference bodies, all examinations were opened and we manually measured the lens thickness in 0° and 90° section.

After this, we took the mean value of these measurements for the four cohorts. Here we recognized that there were no differences between the 1940s to 1960s age groups. So for these three groups a reference body of a diameter of 3.0 mm, a height of 1.6 mm, and a mean lens thickness of 4.23 mm was built. This reference body was used to analyse the lens densitometry for the anterior, center, and posterior segments of the lens (Figure 1). The overlap between the reference bodies constituted 0.2 mm.

For the youngest group we measured thinner lenses, so that we calculated a reference body of 3.0 mm in diameter, 1.4 mm in height, and 3.76 mm in mean lens thickness. The analysis of the lens densitometry was analogous to the other groups explained above.

2.3. Silicone Oil Emulsification. In the retrospective study, 80 eyes out of 101 had been filled with 5000 mPa·s (millipascal seconds) oil, 4 eyes with 4300 mPa·s oil, and 13 eyes with 2000 mPa·s oil and in 4 eyes we had no definite specification. In the prospective study we used 5000 mPa·s oil in 69 eyes, 4300 mPa·s oil in 6 eyes, and 2000 mPa·s oil in 28 eyes. From 19 eyes, silicone oils with different viscosities and peculiar appearances during the f/u were sent to a lab (alamedics GmbH & Co. KG, Dornstadt, Germany) to analyze the different severity of emulsification microscopically. The results

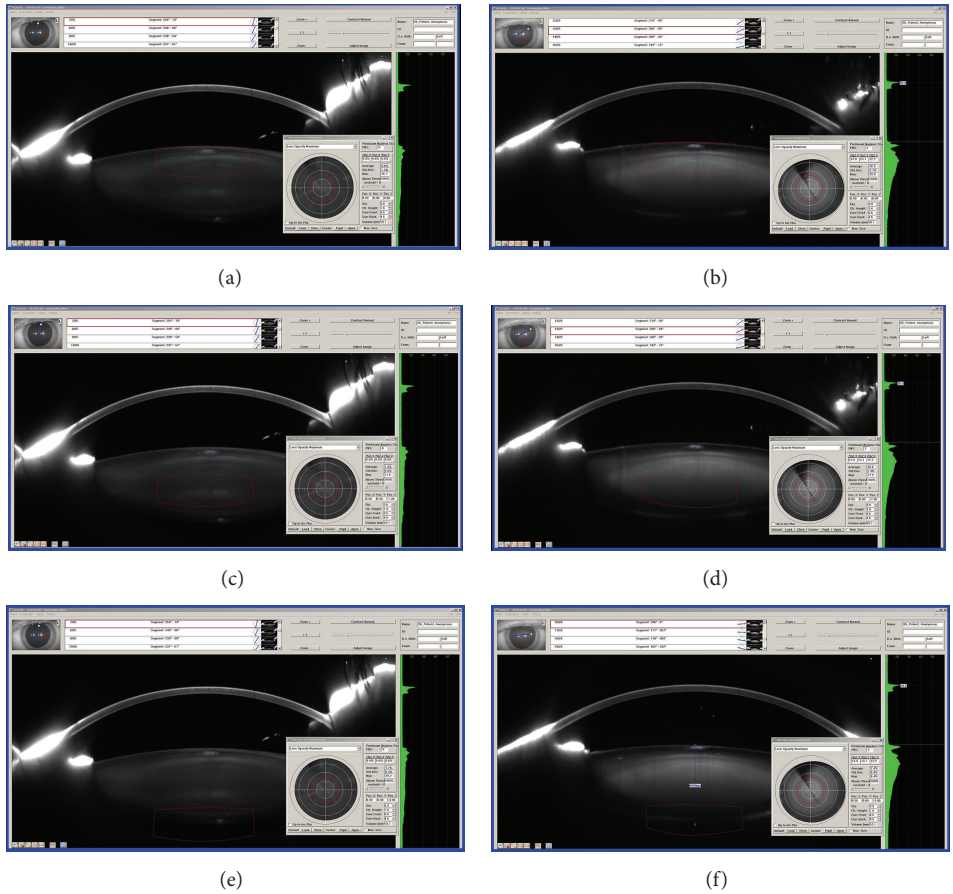

FIGURE 1: Patient sample of group 3. Three-dimensional lens densitometry before/after vitreoretinal surgery with preliminary silicone oil fill, measurements in three segments: upper line: pre-op. (left), anterior segment, post-op. (right); middle line: pre-op. (left), nucleus, post-op. (right); lower line: pre-op. (left), posterior segment, post-op. (right). Red cylinder: reference body for the three segments. Blue circle: light scattering artefact eliminated from densitometry calculations.

were compared to various patient-specific factors to point out the critical ones.

Oil samples were placed immediately after oil removal on a silanized stage. A second, thinner stage was placed in a distance of 0.25 mm to create a chamber with a defined height/volume. The emulsification bubbles were counted and images were taken to allow a software to determine size and number of the bubbles per square centimeter. The results were categorized and evaluated [18].

2.4. Data Pool and Statistical Methods. All the analyses were performed using BiAS V10.12 [22] for Windows. $p \leq 0.05$ was considered to indicate a statistically significant difference.

To compare the retinal redetachment rate in the prospective group with the one in the retrospective group we applied a two-tailed binomial test.

Out of 62 cases, 27 cases could meet the quality requirements of the Pentacam imaging system.

Because a standardized normal (Gaussian) distribution of parameters was not guaranteed in all groups after performing a Kolmogorov-Smirnov test, we chose a Wilcoxon matched-pairs test (with exact p value) for statistical evaluation of pre- and postoperative lens density. The Rosenthal effect size [23] was used regarding the clinical relevance; therefore 0.1 is seen as a small, 0.3 as a medium, and 0.5 as a large effect.

For proof of significance in lens maturation during silicone oil fill between the different age groups, a Kruskal-Wallis test with multiple Conover-Iman comparisons (Bonferroni-Holm-corrected) was performed. Additionally, for better illustration, we performed linear regression after Pearson to show the relation between patients' age and the influence of silicone oil on lens density increase.

To evaluate the influence of lens status and the interferences with the silicone oil for the prospective group, the Fisher-Freeman-Halton Exact Test for contingency tables with Valz and Thompson's algorithm was performed.

3. Results

3.1. Lens Status and Retinal Reattachment Success Rate. From 204 eyes, 101 were followed up retrospectively with 65 eyes staying stable after the oil removal with a redetachment rate of 35,64%. After having designed [16, 17] a standard operation protocol (SOP) and an evaluation protocol (EVALP), 103 eyes were followed up prospectively with 96 eyes staying permanently attached with a significantly reduced redetachment rate of 6,8% ($p = 0.002$).

Table 1: Patient's demographic and baseline characteristics for the subgroup on which Scheimpflug photography was performed and could be analyzed after quality check.

	Group 1	Group 2	Group 3	Group 4
Number of eyes/patients	6	9	7	5
Age group	1940–49	1950–59	1960–69	≥1970
Age (yrs), mean ± SD	69.5 ± 2.93	62 ± 3.11	51 ± 3.24	36 ± 7.46
Gender, number (%)				
Male	3 (50.0)	3 (33.3)	5 (71.4)	1 (20.0)
Female	3 (50.0)	6 (66.7)	2 (28.6)	4 (80.0)
Eye, number (%)				
Right	6 (100.0)	4 (44.4)	6 (85.7)	4 (80.0)
Left	0 (0.0)	5 (55.6)	1 (14.3)	1 (20.0)
Axial length (%)				
Emmetropic	3 (50.0)	3 (33.3)	1 (14.3)	2 (40.0)
Myopic	3 (50.0)	6 (66.7)	6 (85.7)	3 (60.0)
Hyperopic	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
BCVA preop. (decimal)				
Mean ± SD	0.35 ± 0.33	0.1 ± 0.23	0.43 ± 0.39	0.04 ± 0.12
Range	0.0010–0.8	0.0010–0.6	0.0286–0.7	0.0010–0.3
BCVA postop. (decimal)				
Mean ± SD	0.25 ± 0.09	0.2 ± 0.11	0.07 ± 0.14	0.05 ± 0.16
Range	0.2–0.4	0.0010–0.25	0.0010–0.32	0.0010–0.4
Cataract surgery (%)				
Revision surgery	6 (100.0)	7 (77.8)	3 (42.9)	1 (20.0)
In the course	0 (0.0)	2 (22.2)	4 (57.1)	4 (80.0)
PVR stage (%)				
AB/A	1 (16.7)	3 (33.3)	4 (57.1)	0 (0.0)
C1/B	3 (50.0)	0 (0.0)	2 (28.6)	0 (0.0)
C2/C1	1 (16.7)	4 (44.4)	0 (0.0)	2 (40.0)
C3/C2	1 (16.7)	0 (0.0)	0 (0.0)	3 (60.0)
D1/C3	0	0 (0.0)	0 (0.0)	0 (0.0)
D2, D3/D1	0	2 (22.2)	1 (14.3)	0 (0.0)
Preop. fovea situation (%)				
Attached	3 (50.0)	3 (33.3)	2 (28.6)	2 (40.0)
Washed up	2 (33.3)	0 (0.0)	3 (42.9)	0 (0.0)
Detached	1 (16.7)	6 (66.7)	2 (28.6)	3 (60.0)

The retinal reattachment rate was highest in the prospective pseudophakic group with a p value of 0.039.

3.2. Effect of Silicone Oil on Lens Maturation. As mentioned above, by calculating the reference bodies for the lens densitometry, we could detect that there was no difference in the mean value of lens thickness between the 1940s to 1960s age groups. Only for the youngest group (≥1970) we measured thinner lenses, so that we adapted the reference body. The patients' demographic data and the baseline characteristics of these four age groups, which could be finally analyzed by Scheimpflug, are listed in Table 1.

After testing the statistical significance of the lens densitometry values before and after silicone oil fill for the four age groups, all except the youngest group showed significant effects of lens maturation ($p \leq 0.05$) with the reference body aligned through the whole lens (Table 2). We saw that the "middle aged" groups (group 2 and group 3) had the strongest maturation.

Group 3 had a significant lens maturation in all parts of the lens during the silicone oil fill. Group 2 had a highly significant maturation in the anterior and center part of the lens ($p = 0.004$). Only the posterior part was not significantly affected in group 2 ($p = 0.375$). The oldest group (group 1) reacted less compared to the "middle aged" groups. Regarding the different segments of the lens, the strongest effect was seen in the anterior part of the lens ($p = 0.094$). A potential explanation for this is that older patients (group 1) already had a more pronounced cataract before the silicone oil fill as shown in Table 2.

In contrast to the three older age groups, the youngest group is the only one who had no significance either for the whole reference body ($p = 0.313$) or for the anterior ($p = 0.500$), center ($p = 0.438$), or posterior ($p = 0.250$)

Table 2: Change in lens densitometry.

	Group 1	Group 2	Group 3	Group 4
Reference body whole lens (%)				
Preoperative mean	9.5	8.7	8.1	7.8
Preoperative range	9.1–10.3	8.2–9.5	7.7–8.7	7.5–8.1
Mean 4 months after silicone oil fill	10.85	11.4	11.7	8.0
Range 4 months after silicone oil fill	10.2–11.7	9.4–13.4	8.2–13.4	7.6–9.0
p value	0.031	0.004	0.031	0.313
Effect size	0.637	0.628	0.587	0.384
Reference body anterior (%)				
Preoperative mean	10.6	9.2	8.5	7.8
Preoperative range	10.0–12.1	8.8–10.2	7.9–9.6	7.5–8.4
Mean 4 months after silicone oil fill	11.7	10.2–12	11.4	8.0
Range 4 months after silicone oil fill	10.9–13.6	9.4–13.3	8.1–16.5	7.5–9.9
p value	0.094	0.004	0.031	0.500
Effect size	0.514	0.628	0.636	0.436
Reference body center (%)				
Preoperative mean	8.6	8.1	7.3	7.2
Preoperative range	8.0–10.5	7.7–10.7	7.2–7.8	7.1–7.7
Mean 4 months after silicone oil fill	9.8	11.0	11.7	7.5
Range 4 months after silicone oil fill	7.8–11.7	8.1–17.0	7.9–16.3	7.1–9.3
p value	0.156	0.004	0.016	0.438
Effect size	0.455	0.628	0.633	0.343
Reference body posterior (%)				
Preoperative mean	7.4	7.4	7.1	7.4
Preoperative range	7.2–7.6	7.2–8.3	7.1–7.6	7.2–7.5
Mean 4 months after silicone oil fill	7.2	7.4	7.7	7.6
Range 4 months after silicone oil fill	7.1–7.6	7.2–9.7	7.1–9.3	7.5–8.0
p value	0.625	0.375	0.031	0.250
Effect size	0.258	0.294	0.636	0.655

Statistical analysis: Wilcoxon matched-pairs test with exact p value. Effect size: $r = Z/\mathrm{sqr}(2 * n')$: Rosenthal: 0.1, "small effect," 0.3, "medium effect," and 0.5, "large effect."

reference body. The strongest effect (not significant) was seen in the posterior part for the young patients.

To confirm our finding that the "middle aged" groups had the strongest maturation effect because of silicone oil, we used the Kruskal-Wallis test [24] together with the Conover-Iman test of multiple comparisons (Bonferroni-Holm-corrected).

Considering the Kruskal-Wallis test first, there was a statistically significant effect between the different age groups for the whole ($p = 0.017$), anterior ($p = 0.015$), and center part ($p = 0.009$) of the lens.

Only for the posterior part, no significance ($p = 0.080$) could be found between the four cohorts.

Regarding the Conover-Iman test of multiple comparisons, for the whole reference body as well as for the center part, we could find a statistically significant difference in maturation between group 2 versus group 3 and group 2 versus group 4 but not between group 1 and group 4. That confirms our theory that the biggest maturation can be seen in the "middle aged" groups. The increase of lens density in the anterior part of the lens was significant in groups 2 ($p = 0.012$) and 3 ($p = 0.050$) and also in the oldest group 1 ($p = 0.012$) versus the youngest group 4.

3.3. Lens Densitometry in Different Lens Zones. For better illustration of the results in the different age groups, the specific changes in the different layers are plotted against the age in Figures 2(a)–2(d).

You can see that the age distribution is not a linear function, since the transparency loss increases from group 4 (youngest) to groups 3 and 2 but slows down in group 1 (oldest) as approved by the Kruskal-Wallis test above.

3.4. Lab Analysis of Silicone Oils. In general, the 5000 and 4300 mPa·s silicone oils proved to be more stable than the 2000 mPa·s silicone oils without showing any significance onto the outcome of retinal reattachments, visual acuity, or visual function [18].

In the lab we analyzed ten 4300 mPa·s oils, seven 5000 mPa·s oils, and two 2000 mPa·s oils after silicone oil removal. We could not find a significant difference in the severity of emulsification droplets ($p = 0.677$).

Seven of 19 eyes, where the silicone oil could be lab analyzed after removal, had no preceding surgery in the anterior chamber. In 12 eyes surgery in the anterior chamber before detachment, the surgery seemed to increase the degree

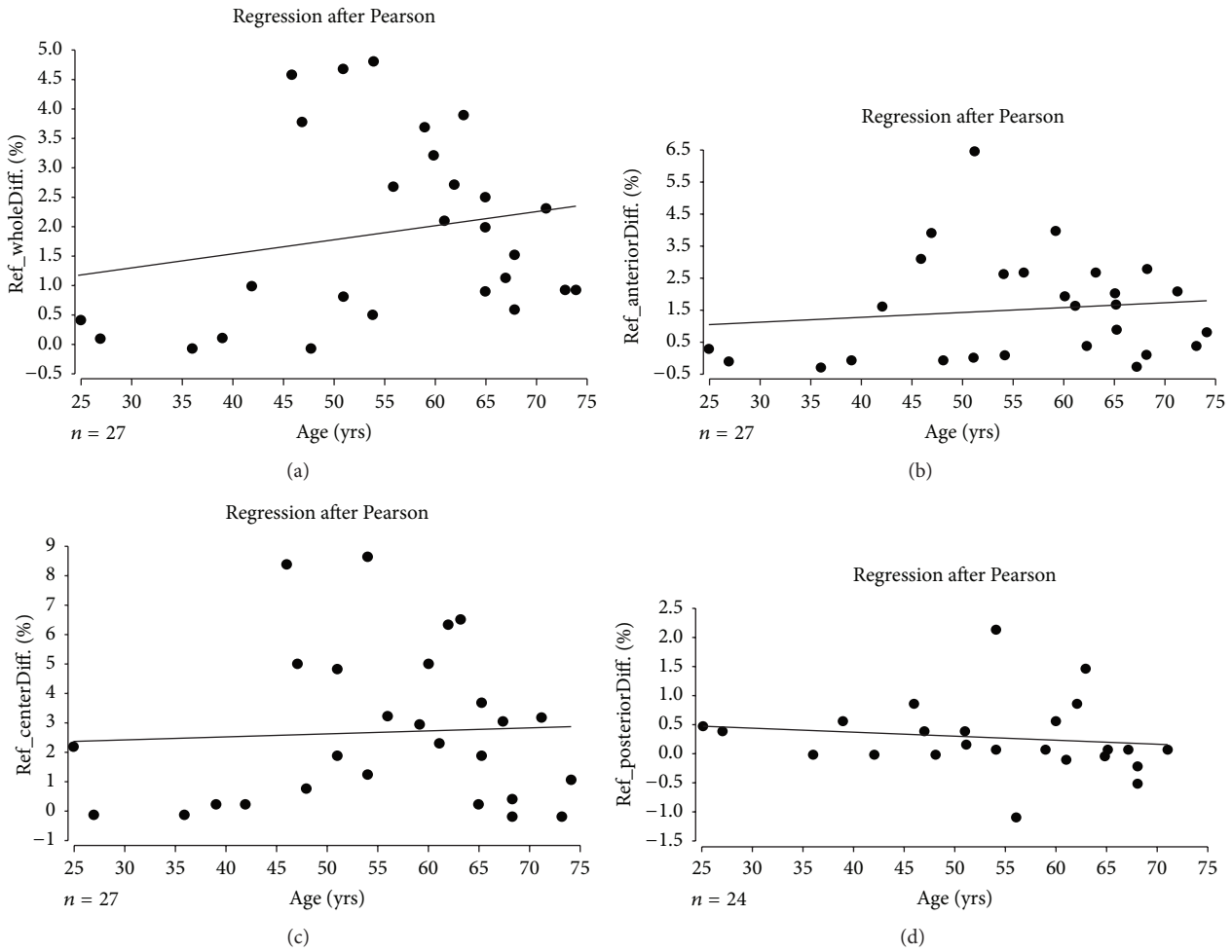

Figure 2: (a)–(d) Lens densitometry change in % for the reference body aligned through the whole lens (Ref_wholeDiff.) (a), for the anterior reference body (Ref_anteriorDiff.) (b), for the central reference body (Ref_centerDiff.) (c), and for the posterior reference body (Ref_posteriorDiff.) (d) with a diameter zone of 3 mm, all plotted against the age. For the posterior reference body three patients could not be adjusted.

of all emulsification with a distinct, but not significant, trend ($p = 0.187$). For better illustration, we highlighted the percentage of moderate, high, and very high emulsification in Figures 3 and 4.

