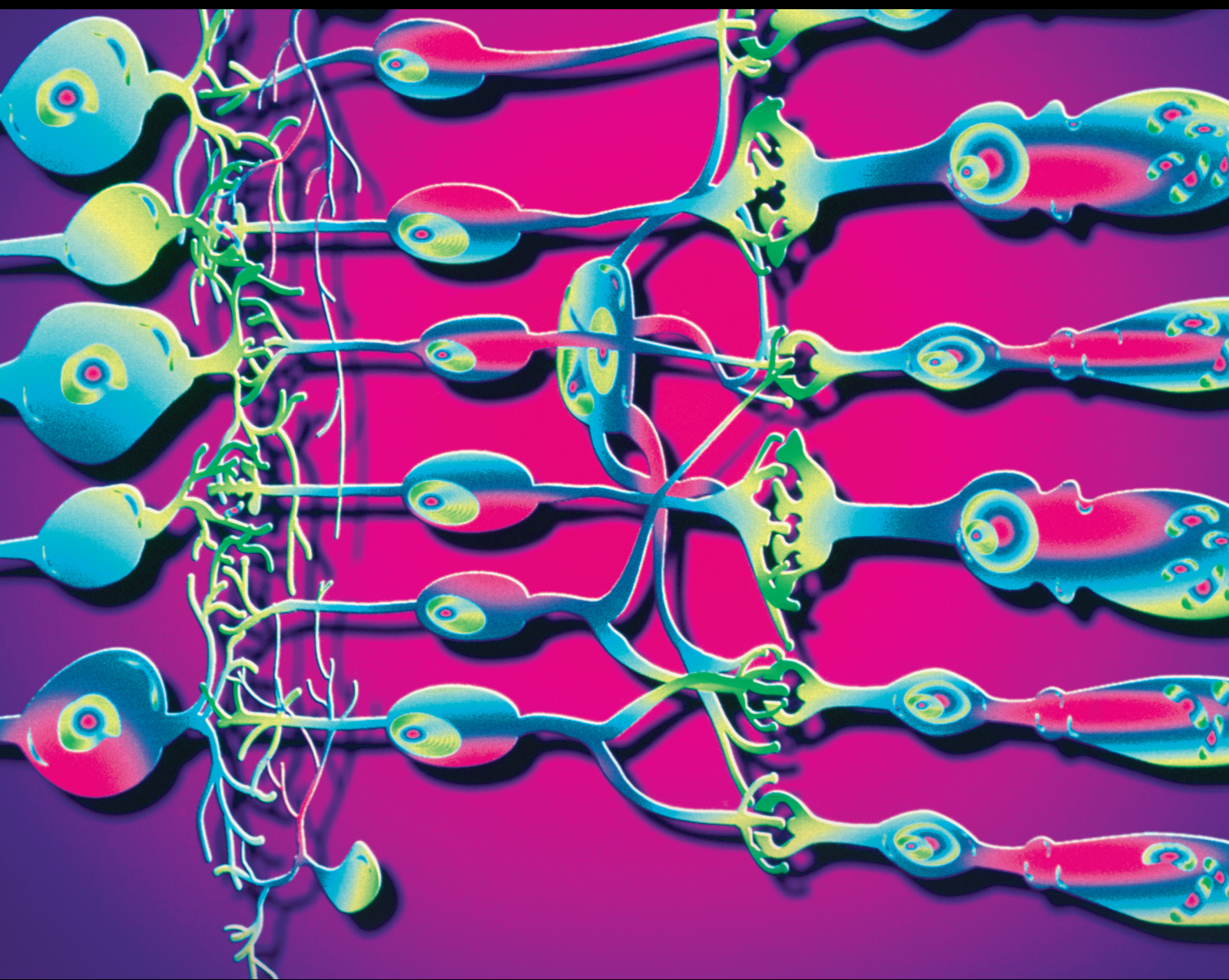
Journal of Ophthalmology

The Management of Retinal Detachment: Techniques and Perspectives

Lead Guest Editor: Elad Moisseiev
Guest Editors: Anat Loewenstein, Ala Moshiri, and Glenn Yiu



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Editorial Board

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Editorial

The Management of Retinal Detachment: Techniques and Perspectives

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Retinal detachments are frequently encountered by ophthalmologists of all subspecialties and are managed by all vitreoretinal surgeons. Over the past century, the treatment of retinal detachment has been revolutionized, and it has evolved from an incurable untreatable condition leading to irreversible vision loss to a repairable occurrence after which visual recovery is possible. As technology and repair techniques continued to evolve, a myriad of therapeutic options are now available for the management of retinal detachments. Although retinal detachments are common, there is still some controversy on the optimal treatment options for different types and presentations of retinal detachment.

This special issue was intended to serve as a platform for sharing current data and new innovations in the management of retinal detachments. Twelve manuscripts have been selected for inclusion in this special issue, authored by ophthalmologists from all over the world, and they encompass the newest developments and innovations in the treatment of retinal detachment.

Improving the outcomes of retinal detachment repair surgery was a common theme of the manuscripts submitted to this special issue. S. Deuchler et al. investigated the risk for retinal redetachment in difficult cases with proliferative vitreoretinopathy or tractional retinal detachment that required silicone oil tamponade. From their detailed analysis of all factors related to these surgeries, they have found that with current techniques, the rate of retinal redetachment may be as low as 7% and suggest that following a standard operating procedure may help achieve the best results. Additionally, they found that better outcomes were achieved by more experienced surgeons and suggest that additional simulator training may improve the outcomes of more novice surgeons. K. Y. Pak et al. report a large comparative study, in which pars plana vitrectomy with gas tamponade for the repair of retinal detachment was compared to the surgery using only air for tamponade. In cases with air tamponade, visual recovery was faster and recurrent detachments were identified sooner, with no difference in the overall success rates. Based on these results, it seems that in eyes with uncomplicated retinal detachment, air tamponade may be considered. Another comparative study by S. Rizzo et al. compared 27-gauge and 25-gauge vitrectomy for the treatment of primary rhegmatogenous retinal detachments. No differences in the outcomes or surgical times were noted between the two, indicating that 27-gauge instrumentation is safe and effective for retinal detachment surgery. As this instrumentation is currently at the forefront of vitreoretinal surgery, it is likely that more surgeons will transition to it in the future and even more complicated cases can be performed using it. Z. Lin et al. reported a very large series with over 500 cases of rhegmatogenous retinal detachment repair surgeries, focusing on the safety and efficacy of adjustable postoperative position. Patients were instructed to maintain postoperative positioning based on the location of the breaks: those with superior and lateral break location were allowed to have facedown position or lateral decubitus position postoperatively and those with inferior break location were allowed to have facedown position. The reattachment and visual recovery rates were excellent, indicating that tailoring the postoperative position appropriately according to retinal

break locations may be advantageous. R. Rejdak et al. investigated the outcomes of retinal detachment repair in children, which are frequently very challenging. They report that most cases also required lensectomy and intraocular lens implantation, as well as silicone oil tamponade. Retinal reattachment was achieved in 86% of eyes, after a mean of 2.3 surgeries per eye. Although visual acuity at presentation was very poor (hand movement or worse), in 50%, a final visual acuity of 20/200 or better was achieved. Analyzing the surgical details of these cases, they recommend performing lensectomy, a complete vitrectomy, and silicone oil tamponade in these difficult cases. Finally, A. Bor'i et al. have studied the surgical treatment of traumatic macular holes and report equal rates of anatomical closure and visual improvement with perflouropropane gas and silicone oil tamponade.