4. Discussion

Needless to say that, among several parameters contributing to a better viewing into the eye and its pathology, first of all, the optics attached to a high quality operating microscope should be as perfect as possible to guarantee the best viewing. This is achieved by using modern wide-field observation systems (like the Super-View System, the Resight, the BIOM, etc.) and high resolution contact lenses for the viewing through contact lenses; the transparency of media might be an even more critical issue.

Furthermore, the distribution and extent of the pathology, for example, an AHFP in diabetics, might decide on the need to sacrifice the lens in an early stage to guarantee no restrictions for membrane peeling and removal in the outermost periphery of the vitreous cavity.

As shown by us in 1994 [25], we should not be surprised about significant changes in all layers of the natural lens in human eyes once silicone oil was applied, even if only for two, four, or six months. In that study, the posterior capsule and cortex of the lenses stayed clear for quite a long time. We had expected the typically described nuclear changes but also found significant changes in the anterior capsule and the subcapsular lens epithelium. This had impeded the performance of the anterior capsular rhexis which could only be compensated by modifications of the rhexis performance strategy and technology with even the development of special electromechanical devices.

As shown in the current study, lenses responded to surgery with silicone oil in all layers, in the "middle aged" groups more than in the younger group or in the age group of 70 years and older.

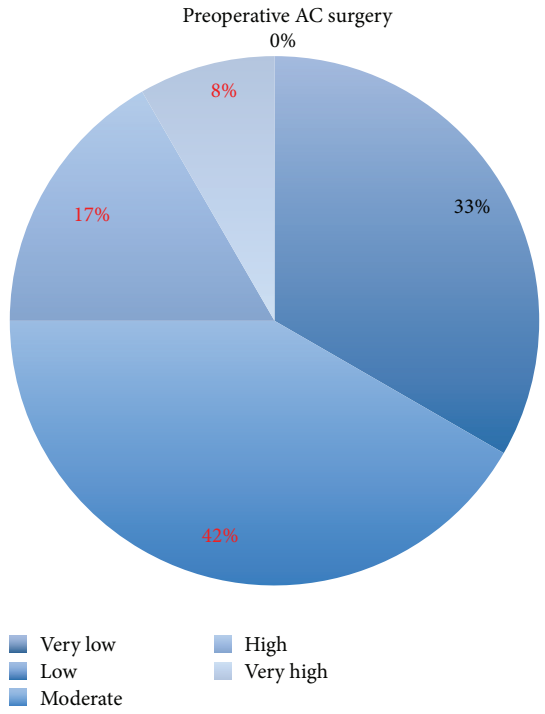

Figure 3: Silicone oil emulsification droplets counted 4 months after oil injection into eyes preoperated on in the anterior chamber (AC) before retina service. Highlighted is moderate (42%) plus high (17%) plus very high (8%) emulsification rate = 67%.

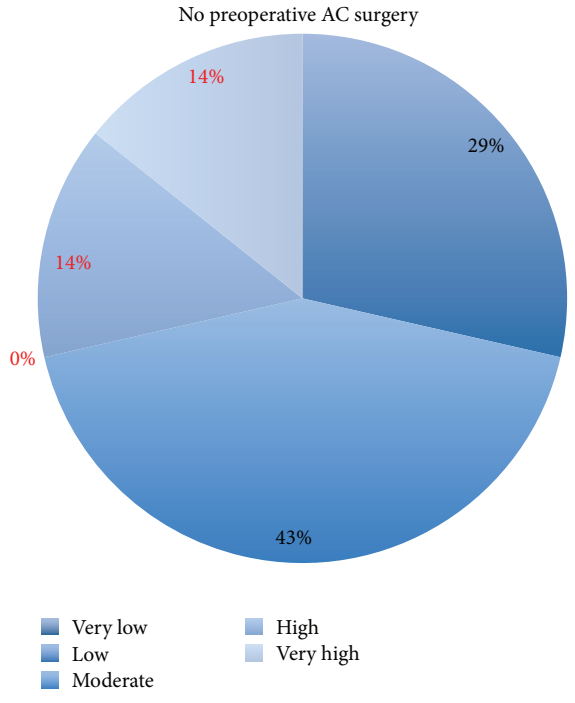

Figure 4: Silicone oil emulsification droplets counted 4 months after oil injection into eyes not preoperated on in the AC before retina service. Highlighted is moderate (0%) plus high (14%) plus very high (14%) emulsification rate = 28%.

It is also obvious that the changes affected the nucleus and the anterior cortex more intensively and rapidly than the posterior segment of the lens.

This is different from modern research analysis of the response to heavy silicone oil which in principle is characterized by more impurities, a higher likelihood to emulsify at an earlier time, and even the development of retrolental membranes because of its interferences with the metabolism of posterior capsule epithelial cells [26].

The microscopic examination of the lens capsule in eyes after the use of heavy silicone oil tamponades demonstrated the presence of macrophages adhering to the lens capsule with epithelioid cells and fibroblastic differentiation, thus adding a probable inflammatory genesis to cataract formation [27]. Our clinical Scheimpflug observations in the current study as well as our older data from microscopic examinations of anterior capsules after silicone oil versus trauma give hints that the release of cytokines and other substances triggered by the oil might pass through the zonula around the lens and affect its anterior surface.

Data from the microscopic paper [25] showed that when the anterior zone of the lenses got thickened, this was caused mainly by multiplication of the epithelial layer. This happened after trauma (no silicone oil) and after temporary silicone oil fill, which allows one to speculate that potentially inflammatory processes might play a role.

And indeed in literature, comparable changes [28–30] are said to be the result of a variety of disturbances such as trauma, chronic inflammation (e.g., iritis), and metabolic impairment. In our cases of silicone-filled vitreous cavities, such disturbances might have been induced by the apposition of the silicone oil to the posterior lens surface, the zonular fibers, and the iris. Besides the silicone oil, also PVR processes and/or side effects of the surgical procedure are potential cofactors.

Since modern silicone oils can lose stability through many factors, for example, the use of perfluorocarbons with incomplete removal from the eye, high energy laser coagulation, high concentrations of inflammatory cells, and less stability after anterior segment surgery, the question of whether lens surgery and vitrectomy with silicone oil outside of the macula pucker and macula hole surgery should better be separated from each other and not performed as a combined procedure in complex pathologies like P(D)VR might be raised.

Once we decide to go for a silicone oil tamponade we should be aware of the principle need for as complete as possible removal of vitreous and oil fill to reduce the risk of emulsification.

It is well known that the raw sources of silicone oil did change in the last decade which challenged all silicone oil providers to work hard on the chemical treatment to guarantee a stable quality for the use in human eyes. Further, the shift of the 19/20-gauge standard for vitrectomy instrumentations down to 23/25- or even 27-gauge standard ends up with an optional more “gentle” surgical approach which often is associated with a trend to a less complete removal of vitreous. Proliferative vitreoretinopathy (PVR) activity includes inflammatory cell activity which might even count more for the emulsification risk if more vitreous in

such a PVR environment is left and brought into temporary contact with the silicone oil. This change of standard might have an impact on the tolerance for vitreous substitutes with subsequent increase of emulsification risks. Together, the increased rate of emulsification plus the higher concentrated accumulation of inflammatory cells and the reaction to this might lead to a poor functional prognosis. Costagliola et al. [31, 32] suggest that the relatively low concentration of surface-active agents only partially accounts for systematic production of emulsions; gravitational instability, originating from the interface by tangential disturbances, is of way more importance for the formation of emulsions. This makes sense from our point of view, especially when we take into consideration our hypothesis of a moderate increase of residual vitreous concentration with more inflammatory cells and more interface for the tangential disturbances as mentioned above and our observation of more air bubbles acccompanying the different oils when injected through the smaller gauge needles.

As a matter of fact, new silicone oil manufacturing issues had forced us during our retrospective-to-prospective study between 2010 and 2015 to give up on a two-port "passive" oil removal 4 months after instillation because of an increased rate of emulsification and phenomena like residual oil bubbles sticking to the retina or to the lens surface ("sticky oil") [33]. However, once we had washed out the eye routinely via a 3-port revision surgery, the final outcome was adequate.

5. Conclusions

Surgery for retinal reattachment seems to benefit from preoperative cataract removal. Interestingly, we found specific lens changes not only in the nucleus and the layers posterior but also in the layers anterior to it. This corresponds to the histology of the lens epithelium published before and affects the anterior capsulorhexis maneuver.

If side effects of the preliminary silicone oil fill do affect the lens surface opposite to the silicone oil contact plane (anterior lens capsule) and modern silicone oils, no matter what type they are, developing instability earlier, we might be a bit more critical in combining anterior and posterior segment surgery in very complex pathologies and also restrict the oil fill period to the maximum time necessary to slow down active inflammatory processes. At the end of the day, an increased rate of emulsification plus the higher concentrated accumulation of inflammatory cells and the reaction to that might include a risk of poor functional prognosis.

Abbreviations

AC:	Anterior chamber
AHFG:	Anterior hyaloid fibrovascular proliferation
EVALP:	Evaluation protocol
f/u:	Follow-up
mPa·s:	Millipascal seconds
P(D)VR:	Proliferative (diabetic) vitreoretinopathy
SLP:	Scheimpflug lens photography
SOT:	Silicone oil tamponade
SOP:	Standard operation procedure.

Conflict of Interests

Svenja Deuchler, Thomas Kohnen, Pankaj Singh, Michael Müller, Hanns Ackermann, Rachid Benjilali, and Frank Koch have no conflict of interests regarding the publication of this paper. Joerg Iwanczuk is employed by Oculus Optikgeräte GmbH, Wetzlar, Germany.

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Clinical Study

Surgical and Functional Results of Hybrid 25-27-Gauge Vitrectomy Combined with Coaxial 2.2 mm Small Incision Cataract Surgery

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Purpose. To investigate outcomes after coaxial 2.2 mm small incision cataract surgery combined with hybrid 25-27-gauge vitrectomy in eyes with vitreoretinal disease and age-related cataract. *Methods*. A single-center, retrospective case series study of 55 subjects (55 eyes) with a mean age of 70 years who underwent combined small incision phacoemulsification, intraocular lens (IOL) implantation, and hybrid 25-27-gauge vitrectomy during the 12-month period to December 2014. Intraoperative and postoperative complications and visual results were the main outcome measures. *Results*. The mean follow-up period was 6 months (range: 2–18 months). Intraoperative findings were 3 retinal breaks (5.5%). No cases required corneal or scleral suture or conversion to larger-gauge vitrectomy. Postoperative complications consisted of posterior capsule opacification (12.7%), elevated intraocular pressure >30 mmHg (1.8%), and fibrin reaction (5.5%). There were no cases of hypotony (<7 mmHg), IOL decentration, or postoperative endophthalmitis. Visual acuity (mean ± SD) improved from 0.52 ± 0.6 logMAR preoperatively to 0.22 ± 0.46 logMAR at final postoperative visit ($P < 0.0001$). *Conclusion*. Surgical and visual outcomes suggest hybrid 25-27-gauge vitrectomy combined with small incision phacoemulsification and IOL implantation is feasible, safe, and effective as a one-step surgical procedure for the management of vitreoretinal pathologies and concurrent cataract.

1. Introduction

Small incision phacoemulsification and microincision cataract surgery (MICS) involving sub-2 mm clear corneal incisions are safe and effective standard surgical procedures [1–4]. The potential benefits of MICS relate to reduced wound leakage, good anterior chamber stability, and safety, minimizing surgically induced astigmatism, reducing higher-order corneal aberrations and promoting rapid postoperative wound healing [5, 6]. For treating vitreoretinal pathologies, transconjunctival sutureless microincision vitrectomy surgery (MIVS) using small-gauge (23-, 25-, or 27-gauge) instrumentation offers the potential for less inflammation, reduced operating time, and often faster visual rehabilitation after surgery compared with conventional 20-gauge vitrectomy [7–9]. Moreover, 25- and 27-gauge vitrectomy instrument system for MIVS effectively produces self-sealing sclerotomies that may alleviate concerns over wound sealing-related complications in selected vitreoretinal cases [10]. "Hybrid" is used to underline the mixed character of different seized infusion and working ports. Treating cataract and vitreoretinal pathologies in a combined one-step microincision phacovitrectomy procedure is an efficient well-tolerated technique that is becoming increasingly common [11–14]. Combined phacovitrectomy eliminates the need for a second operation, allows improved access to the retinal periphery during phacoemulsification, and offers potential for better vitrectomy outcomes [13, 15, 16].

The aim of this present interventional case series study was to retrospectively investigate and review surgical indications, intraoperative and postoperative complications, and visual acuity outcomes in eyes undergoing combined coaxial

2.2 mm small incision cataract surgery with intraocular lens (IOL) implantation and hybrid 25-27-gauge MIVS for the treatment of vitreoretinal disease and concurrent age-related cataract.

2. Materials and Methods

The authors report a single-center, retrospective, consecutive surgical case series that underwent small incision cataract surgery with IOL implantation combined with transconjunctival sutureless hybrid 25-27-gauge vitrectomy. All medical records and surgical charts of 102 patients (116 eyes) who underwent combined small-gauge phacovitrectomy surgery performed at Helios Klinikum Pforzheim, Pforzheim, Germany, between January and December 2014 were reviewed. Cases operated using 23-gauge vitrectomy or microincision coaxial phacoemulsification, where postoperative follow-up was less than 2 months, were excluded. Overall, 55 patients (55 eyes) were identified who had undergone coaxial small incision cataract surgery and IOL implantation combined with hybrid 25-27-gauge MIVS, who were all included in this study.

All patients in this series had preoperative lens opacification, which was graded mild or moderate in 36 of 55 eyes (65.5%). Demographic data and preoperative patient characteristics are presented in Table 1; surgical indication and cataract grade are shown in Table 2. Postoperative follow-up ranged between 2 months and 18 months (mean 6 months; standard deviation [SD] ±4.05). All patients were examined and assessed between 1 week and 4 weeks following the first postoperative day.

Combined phacovitrectomy procedures were carried out in single-session operations performed by the same surgeon, Fabian Höhn. Surgeries were completed throughout using a single phacovitrectomy console and the EVA ophthalmic surgical system (DORC International, Zuidland, Netherlands), together with a 25-gauge two-dimensional cutting (TDC) vitrectomy probe. The EVA surgical system is designed for use in anterior and posterior segment procedures that require infusion, vitreous cutting, aspiration, illumination, irrigation, lens emulsification and fragmentation, cautery, and diathermy as well as photocoagulation.

Preoperative data collected included patient demographics, visual acuity, intraocular pressure (IOP) measured in millimeters of mercury (mmHg) by Goldmann applanation tonometry, and diagnostic indication for combined phacovitrectomy surgery. Intraoperative data collected included suture placement if required, corneal incision and sclerotomy wound stability, and other complications observed during surgery. Postoperative visual acuity, IOP, degree of ocular inflammation, and IOL-related complications were analyzed.

2.1. Surgical Methods and Techniques. Following consultation and informed consent, patients underwent combined phacovitrectomy surgery under general anesthesia. Coaxial small incision cataract surgery was performed through a 2.2 mm corneal incision. A 27-gauge valved trocar (DORC) was preplaced in the inferior temporal quadrant 4 mm from the limbus, then a 2.2 mm clear corneal incision for cataract surgery was made at the 10-o'clock position, using a 2.2 mm ophthalmic phaco knife (MANI, Tochigi, Japan). For the side instrument, a 1.2 mm limbal incision was made at the 2-o'clock position left of the main incision using the same phaco knife. Following creation of clear corneal incision, viscoelastic material was injected into the anterior chamber.

5 mm continuous curvilinear capsulorhexis was performed with microcapsulorhexis forceps suitable for 2.2 mm incision. After hydrodissection and rotation, a stop-and-chop phacoemulsification technique was utilized for nucleus removal. The cortex was removed and the capsular bag was filled with viscoelastic material. A hydrophilic, acrylic monofocal aspheric IOL, TECNIS iTec (Abbott Medical Optics AMO, Illinois, USA), was placed in the capsular bag by docking onto the inner lip of the main clear corneal incision. The corneal wound was hydrated with balanced salt solution following removal of viscoelastic material. The valve of the preplaced trocar was removed by surgical forceps, and the high-flow infusion line of the EVA surgical system was then connected. The eye was pressurized, allowing for controlled placement of two 25-gauge vitrectomy trocars in the superior quadrants 3.5 mm from the limbus. A 27-gauge twin light chandelier was placed at 11 and 1 o'clock position (Figure 1).

Vitreous surgery was performed using a 25-gauge TDC vitreous cutter controlled using the EVA vacuum vitrectomy unit. The vacuum level was placed at maximum 600 mmHg, and the vitreous cutter rate set at 8,000 cuts per minute

Table 1: Demographic data and preoperative clinical features.