Another common theme in this special issue is the innovative use of drugs and technologies for retinal detachment surgery. X. Chen et al. investigated the combination of ketorolac with local anesthesia in patients undergoing retinal detachment surgery. They found that its addition resulted in reduced postoperative pain and the need of additional analgesia, as well as nausea and vomiting. A. N. Kulikov et al. also compared postoperative 360-degree laser retinopexy using a navigated pattern laser system, single-spot slit-lamp laser delivery, and single-spot indirect ophthalmoscope laser delivery. They have shown that the navigated pattern approach allows for more rapid treatment time and reduced pain in performing this procedure.

A basic science study by Z. Dvashi et al. investigated the use of OM-101, an inhibitor of TAK1, as a potential therapy for reducing the fibrotic response of proliferative vitreoretinopathy in an animal model. In this study, OM-101 was found to be safe and effective in reducing the incidence of retinal detachment, the number of proliferating and migrating retinal pigment epithelial cells, and the degree of fibrotic response. These results indicate that OM-101 may have the potential to improve or prevent proliferative vitreoretinopathy in patients with retinal detachment and could possibly be developed into a therapeutic modality in the future.

This special issue also includes several review articles. S. Mohamed et al. provide a thorough overview of the evolution of pars plana vitrectomy from 20-gauge instrumentation to the development of 27-gauge instrumentation, along with a discussion of the advantages and disadvantages of small-gauge vitrectomy, available instrumentation, and techniques. C. Alovisi et al. detail the development of vitreous substitutes, discussing both currently available types and those under development that may change the way retinal detachment surgeries are performed in the future. Finally, A. Nemet et al. reviewed recent innovations in surgical management of rhegmatogenous retinal detachment and proliferative vitreoretinopathy, focusing on the most recent literature, and discussed scleral buckling, vitrectomy, and pneumatic retinopexy techniques.

The guest editors would like to thank the authors of all the papers submitted to this special issue. The editors also wish to thank the many reviewers, who devoted their time, energy, and expertise and whose insightful comments helped improve the manuscripts selected for this special issue. We hope that the readers of this special issue will enjoy reading it and find its contents interesting and clinically valuable.

Elad Moisseiev
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Glenn Yiu

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Research Article

OM-101 Decreases the Fibrotic Response Associated with Proliferative Vitreoretinopathy

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Purpose. This study aimed to investigate the effect of OM-101 on the fibrotic response occurring in proliferative vitreoretinopathy (PVR) in an animal model. *Methods*. Antifibrotic effect of OM-101 was investigated *in vivo*. As control, eight weeks old c57black mice underwent intravitreal injection with Hepes (group A) or dispase (0.3 units), to induce retinal detachment (RD) and PVR. The dispase-injected mice were randomly divided into two groups B and C ($N = 25$ mice); in group C, the eyes were treated with intravitreal injection of OM-101 (3 μl), and group B with PBS, as a control. After additional five days, mice were injected with the same initial treatment. Three days later, mice were euthanized, and the eyes were enucleated and processed for histological analysis. *Results*. Intravitreal injection of dispase caused RD in 64% of the mice in group B, and 93% of those mice had PVR. Only 32% of mice treated with OM-101 and dispase (group C) developed RD, and only 25% of those developed PVR. *Conclusions*. OM-101 was found effective in reducing the incidence of RD and PVR maintaining the normal architecture of the retina. This study suggests that OM-101 is a potentially effective and safe drug for the treatment of PVR patients.

1. Introduction

Proliferative vitreoretinopathy (PVR) is a severe complication of rhegmatogenous retinal detachment (RD) [1, 2]. PVR occurs in 8–10% of the eyes undergoing repair of RD and represents 10–45% of open global trauma in USA [3, 4]. In spite of repeated surgeries, it may result in visual loss. Current therapy modalities that aimed to limit or reverse PVR have failed to achieve significant clinical benefits.

PVR is a fibrotic process characterized by proliferation and migration of cells, inducing formation of contractile epi-retinal membranes [5]. The primary cells involved in epi-retinal proliferation are retinal pigment epithelial (RPE) cells. Epithelial to mesenchymal transition (EMT) of RPE cells to fibroblasts is the cellular event that underlies PVR. A key protein in the EMT process is transforming growth factor beta-activated kinase 1 (TAK1) that acts in the noncanonical pathway of TGF-β [6, 7]. Previous studies performed in our laboratory demonstrated that TAK1 acts as a critical player in the regulation of RPE cells during EMT. By applying TGF-β1 on human ARPE-19 cells in culture and utilizing various experimental approaches, we show that inhibition of TAK1 by a specific inhibitor, 5Z-7 oxozeaenol, reduces cell migration, alpha-smooth muscle actin (α-SMA) expression, and cell motility, all of which are considered hallmarks of fibrosis during PVR [8]. TAK1 inhibitor 5Z-7 oxozeaenol contains a cis enone at its 6′ to 8′ position that could function as Michael acceptor for an appropriately positioned thiol functional group of a cysteine residue of TAK1 to form an irreversible kinase-inhibitor complex [9]. Lastly, utilizing collagen contraction assay and TAK1 inhibitor, we demonstrate that TAK1 is a general regulator of the fibrotic response in RPE cells.

Those results point to the prominent roles of TAK1 in inflammation and fibrosis events, such as PVR [8].

This study aimed at examining the use of OM-101 (formulation of 5Z-7 oxozeaenol) in an animal model, as a new horizon in the treatment of PVR.

2. Material and Methods

2.1. Proliferative Vitreoretinopathy (PVR) Induction and Treatment. PVR was induced by intravitreal injection of dispase as previously described [10]. Briefly, mice were anesthetized by intraperitoneal injection of ketamine (100 mg/kg) and xylasin (10 mg/kg) mixture. Then, 3 μl of Dispase II (10 mg/ml, Sigma number D493, dissolved in Hepes/KOH pH = 7.4, 50 mM NaCl buffer) was injected intravitreally to the right eye. As control, mice in group A were injected with 3 μl of the Hepes solution ($N = 5$ mice). Three days later, dispase-injected mice were randomly divided into two additional groups (groups B and C, $N = 5$ mice each group). Group C was treated with an intravitreal injection of OM-101 (3 μl, 1 μM), while groups A and B were injected with PBS; all injections were to the right eye only. After additional five days, mice were injected with the same treatments. Three days later, the mice were euthanized and the eyes were enucleated and processed for histological analysis. Blood was collected to evaluate the safety of OM-101 tissue samples including the brain, liver, lung, spleen, kidney, and the left eye that were histology evaluated for abnormal morphology.

All experiments were compliant with the ARVO Statement for the Use of Animals in Ophthalmic and Vision Research and approved by the Institutional Animal Care and Use Committee at Hebrew University of Jerusalem.

2.2. OM-101 Preparation. 1 mg of 5Z-7 oxozeaenol was dissolved in 276 μl of DMSO for a final concentration of 10 mM or 3.623 μg/μl and further diluted 1 : 2000 in PBS for a final concentration of 5 μM or to 1.811 ng/μl. 5 μl (9 ng) of this dilution was used for injections.

2.3. Funduscopy and Optical Coherence Tomography (OCT). Mice were anesthetized by intraperitoneal injection of ketamine (100 mg/kg) and xylasin (10 mg/kg) mixture. The eyes were topically anesthetized with one drop of Localin drops. The corneas were kept moist with regular application of 2.5% methylcellulose, and pupils were dilated with Tropicamide 1%. Eyes were examined using the Micron III retinal imaging system (Phoenix Research Labs, CA, USA), and raw images were adjusted for levels, enhanced contrast, and sharpened by applying an unsharp mask (100%, 2px, 0) using Photoshop CS6 (Adobe, Ca, USA).

2.4. Histological Staining. Nine μm paraffin embedded sections of the eye tissues were stained with hematoxylin and eosin (H&E) as described in previous reports [11]. Histological evaluation was performed to assess the RD and PVR. The severity of PVR was defined by infiltration of white blood cells such as macrophages or B cells (0—absence of cells, 1—low frequency, 2—moderate frequency, and 3—high frequency), edema, and the appearance of pigment cells in the retina (cell migration).

2.5. Blood Marker Assessment. Blood was collected into K3 EDTA tubes and underwent examination and analysis according to standard procedures. Liver functionality was manifested by alanine transaminase (ALT) and aspartate aminotransferase (AST) markers. Pancreas functionality was manifested by glucose levels and kidney by NA and urea levels.

2.6. Statistics. Statistics were computed using Student's t-test and two-tailed distribution. Values of $P < 0.05$ were considered significant.

3. Results

In this paper, we have used dispase to generate retinal detachment and subsequently proliferative vitreoretinopathy (PVR). Dispase, a proteolytic enzyme able to harvest and culture cells due to its ability to cleave the basal membrane in various tissues, can be used as an intravitreal injection material to induce PVR in the eyes of mice. Mice were injected with dispase as described by Tan et al. [12] and underwent fundus and OCT analyses to verify RD formation (Figure 1). Mice injected with Hepes (group A) demonstrated a normal retina, whereas dispase-treated mice showed RD seen in both fundus (Figure 2(a), upper) and OCT analyses (Figure 2(a), lower). Dispase-injected mice were randomly divided into two groups: PBS-injected (group B) and OM-101-injected (group C) mice. PVR-like traces could be clearly found after 10 days in group B. H&E-stained sections showed marked proliferative membranes, retinal detachment, serous fluid between the RPE and the sensory retinas, and destructed retinas (Figure 2(a), middle). Furthermore, infiltration of the RPE cells into the center of the retina was detected in group B, thus demonstrating increased migratory capacity of these cells. In contrast, mice injected with OM-101 demonstrated only RD, with normal retinal structure and clear form RPE cells (Figure 2(a), right). Quantitative evaluation of mice with RD or PVR from the different groups demonstrated that intravitreal injection of dispase triggers RD in 64% of mice in group B, and 93% of those mice had PVR. In contrast, only 32% of OM-101-treated mice (group C) developed RD, and 25% of those developed PVR (Figure 2(b)). In mice injected only with Hepes and PBS (group A), neither RD nor PVR was found. Importantly, the severity of the PVR measured in the mice of group B was significantly higher than in mice treated with OM-101 in all parameters (Figure 2(c)), demonstrating marked infiltration of macrophages and a fibrotic response.

These results demonstrate the positive effect of OM-101 in reducing the occurrence of PVR in the dispase model system. To consider OM-101 as an optional therapeutic avenue for PVR, safety experiments were performed. Injection of mice intravitreally with OM-101 did not affect the morphology of different organs such as the brain, liver, lung, spleen, and kidney (Figure 3(a)). Correspondingly, blood markers from OM-101-treated mice demonstrated normal liver, kidney, and pancreas functions following OM-101 injection.

4. Discussion

This study shows that treatment with OM-101 can inhibit and prevent PVR by preserving normal architecture in

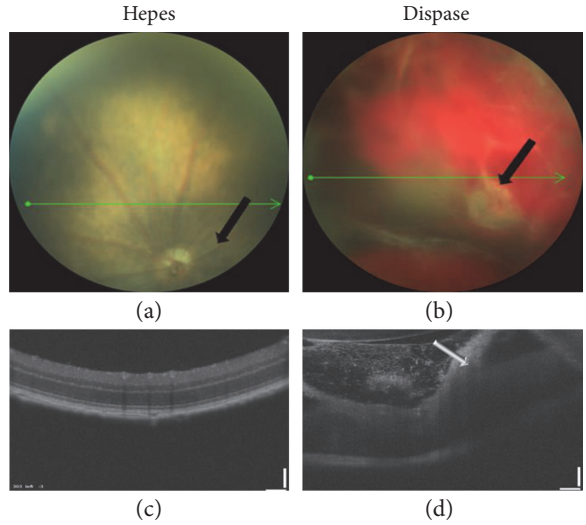

Figure 1: Funduscopy and OCT in mice eyes after dispase injection. Mice injected with Hepes only (control) demonstrated normal retina (a). Mice injected with dispase demonstrating RD with fibrotic tissue in front of the retina (b). Normal retina on OCT (c) and detached retina with loss of normal appearance of the retina (d).

dispase-induced RD, manifested by decreased number of proliferating RPE cells and by reduced fibrotic response.

During retinal detachment, the RPE cells disseminate into the vitreous cavity and onto the retinal surface, as well as proliferate and migrate throughout the retina and towards the vitreous, transdifferentiate into mesenchymal-like α-smooth muscle actin- (α-SMA-) positive cells that produce extracellular matrix, and contribute to the accumulation of fibrous scar tissue. Such transdifferentiation is considered to be a process of epithelial-mesenchymal transition (EMT), a program of differentiation whereby cells lose their epithelial morphologic features and acquire more mesenchymal-like morphologic features in association with expression of mesenchymal markers such as α-SMA [13].

Although various growth factors are reportedly involved in the pathogenesis of PVR, transforming growth factor β (TGF-β) is the key regulator for those processes [1, 3, 14]. A key protein in the process is TAK1 that acts in the noncanonical pathway of TGF-β [6, 7].

Even though TAK1 activation was first identified as a mediator of TGF-β1 signaling, it is well-known today that TAK1 can also be activated by various other stimuli, including environmental stress and proinflammatory factors such as tumor necrosis factor- (TNF-) α, interleukin- (IL-) 1, and lipopolysaccharides (LPS) [15]. Previous work performed in our laboratory has demonstrated that stimulation of RPE cells with TGF-β1 increases α-SMA expression, cell migration, and cell contractility, all of which are EMT features. Remarkably, addition of TAK1 inhibitor abolished all these processes, suggesting that the outcome of the TGF-β-induced response in RPE cells is TAK1-dependent. Those results point to the prominent roles of TAK1 in inflammation and fibrosis events, such as PVR inhibiting [8].

The use of a specific inhibitor for TAK1 abolished all EMT characteristics that were induced in RPE cells by TGF-β [8]. Furthermore, we demonstrated that TAK1 inhibitor reduced the activation of both the canonical and noncanonical pathways of TGF-β1 signaling [8]. Those *in vitro* results stood as the basis of this current research examining the effects of OM-101 on PVR induced in mice.

In PVR, when RPE cells become dislodged into the vitreous cavity or beneath the neurosensory retina, they experience an environmental change regarding exposure to cytokines and growth factors, and their normal cell-cell and cell-matrix interactions are disrupted. This process causes enhanced cell migration, high levels of α-SMA expression, and increased contractility [16]. Our results demonstrate that by inhibiting TAK1 activity, these processes are significantly attenuated *in vitro*. Besides, specific inhibition of TAK1 maintains the quiescent and naive form of the RPE cells [17]. Furthermore, we have previously shown that the role of TAK1 in the process of EMT is not restricted to TGF-β1 signaling, rather it is a general function, as established by the collagen contraction assay. The event of impaired RPE contractility in the presence of TAK1 inhibitor occurs in full serum medium where all chemokines and cytokines play a part, thus demonstrating a TAK1 general role in the process of EMT in RPE cells.