Variable	Data
Number of patients (eyes)	55 (55)
Gender (male : female)	23 : 32
Age (mean ± SD)	70.0 ± 10.33 years
Laterality (OD : OS)	26 : 29
Preoperative logMAR BCVA (mean ± SD)	0.52 ± 0.6

SD, standard deviation; OD, right eye; OS, left eye; logMAR, logarithm of the minimum angle of resolution; BCVA, best-corrected visual acuity.

Table 2: Vitreoretinal indication and cataract grade.

Variable	Patients, *n* (%)
Diagnosis	
Rhegmatogenous retinal detachment	2 (3.6)
Epiretinal membrane	26 (47.3)
Macular hole stage 4	11 (20)
Vitreous hemorrhage	3 (5.5)
Vitreomacular traction	6 (10.9)
Proliferative diabetic retinopathy	5 (9.1)
Subretinal hemorrhage	2 (3.6)
Cataract grade	
Mild nuclear sclerosis ± cortical spoking	22 (40)
Moderate	14 (25.5)
Dense brunescent	12 (21.9)
Dense posterior subcapsular	3 (5.5)
Degree and type of cataract not recorded	4 (7.3)

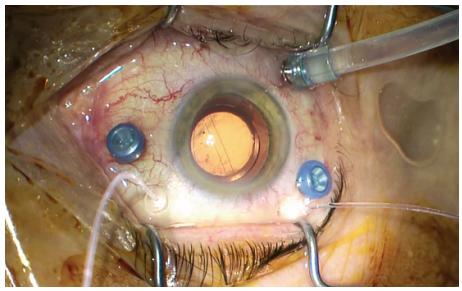

Figure 1: Hybrid 25-27-gauge vitrectomy setting following coaxial 2.2 mm small incision cataract surgery.

(cpm). The TDC vitrectomy has a second port in the distal part of the inner pipe, which enables permanent aspiration, constant flow, and doubling of vitreous cut rate to an effective operating speed of 16,000 cpm. Vitrectomy was undertaken to achieve complete evacuation of the posterior vitreous and extensive removal of peripheral vitreous. In some patients, vitrectomy was combined with epiretinal membrane dissection and/or internal limiting membrane peeling. Fluid-air or gas exchange was performed to prevent postoperative hemorrhage and hypotonia in all cases.

Ocular surface preparation prior to surgery consisted of rinsing the conjunctival sac of the eye to be operated on with povidone-iodine and careful application of povidone-iodine via swabbing to the periocular skin of both eyes. No antibiotic agent was added to the irrigation fluid or anterior chamber. Patients received a course of topical ophthalmic corticosteroid therapy with dexamethasone together with gentamicin antibiotic treatment for between 4 weeks and 5 weeks postoperatively.

2.2. Data Analysis. A series of prespecified primary and secondary outcome measures were analyzed retrospectively. Primary intraoperative outcome measures were leaking corneal and scleral incision requiring suturing, posterior capsule tear, conversion to larger-gauge vitrectomy, and retinal break. Primary postoperative outcome measures were IOP change, fibrin in the anterior chamber, IOL capture or decentration, posterior capsule opacification (PCO), choroidal effusions, retinal or choroidal detachment, and endophthalmitis.

Visual acuity was assessed as the main secondary outcome measure. For statistical analysis, standard Snellen measurements were converted to logarithm of the minimum angle of resolution (logMAR) values. Preoperative and postoperative logMAR visual acuities were compared using the paired two-tailed Student's t-test method. In the case series analysis, a postoperative IOP reading of less than 7 mmHg was classified as hypotony.

3. Results

3.1. Study Population and Baseline Characteristics. A total of 55 patients (55 eyes) underwent combined small incision phacoemulsification, IOL implantation, and hybrid 25-27-gauge vitrectomy surgery. The average patient age was 70 years, with 23 male and 32 female subjects. The mean postoperative follow-up was 6 months (range: 2–18 months).

Table 3: Main outcomes: intraoperative and postoperative findings.

Variable	Patients, n (%)
Intraoperative findings	
Retinal break	3 (5.5)
Posterior capsule tear	0 (0)
Corneal suture	0 (0)
Scleral suture	0 (0)
Conversion to larger-gauge vitrectomy	0 (0)
Postoperative findings	
Fibrin in the anterior chamber	3 (5.5)
Hypotony (<7 mmHg)	0 (0)
Elevated intraocular pressure (>30 mmHg)	1 (1.8)
Retinal or choroidal detachment	0 (0)
Endophthalmitis	0 (0)
Posterior capsule opacification	7 (12.7)
Intraocular lens capture or decentration	0 (0)

The most common indication for vitrectomy surgery was epiretinal membrane (26 eyes, 47.3%), followed by macular hole stage 4 (11 eyes, 20%), vitreomacular traction (6 eyes, 10.9%), and proliferative diabetic retinopathy (5 eyes, 9.1%). Internal tamponade was performed with 20% sulfur hexafluoride (SF6) or air; the decision and selection regarding tamponade procedure were based on assessment of preoperative and intraoperative clinical characteristics.

3.2. Primary Intraoperative and Postoperative Outcome Measures. Intraoperative and postoperative findings are shown in Table 3. None of the eyes in the case series required a corneal suture to seal the corneal tunnel, no sclerotomy sutures were needed, and all cases were completed without conversion to larger-gauge vitrectomy (23- or 20-gauge). A retinal break occurred in 3 eyes (5.5%). None of these 3 eyes had an iatrogenic retinal break, and the break was classified as a preexisting retinal break. All breaks were successfully managed with endolaser treatment using a curved 25-gauge endolaser probe (DORC).

The preoperative IOP (mean ± SD) was 15.2±2.84 mmHg, and the postoperative IOP was 14.29 ± 6.96 mmHg. There were no cases of postoperative hypotony (IOP < 7 mmHg). One eye (1.8%) experienced elevated IOP greater than 30 mmHg on Day 1 after surgery, requiring topical hypotensive medications, and normalized IOP was achieved at the next examination.

Fibrin reaction in the anterior chamber was observed in 3 eyes (5.5%) the day after surgery, which was resolved following topical steroid treatment. During follow-up, there were no cases of lOL decentration or capture, while PCO developed in 7 eyes (12.7%). There were no cases of postoperative endophthalmitis or choroidal detachment.

3.3. Secondary Outcome Measures. The preoperative logMAR visual acuity (mean ± SD) in the current case series was 0.52 ± 0.6. At the final follow-up visit, logMAR visual acuity (mean ± SD) was 0.22 ± 0.46, which was a statistically significant improvement ($P < 0.0001$) from baseline, and represents

an average improvement in visual acuity of 0.30 logMAR. Overall, at last postoperative follow-up visit, visual acuity had improved in 49 eyes (89.1%), was unchanged in 3 eyes (5.5%), and worsened in 3 eyes (5.5%). Monitored visual loss occurred as a result of progressive diabetic macular edema in one case and a conversion into exsudative age-related macular degeneration in two patients.

4. Discussion

In a series of 85 eyes, Canan et al. [17] found that phacovitrectomy using combined 20-gauge vitrectomy and 2.8 mm phacoemulsification with a standard phaco-chop technique was safe and effective for proliferative diabetic retinopathy. Developments in small incision cataract surgery together with enhancements in smaller-gauge vitrectomy instrumentation systems provide additional opportunities for securing effective and safe outcomes in combined phacovitrectomy for complex vitreoretinal diseases with simultaneous cataract [8, 14, 18–20]. Phacovitrectomy with either conventional 20-gauge vitrectomy or MIVS reduces surgical trauma for patients with vitreoretinal disease and cataract, while high-speed small-gauge vitrectomy cutters improve vitrectomy surgery by generating less vitreous traction and more efficient vitreous removal [21]. Moreover, studies confirm that phacovitrectomy improves visualization during the vitrectomy procedure in cases where there is a clinically significant lens opacity and speeds visual rehabilitation after surgery [22, 23].

The present clinical study was designed specifically to evaluate the potential intraoperative and postoperative complications and visual results of a hybrid 25-27-gauge microincisional sutureless vitrectomy in combination with coaxial small incision cataract surgery, and the primary and secondary outcomes have been reported above.

None of the 55 eyes in our case series required suture of the cornea wound or sclerotomy site at the end of the surgery, and there were no serious complications related to corneal wound leakage. A similar retrospective study which evaluated combined 1.8 mm microincision cataract surgery and 23-gauge vitrectomy found corneal suturing was required in 6 of 50 eyes (12%), with a sclerotomy suture in 4 eyes (8%) [15]. One possible explanation for the incidence of suturing could be the pressure force created during the insertion of a 23-gauge trocar instrument. For our case series, the 25- and 27-gauge trocars that were used require less insertion force than larger-sized trocars because they have a smaller diameter. Another contributing factor explaining sutureless procedures could be related to preplacement of the infusion trocar prior to creating a 2.2 mm tunnel incision. A ases series of 60 patients treated with combined 23-gauge phacovitrectomy found that vitrectomy ports were self-sealing in all eyes except 4 (6.7%) [24]. From another case series, Jalil et al. [16] reported that 4 of 43 cases (9.3%) required suturing of one or more ports during 23-gauge phacovitrectomy. The fact that in our series no eyes required scleral suturing suggests combined 25- and 27-gauge sclerotomies immediately self-seal following trocar removal, leading to faster visual rehabilitation and minimal ocular inflammation [24].

Intraoperative complications commonly associated with pars plana vitrectomy (PPV) procedures are iatrogenic retinal breaks, lens touch, and iatrogenic retinal tears [25]. There were 3 cases (5.5%) of intraoperative retinal break observed in our case series, although none of these eyes developed retinal detachment postoperatively. Higher incidences of retinal break during vitrectomy have been reported in the literature. Analysis of 2,471 primary PPV operations between 2001 and 2010 found that intraoperative iatrogenic retinal breaks developed in 10.09% of eyes overall, with an incidence of 32.45% in eyes with tractional retinal detachment and 16.3% of eyes with macular hole [26]. Risk factors include phakia and absence of a preoperative PVD [26, 27]. Intraoperative iatrogenic peripheral retinal breaks occurred in 15.2% (98 of 645 eyes) of cases involving 20-gauge PPV, approximately 4 in 10 breaks related to traction at sclerotomy entry site, in a large interventional case series study by Ramkissoon et al. [28]. Induction of PVD during vitrectomy is associated with a significantly higher incidence of retinal breaks [29, 30]. The frequency of retinal breaks related to the PPV operation was 6.9% in patients with epiretinal membrane and 14.6% in patients with macular hole, in a retrospective, comparative study by Chung et al. [29]. An intraoperative retinal break in 9 of 50 eyes (18%) undergoing MICS and 23-gauge vitrectomy for posterior segment disease was reported by Czajka et al. [15]. Prospective study data show that entry site retinal breaks are uncommon in patients undergoing small-gauge (23-, 25-gauge) vitrectomy, while a 2-year observational study involving a large series undergoing 20-gauge or 23-gauge vitrectomy found a significantly lower incidence of anterior iatrogenic retinal breaks in patients treated with the smaller-gauge surgery (7.8% versus 16.7% for 20-gauge vitrectomy) [31, 32].

No case of capsule tear was observed during phacovitrectomy surgery. Treumer et al. [33] reported posterior capsule tears in 7 of 111 eyes (6.3%) treated with combined PPV, phacoemulsification, and IOL implantation compared with 4 of 50 eyes (8%) in eyes that underwent sequential PPV and cataract surgery. An evaluation of 114 eyes undergoing combined 23-gauge phacovitrectomy between January 2006 and March 2009 found that capsular tears were more frequent in eyes with a prior history of radiation or vitrectomy [14]. Similar to the study presented here, a case series of 52 eyes that underwent combined MICS and PPV, mostly 23-gauge, reported posterior capsule rupture in 2 patients (3.8%) [16].

There were no occurrences of postoperative hypotony in the present study. In a smaller series of 30 eyes, Moon et al. [34] found a low risk of postoperative hypotony following combined 23-gauge sutureless vitrectomy and clear corneal phacoemulsification for rhegmatogenous retinal detachment repair. Only one eye (0.7%) experienced severe postoperative hypotony (<6 mmHg) despite the absence of suturing of sclerotomy sites, in an interventional cases series of 108 patients (136 eyes) with proliferative diabetic retinopathy who underwent combined 23-gauge phacovitrectomy [35]. A study evaluating 23-gauge phacovitrectomy using microincision phacoemulsification reported that hypotony (IOP < 9 mmHg) occurred in 18% (9/50) of eyes [15]. Oshima et al. [10] found that all sclerotomies were self-sealed without

hypotony (IOP ≤ 7 mmHg) from Day 1 postoperatively in an experimental study evaluating a new 27-gauge instrument system for transconjunctival MIVS. No eyes in our series developed choroidal detachment postoperatively.

It was decided not to administer antibiotics to the anterior chamber at the end of the phacovitrectomy case; Delyfer et al. [36] reported that intracameral injection of high doses of cefuroxime at the end of uneventful cataract surgery induced anterior and posterior inflammation, with extensive macular edema associated with a large serous retinal detachment. There is nonetheless evidence of benefit that may justify the use of intracameral cefuroxime to reduce the rate of acute endophthalmitis after cataract surgery [37, 38].

Formation of posterior synechia of the iris is a postoperative complication of combined phacoemulsification and PPV. Oh et al. [39] identified postoperative synechia in 6.1% of 263 eyes treated with 23-gauge phacovitrectomy, which is a relatively low incidence when compared with other studies, with reported frequencies as high as 30% observed after phacovitrectomy in patients with proliferative diabetic retinopathy [40]. In our case series, 3 patients (5.5%) were identified with postoperative anterior chamber fibrin deposition, a known risk factor of posterior synechia, although no patient developed postoperative iris synechia in the present case series.

With regard to other postoperative anterior segment complications, the rate of posterior capsule opacification over the follow-up period was 12.7% (7 eyes), which is at the lower end of the range reported from similar investigations. Posterior capsule opacification is a common postoperative anterior segment complication associated with combined phacovitrectomy, with incidence rates of up to 51% reported in the literature [41]. Wensheng et al. [42] observed a PCO rate of 21.5% in 186 eyes of 149 patients who underwent combined phacoemulsification and vitrectomy for coexisting cataract and vitreoretinal diseases. Studies indicate a lower PCO rate in eyes undergoing transconjunctival 23-gauge phacovitrectomy compared with eyes treated using 20-gauge phacovitrectomy [43, 44]. Contributing factors for the development of PCO are increased surgical manipulation and inflammation, rhegmatogenous retinal detachment, gas tamponade, intraoperative/postoperative complications, and postoperative posturing [44]. Minimal fluid-air exchange during combined small-gauge phacovitrectomy may be beneficial in reducing the possibility of postoperative hypotony and IOL-related complications [45].

There were no cases of intraocular lens capture or decentration following combined phacovitrectomy surgery. A case series evaluation of sub-2 mm MICS combined with 23- or 20-gauge vitrectomy using an IOL with a 4-point fixation design similarly reported no cases of IOL decentration [16]. Compared with 25-gauge phacovitrectomy, more frequent IOL decentration has been observed with 20-gauge vitrectomy combined with phacofragmentation [46]. Better centration has been recorded with a 4-point haptic design IOL compared with an intraocular lens incorporating a 2-point haptic design [47]. In a comparative study, Leiderman et al. [48] revealed that single-piece acrylic IOLs are associated with a low rate of surgical complications after combined phacovitrectomy.

Visual results that were recorded in our study population are generally consistent with published outcomes from other clinical studies, demonstrating that good functional outcomes are achievable with combined hybrid MIVS and phacoemulsification using 2.2 mm microincision corneal wounds. Combining phacoemulsification, IOL implantation and vitrectomy offer clearer visualization during surgery compared with sequential procedures, and often time decreases visual rehabilitation time in cases with early or visually significant cataracts [22, 49]. Good success rates have been reported, with 95% of patients achieving a 2-line or greater improvement in visual acuity within 6 weeks of combined phacovitrectomy surgery in one institution in the United States [23].

To summarize, surgical and visual outcomes demonstrate that a single-session approach is safe, feasible, and effective for the treatment of vitreoretinal pathology and coexisting cataract, with minimal incremental surgical risk. Additional clinical studies evaluating multicenter practice outcomes utilizing combined phacovitrectomy will help guide practitioners as they transition toward more efficient minimally invasive combination approaches for a variety of vitreoretinal pathologies with and without visually significant cataract.

Conflict of Interests

Mitrofanis Pavlidis is a consultant to DORC International and declares a proprietary financial interest. None of the other authors have any conflict of interests to disclose.

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Research Article

Prophylactic Circumferential Retinal Cryopexy to Prevent Pseudophakic Retinal Detachment after Posterior Capsule Rupture during Phacoemulsification

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Purpose. To evaluate whether prophylactic circumferential retinal cryopexy (CRC) can prevent pseudophakic retinal detachment (PRD) development after posterior capsule rupture (PCR) during phacoemulsification. *Methods*. Retrospective patient chart analysis of eyes experiencing a PCR during phacoemulsification. Comparison of PRD development between eyes receiving CRC (cryo+ group) or not (cryo− group). *Results*. Overall 106 patients were analyzed, thereof 61 (58%) in the cryo+ and 45 (42%) in the cryo− group. In both clusters a total of 10 PRDs (9.4%) occurred, thereof 3 (30%) in the cryo+ as well as 7 (70%) in the cryo− group ($p = 0.087$), 79.8 ± 81.58 weeks after PCR. Relative/absolute risk reduction in CRC-treated eyes was calculated to be 68%/11%. Prophylactic CRC reduced PRD development 0.3-fold. Number needed to treat was estimated to be 9.4. *Conclusion*. Prophylactic CRC might be a useful treatment option in eyes with PCR to hamper PRD development in the further course. Further research is indicated to evaluate this beneficial effect between eyes with and without a rupture of the anterior vitreous cortex and accompanying vitreous loss in an expanding number of eyes.