Several studies investigated the roles of TGF-β signaling in PVR; however, these papers did not show significant reduction in the complication underlying PVR following perturbations of TGF-β signaling [18, 19]. Furthermore, TGF-β is a pivotal player in numerous molecular events; thus, inhibition of this growth factor might result in severe pathologies. In contrast, OM-101 that affects downstream proteins in the TGF-β cascade is safer and inhibits specific events related to fibrosis.

In this study, we used the dispase model system to investigate OM-101 effects during PVR [10]. Dispase initiated the development of PVR without the addition of exogenous cells, growth factors, or cytokines typically found in PVR membranes. A cascade of events was triggered by dispase, causing

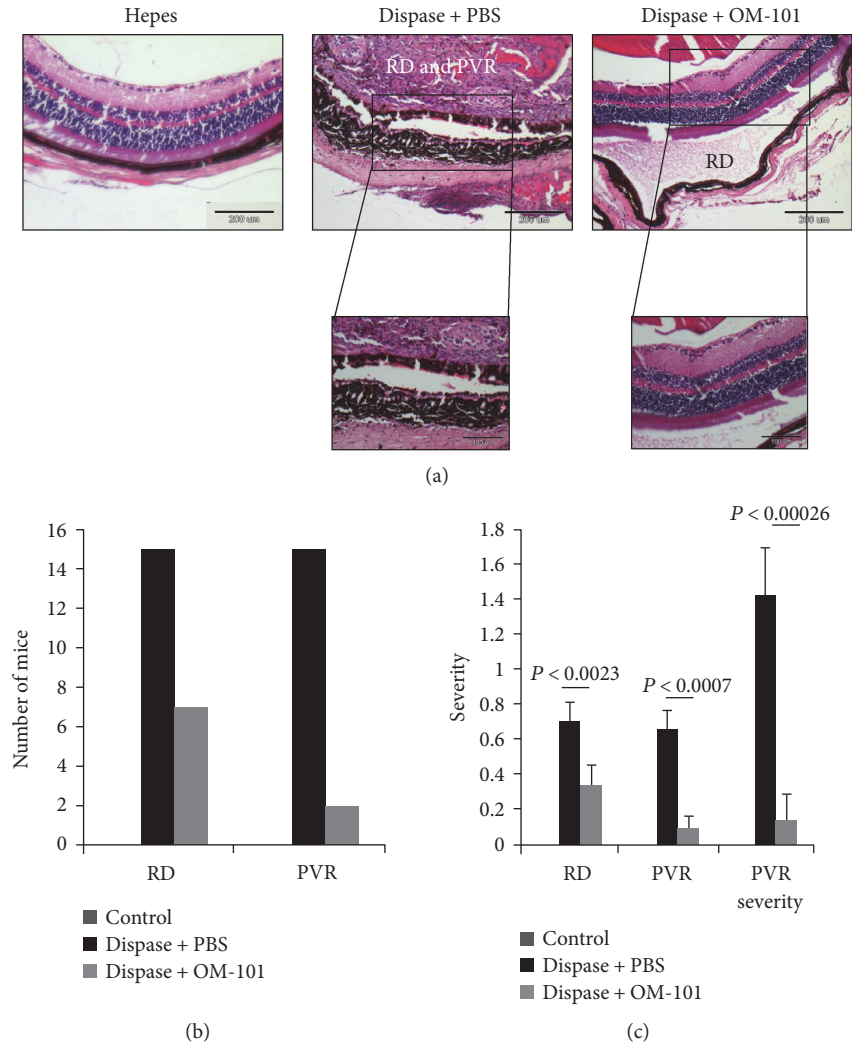

Figure 2: Histological staining (H&E) of induced RD and PVR in retina treated with OM-101. (a) Histological staining (H&E) demonstrated the following: left (control/Hepes), normal architecture; middle (dispase + PBS), abnormal morphology with inflammatory cells, fibroblasts, and pigment stain RPE cells through the retina denoting PVR; and right (dispase + OM 101), OM 101 treatment maintained the normal structure of the retina. Scale bar 100 μm or 200 μm. (b) Number of mice developing RD or PVR. (c) Severity score of the mice retina measured by thickness of the RD, number of inflammatory cells, loss of normal structure, and the appearance of RPE cells inside the retina ($N = 25$). Statistics were computed using Student's t-test (two-tailed distribution equal variance). Data is expressed as the mean ± SD.

native cells and factors to produce PVR [12]. The dispase model of PVR is technically easy to perform, permitted a clear view of the retina, and had a high success rate in development of PVR.

There is an emerging complex picture around the biochemical and the molecular events that drive the pathogenesis of PVR. It is becoming clearer that interplay exists between various cytokines and growth factors, matrix proteins, and the different cell types that drive the undesirable formation of epi-retinal membranes [20]. As we and others showed, a key growth factor involved in this process is TGF-β. Thus, proper inhibition of this pathway may be effective to reduce the complications of PVR. This fundamental understanding, added to the unsatisfactory success rate of surgery, is aiding in identifying the efficacy of different agents that can block the cellular events intrinsic to PVR. Still, we cannot rule out that OM-101 in consequence modifies the early inflammatory response but its impact on PVR has a need to be further elaborated.

Our data is demonstrating for the first time the positive effect of OM-101 reducing the occurrence of PVR in an animal model. PVR develops as a complication of RD or open globe trauma (OGT). PVR occurs in about 10% of patients undergoing primary RD surgery and leads to RD surgical failure. In OGT, an average of 25% of patients may develop PVR. The results of surgery are often unfavorable accompanied by poor visual outcome. Thus, it should be noted that even though OM-101 effect on PVR was tested in this paper during the progression of the disease, OM-101 treatment can be considered as a potential prophylaxis treatment after RD or OGT. This may bring a new horizon in the treatment