1. Introduction

Cataract is the most common cause of reversible vision loss in the world. Many advances have been made within the last decades to improve the surgical lens removal procedure, such as phacoemulsification technique, small incision surgery, the use of viscoelastics, and the development of intraocular lenses [1]. This ensures a less traumatic approach to the eye, reduces complication rates, and backs up rapid visual recovery in most cases [1, 2]. Therefor cataract surgery has ascended to be the most frequently performed surgical intervention in developed countries nowadays [3]. Despite these major improvements various complications, including endophthalmitis, acute corneal decompensation, raised intraocular pressure (IOP), or postsurgical cystoid macular edema, may occur [4]. Posterior capsule rupture (PCR) during the surgical maneuver is another major complication raising the risk for pseudophakic retinal detachment (PRD) in the further postsurgical course [5]. Former research described a protective effect of prophylactic circumferential retinal cryopexy (CRC) in aphakic eyes [6] or in eyes with peripheral retinal breaks [7] in respect to retinal detachment (RD) development. Thus, the purpose of this investigation was to evaluate whether prophylactic CRC after PCR during a complicated phacoemulsification procedure can prevent PRD development.

2. Material and Methods

A retrospective patient chart analysis was performed including all phacoemulsification cases performed at Department of Ophthalmology, Philipps-University Marburg, Germany, in which a PCR occurred during the operation between July 1996 and December 2012. To be included into this investigation, patients needed to be 40 years of age or older scheduled for a routine age-related cataract removal procedure using phacoemulsification technique. The postsurgical observation period needed to extend 2 years at a minimum. Exclusion criteria were eyes with an axial length (AL) of more than 25 mm, congenital or traumatic cataract formation,

Table 1: Baseline characteristics of patients receiving prophylactic circumferential retinal cryopexy (cryo+) or not (cryo−) after posterior capsule rupture during phacoemulsification.

	Cryo+ group (n = 61/58%)	Cryo− group (n = 45/42%)	p value
Gender (male/female)	31 (51%)/30 (49%)	37 (55%)/30 (45%)	0.771
Age (phacoemulsification)	75.1 ± 8.3 years	75 ± 8.6 years	0.931
Eye affected (right/left)	32 (52%)/29 (48%)	27 (60%)/18 (40%)	0.285
Axial length (mm)	23.16 ± 0.78	23.14 ± 0.96	0.977

previously vitrectomized eyes, and any combination of the phacoemulsification procedure with other ocular surgical procedures, such as keratoplasty, glaucoma operations, or posterior segment surgery.

2.1. Statistical Analysis. Tables were prepared using Microsoft Word 2007 (Microsoft©). Statistical analysis was performed with Office Excel 2007 (Microsoft©) and SPSS Statistics 20 (IBM©). To test baseline value differences between groups, binomial distribution test and Mann-Whitney U test were performed. To test the effect of retinal cryocoagulation in respect to PRD rates, logistic regression was executed including cryo+/−, axial length (AL), time till cryocoagulation, and patients' age and gender as covariates. Significant results were assumed if p values were less than 5% ($p < 0.05$).

3. Results

Overall 106 patients were included into this analysis, thereof 55 male (51.9%) and 51 female (48.1%) subjects with an overall age of 75.1 ± 8.4 years (mean value ± standard deviation). Patients were split into a cryocoagulation (cryo+) and a noncryocoagulation (cryo−) group depending on whether prophylactic CRC was performed after PCR or not. Patients' baseline characteristics of each group are displayed in Table 1.

In the cryo+ group prophylactic CRC was performed 11.6 ± 27.2 weeks after PCR. A total of 10 (9.4%) PRD occurred in both groups, thereof 3 (30%) in the cryo+ as well as 7 (70%) in the cryo− group ($p = 0.087$). Relative/absolute risk reduction in CRC-treated eyes was calculated to be 68%/11%. Prophylactic CRC reduced PRD development 0.3-fold. Number needed to treat (NNT) was estimated to be 9.4. Axial length ($p = 0.484$), time till cryocoagulation ($p = 0.657$), and patients' age ($p = 0.394$) and gender ($p = 0.498$) did not have a significant impact on PRD development.

Overall PRD occurred 79.8 ± 81.58 weeks after the eventful phacoemulsification. In all cases pars plana vitrectomy (ppV) was performed for successful RD repair.

4. Discussion

Major improvements in extracapsular cataract extraction (ECCE) procedures have been made within the last decades, especially the replacement of manual nuclear extraction by phacoemulsification [8]. Additionally, a stepwise improvement of the latter resulted in a further significant decrease of complication rates. Hereby, the number of posterior capsule ruptures (PCR) and anterior vitrectomies (AV) halved despite substantially increasing procedure counts [8]. PCRs were reported to occur in between 0.45% and 16% of all phacoemulsification procedures mostly dependent on surgical experience [4, 9–11] and other various risk factors [12]. Thus, PCRs remain one of the most common complications in cataract surgery with a major risk of compromised final visual outcome [4, 9]. PCRs oftentimes occur during the phacoemulsification (roughly 60%) or irrigation/aspiration (about 25%) process [4]. Accompanying vitreous loss (VL) is associated with an even poorer visual acuity (VA) outcome and typically occurs, in about 1.0% to 75% of PCR cases, during nuclear disassembly and removal [4, 11, 13].

Former reports indicated a fivefold increase of retinal detachments in pseudophakic eyes in which a PCR and VL occurred during the phacoemulsification procedure in comparison to uncomplicated cataract surgeries [4, 5]. Contrariwise, prophylactic circumferential retinal cryopexy (CRC) was successfully used in eyes prior to cataract surgery in patients prone to retinal detachments [14] and in several patients undergoing pars plana vitrectomy [15, 16]. Prophylactic CRC is also administered for various peripheral lesions like retinal breaks, tears, and others such as lattice degeneration to prevent RD development [17], if not addressable with laser photocoagulation. Thus, the question arises, whether prophylactic CRC after an eventful phacoemulsification procedure can reduce PRD development in the further course. As demonstrated herein there was a meaningful reduction in PRD development in the cryo+ group (relative/absolute risk reduction in prophylactic CRC-treated eyes of 68%/11%) although statistical significance failed. This in turn is essentially attributed to the marginal number of overall PRD developments of 9.4% (cryo+: 3 PRDs in 61 PCR cases; cryo−: 7 PRDs in 45 PCR events) in this series. According to this data, calculation of number of cases to show statistically significant differences revealed group sizes of 139/179 PCR cases in each group to reach a statistical power of 80%/90%. In particular the NNT of 9.4 cases emphasizes the benefits of prophylactic CRC in routine patient care when comparing with NNT of 25 for prophylactic warfarin intake to prevent stroke in atrial fibrillation [18] for instance. This in turn awards a positive risk-benefit profile of prophylactic CRC in PCR cases. Nevertheless there are potential risks such as macular pucker formation, proliferative vitreoretinopathy (PVR), or surgically induced scleritis [17, 19], and therefore, individual risks and benefits for each patient have to be weighted. In this regard the technique of CRC is also important and a mild CRC (just visible whitening of the retina) should be preferred over distinctive freezing [20, 21]. Alternatively 360° laser retinopexy might be another option

to prevent PRD development as laser treatment is routinely used to seal peripheral retinal breaks or degenerative areas prone to RD accruement, at least if they are symptomatic [22]. So far there is no report in the literature about the efficacy of prophylactic 360° laser retinopexy in eyes with PCR during phacoemulsification. Specific complications in the anterior [23] as well as posterior segment [24] can occur and have been reported as well. Contrariwise laser retinopexy is less traumatic to the eye and therefore a prospective study using laser instead of cold for prophylactic retinal treatment is indicated.

In theory, CRC can be used to induce permanent chorioretinal scar development and thus "glue" the retina to the underlying choroid. This could be of importance after a PCR due to the anterior movement of the vitreous towards the anterior segment of the eye. This anterior shift is additionally increased after anterior vitreous cortex (AVC) rupture with vitreous loss and a consequently performed anterior vitrectomy [25]. As the vitreous cortex is attached to the peripheral retina, the anteriorly directed drive of the vitreous body causes vitreoretinal traction and can induce retinal break or tear formation and thus induce PRD development [25, 26]. Thus a prophylactic CRC seems reasonable and the data herein support its routine use.

The strength of this evaluation is, to the best of our knowledge, to be the first investigation to evaluate whether prophylactic CRC after PCR during a complicated phacoemulsification procedure can prevent PRD development. A reasonable number of patients were included and observed over a long postoperative time. The limitation is the retrospective study design. Furthermore, the effect of prophylactic CRC may differ between eyes with and without AVC rupture and accompanying vitreous loss. Performing anterior vitrectomy in these scenarios can additionally prevent PRD significantly [27]. The position of the lens implanted (sulcus ciliaris, in the bag, optic capture) and whether the eye stays (temporarily) aphakic or not [11] might also be of key interest in this regard. Due to the small number of PCR and accompanying PRD cases eligible for this evaluation within a 16.5 years' observation period, a separated and additional evaluation of these unanswered questions was not possible and would need some decades to gain enough patients. Nevertheless, these essential questions need further evaluation on a larger number of eyes affected in the future.

Conflict of Interests

Thomas Bertelmann is Medical Advisor at Novartis Pharma GmbH, Nuremberg, and scientific staff of Philipps-University Marburg, Germany.

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Research Article

Wide-Field Landers Temporary Keratoprosthesis in Severe Ocular Trauma: Functional and Anatomical Results after One Year

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Purpose. To evaluate longitudinal functional and anatomical results after combined pars plana vitrectomy (PPV) and penetrating keratoplasty (PKP) using a wide-field Landers intraoperative temporary keratoprosthesis (TKP) in patients with vitreoretinal pathology and corneal opacity due to severe ocular trauma. *Material and Methods*. Medical records of 12 patients who had undergone PPV/PKP/KP due to severe eye trauma were analyzed. Functional (best-corrected visual acuity) and anatomic outcomes (clarity of the corneal graft, retinal attachment, and intraocular pressure) were assessed during the follow-up (mean 16 months). *Results*. Final visual acuities varied from NLP to CF to 2 m. Visual acuity improved in 7 cases, was unchanged in 4 eyes, and worsened in 1 eye. The corneal graft was transparent during the follow-up in 3 cases and graft failure was observed in 9 eyes. Silicone oil was used as a tamponade in all cases and retina was reattached in 92% of cases. *Conclusions*. Combined PPV and PKP with the use of wide-field Landers TKP allowed for surgical intervention in patients with vitreoretinal pathology coexisting with corneal wound. Although retina was attached in most of the cases, corneal graft survived only in one-fourth of patients and final visual acuities were poor.

1. Introduction

Severe ocular trauma is usually associated with combined anterior and posterior segment damage and is a surgical challenge. Many eyes (about 50%) with perforating injuries have entrance wound in the cornea [1]. Small and thin corneal scars make it possible to perform pars plana vitrectomy (PPV). However, the view of the retina and vitreous may be difficult due to massive corneal epithelium edema, scar formation, blood staining, or neovascularization of the cornea. Thus, it may be not easy to attach the retina, shave the vitreous body, or remove intraocular foreign body (IOFB) during PPV. Endoscopy-assisted PPV is one option in these cases [2]; however it requires specialized equipment and training (steep learning curve).

Development of temporary keratoprosthesis (TKP) allows performing elaborated surgery adequately in severely traumatized eyes requiring PPV with an opaque cornea.

Use of TKP during PPV was first described by Landers et al. in 1981 [3]. The first TKP was biconcave optical cylinder 5 mm in length made of polymethyl methacrylate (PMMA) and had 7.2 mm in diameter (Figure 1). In 1987 Eckardt [4]

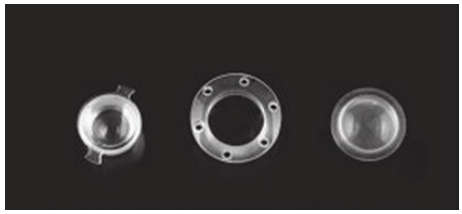

Figure 1: Original Landers PMMA keratoprosthesis (left), wide-field Landers PMMA keratoprosthesis (middle), and Eckart silicone keratoprosthesis (right). Picture from a book by Narendran et al. [5].

proposed a modification of TKP made of silicone and having a diameter of 10 mm of the outer cylinder and a diameter of 7 mm of the inner cylinder with 2.8 mm in length. However, Eckardt TKP became cloudy after reusing as there were no holes for sutures and the silicone became damaged after multiple suture trucks [5]. Moreover, the view into the peripheral retina was limited. The modification is Landers third-generation wide-field TKP which is hard plastic PMMA device with a 1 mm cylinder protruding to the anterior chamber (choice of diameters: 6.2 mm, 7.2 mm, or 8.2 mm) with a mushroom-shape corneal surface of a diameter 15.5 mm and 6 suture holes in the periphery [5]. Landers wide-field TKP is durable and reusable and can be sutured firmly to the globe; moreover it has a convex anterior surface to facilitate viewing to the posterior pole and periphery of the retina [5]. The latest improvement is trunkless Landers wide-field TKP with no central trunk extending down into the opening in the cornea [6]. Additionally, there are models including 20 G stainless steel infusion line [6]. Thus, the major differences between three generations of TKPs are material (PMMA or silicone) and dimensions of the cylinder and the corneal surface to have a better view to the retina.

The aim of this study was to show functional and anatomical results after one year in patients after severe ocular trauma treated with combined surgery: PPV with wide-field Landers TKP and PKP.

2. Methods

This interventional case series included patients, who had combined PPV and TKP and PKP surgery performed between March 2009 and December 2011 in the Department of General Ophthalmology of Medical University of Lublin, Lublin, Poland. The study followed the tenets of the Declaration of Helsinki. The patients gave their written informed consent. The inclusion criteria were as follows: (1) severe open eye injury with corneal or corneoscleral laceration, (2) retinal detachment, (3) combined PPV/TKP/PKP surgery, and (4) follow-up of at least 10 months. In all cases corneal wound (Figure 2) was sutured during the first operation (Figure 3) as an emergency procedure; TKP/PKP/TPPV was performed as a second surgery, few days later (mean period of 24 days).

The patient data were recorded including age, gender, visual acuity, intraocular pressure, and history of ocular injuries. Ocular trauma data included the mechanism and type of injury classified according to the Ocular Trauma Classification [7, 8]. All included eyes underwent open-globe injury (injury with full thickness wound to the cornea or/and sclera), penetrating, IOFB, or eye rupture. The site of the injury was classified as zones I, II, and III depending on the location of the wound within the cornea or sclera. Zone I injuries are confined strictly to the cornea, zone II injuries involve the anterior sclera of 5 mm from the limbus, and zone III injuries involved full thickness scleral defects more posterior than 5 mm from the limbus [7, 8].

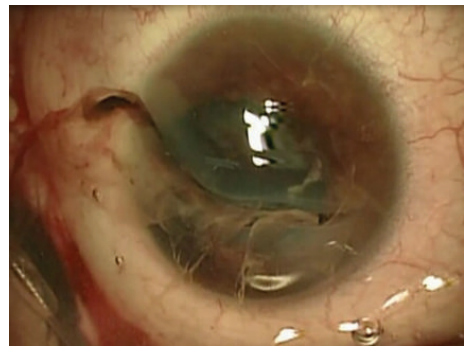

Figure 2: Extended corneal laceration (zone II) with iris and vitreous prolapse due to penetrating trauma: case number 3.

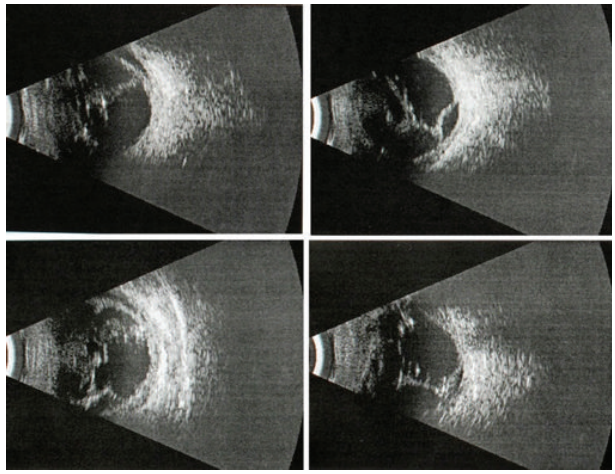

Figure 3: Retinal detachment seen in ultrasonography in patient with corneal laceration.

As initial and final visual acuities were poor and not measured using Snellen charts, hand motion (HM), finger counting (FC), light perception (LP), and no light perception (NLP) forms were used to describe visual acuities of included patients. The preoperative examination included visual acuity, intraocular pressure, and B-scan ultrasonography (Figure 4). The follow-up examination included visual acuity, intraocular pressure, corneal graft transparency, and retinal attachment.

The mean follow-up period was 16 months (range 10–29 months). The schedule of control examinations after surgery was planned as follows: next day, one week, one month, three months, six months, one year, one and half of a year and two years after operation.

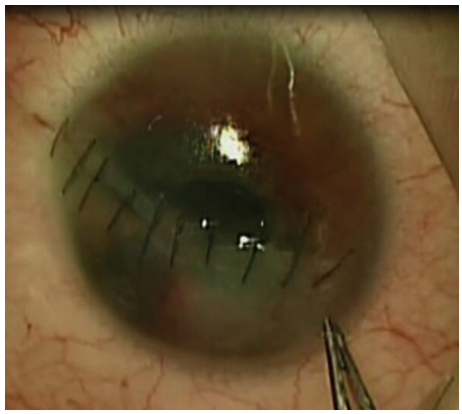

Figure 4: Sutured corneal wound during an emergency operation.

Functional (best-corrected visual acuity: improved, stable, and worsened) and anatomic outcomes (clarity of the corneal graft, retinal attachment, and intraocular pressure) were assessed during the follow-up.

3. Surgical Technique

All surgeries were performed under general anesthesia by two surgeons, anterior segment surgeon and vitreoretinal surgeon. Mean operation time was 3 hours (range 2–4 hours).