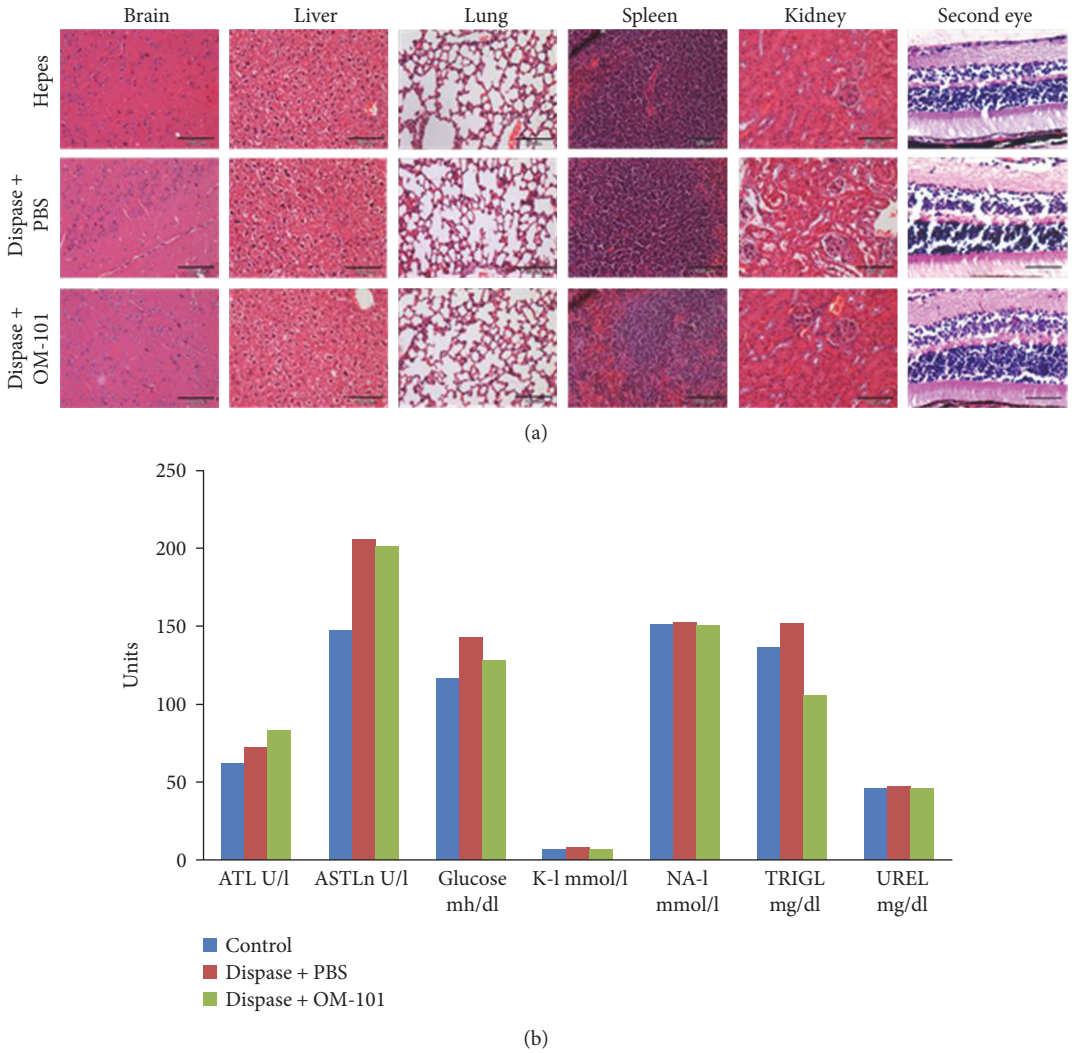

Figure 3: Safety studies of OM-101 organs (a) and blood (b) were collected from all groups. All blood parameters were found normal compared to the control group. No abnormalities were found in the histological section. Scale bar 100 μm.

of PVR, and OM-101 may be used as a novel therapeutic approach for the treatment of PVR, thus preventing subsequent blindness.

Conflicts of Interest

All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements) or nonfinancial interest (such as personal or professional relationships, affiliations, knowledge, or beliefs) in the subject matter or materials discussed in this manuscript.

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Clinical Study

Outcomes of Vitrectomy in Pediatric Retinal Detachment with Proliferative Vitreoretinopathy

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Aim. To report outcomes of pars plana vitrectomy (PPV) in pediatric retinal detachment (RD) with proliferative vitreoretinopathy (PVR), complications, factors influencing the final anatomical and functional results. *Methods*. Retrospective consecutive case series of 14 eyes. Average postoperative follow-up period was 34 months. *Results*. Mean age of patients was 10 years; eleven patients (79%) were males. The most common etiology was trauma (57%), the second—myopia (36%) and one case of uveitis (7%). At the day of presentation, the best-corrected visual acuity (BCVA) was worse than hand motion (50%); macula was detached in 86% of cases. Simultaneous PPV and phacoemulsification with intraocular lens (IOL) implantation were performed in 12 cases (86%). The most common endotamponade during PPV was silicone oil (93%). Anatomic reattachment was accomplished in 86% of cases. Final BCVA was equal or better than 0.1 in 50% of patients. The postoperative complications were found in 5 eyes (36%). *Conclusion*. Complete PPV was allowed for anatomically reattached retina and preserved vision in pediatric complex RD with PVR. However, visual outcomes were not satisfactory. Preserving vision in children with RD is of great importance for their future motor and intellectual development. This trial is registered with ClinicalTrials.gov Identifier: NCT03208205.

1. Introduction

The occurrence of retinal detachment (RD) in children is less frequent than that in adults. Pediatric RD constitutes for 3.2–6.6% of all cases of RD [1]. Some publications indicate that the frequency of RD in children is higher and may affect even 12.6% of all patients suffering from RD [2]. There are many differences between pediatric and adolescent RDs. RD in children differs in the etiology, anatomical characteristics, and prognosis [3, 4]. Ocular comorbidities, such as congenital developmental anomalies, myopia and trauma, or previous intraocular surgeries, have been reported to be the most prevalent predisposing factors for pediatric RD [2, 4]. As reported in previous studies, anatomical success of RD surgery in pediatric patients is lower than that in adults—from 10% to 80% with different surgical approaches [5, 6]. Consequently, pediatric RD is a great challenge for ophthalmologists.

Children usually present late and have clinical features of longstanding RD such as macular involvement and proliferative vitreoretinopathy (PVR). Histologically, PVR is the formation of abnormal cellular accumulations in the vitreous cavity and subretinal space produced by the retinal pigment epithelium (RPE) and Müller cells [7]. The PVR process is characterized by formation of periretinal fibrocellular membranes, intraretinal fibrosis, and subretinal bands [8]. Treatment of RD in eyes with PVR is challenging and requires complex vitreoretinal surgery.

The aim of this study was to review outcomes of pars plana vitrectomy (PPV) in pediatric RD accompanied with PVR as well as factors influencing the final anatomical and functional results.

2. Methods

This is the retrospective study of 14 consecutive patients younger than 18 years of age who underwent primary PPV at the Department of General Ophthalmology of Medical University of Lublin in a time period from 1st January 2006 to 1st January 2017. This study followed the tenets of the Declaration of Helsinki. The treatment chosen in the study was a part of a standard care. Written informed consent was taken from all subjects. All patients underwent vitreoretinal surgery due to RD (rhegmatogenous, tractional, or combined rhegmatogenous and tractional). Exclusion criteria from the study was the time of follow-up less than 6 months.

The average age at the time of the presence of RD was 10 ± 4.7 years (range 4–17 years). Pre- and postoperative data were collected. Descriptive statistical analysis included gender, age at the presentation, laterality, etiology, duration of presenting symptoms, presences of ocular comorbidities, macular status (attached or nonattached), presence of PVR grade C, initial and final best-corrected visual acuity (BCVA), number of procedures, type of endotamponade during PPV, final lens status, duration of the follow-up, anatomical success, and complications. Indications for PPV were as follows: presence of advanced PVR and/or total RD and/or multiple breaks, giant retinal tears. PVR was graded according to the Retina Society Terminology Classification [9]. Visual acuity was measured by Snellen charts. The anatomical success was defined as persistent retinal reattachment at the last follow-up visit (regardless of presence or absence of silicone oil tamponade).

Statistical computations were performed using STATISTICA 13PL (Stasoft, USA) programme.

3. Surgical Procedure

Surgeries were performed under general anesthesia. Complete 23G PPV with scleral indentation was performed using the Constellation system (Alcon, Fort Worth, Texas, US). Posterior vitreous detachment (PVD) was induced very carefully by the cutter probe using aspiration. An amount of fifty microliters of triamcinolone acetonide (TA) aqueous suspension (Kenacort 40 mg/ml, Bristol-Meyers Squibb, Princeton, NJ, USA) was injected into the midvitreous with a cannula and entrapped in the vitreous gel. Additional delamination of posterior hyaloid was required in half of the cases. At this step, high magnification was achieved by the macula lens (60D) of binocular indirect ophthalmo-microscope (BIOM). The posterior hyaloid was undermined with 25G needle and carefully dissected by PPV probe. No vitreous was left attached to the retina posterior to the vitreous base. There were no iatrogenic breaks created during PVD induction. Peeling of the epiretinal membranes (ERMs) and internal limiting membrane (ILM) was performed after staining with Brilliant Blue G. A heavy perfluorocarbon liquid (perfluoronoctane, HPFCL) was injected slowly up to the posterior side of the retinal break to stabilize the central retina in all eyes. The peripheral vitreous was removed in all eyes with 360° of the vitreous base shaved under scleral indentation. Subretinal membranes were extracted wherever they caused significant traction. If retinal attachment was not achieved, relaxing retinectomy was performed after endodiathermy. After complete retinal attachment was achieved, endolaser photocoagulation was applied around the retinal break(s) as three to four rows of burns or/and cryopexy under HPFCL. Then, a HPFCL/air/5000cst silicone oil exchange was performed. In one eye, only HPFCL/air exchange was performed. Sclerotomies were sutured when needed with Vicryl 8.0 sutures.

4. Results

Clinical features of pediatric RD at the day of presentation and further status of the retina are detailed in Table 1.

Eleven patients (79%) were males. The right eye was equally involved as well as the left eye (50%). Visual acuity was improved after surgery in 50% ($n = 7$) and was the same in 5 patients (36%). Trauma was the most prevalent (57%, $n = 8$) cause of RD, while the second one was high myopia (spherical equivalent ≤ -6.0 D) 36% ($n = 5$); in one case (7%), uveitis was diagnosed. Duration of presenting symptoms reported by patients and their parents oscillated around 8.57 ± 16 days. Demographical and clinical data of each patient in the study group are presented in Table 2. Preoperative BCVA was as follows: light perception in 6 patients (42.8%), hand motion in 1 patient (7.1%), counting fingers in 1 patient (7.1%), 0.004–<0.1 in 4 patients (28.6%), 0.1 in 2 patients (14.3%), and 0.2 in 2 patients (14%). Final BCVA was as follows: light perception in 3 patients (21.4%), hand motion in 1 patient (7.1%), counting fingers in 2 patients (14.3%), 0.001–0.004 in 4 patients (28.6%), 0.5 in 1 patient (7.1%), and 0.6 in 1 patient (7.1%).

Most cases were pure rhegmatogenous RDs (79%). In all cases, PVR grade C was reported. Most of the eyes presented detached macula at the time of diagnosis (86%). In 12 eyes (86%), simultaneous phacoemulsification with intraocular lens (IOL) implantation was performed during the first surgery. In one case (7%), cataract surgery was performed during the second approach, and in another one case, the eye remained phakic after silicone oil removal. The most common endotamponade was silicone oil (93%). In one case, because of the massive vitreous hemorrhage and peripheral RD, air was used as a tamponade. The average number of surgeries was 2.3 ± 1.14. In 4 patients (29%), two surgical procedures were performed. Twenty-six percent of subjects underwent only one procedure. In one case (7%), the number of surgeries was five. Anatomical success was achieved in 86% of cases. Silicone oil was finally removed in 6 cases. Average time of the presence of silicone oil in the vitreous cavity was 10 months in these eyes. After the last surgery (silicone oil removal), patients were kept under strict control of the mean of 31 months. Moreover, in this patient group, we did not observe retinal redetachment. In another 4 cases, silicone oil was exchanged and 3 eyes remained silicone

Table 1: Characteristics of retinal detachment (RD) in a presented study group of 14 children.

Parameter		Number of subjects	Percentage of subjects
Etiology	High myopia	5	35.7
	Trauma	8	57.1
	Uveitis	1	7.1
Type of retinal detachment	Mixed rhegmatogenous and tractional detachment	2	14.3
	Rhegmatogenous detachment	11	78.6
	Tractional detachment	1	7.1
Status of the macula	On	2	14.3
	Off	12	85.7
Anatomical success	Persistent retinal reattachment	12	85.7
	Retina detached	2	14.3
Endotamponade	Silicone oil	13	92.3
	Air	1	7.14

oil-sustained, and in one case, air was used as a tamponade and the retina remained attached at the end of the follow-up. Different postoperative complications, such as silicone oil under conjunctiva, posterior capsule opacity, temporary ocular hypertension, iris and corneal neovascularisation, band keratopathy, postoperative mydriasis, and retinal redetachment, were observed in 5 patients (36%).

5. Discussion

The current study was performed to delineate the clinical characteristics and surgical outcomes of pediatric RD accompanied with PVR. Predisposing factors or underlying retinal conditions were present in 100% of the analyzed patients; trauma was the most important etiologic factor (57.1%) followed by high myopia (35.7%). As reported in previous studies, trauma is the most often cause of pediatric RD, ranging from 36 to 45% [10, 11]. Soheilian et al. also evaluated the clinical features and functional and anatomical outcomes after surgical intervention in pediatric rhegmatogenous RD and found that trauma and congenital developmental anomalies are leading etiologies in pediatric rhegmatogenous RD [12]. In many studies, myopia is indicated to be a common etiological factor of pediatric RD (18.1–38%) [2, 13, 14]. We also found a strong male predominance (79%) similar to another series [13]. The higher rate of pediatric RD in males may be due to higher exposure to trauma due to gender pattern of behavior. In our study, RD was diagnosed at the mean age 10 which is consistent with other studies [2, 4]. In this age range, trauma and congenital or developmental anomalies were the most common etiologies. We concluded that the higher rate of RD occurrence at the age of 10 may be related to more susceptibility to trauma as well as the progressive nature of congenital and structural pathologic processes. In one of the studies, it has been reported that bilateral RD is more common in children [4]. In the current study, about 80% of RDs were rhegmatogenous. All of the patients required PPV as the initial surgical procedure which was due to the complexity of RD and presence of PVR, giant tears, and multiple retinal breaks. Silicone oil was necessary for intraocular tamponade in most of the patients (93%). Final anatomical success rate was 86% in our study. Our anatomical success rates were similar to the previous studies. Butler et al. analyzed 15 cases and reported similar success rates (86.6%) [5]. Gurler et al. reported attached retina in 80% children after primary surgery [15]. They also indicate significantly higher final BCVAs in children with trauma-associated RD than in group with myopia-associated RD. We have not found a similar relationship. The authors explain better functional outcomes after surgery in RD caused by trauma, immediate admission to the hospital without a delay after an ocular trauma.

Interestingly, in the current study, retina remained detached only in two cases of total posttraumatic RD.

In pediatric subjects, PPV seems to be more difficult and challenging due to the strong vitreororetinal adhesions and few areas with posterior vitreous detachment. Therefore, an external approach such as scleral buckling (SB) is chosen by some surgeons [2]. Errera et al. in their retrospective consecutive case series reported outcomes of primary SB procedures for pediatric RD. They achieved retinal reattachment with 1 operation in 73% of cases (76 of 104 eyes). The authors found the factors associated with a statistically significant increased risk of failure. Based on their results, it can be concluded that primary SB is a proper solution in pediatric RD excluding cases with more than one break, three or more quadrants of detachment, horseshoe tears, no breaks seen on preoperative examination, and Stickler syndrome [16].