Anterior chamber maintainer was first put into anterior chamber. Next, corneal trephination was performed (Figure 5) using handheld trephine and microcorneal scissors (diameter of the corneal button 7.5 mm). The traumatic cataract was then removed with phacoemulsification and next a scleral fixation of artificial intraocular lens was performed. The Landers wide-field TKP (Ocular Instruments, Bellevue, WA) with 1 mm trunk was then placed into the corneal bed and sutured to the limbus using Vicryl 8.0 sutures (Figure 6). Infusion cannula was put to the vitreous cavity and visualized. Additional sclerotomies for the cutter and light pipe were done around the TKP to perform 23-gauge (G) PPV (Constellation, Alcon, Fort Worth, Texas) including posterior vitreous detachment and shaving of the vitreous base. After dying with indocyanine green, internal limiting membrane (ILM) peeling was done (Figure 7). Perfluorocarbon liquids were used to attach the retina. At the end of the operation TKP was removed and the donor cornea button (diameter 7.75 mm) was sutured in place using Nylon 10.0 full thickness sutures after removal of the TKP. Next, fluid-air and air-silicone oil (5 000 cSt) exchange was done. The sclerotomies were closed with Vicryl 7.0 sutures.

4. Results

The inclusion criteria were met by 12 patients (Table 1). The mean age of included patients was 42 years (range 21–71 years); there were 10 males and 2 females. As a mechanism of trauma (Birmingham Eye Trauma Terminology (BETT) scale) there were 7 lacerations, IOFB was present in four cases, and there was one eye rupture. Wound location was classified according to Ocular Trauma Classification Group as zone I in 5 eyes, as zone II in 5 eyes, and as zone III in 2 eyes. Visual acuities at presentation were as follows: 4 NLP eyes, 2 light perception eyes, HM in 5 eyes, and CF in 1 eye. There was an improvement of the visual acuity in 7 eyes (59%), no change in 4 (33%) eyes, and worsening in 1 case (8%). There were three NLP eyes that did not improve in the visual acuity. One revealed hypotony, one phthisis bulbi. Final visual acuities were as follows: 4 NLP eyes, 1 HM eye, and 7 CF eyes, the best CF to 2 m (case 3).

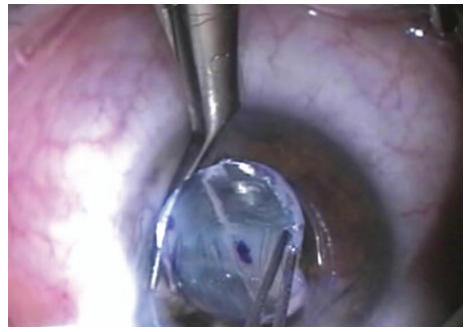

Figure 5: Trephining the cornea during combined vitrectomy/penetrating keratoplasty/temporary keratoprosthesis surgery.

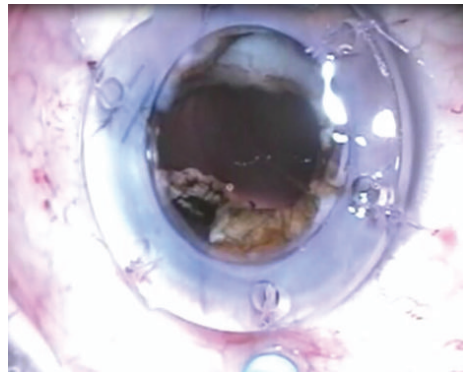

Figure 6: Wide-field temporary keratoprosthesis sutured to the corneal bed using six Vicryl sutures.

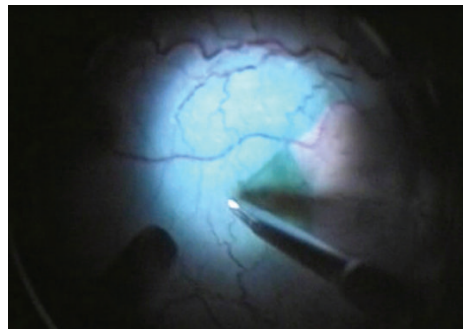

Figure 7: Internal limiting membrane peeling visualized through the temporary keratoprosthesis after dying with indocyanine green during vitrectomy.

Table 1: Patients' characteristics: age, gender, type of injury, initial and final visual acuity, intraocular pressure, clarity of the corneal graft, attachment of the retina, complications, follow-up period, time from injury, and operation time.

Number	Gender	Age (years)	Type of injury, zone	Initial visual acuity, intraocular pressure	Final visual acuity, intraocular pressure	Clarity of the corneal graft, attachment of the retina	Complications	Follow-up period (months)	Days from injury	Surgical time (hours)
1	Male	59	Penetration, zone I	Counting fingers, 12 mmHg	Counting fingers to 50 cm, 14 mmHg	Opaque cornea, retina attached	Graft failure	14	24	3.5
2	Female	39	Penetration, zone I	Hand motion, 14 mmHg	Counting fingers to 30 cm, 20 mmHg	Clear cornea, retina attached	Secondary glaucoma, implantation of the Ahmed valve	18	30	3.0
3	Male	20	Penetration, zone II	Light perception, 8 mmHg	Counting fingers to 2 m, 9 mmHg	Opaque cornea, retina attached	Graft failure, hypotony, anterior synechiae	12	14	2.5
4	Male	71	Penetration, zone III	Hand motion, 16 mmHg	No light perception, 7 mmHg	Opaque cornea, retina attached	Phthisis bulbi	13	19	4.0
5	Male	43	Penetration, zone II	Hand motion, 17 mmHg	Hand motion, 13 mmHg	Opaque cornea, retinal detachment, PVR	Graft failure, anterior synechiae, retinal detachment	14	25	4.0
6	Male	48	Rupture, zone III	No light perception, 16 mmHg	No light perception, 14 mmHg	Opaque cornea, retina attached	Phthisis bulbi	13	23	3.5
7	Male	24	Intraocular foreign body, zone I	Hand motion hypo	Counting fingers to 70 cm, 14 mmHg	Cornea clear, retina attached	None	12	13	3.5
8	Male	64	Penetration, zone I	No light perception, 17 mmHg	No light perception, 15 mmHg	Opaque cornea, retina attached	Graft failure	29	45	4.0
9	Male	62	Intraocular foreign body, zone I	Hand motion, 12 mmHg	Counting fingers to 20 cm, 13 mmHg	Opaque cornea, retina attached	Graft failure	12	20	3.0
10	Female	21	Intraocular foreign body, zone II	No light perception, 13 mmHg	Counting fingers to 1 m, 25 mmHg	Opaque cornea, retina attached	Graft failure, secondary glaucoma, implantation of the Ahmed valve	24	14	2.5
11	Male	31	Intraocular foreign body, zone II	No light perception, 8 mmHg	No light perception, 7 mmHg	Clear cornea, retina attached	Hypotony	12	32	3.0
12	Male	22	Penetration, zone II	Light perception, 11 mmHg	Counting fingers, 12 mmHg	Opaque cornea, retina attached	Graft failure, anterior synechiae	16	24	3.0

The corneal graft was transparent during the follow-up in 3 cases (25%) (Figure 8). Graft failure was observed in 9 eyes (75%) (Figure 9). Ahmed valve was implanted in two eyes due to uncontrolled glaucoma, cases 2 and 10. Overall, phthisis bulbi evolved in 2 cases (16%), cases 4 and 6; hypotony evolved in another 2 cases (16%), cases 3 and 11. Silicone oil was used as a tamponade in all cases; retina was reattached in 92% of cases. No eye was enucleated; no eye revealed signs of sympathetic ophthalmia. All eyes were silicon-oil sustained.

5. Discussion

Wide-field Landers TKP is a useful intraoperative tool to visualize the posterior segment even in case of large posttraumatic corneal wounds. By performing combined PPV/TKP/PKP procedure many maneuvers are possible during PPV: ILM peeling, vitreous shaving, and fluid-air and air-silicone-oil exchange, using perfluorocarbon liquids. Landers wide-field TKP is not leaking during indenting and is reusable.

Nevertheless, both functional and anatomical outcomes of our case series of 12 patients were not favorable probably because of severity of the initial trauma. However, the natural course of the disease would be much more worse resulting in phthisis bulbi in most of the cases.

The reason for these unsatisfactory results in our case series was mostly corneal graft failure (75%) or hypotony due to ciliary body dysfunction (16%) or glaucoma (16%).

All eyes in our study were silicone-oil sustained and it is known that silicone oil may stress the donor endothelium and may result in decompensation of the graft [9, 10]. Moreover, in eyes with long-term silicone oil tamponade, silicon oil may be present in the anterior chamber causing keratopathy by direct contact with corneal endothelium [5].

In other case series the percentage of eyes with clear corneas after longitudinal follow-up following combined PPV/TKP/PKP ranged from 15% [11] to 75% [12]. It has been already shown that the risk of corneal graft failure is increased if PKP is performed during the first 2 months after ocular trauma [11]. In our series the mean time from injury to PPV/TKP/PKP was 24 days. On the other side it is recommended to perform PPV after severe ocular trauma and retinal detachment in the first two weeks [13, 14]. Dong and colleagues [12] suggest performing this combined surgery within 1 month from injury. They reported results of 78 eyes operated with Landers keratoprosthesis after 24 months of observation. Unsatisfactory postoperative visual acuity in their study was due to graft failure, recurrent PVR, or secondary glaucoma.

In the literature, the final retinal reattachment varied from 43% [15] to 91% [16]. In our case series reattachment rate was quite high and amounted to 92%.

In the prediction of the good visual outcome after open-globe injury several factors have been identified: initial visual acuity [7], afferent pupillary defect, type of trauma, wound location, and retinal detachment [13]. Thus, it should be considered in patients with both anterior and posterior segment damage after severe eye trauma classified for combined surgical procedure.

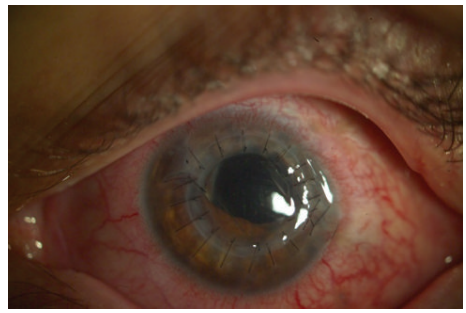

Figure 8: The eye after one month of the follow-up after combined surgery, clear corneal graft.

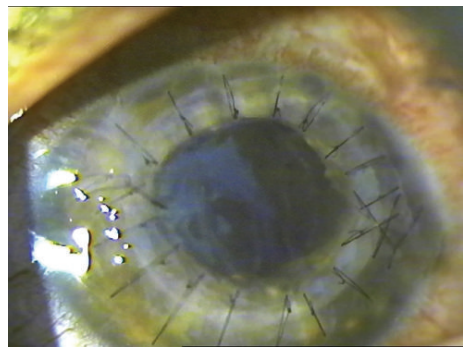

Figure 9: Graft failure after one year of the follow-up after combined surgery.

Some authors [17] prefer to perform TKP-assisted PPV first and suture back the corneal button. They perform TKP later, after one year, as a second procedure in selected cases, when intraocular pressure is more than 8 mmHg. However, in a study of Chen et al. 13% of eyes were enucleated due to atrophia bulbi, 62% were silicone-oil sustained, 20% of eyes were anatomically restored and 4% evolved recurrent retinal detachment [17].

Chun et al. published a study comparing application of temporary keratoprosthesis and endoscopy [18]. Authors concluded that the major differences observed between the two techniques are that endoscopy allows earlier intervention and shorter surgical times than does TKP.

In conclusion, combined PPV/TKP/PKP provides the opportunity to salvage the eyes after severe ocular trauma. However, patients should be informed about the longitudinal results of this combined surgery and that visual recovery is rather poor. Careful selection of patients should be done in order to reduce the risk of complications.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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Clinical Study

Clear Corneal Phacovitrectomy with Posterior Capsulorhexis and IOL Implantation in Management of Selective Vitreoretinal Cases

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Purpose. To describe our technique, clear corneal phacovitrectomy with posterior capsulorhexis (CCPV), for the management of selected posterior segment intraocular foreign body (IOFB), posteriorly dislocated lens fragments (PDLF), and proliferative diabetic retinopathy (PDR) cases. *Methods*. This was a single-center retrospective interventional case series. In 21 patients (21 eyes) we performed phacovitrectomy through three clear corneal tunnel incisions (CCTI) and posterior capsulorhexis to remove IOFB ($n = 8$), PDLF from the vitreous cavity after complicated phacoemulsification ($n = 6$), and vitreous hemorrhage and epiretinal membranes in PDR ($n = 7$). The procedure was completed with implantation of a hydrophobic acrylic IOL through the CCTI. *Results*. The mean visual acuity (logMAR) was 0.90 preoperative and improved to 0.26 over a mean follow-up of 8.7 months (range, 6–12 months). The intraocular lens was implanted into the capsular bag ($n = 12$) or onto the anterior capsule ($n = 9$). One PDR patient experienced an intraprocedural complication, hemorrhage from isolated fibrovascular adhesions. One IOFB patient developed apparent anterior proliferative vitreoretinopathy and required a repeat intervention. *Conclusion*. Selected vitreoretinal IOFB, PDLF, and PDR cases can be successfully managed by a combined surgical approach involving clear corneal phacovitrectomy with posterior capsulorhexis and implantation of an IOL, with good visual outcome and a low complication rate.

1. Introduction

The advent of minimally invasive technique has changed the surgical approaches to management of both anterior and posterior segment disorders and provided the potential for performance of multiple surgical procedures in all ocular structures within the same operation, with prompt switching from one of the numerous entry sites and/or instruments to another. It is especially helpful in an open-globe injury (OGI), where a variety of alternating anterior and posterior segment maneuvers "pole to pole surgery" within the same operation are often required [1]. To deliver the best possible surgical outcome in a short time, the surgeon is to be skilled in both anterior segment (e.g., cataract and iris) and vitreoretinal surgery (VRS). Such a requirement occurs not only in ocular traumas (particularly intraocular foreign body (IOFB) injuries [2–5]), but also, for example, when the surgeon has to remove lens fragments from the fundus after complicated phacoemulsification surgery [6, 7] or to repair alterations in the central vitreoretinal interface in proliferative diabetic retinopathy (PDR) [8–10].

Therefore, the aim of this study was to describe our combined surgical approach involving clear corneal phacovitrectomy with posterior capsulorhexis (CCPV) and implantation of an IOL, for the management of selected posterior segment IOFB, posteriorly dislocated lens fragments (PDLF), and PDR cases.

2. Material and Methods

This study was conducted at Military Medical Academy (St. Petersburg, Russia) during 2010 to 2014. The study was approved by Ethics Committee of Military Medical Academy.

We retrospectively analyzed the surgical outcomes in 21 eyes of 21 patients who underwent CCPV for removal of 2 to 5-mm IOFB in type C OGI ($n = 8$) (according to the International Society of Ocular Trauma (ISOT) classification) [11, 12], lens nuclear fragments and lenticular matter from the vitreous cavity after complicated phacoemulsification surgery ($n = 6$), and vitreous hemorrhage in PDR ($n = 7$).

The main inclusion criterion for the procedure was the central vitreous cavity location and/or central fundus location of either IOFB or critical pathologically altered structures to be removed. The patients had had lens damage or opacities requiring phacoemulsification surgery ($n = 15$) or aphakia after complicated phacoemulsification surgery ($n = 6$). All of them underwent operation at our institution.

Retrospectively, the following characteristics were assessed: (1) preoperative, early postoperative (within 7 days), and final postoperative (6–12 months) visual acuity levels; (2) the potential to achieve the surgical goals: removal of cataract, IOFB, lens fragments, vitreous hemorrhage and proliferative tissue, and implantation of an IOL; (3) the occurrence of any of the following complications: (a) critical complications making the surgeon change the surgery plan, (b) noncritical complications hampering the procedure, and (c) late follow-up complications; (4) intraoperational pupillary changes; (5) the state of posterior capsulorhexis depending on its size and shape; (6) the potential to implant an IOL into the capsular bag or onto the anterior capsule; and (7) self-sealing characteristics of the incisions in the CCPV.

2.1. Preoperative Evaluation. Preoperatively, routine examination and, if indicated, ultrasound B-scan, roentgen, or computer tomography imaging were performed to localize IOFBs. Visual acuity was assessed using the Snellen Chart, and the results were converted to logMAR visual acuity for analysis.

2.2. Surgical Technique. The Infiniti Vision System (Alcon Laboratories Inc., Fort Worth, TX) and Accurus Vitrectomy System (Alcon Laboratories Inc.) were used to perform phacoemulsification of the lens and 25G+ vitrectomy, respectively.