In our study, we have found that 93% PPV was combined with phacoemulsification and IOL implantation. Therefore, we deliberated that phacoemulsification with IOL implantation allows for more proper management of the vitreous base. Near-complete removal of the vitreous and all tractional membranes is important in primary surgery for good retinal reattachment rate. Although there have been various advances in PPV techniques and equipment, the transparency of the vitreous can pose some difficulties during PPV. Peyman et al. first described the use of intravitreal TA as an aid to visualize the vitreous and the posterior hyaloid during PPV [17]. We used TA intraoperatively to remove strongly attached vitreous efficiently. Intraoperative use of TA has been already reported to increase the visibility of

Table 2: Patients' data (age, gender, and initial and final best-corrected visual acuity—BCVA).

Patient no.	Age (years)	Gender (F: female, M: male)	Initial BCVA* (Snellen chart)	Final BCVA (Snellen chart)	Duration of the follow-up (months)	Surgical management (number of operations)	Postoperative complications	Average time to remove silicone oil (months)
1	9	F	0.04	0.06	42	(1) phaco** + IOL*** + PPV + ILM peeling**** + +silicone oil (2) PPV + silicone oil exchange (3) silicone oil removal		12
2	12	M	Counting fingers	Counting fingers	38	(1) phaco + IOL + PPV++ air		
3	15	M	0.01	0.1	44	(1) phaco + IOL + PPV + silicone oil (2) silicone oil exchange (3) silicone oil removal	Silicone oil under conjunctiva	14
4	10	M	Light perception	0.004	29	(1) phaco + IOL + PPV + ILM peeling + silicone oil	Posterior capsule opacity	
5	17	M	0.04	0.2	6	(1) phaco + IOL + PPV + silicone oil		
6	16	M	0.04	0.04	49	(1) phaco + IOL + PPV + ILM peeling + silicone oil (2) silicone oil removal		13
7	17	F	Light perception	0.1	29	(1) Phaco + IOL + PPV + silicone oil (2) silicone oil removal + SF6***** gas		5
8	4	F	Hand motion	Counting fingers	32	(1) PPV + silicone oil (2) silicone oil removal		8
9	5	M	Light perception	Light perception	41	(1) phaco + IOL + PPV + silicone oil (2) silicone oil exchange	Iris and corneal neovascularisation, retinal redetachment	
10	4	M	0.5	0.1	11	(1) phaco + IOL + PPV + silicone oil		
11	9	M	Light perception	Hand motion	74	(1) PPV + silicone oil (2) phaco + IOL + PPV + silicone oil exchange (3) PPV + silicone oil removal + SF6 gas (4) PPV + silicone oil (5) PPV + silicone oil exchange	Temporary ocular hypertension	
12	6	M	Light perception	Light perception	36	(1) phaco + IOL + PPV + silicone oil (2) PPV + silicone oil exchange (3) chelation + PPV + silicone oil exchange	Band keratopathy and postoperative mydriasis, retinal redetachment	
13	8	M	Light perception	Light perception	20	(1) phaco + IOL + PPV + ILM peeling +silicone oil (2) silicone oil exchange (3) silicone oil exchange		
14	8	M	0.6	0.2	20	(1) phaco + IOL + PPV + silicone oil (2) silicone oil exchange (3) silicone oil removal		8

*BCVA: best-corrected visual acuity. **Phaco: phacoemulsification. ***IOL: intraocular lens. ****ILM: internal limiting membrane. *****SF 6: sulphahexafluoride.

the hyaloid and ERM, allowing more complete and safer PVD [18, 19]. Enaida et al. studied the advantages of TA-assisted PPV for various retinal diseases and reported that it may reduce the incidence of reoperation due to preretinal fibrosis [20]. TA reduces also postoperative inflammatory response which is very high in children [21]. Bimanual technique for dissection of the posterior hyaloid is very well established in diabetic RD [22]. PPV combined with delamination and dissection of the preretinal fibrovascular membranes provides relief of the retinal traction and is one of the major causes of the anatomical success.

Final BCVA in our study was unsatisfactory which may be due to the high incidence of trauma as the cause of RD in our series. The morphologic and functional outcomes of traumatic RD surgery are not favorable due to the longer duration of RD, frequent macular involvement, and high rate of PVR [13]. The longest period of time of presenting symptoms in currently reviewed group was 60 days. The duration time was determined by reported symptoms. Children, especially in lower age, do not notice changes in visual field or acuity. Even if they found disturbance in vision, they postpone the compliance because of the fear associated with the hospitalization, examination, and treatment. Late diagnosis in pediatric patients leads to more frequent macula-off status, with extensive multiple-quadrant RD and higher rates of PVR development. In our series, macula-off status was detected in 86% at presentation, similar to 80% [2] and 81.9% [14] reported by other investigators. On the contrary, in another study, lower rate (50%) of macula-off status was reported but still it was due to late diagnosis, as described by the authors [10]. In our research, PVR Grade C was noted in 100% of eyes at presentation and was higher than in other studies (70% [10] and 69.1% [14]). Higher rate of advanced PVR is probably associated to late diagnosis and in most cases posttraumatic changes in eyeball. Moreover, in the pediatric age group, delayed diagnosis accompanied with a higher degree of intraocular cellular activity and proliferation may result in higher PVR occurrence.

The mismatch between anatomical and functional success rates may be due to the high risk of amblyopia in children; however, other factors, such as corneal irregularity due to corneal laceration, simultaneous traumatic optic neuropathy or choroidal detachment, and the presence of PVR, may also be important in functional visual loss.

The current case series study is limited by its retrospective nature and relatively small group of patients.

6. Conclusions

In summary, pediatric RD is commonly associated with an underlying condition. Although children often present chronic RD and PVR, the anatomical outcomes following surgical intervention are favorable in most cases. A higher number of RD procedure in children, compared to adults, are associated with worse anatomical outcomes. Anatomic and functional outcomes in pediatric RD are not as good as those in adults. Preserving vision in children with RD is of great importance for their future motor and intellectual development.

Conflicts of Interest

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

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Clinical Study

Pars Plana Vitrectomy with Internal Limiting Membrane Peeling in Traumatic Macular Hole: 14% Perfluoropropane (C_3F_8) versus Silicone Oil Tamponade

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Purpose. To evaluate the outcome of 23 G PPV and ILM peeling with 14% C_3F_8 compared with silicone oil tamponade in cases of TMHs without spontaneous closure. *Methods*. A retrospective comparative study included 33 eyes with TMHs; 7 eyes healed spontaneously, and the remaining 26 eyes have been treated with PPV and ILM peeling. Silicone oil was used as a tamponade for children or adults who refused to adopt face-down position (10 cases). In all other cases (16 cases), 14% C_3F_8 was used. These cases were followed up for 6 months postoperatively. *Results*. 26 cases (22 males and 4 females) were reviewed, including 10 cases treated with silicone oil and 16 cases treated with 14% C_3F_8. Patients' age ranged from 9 to 54 years. The success rate was 90% in the silicone-filled (9/10) and 94% in the gas-filled (15/16) eyes. At 6 months, the mean BCVA was 0.3 ± 0.25 in the silicone group and 0.2 ± 0.13 in the gas group ($p < 0.05$). *Conclusions*. Cases of TMHs should be observed for spontaneous closure. PPV with ILM peeling should be conducted for nonclosing cases. Gas and silicone oil tamponades are equally successful in anatomical and visual outcomes. This trial is registered with CTRI/2017/06/008765.