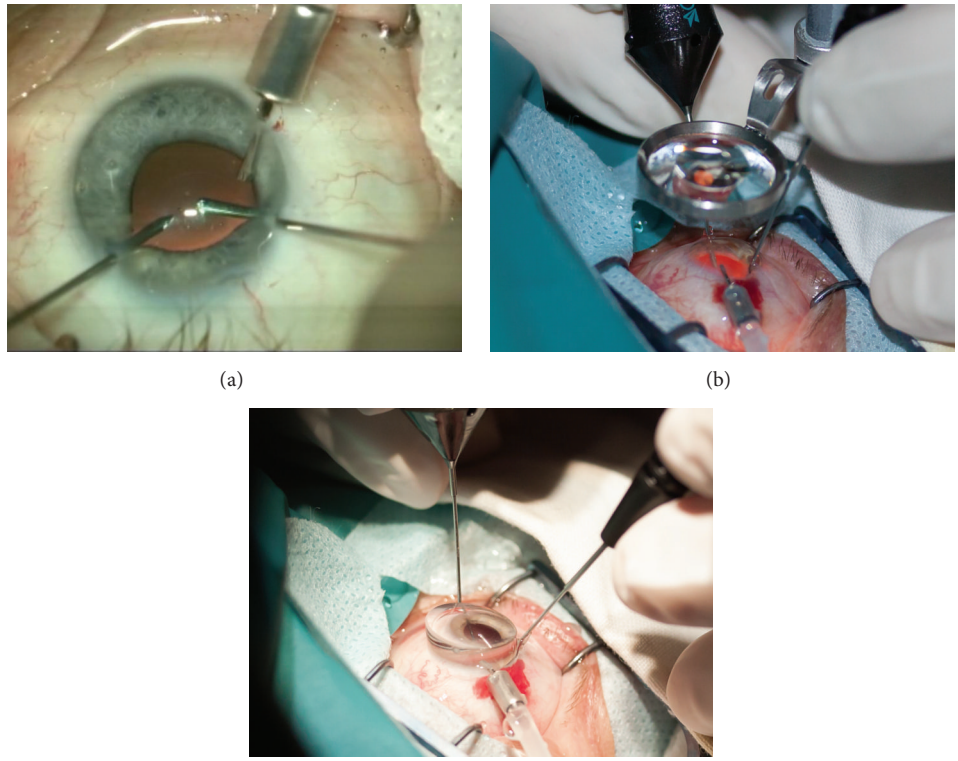
2.2.1. Phaco Surgery Stage. First, three clear corneal tunnel incisions (CCTI) were made in a standard manner in the superonasal, superotemporal, and inferotemporal quadrants (if the phacoemulsification stage was present, one 2.2-mm superonasal or superotemporal and two 1.0-mm incisions were made; if not, all the incisions were as wide as 1.0 mm). Phacoemulsification or, in eyes with soft nucleus ($n = 5$), phacoaspiration was then performed. In 15 cases undergoing planned phacovitrectomy, to secure the capsular bag and prevent iatrogenic damage to it, a capsular tension ring was implanted after performance of an anterior capsulorhexis with the diameter reduced to 4.5 mm.

2.2.2. Vitrectomy. In 6 cases undergoing planned phacoemulsification only surgery, it was converted to phacovitrectomy after damage to the posterior capsule and dislocation of nuclear fragments smaller than one-fourth the size of the lens nucleus to the vitreous cavity. Before the vitrectomy, an infusion cannula was inserted through the inferotemporal CCTI. 25G+ light probe and vitreous cutter were introduced through the original CCTIs in both superior quadrants (Figure 1(a)), and the cutter was used to make a posterior circular (3.5–4.0-mm diameter, $n = 6$) or oval (3.5 mm × 6.0 mm dimensions, $n = 9$) capsulorhexis. Vitrectomy was thereafter performed. During vitrectomy in OGI with IOFB, special care was given to the sites of vitreous strand attachment, retinal injury, and IOFB occurrence. A BIOM 3 system (Oculus, Wetzlar, Germany) with SDI II m invertor (Oculus) (Figure 1(b)) and 8-mm diameter lenses of Pediatric Vitrectomy Lens Set (Ocular Instruments Inc., Bellevue, WA) (Figure 1(c)) were used for the posterior segment work. The posterior hyaloid was removed in each patient. If there was no posterior vitreous detachment, triamcinolone acetonide (40 mg/1 mL) was injected for better visualization of the cortical vitreous. In two cases with IOFB, a cohesive ophthalmic viscosurgical device (OVD), Provisc (Alcon Laboratories Inc.), was injected intraoperatively to stabilize and protect the retina. A viscous dispersive OVD, DisCoVisc (Alcon Laboratories Inc.), was used to stabilize the anterior chamber and capsular bag and protect the corneal endothelium [13].

2.2.3. Removal of Posterior Segment IOFB in Type C OGI. After completion of the phacoemulsification (Figure 2(a)) and vitrectomy, the foreign body, if any, was grasped with forceps ($n = 6$) (Figure 2(b)) or a magnet tip ($n = 2$) introduced through the CCTI and posterior capsulorhexis. If successfully grasped with forceps, the IOFB was delivered to the anterior chamber.

In 4/8 of IOFB cases, the IOFB was temporarily left on either the iris or anterior/posterior lens capsule (Figure 2(c)), outside of the capsulorhexis, enabling the surgeon to choose the most suitable forceps and incision width for its successful removal (Figure 2(d)) after removal of the BIOM 3 (from optical microscope system) or corneal lens. When a magnet was required to grasp a large IOFB, the vitreous cavity was filled with perfluorocarbon liquid (PFCL) to maintain the eye shape and immobilize the retina, and this IOFB was removed immediately through capsulorhexes and the CCTI. The PFCL was then easily removed from the eye through the original CCTI by aspiration. At the IOFB site and retinal injury site, barrier laser photocoagulation of the retina was performed when required ($n = 4$ and $n = 2$, resp.).

2.2.4. Removal of PDLF from the Vitreous Cavity after Complicated Phacoemulsification Surgery. To remove lens nuclear fragments from the fundus, only core vitrectomy, without thorough surgical manipulations of the peripheral vitreous, was performed. The main goal of vitrectomy in those eyes was to prevent anterior chamber vitreous prolapse and vitreous incarceration in the CCTI wounds. Additionally, the lens fragments usually retained in the central fundus were to be removed completely from the eye. If the retained lens fragments were large and very dense ($n = 1$), PFCL was



(a) (b)

(c)

Figure 1: Intraoperative photographs showing the positions of the instruments at different stages of CCPV. (a) Initial stage (making the posterior capsulorhexis). (b) Use of BIOM 3 system with SDI II m invertor for posterior segment work. (c) Use of 8-mm diameter lenses of Pediatric Vitrectomy Lens Set.

introduced intraoperativey to make them immobilized and to prevent iatrogenic retinal damage. After being crushed between vitreous cutter and fibre-optic probe, nuclear fragments were removed with the cutter.

2.2.5. Removal of Vitreous Hemorrhage and Epiretinal Membranes in PDR. In patients with PDR, after core vitrectomy (involving subtotal removal of vitreous hemorrhage with the cutter, if required), epiretinal membranes were peeled (Figures 3(a) and 3(b)), and panretinal laser photocoagulation was performed. Hemorrhages were stopped with endodiathermy (Figure 3(c)), if required.

It must be emphasized that such manipulations were possible in patients with pathological vitreoretinal alterations located only at the central fundus. Vitreoretinal part of the operation was completed with the eye filled with BSS PLUS Sterile Intraocular Irrigating Solution (Alcon Laboratories Inc.). Additionally, in IOFB cases, the retinal periphery was examined using scleral depression with the BIOM. Thereafter, in all eyes of the study, a hydrophobic acrylic IOL, Acrysof IQ SN60WF (Alcon Laboratories Inc.), was implanted into the capsular bag or placed onto the anterior capsule through the CCTI (Figure 3(d)).

3. Results

Mean preoperative LogMAR visual acuity was 0.90 (range 3.0–0.30) and improved to 0.21 (range 1.0–0) in the early follow-up. Moreover, it remained 0.26 (range 1.0–0) over a mean follow-up period of 8.7 months (range 6–12 months) (Table 1).

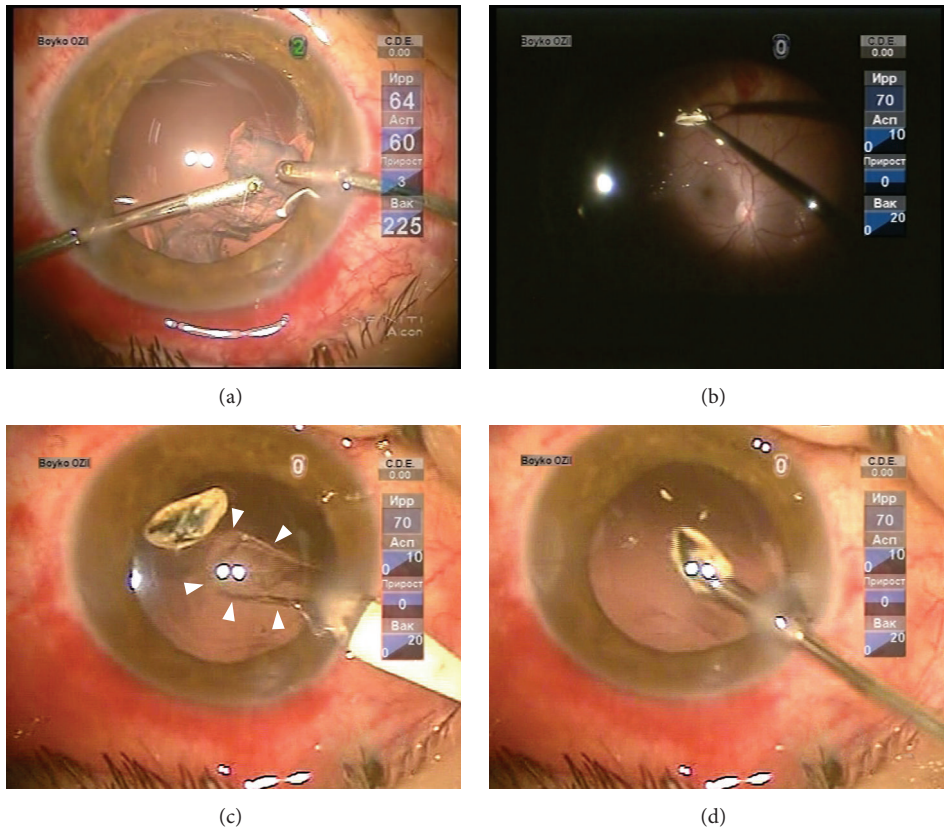
In all patients, the CCPV made it possible to achieve surgical goals (removal of cataract, IOFB (Figures 4(a) and 4(b)), lens matter, or vitreous hemorrhage and epiretinal proliferative membranes), to implant the IOL (Figure 4(c)) (in 9 eyes, it was placed onto the anterior capsule) and to perform endolaser photocoagulation of the retina (Figure 4(d)).

In the vast majority of the patients (19/21, 90.5%), CCPV was performed without complications and technical problems. No critical complications making the surgeon change the surgery plan were noted. Corneal edema, however, developed in one patient. One PDR patient experienced an intraprocedural complication, hemorrhage from isolated fibrovascular adhesions. In the latter patient, to complete the vitrectomy stage of the operation and to ensure adequate access to the source of hemorrhage, the surgeon had to convert to conventional 25G+ pars plana vitrectomy. In one IOFB patient with type C OGI related to zone II (the ciliary body injury of this zone is of the highest potential risk for the development of anterior proliferative vitreoretinopathy (PVR) in the posttraumatic eye), apparent anterior PVR did develop during the late follow-up (6 months postoperatively). This resulted in tractional retinal detachment, thus requiring a repeat intervention (vitreomembranectomy with a silicone tamponade of the vitreous cavity). Following this reintervention, visual acuity was 20/200.

Table 1: Baseline and follow-up visual acuity.

Reason for surgery	Baseline VA (*n*, eyes)			VA in the near follow-up (*n*, eyes)	VA, 6–12 months postoperatively (*n*, eyes)
	20/20–20/200	<20/200–20/2000	<20/2000–light perception	20/20–20/200	20/20–20/200
OGI and IOFB	2	4	2	8	8
Lens nuclear fragments and lens matter after complicated phaco surgery	6	—	—	6	6
PDR	2	3	2	7	7
Total	10	7	4	21	21

VA: visual acuity; OGI: open globe injury; IOFB: intraocular foreign body; PDR: proliferative diabetic retinopathy.



(a) (b)

(c) (d)

Figure 2: Intraoperative photographs showing the steps of CCPV in the patient with IOFB and traumatic cataract. (a) Completion of phacoemulsification: aspiration and irrigation of the lens material. (b) After vitrectomy, the IOFB was grasped with gripping forceps introduced through the clear corneal tunnel incision. (c) The IOFB was left on the posterior capsule of the lens for the time required to widen the clear corneal tunnel incision. The anterior chamber was filled with a cohesive ophthalmic viscosurgical device. Note the well-defined contour of the posterior capsulorhexis (arrowheads). (d) IOFB removal through the clear corneal tunnel incision of adequate width.

In most patients with initially wide pupil, the pupil size was maintained till the end of the procedure. However, in some eyes, the pupil became smaller by the end of the operation due to iris touch to the instrument. Intraoperational changes in pupil size are presented in Table 2.

In the first six IOFB and PDR cases, a 3.5–4.0-mm posterior circular capsulorhexis was used, and posterior capsule tear was noted in 3/6 patients (50%). In the next nine IOFB and PDR cases patients, we changed to the use of a posterior oval capsulorhexis of 3.5 mm × 6.0 mm dimensions, thus making it possible to avoid its significant ruptures. However, insignificant damage to capsulorhexis (marginal tears up to 2 mm) was noted during manipulations in 2/9 cases (22.2%).

At the end of the operation, "in the bag implantation" and "onto the anterior capsule placement" of the IOL were used in 12/21 patients (57.1%) and 9/21 patients (42.9%), respectively. Out of 9 cases of "onto the anterior capsule placement"

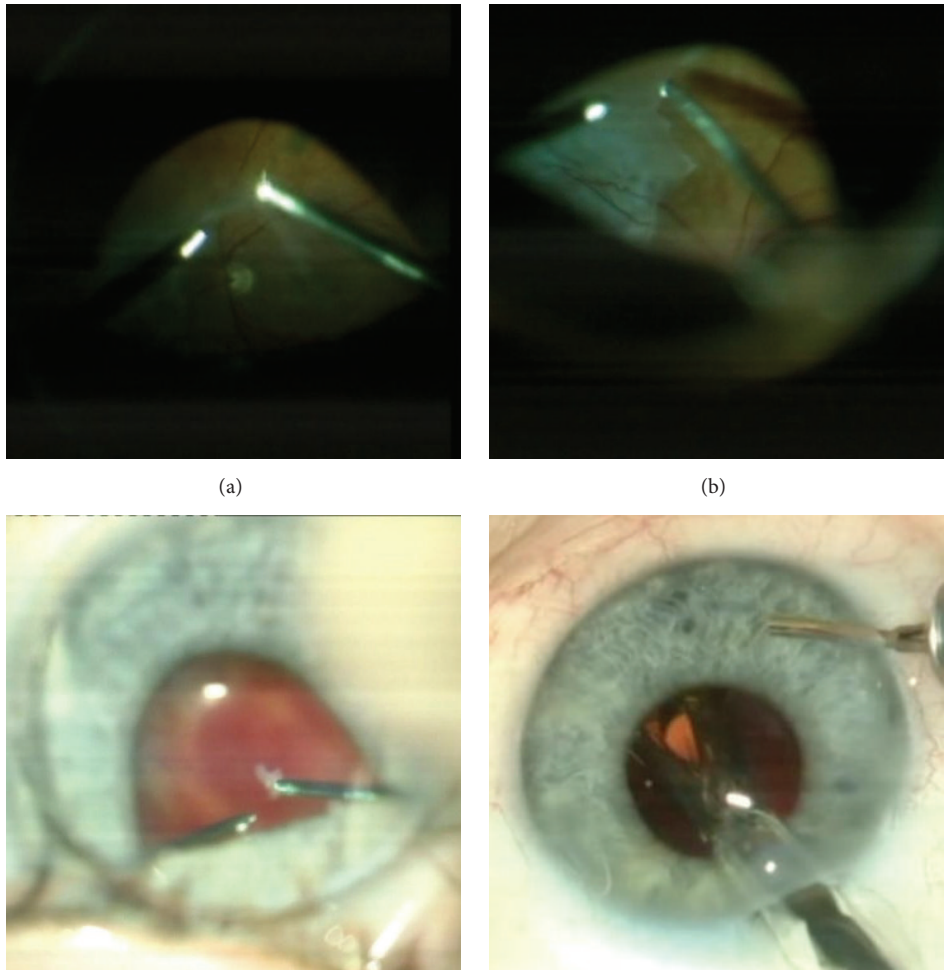


Figure 3: Intraoperative photographs showing the steps of CCPV in the patient with proliferative diabetic retinopathy. (a) Separation of the posterior hyaloid from the retina after a core vitrectomy. (b) Cutting and removal of preretinal membranes. (c) Endodiathermy of the bleeding vessel. (d) Foldable IOL implantation in the capsular bag.

Table 2: Intraoperational changes in pupil size.

Pupil size	Immediately prior to the operation (n, number of eyes)	At the end of the operation (n, number of eyes)
>6 mm	17	10
3 to 6 mm	3	7
<3 mm	1	4

of the IOL, 5 (3 cases of 3.5–4.0-mm posterior circular capsulorhexis and 2 cases of posterior oval capsulorhexis of 3.5 mm × 6.0 mm) were associated with intraoperational damage of the capsular bag, and 4 cases were associated with preoperative OGI-related damage of the capsular bag. In the late follow-up, the IOL remained stable and well-centered. Moreover, examination of retinal periphery revealed no iatrogenic retinal tear in any of IOFB cases.

Usually, the 2.2-mm CCTI maintained its resistance to leakage. However, in cases involving the removal of a large IOFB through the tunnel, the surgeon had to enlarge the latter, and leaks did occur in spite of filling the anterior chamber with viscoelastic. In two cases, a 10–0 nylon suture was placed at the incision site after enlarging the 2.2-mm CCTI. One mm wide CCTIs demonstrated reliable resistance to leakage during phacoemulsification irrigation/aspiration and satisfactory resistance to leakage during the use of 25G+ instruments.

4. Discussion

The CCPV technique proposed makes it possible to achieve good functional outcomes in (1) OGI with IOFB and traumatic cataract, (2) posteriorly dislocated lens fragments after complicated phaco surgery, and (3) PDR with complicated cataract.

Our results with this technique are rather similar to those achieved by other authors with conventional phacovitrectomy involving separate corneal and transscleral accesses in

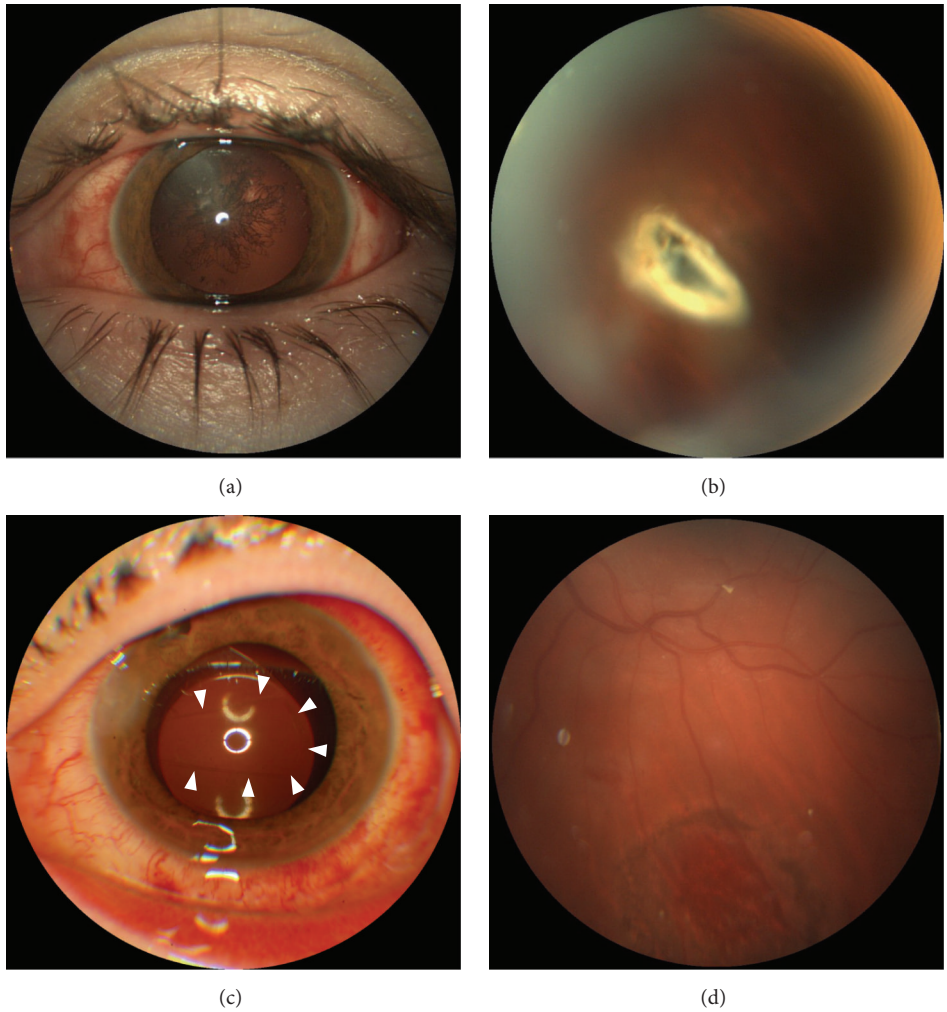


Figure 4: Preoperative (top) and postoperative (bottom) photographs of the eye of the patient with IOFB, with preoperative visual acuity of 20/80 and postoperative acuity of 20/40. (a) Traumatic cataract. (b) Intraretinal metallic IOFB at the midretinal periphery. (c) The IOL implanted into the capsular bag through the posterior capsulorhexis (arrowheads). (d) Chorioretinal scar at the IOFB site.

combined anterior and posterior segment surgery [14, 15] as well with the similar "clear corneal vitrectomy" technique in other clinical situations [D].

In addition to this, our technique has certain advantages over conventional phacovitrectomy. The main of these advantages is the absence of surgical trauma to the ciliary body and basal vitreous during the introduction or removal of vitreous instruments and removal of IOFB, if any. There is no requirement for placement of scleral ports in the pars plana and all incisions are made in avascular limbal zone without the use of ports. Therefore, the CCPV technique may be called a port-free vitrectomy.

Therefore, there are (1) no risks of vitreous prolapse to a sclerotomy wound, vitreous incarceration, or hemorrhage from the wound and (2) no such a source of additional tractions as vitreous fibrils attached to the inside of the wound. This is important in the treatment of PDR, since it prevents the development of neovascularization at sclerotomy sites and risks of recurrent vitreous hemorrhage related to these sites [16, 17]. Moreover, with our approach, the risk of iatrogenic potentiation of anterior PVR is minimized [18, 19].

Such an approach can involve the use of the instruments of larger diameter (23G), as it has been shown by Li et al. [20]. We used a 25G+ vitrectomy instrumentation system since, compared with a 23G-system, it is beneficial for reduced anterior segment trauma. Although the use of the instruments of a smaller diameter (27G) also seems possible, it would result in increased vitrectomy time compared to our choice. Additionally, since no trocars are used, one may expect problems associated with deformation of the instruments and leakage through CCTI in this case. In the CCPV, the maximal possible mydriasis is required not only for good visualization, but also for the prevention of iris trauma with the instruments. However, even if the pupil is narrow initially or becomes narrower intraoperatively, the vitreous instruments introduced ensure good mechanical pupil dilation and, thereby, provide the surgeon with sufficient visualization. Therefore, a narrow pupil is not a limitation of our approach.

Posterior capsulorhexis formation is a key feature of the phacovitrectomy technique proposed. The posterior capsular window allows the surgeon to get the very "bottom" of the eye and to deliver an IOFB from the posterior to the anterior segment. The window size should correspond first to the dimensions of the IOFB to be removed and second to the diameter of optics and design features of the IOL haptics.

Another advantage of this approach is that posterior capsulorhexis prevents posterior capsule opacification and enables successful removal of the anterior hyaloid membrane, which is not always achieved with the saved crystalline lens. It is of major importance, since the membrane provides a scaffolding for the development of (1) anterior PVR and retinal detachment in OGI and (2) fibrovascular proliferation in diabetes.

Whenever possible, the posterior capsulorhexis should be completed with a smooth edge to maintain the mechanical strength, elasticity, and integrity of the capsule. Such an approach makes it possible (1) to perform manipulations in the vitreous cavity freely when working with its structures and even with the retina and (2) to implant an IOL into the capsular bag easily on completion of vitreoretinal surgery.

Our findings showed that performance of a clear corneal phacovitrectomy with a posterior capsulorhexis of a 3.5–4.0-mm diameter may be hampered by capsulorhexis extension (by vitreoretinal instruments), tear and radialization, with the resultant requirement for "onto the anterior capsule" implantation. At the final stage of the development of the methodology of the CCPV, we changed to the use of posterior oval capsulorhexis of 3.5 mm × 6.0 mm dimensions, which allowed us to prevent significant iatrogenic damage to the posterior capsule.

IOFB removal through a CCTI offers significantly improved visual control during withdrawal of the IOFB from the fibrous capsule of the eye. Additionally, to safeguard against IOFB entrapment and falling, we use two tools in the posterior and anterior chambers for catching this IOFB. In IOFB removal through the nontransparent sclera, the possibility of the improved visual control is absent, and if the IOFB size does not correspond to that of the scleral wound, the IOFB may get trapped in the wound or fall onto the retina. Furthermore, the risks of hemorrhage and of the development of anterior PVR are minimized due to the absence of trauma to the ciliary body and basal vitreous.

In IOFB removal through a CCTI, after viscoelastic injection, the surgeon can protect the retina through better control of the shape, size, and turgor of the globe, which is sometimes difficult to ensure when a large (at least 5-mm) IOFB is removed by a transscleral route.

In most patients, an IOL was implanted into the capsular bag in spite of the presence of posterior capsulorhexis and absence of vitreous support. However, in some patients (in eyes with posteriorly dislocated lens fragments after complicated phaco surgery and in iatrogenic tears of a small-diameter posterior capsulorhexis), we had to implant the IOL onto the anterior capsule. Despite being technically simpler than intracapsular implantation, this method is less preferable. In such cases, whenever possible, IOL optics should be captured within the anterior capsulorhexis to avoid iris contact, adhesion to the iris, and further development of myopia.

The globe's resistance to leakage was maintained during CCPV in all patients reported here. However, to ensure the required resistance, the surgeon should use CCTIs of reduced length and width (a more vertical incision profile) and maintain a deep anterior chamber by repeated viscoelastic injections throughout the operation, especially at the time of IOFB removal. Another advantage of the technique reported here is that it allows for the possibility of providing reliable and controllable resistance of CCTIs to leakage under IOP on completion of the procedure. This is a fundamental difference from scleral access incisions used in 25G+ vitrectomy. The latter incisions cannot be made resistant to leakage due to the following reasons: interference from the conjunctiva covering them, poor visualization, vitreous incarceration, and a risk of getting the liquid into the suprachoroidal space. Therefore, in some cases, to minimize the risks of postoperative hypotony and of hemorrhagic and inflammatory complications, [21] the surgeon has to coagulate the scleral access incisions [21] and even close them with sutures.

When we were on a "discovery curve" of CCPV, the operative time exceeded that of conventional phacovitrectomy; however, after a period of time, there is no significant difference in operative time. In comparison with the conventional separate performance of posterior and anterior segment surgeries, conventional combined phacovitrectomy reduces overall healthcare costs [22, 23], time of both overall postoperative recovery course, and visual rehabilitation of patients [24, 25]. Since the CCPV technique retains the basic features of conventional combined phacovitrectomy, it will share the above-mentioned advantages of the combined approach.

Nevertheless, the CCPV approach has the following limitations. First, the instruments are positioned more vertical than in conventional vitrectomy; therefore, the anterior and central vitreous cavities are the most comfortable sites for the surgeon's work [26]. Second, access to the peripheral fundus is possible but, for two instruments, is complicated due to, among other things, limited visualization. Third, with the surgeon's instruments and hands positioned vertically, they often touch and displace the BIOM lens, thus impairing visualization of deeper lying structures. The transition to use of smaller diameter contact lenses is, however, helpful in this case. Fourth, in manipulations of the tips of vitreous instruments with a limbal fixation point, the corneal surface is subjected to deformations; this may also impair visualization. The problem can be solved with the use of contact lenses and viscoelastic as immersion medium. Fifth, if corneal contact lenses are used, they often hinder the maneuvers of the instruments, and the latter may cause lens displacement, thus also impairing visualization. Sixth, since utilization of CCPV technique impedes access to the basal vitreous, this tactics is not recommended if manipulations of the most peripheral fundus are envisaged, including those involving the basal vitreous. Additionally, positions of the instruments hamper unobstructed examination of retinal periphery for identification of iatrogenic retinal tears. This limitation can be partially overcome by performing examination with scleral

depression (in the study reported, it was performed in IOFB patients and revealed no iatrogenic retinal tears). Moreover, in CCPV, the risk for peripheral retinal tears will be lower than in conventional pars plana vitrectomy because of absence of mechanical detachment of the vitreous (since no removal of the basal vitreous is performed) and sclerotomy wounds, two important risk factors for this complication [27, 28]. Seventh, since a high risk of iatrogenic damage to the capsular bag might be a key problem of CCPV technique, the surgeon should perform a number of intraoperational measures (implanting a tension ring and using a posterior oval capsulorhexis of a rather wide, 3.5 mm × 6 mm, pattern) to reduce this risk. Nevertheless, in our case series, we observed no cases of critical damage to the capsular bag that could worsen the functional outcome. Moreover, no significant capsular bag damage-related problems have been mentioned in the works describing "23G vitrectomy via corneal approach" [20] and "clear corneal vitrectomy combined with phacoemulsification and foldable intraocular lens implantation" [29] in other clinical situations. Finally, the lengths of standard instruments may be not sufficient for comfortable work in all the parts of vitreous cavity, particularly in eyes with an axial length greater than 27 mm. Additionally, the CCPV technique might compromise corneal endothelium; however, analysis has revealed no significant difference between 25-G clear corneal vitrectomy combined with phacoemulsification and 25-gauge pars plana vitrectomy with corneal incision cataract surgery in endothelial cell density loss [29], so we did not assess this index in our study.

It should be noted that the possibility of conversion to a standard pars plana 25G+ vitrectomy always exists while performing the vitrectomy part of the procedure described above, if it becomes mandatory to expand the scope of surgery. Development of new relevant (1) visualization systems and (2) vitreous instruments with a 3–5 mm longer or curved design similar to that proposed for avoiding the crystalline lens touch [30] would be beneficial for further improvement of the technique.

The experience gained in this work showed that the technique proposed can yield good results provided the cases are carefully selected to meet all the following criteria: (1) pathologically altered ocular structures and IOFBs that need to be removed are located only at the central fundus, (2) in phakic eyes, lens extraction is indicated, and (3) surgical manipulation of the peripheral fundus is not required.

5. Conclusion

The CCPV technique proposed can yield good results in (1) OGI with IOFB and traumatic cataract, (2) posteriorly dislocated lens fragments after complicated phaco surgery, and (3) PDR with complicated cataract and might be successful in some other selective vitreoretinal cases; however, further refinement of the surgical technique, equipment, and instruments is required.

Disclosure

The authors have no proprietary or financial interest in any aspect of this report.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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Clinical Study

Small-Gauge Pars Plana Vitrectomy for the Management of Symptomatic Posterior Vitreous Detachment after Phacoemulsification and Multifocal Intraocular Lens Implantation: A Pilot Study from the Pan-American Collaborative Retina Study Group

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Purpose. To determine the efficacy of 23-gauge pars plana vitrectomy (PPV) for symptomatic posterior vitreous detachment (PVD) on visual acuity (VA) and quality after multifocal intraocular lenses (IOLs). *Methods*. In this prospective case series, patients who developed symptomatic PVD and were not satisfied with visual quality due to floaters and halos after multifocal IOL implantation underwent PPV. Examinations included LogMAR uncorrected visual acuity (UCVA), intraocular pressure, biomicroscopy, and indirect ophthalmoscopy at baseline and 1, 7, 30, and 180 days postoperatively. Ultrasonography and aberrometry were performed. The Visual Functioning Questionnaire 25 (VFQ-25) was administered preoperatively and at 30 days postoperatively. Both the postoperative UCVA and questionnaire results were compared to preoperative findings using the Wilcoxon test. *Results*. Sixteen eyes of 8 patients were included. VA significantly improved from 0.17 to 0.09 postoperatively ($P = 0.017$). All patients reported improvement of halos, glare, and floaters. VFQ-25 scores significantly improved in general vision ($P = 0.023$), near activities ($P = 0.043$), distance activities ($P = 0.041$), mental health ($P = 0.011$), role difficulties ($P = 0.042$), and driving ($P = 0.016$). *Conclusion*. PPV may increase UCVA and quality of vision in patients with bilateral multifocal IOLs and symptomatic PVD. Larger studies are advised.

1. Introduction

Posterior vitreous detachment (PVD) is defined as the separation of the posterior hyaloid from the internal limiting membrane [1]. It is age-related and becomes noticeable after the sixth decade of life (up to 63% prevalence) and is related to synchysis senilis [2]. Vitreous separation can cause visual symptoms such as photopsia from vitreoretinal traction and floaters resulting from the presence of condensed vitreous collagen [3]. About 30% of patients have floaters after development of PVD; however, most patients tolerate their symptoms [1, 2, 4]. A minority of patients report that these floaters are troublesome, in particular young myopic patients

and those whose work requires detailed visual tasks. Pseudophakic patients frequently report floaters, which may be explained by the improved postoperative contrast sensitivity related to the intraocular monofocal lens, which increases the perception of floaters in the visual field [2, 4]. PVD incidence is also increased after cataract surgery by phacoemulsification with implantation of a posterior chamber intraocular lens (IOL) [4].

Multifocal IOLs were designed to reduce the need for spectacles by providing two or more points of focus. Adverse effects include reduced contrast sensitivity and the subjective experience of halos around lights [5].

The apodized diffractive multifocal AcrySof ReSTOR IOL (Alcon, Fort Worth, TX) was designed specifically to reduce glare and halos and provide increased dominant distance vision for patients with large pupils [5]. This lens has a central 3.6 mm apodized optic area with 12 concentric diffractive zones on the anterior surface for gradual reduction of the diffractive increments from the center to the periphery [6]. Rayner M-flex multifocal IOLs (Rayner, London, UK) are based on multizoned refractive aspheric optic technology, with either four or five annular zones (depending on the IOL base power [7, 8]).

The multifocal IOL design with concentric rings of optical zones creates positive dysphotopsias, also called photic phenomena. Visual phenomena interfering with vision strongly affect patient satisfaction [9]. Tolerance to visual phenomena caused by multifocal IOLs usually improves over time. Researchers believe the brain adjusts to the altered visual input over time through neural adaptation [9]. To experience the full visual benefits of multifocal IOLs, most patients require a neuroadaptation period of about 6 months [10, 11].

In the present study, the authors investigated the role of sutureless pars plana vitrectomy treatment in patients with symptomatic PVD in terms of visual acuity (VA) and visual satisfaction (measured through a standardized questionnaire) in patients who previously underwent bilateral implantation of the ReSTOR +3 (Alcon, Fort Worth, TX) or the M-Flex IOLs (Rayner, London, UK).

2. Methods

This prospective case series included patients who were not satisfied with their VA and complained of halos, glare, and floaters for at least 6 months after having undergone bilateral phacoemulsification using a 2.2 mm microincision technique and implantation of ReSTOR +3 (Alcon, Fort Worth, TX) or M-Flex IOLs (Rayner, London, UK).

Patients underwent a complete preoperative ophthalmologic examination including evaluation of refractive status, measurement of far uncorrected VA (UCVA) and best-corrected VA (BCVA), slit-lamp examination, Goldmann applanation tonometry, and indirect ophthalmoscopy. Ultrasonography, automated visual field measurement using the Humphrey 750i Visual Field Analyzer (Zeiss, Germany), and optical coherence tomography (OCT, Spectralis OCT, Heidelberg, Germany) were also performed, as well as a corneal aberrometry measurement (Galilei Dual Scheimpflug Analyzer, Ziemer Ophthalmology, Switzerland). The National Eye Institute Visual Function Questionnaire 25 (NEI VFQ-25) was administered before and 30 days after pars plana vitrectomy (PPV). All eyes were submitted to YAG-laser capsulotomy (Alcon, USA) at distinct periods after cataract surgery. Patients were informed about the possibility of being submitted to a sutureless PPV surgery to clear media opacities to obtain better focus of the multifocal IOL on the retina. All patients provided informed consent for sutureless 23-gauge PPV assisted by triamcinolone acetonide. The study protocol was approved by the Ethics Committees of the Federal University of São Paulo. The study was conducted according to the Declaration of Helsinki.

Patients were evaluated on postoperative days 1 and 7 and at 1, 3, and 6 months postoperatively. Ultrasonography was repeated at 7 days and 1 month after surgery. A new aberrometry was performed 6 months postoperatively.

Patients were included in the study if they were previously submitted to cataract surgery with multifocal IOL implantation and had been diagnosed with symptomatic PVD of at least 6 months of duration. Symptomatic PVD was defined as PVD detected by indirect ophthalmoscopy and fundus biomicroscopy revealing vitreous debris (which could include a Weiss Ring but that was not mandatory) in a patient with PVD-related visual symptoms (floaters and/or photopsias). Additionally, ultrasonography had to disclose PVD in the axial, temporal, nasal, inferior, and superior planes. The refractive error based on objective and subjective dynamic refraction could not exceed ±0.25 of spherical and no cylindric refractive errors. Patients also had to have aberrometry showing a root mean square (RMS) of less than 1.2 in both eyes. In addition, macular/retinal diseases had to be ruled out by spectral-domain OCT, fluorescein angiography, and automated visual fields (patients excluded if mean deviation values were not between +1.00 and −7.00 decibels).

Exclusion criteria were diabetes mellitus, age less than 45 years, a previous stroke or neurosurgical procedure, glaucoma or uveitis, previous ocular surgery other than cataract and multifocal IOL implantation, intraoperative complications during a previous phacoemulsification such as capsular tears, previous corneal diseases or scars, irregular corneal astigmatism, iris abnormalities, macular degeneration, neuroophthalmic disease, and postoperative complications such as macular edema and retinal detachment.

Vitreoretinal surgeries were performed by the same experienced surgeon (MM). Four-port PPV using three 23-gauge valved trocars (DORC, Amsterdam, Netherlands) was performed. A Tornambe (Synergetics, Missouri, USA) chandelier light pipe connected to a Photon II light source (Synergetics, MO, USA) was inserted into an additional 25-gauge sclerotomy. The surgical procedure was performed using the Stellaris PC vitrectomy system (Bausch & Lomb, USA) and a standard 23-gauge vitrectomy probe and the binocular indirect ophthalmomicroscope (BIOM) (Oculus, Germany) for visualization of the vitreous cavity. A core vitrectomy was performed using 5,000 cuts/minute and an aspiration rate of 200 mmHg for approximately 5 minutes followed by central posterior capsulectomy. In all cases, a flush of 0,3 mL of triamcinolone acetonide 4 mg/mL (Ophthalmos,

Table 1: Baseline patients' characteristics and uncorrected visual acuity testing in both eyes prior to and after 23-gauge sutureless pars plana vitrectomy.

Patient	Gender	Age (years)	Time interval between symptoms onset and PPV (months)	Eye	Preoperative UCVA (log MAR)	Postoperative UCVA (log MAR)	Preoperative corneal aberrometry (RMS)	Postoperative corneal aberrometry (RMS)	Preoperative OCT central foveal thickness (μm)	Preoperative automated visual field MD (dB)
1	F	67	12	OD	0.17	0.17	1.1	1.1	226	−1.68
				OS	0.17	0.17	1.0	1.0	246	−1.54
2	M	58	12	OD	0.30	0.09	1.1	1.1	250	−1.0
				OS	0.30	0.09	1.1	1.0	227	−0.5
3	F	54	6	OD	0.09	0.00	0.8	0.7	260	−0.2
				OS	0.09	0.00	0.8	0.8	264	−0.4
4	M	44	8	OD	0.09	0.00	0.4	0.4	246	−1.0
				OS	0.09	0.00	0.6	0.5	249	−0.5
5	F	50	7	OD	0.30	0.17	0.4	0.3	232	+0.5
				OS	0.30	0.17	0.5	0.4	230	0.0
6	M	62	10	OD	0.09	0.09	1.0	1.0	228	−2.92
				OS	0.09	0.09	1.1	1.1	244	−2.32
7	M	64	12	OD	0.30	0.17	0.6	0.4	262	−0.54
				OS	0.30	0.17	0.4	0.4	248	−0.64
8	M	62	11	OD	0.17	0.09	1.0	0.9	196	−6.73
				OS	0.30	0.17	0.9	0.9	198	−5.72

RMS: root mean square.
MD: mean deviation.

Brazil) was used to confirm the posterior hyaloid removal; if still present, it was detached by direct aspiration with the vitrectomy probe with a vacuum rate set at 500 mmHg. Scleral indentation was performed and aspiration was reset at 200 mmHg for complete removal of the vitreous base and identification of possible retinal breaks. In bilateral cases, the same surgical technique was used 7 days later to treat the fellow eye.

The questionnaire of vision quality (NEI VFQ-25) was applied before and after PPV, in a 1-month interval. NEI VFQ-25 includes 25 questions that measure different components of visual function, with six additional optional items that enhance the reliability of the near and distance activity subscales. These were included in the Minimally Classic/Occult Trial of the Anti-VEGF Antibody Ranibizumab in the Treatment of Neovascular AMD (age-related macular degeneration) study and Anti-VEGF Antibody for the Treatment of Predominantly Classic Choroidal Neovascularization in AMD clinical trial [12]. The scores ranged from 0 (worst vision) to 100 (best, perfect vision-related function). There are 12 subscales: one general health subscale and 11 vision subscales, including general vision, difficulties related to near and distance vision activities, difficulties related to driving, vision-specific dependency, social functioning, role difficulties, limitations in peripheral and color vision, ocular pain, and mental health issues related to vision. The overall composite score was calculated using the mean of the subscales, excluding the general health subscale.

A Portuguese version of the questionnaire was applied and reliability was assessed using Cronbach's alpha coefficient, intraclass correlation coefficient, and interrater reliability coefficient. To estimate the power of the test, we considered simple random sampling and normal distribution for the VFQ-25 subscale scores. Given these assumptions, the estimated power of the test was between 50 and 90%, depending on the subscale [13].

The preoperative and postoperative NEI VFQ-25 scores and UCVA using logarithm of the minimum angle of resolution (LogMAR) charts were compared using the nonparametric Wilcoxon test. $P < 0.05$ was considered significant. The analysis was performed using SPSS software v. 21.0 (IBM, New York, USA).

3. Results

Sixteen eyes of eight patients were included in the analysis and all patients had improvement in UCVA after vitrectomy. All studied eyes were submitted to previous YAG-laser capsulotomy during the 6-month evaluation before the vitrectomy. Baseline data and UCVA values are shown in Table 1. All of the refraction values ranged from −0.25 to +0.25 diopters with no astigmatism preoperatively and did not change after PPV; hence, there were no differences between UCVA and BCVA values. Table 2 shows the changes in the postoperative VFQ-25 scores on its subscales and the comparison between the

Table 2: Results of the VFQ-25 subscales and uncorrected visual acuity (UCVA) used to compare the preoperative period to the postoperative one.

Parameter	Preoperative Median (range)	Postoperative Median (range)	P^1	n^2
General health	75 (50–100)	75 (50–100)	*0.157*	2 (25%)
General vision	60 (40–80)	80 (60–100)	*0.023**	6 (75%)
Ocular pain	81 (38–100)	81 (63–100)	*0.180*	2 (25%)
Near activities	75 (42–100)	92 (58–100)	*0.043**	5 (63%)
Distance activities	67 (58–100)	100 (75–100)	*0.041**	5 (63%)
Social functioning	94 (75–100)	100 (88–100)	*0.083*	3 (38%)
Mental health	75 (38–81)	94 (50–100)	*0.011**	8 (100%)
Role difficulties	88 (25–100)	100 (75–100)	*0.042**	5 (63%)
Dependency	100 (58–100)	100 (83–100)	*0.102*	3 (38%)
Driving	67 (50–67)	92 (75–100)	*0.016**	7 (100%)
Color vision	100 (50–100)	100 (100–100)	*0.317*	1 (13%)
Peripheral vision	75 (50–100)	100 (75–100)	*0.059*	4 (50%)
UCVA (log MAR)	0.17 (0.09–0.30)	0.09 (0.00–0.17)	*0.017*	

[1]Wilcoxon test.
[2]Number of patients that got better scores after surgery.
UCVA: uncorrected visual acuity.
* $P < 0.05$.

preoperative and postoperative scores of the VFQ-25. The LogMAR UCVA levels are also presented (Tables 1 and 2).

VA significantly improved from a median value of 0.17 preoperatively to 0.09 postoperatively ($P = 0.017$) (Tables 1 and 2). All patients with symptomatic PVD confirmed by ultrasonography (Figure 1) who underwent PPV reported not only improvement of VA but also improvement regarding halos, glare, and floaters (each of these symptoms was reported preoperatively by all patients). The following postoperative NEI VFQ-25 subscales median scores significantly improved: general vision (from 60 preoperatively to 80 postoperatively, $P = 0.023$), near activities (from 75 to 92, $P = 0.043$), distance activities (from 67 to 100, $P = 0.041$), mental health (from 75 to 94, $P = 0.011$), role difficulties (from 88 to 100, $P = 0.042$), and driving (from 67 to 92, $P = 0.016$) (Table 2 and Figure 2).

At 6-month follow-up, there were no complications reported; specifically, no cases of rhegmatogenous retinal detachment and/or macular edema occurred in our series. Only 2 eyes underwent surgical induction of PVD. In the remaining 14 eyes, the posterior hyaloid was already detached at the time of surgery.

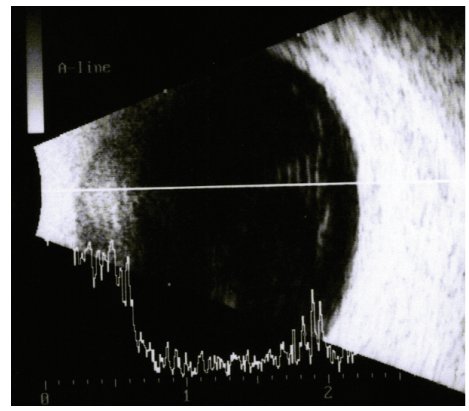

Figure 1: Example of ultrasonography image showing symptomatic PVD in one eye 7 months after multifocal IOL implantation in a patient complaining of floaters, halos, and poor quality of vision.

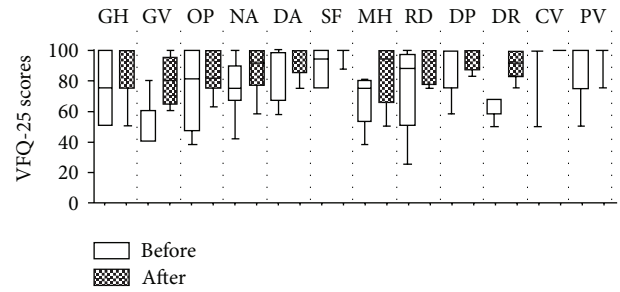

Figure 2: Boxplot of the preoperative and postoperative NEI VFQ-25 scores in the subscales of general health (GH), general vision (GV), ocular pain (OP), near activities (NA), distance activities (DA), social functioning (SF), mental health (MH), role difficulties (RD), dependency (DP), driving (DR), color vision (CV), and peripheral vision (PV).

4. Discussion

Vitreous floaters are common symptoms that are classically treated by observation only [14]. Floaters may even be considered physiologic and age-related. However, they can be inconvenient and decrease the VA and visual quality of many patients [2]. These symptoms may be exacerbated by multifocal IOLs, since both PVD and these lenses are known to be responsible for increasing light scattering in ocular media [15, 16]. Diffractive multifocal IOLs generate two images simultaneously on the retina [17]. We hypothesize

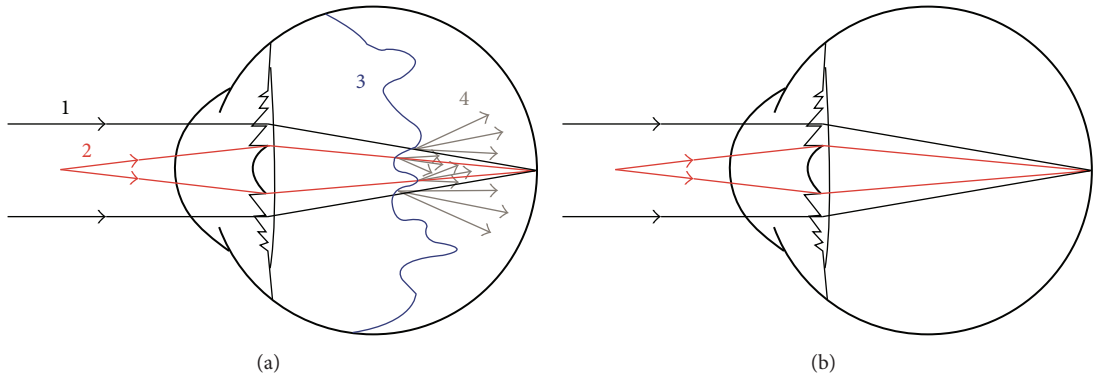

Figure 3: (a) Drawing showing an eye with a multifocal IOL and PVD. The light rays first pass through the cornea and then the IOL. The high density of the PVD causes dispersion of the light rays. (1) The light ray in black represents distance vision. (2) The light ray in red represents near vision. (3) The wavy blue line represents vitreous detachment. (4) The gray arrows show dispersion of the light rays when they pass through the dense vitreous causing halos, floaters, and blurred vision. (b) The drawing shows the light rays reaching the retina without interference from the vitreous detachment after PPV, indicating the potential for good near and distance vision without glasses. The red lines indicate the light rays for near vision.

that symptomatic PVD associated light scattering [1, 18, 19] enhances this phenomenon by diffracting light rays in many directions thus worsening VA and quality of vision (Figure 3(a)). When there are no media opacities (such as after PPV), both near and far light rays can reach the retina at the same point of focus (Figure 3(b)).

PPV is a procedure that is usually reserved for complicated posterior segment disease. It has a well-known risk profile and, justifiably, there is reluctance to perform this surgery to treat floaters [2]. However, technological advances in both instrumentation and techniques have made PPV a much safer procedure [20, 21]. Small-gauge vitrectomy offers the advantages of minimal invasiveness, reduced postoperative inflammation and complications, and faster recovery [21].

The surgical management of floaters with PPV remains highly controversial among vitreoretinal surgeons. Plenty of evidence suggests that quality of life is improved in successfully operated patients [22–25]. The real issue remains, that is, the safety of this procedure [20, 26]. Induction of PVD during surgery is a major risk factor for the development of postoperative rhegmatogenous retinal detachment. In the current small series, we tried to include only eyes with complete PVD to reduce the risk of retinal detachment. However, even with preoperative ultrasonographic examination, 12.5% of eyes in our series still required intraoperative induction of PVD. No complications developed 6 months after vitrectomy. However, we should remain cautious given the small sample size and the relatively short follow-up. The authors think that the inclusion of only cases of bilateral disease was coincidental, or there is also the possibility that these patients have more intense symptoms related to PVD.

The results of the current study demonstrate the benefits of PPV in specific eyes with a multifocal IOL and symptomatic PVD. A statistically significant ($P = 0.017$) improvement in UCVA (Tables 1 and 2) was observed following PPV. The authors chose to report UCVA instead of the most common BCVA levels because usually patients with a multifocal IOL are expected to have a satisfactory good visual acuity without the need to use glasses or contact lenses; also, all patients presented no significant refractive error. All patients reported improvement regarding halos, glare, and floaters. To evaluate quality of vision, we compared the results of the VFQ-25 before and after vitrectomy in eyes that underwent previous bilateral multifocal IOL implantation (Table 2). The results showed significantly ($P < 0.05$ for all comparisons) improved postoperative VFQ-25 scores in all subscales tested (near and distance activities, mental health, role difficulty, and driving) (Table 2). A comparison between the VFQ-25 results in the pre- and postoperative periods at only 1-month interval after vitrectomy was performed in order to avoid the fact that binocular neurosensory adaptation could play a role in vision improvement; additionally at least 6 months was used as inclusion criteria since the initial symptoms, after the cataract surgery, until the indication of vitreoretinal surgery.

Some limitations of the current study must be addressed: first, the small number of patients enrolled, the short follow-up period, and absence of control subjects, since this was a pilot investigation; second, the lack of contrast sensitivity data, which was not included since the main objective was to observe the response of patients to surgery in terms of visual acuity and quality of life (as measured by the VFQ-25); third, the inclusion of posterior capsulotomy/capsulectomy in all eyes (capsulotomy at the preoperative period using the YAG-laser and capsulectomy during PPV). Previous capsulotomy was performed because capsular opacification may be related to the symptoms described [27]. Additionally, we hypothesized that residual capsular fragments or residual vitreous present at the posterior surface of the multifocal lens could also be related to these symptoms reported. Finally, the explanation of lack of wavefront analysis is based on the argument that we believe the clinical exam, the absence of astigmatism, and also the RMS value limit used (less than 1.2) are enough evidences to exclude that possible corneal problems, could be the cause of decrease in quality of vision.

Despite these, our preliminary results are exciting. To the best of our knowledge, this is the first study to address the importance of the posterior vitreous surgery in VA and quality of vision in eyes implanted with bilateral multifocal IOLs. On the basis of these preliminary data, it is reasonable to conclude that the status of the vitreous is important in patients who may undergo multifocal IOL implantation. Preoperative evaluation of candidates for these intraocular lenses implantations should include an assessment of the vitreous. Patients with symptomatic PVD who are not satisfied with their VA and quality of vision may benefit from small-gauge PPV in specific situations reported. However, additional clinical trials with large series of patients performed by different surgeons are necessary to confirm these preliminary observations.

Summary Statement

Pars plana vitrectomy improves visual acuity and quality of vision in patients implanted with a multifocal intraocular lens who have clinically relevant posterior vitreous detachment and are not satisfied with their vision.

Conflict of Interests

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