1. Introduction

Macular holes, which are full-thickness defects that disrupt the foveal contour, are commonly idiopathic or age-related, but they may be traumatic due to blunt injury to the globe and are usually associated with localised or diffuse retinal edema, vitreous haemorrhages, retinal breaks and disinsertion, and choroidal rupture [1, 2].

Verifiably, Knapp [3] published the first case study of TMH in a patient with blunt eye trauma in 1869. Noyes [4] was the first to discover that TMH was a full-thickness defect inside the centre of the macula. The incidence of TMH varies from 1 to 9% between different studies and is more common in young male population [5–8].

The mechanism that derives the formation of TMH has remained a controversial subject. There are numerous speculations regarding the pathogenesis of TMH [8–12]. In the mid-1900s, one of the most widely accepted hypotheses stated that TMH potentially arose from retinal stretching caused by deformation during the trauma and/or the direct impact of the trauma on the posterior pole [8, 9]. Today, TMH is thought to be created not only by direct concussion of the globe but also by vitreous traction [13, 14]. Clinicians should observe patients with TMH for 4–6 months rather than attempt to surgically repair the injury, which has been advocated because of the possibility of spontaneous closure [15–19]. In this study, we evaluated the outcome of 23 G pars plana vitrectomy (PPV) and ILM peeling with 14% C_3F_8 tamponade versus silicone oil tamponade in cases of TMH without spontaneous closure.

2. Patients and Methods

Retrospective comparative study was done from May 2014 to September 2016. Thirty-three eyes of 33 patients (29 males

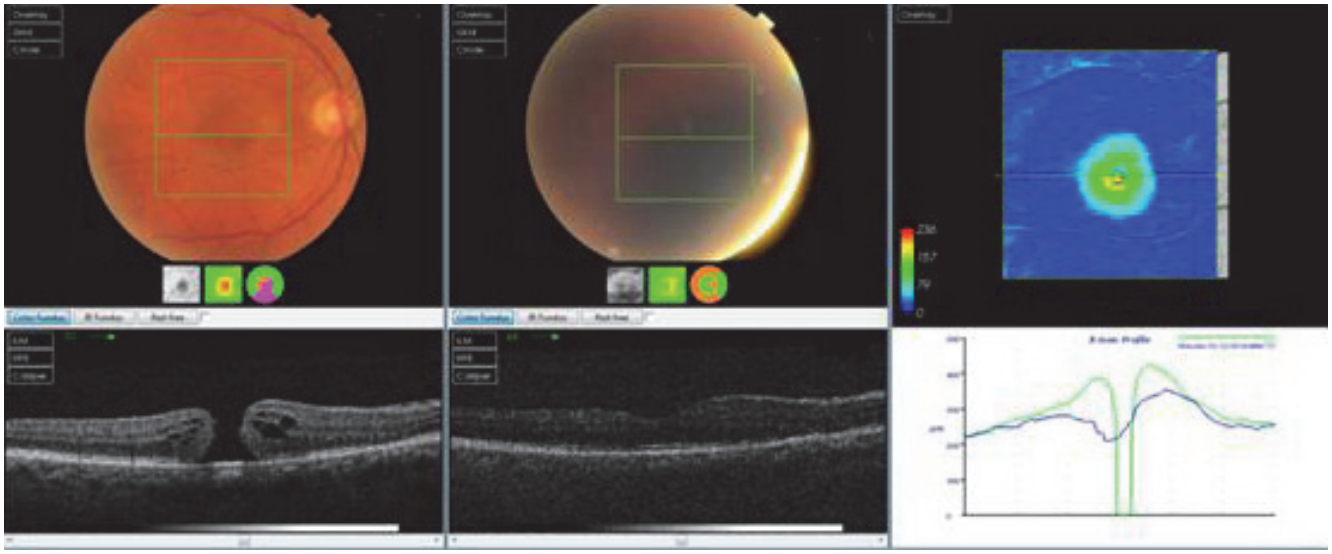

Figure 1: OCT scan of one of the cases in the silicone oil group (preoperative and 6 months postoperative).

and 4 females) with TMH were operated upon during this period. Eyes with submacular haemorrage, choroidal rupture, and rhegmatogenous retinal detachment were excluded from the study. All cases were subjected to full ophthalmic history taking and examination including LogMAR best-corrected visual acuity (BCVA), slit lamp of the anterior segment, applanation tonometry, and fundus slit lamp biomicroscopy. The diagnosis of macular hole was established both clinically and by optical coherence tomography (OCT). All cases were followed for at least 6 months anticipating spontaneous closure, which has been reported in similar cases. Seven cases were excluded due to spontaneous closure. Finally, 26 cases (22 males and 4 females) were included.

2.1. Surgical Method. After approval from the ethical committee, the surgical procedure was explained to all patients or their relatives, and written consent was signed. For children or adults who refused to adopt the strict face-down position, we used silicone oil as a tamponade (10 cases). In all other cases, 14% perfluoropropane (C_3F_8) was used. All surgeries were performed under general anaesthesia. Standard 23 G three-port sclerotomies were conducted, followed by vitrectomy with induction of posterior vitreous detachment if not already detached and fluid air exchange followed by ILM staining with blue dye. Then, the dye was washed away with fluid air exchange. The ILM was then peeled in a rhexis manner, with Eckardt end-gripping pick forceps. The aim was to peel at least 2 disc diameter areas of ILM 360° around the hole. Fluid air exchange was then performed.

For the gas-treated eyes, a 20 mL syringe containing 14% C_3F_8 gas was connected to an infusion cannula. The assistant injected 17 mL through the infusion cannula while the main surgeon allowed gas and air to escape from the superior temporal sclerotomy site via a flute needle. With this method, the vitreous cavity is filled with 14% C_3F_8. Sclerotomy ports were removed and their sites were tested for any leakage, which was closed with 7-0 Vicryl sutures. For young patients, all sclerotomy sites were sutured. If hyponony was encountered when eye tension was digitally tested at the end of the procedure, then the remaining 3 mL of gas was added to the tamponade by injection through the pars plana with a 30g needle.

For silicon-treated eyes, after fluid air exchange, one of the upper 2 sclerotomies was used to inject silicone while air is allowed to escape via a flute needle in the other sclerotomy.

Subconjunctival cefuroxime and dexamethasone were injected at the end of the procedure. Postoperatively, combined antibiotic-steroid drops (tobramycin 0.3% with dexamethasone 0.1%) were used 5 times daily for four weeks and atropine drops were applied three times a day for 2 weeks.

For gas-filled eyes, the patients were instructed to position their faces down until 50% of the gas was absorbed or for at least 2 weeks. For silicon-filled eyes, the patients were instructed to position their faces down as much as possible (at least 50% of daytime) for 2 weeks.

2.2. Follow-Up. Gas-filled eyes were followed up the day after the operation, after 1 week, and every month until the gas was absorbed; then, follow-up was conducted every 2 months for at least 1 year after the last surgery. Silicone oil-filled eyes were followed up the day after the operation, after 1 week, after 2 months, the day after silicone oil removal (4 months after the surgery), and every 2 months for at least 6 months after silicone oil removal. At every follow-up, visual acuity, intraocular pressure, slit lamp, and fundus exams were performed. OCT was performed every 2 months until the last follow-up, as shown in Figures 1 and 2.

The results were collected and statistically analysed.

3. Results

Thirty-three cases with traumatic macular hole were recruited during the study period. All cases were followed

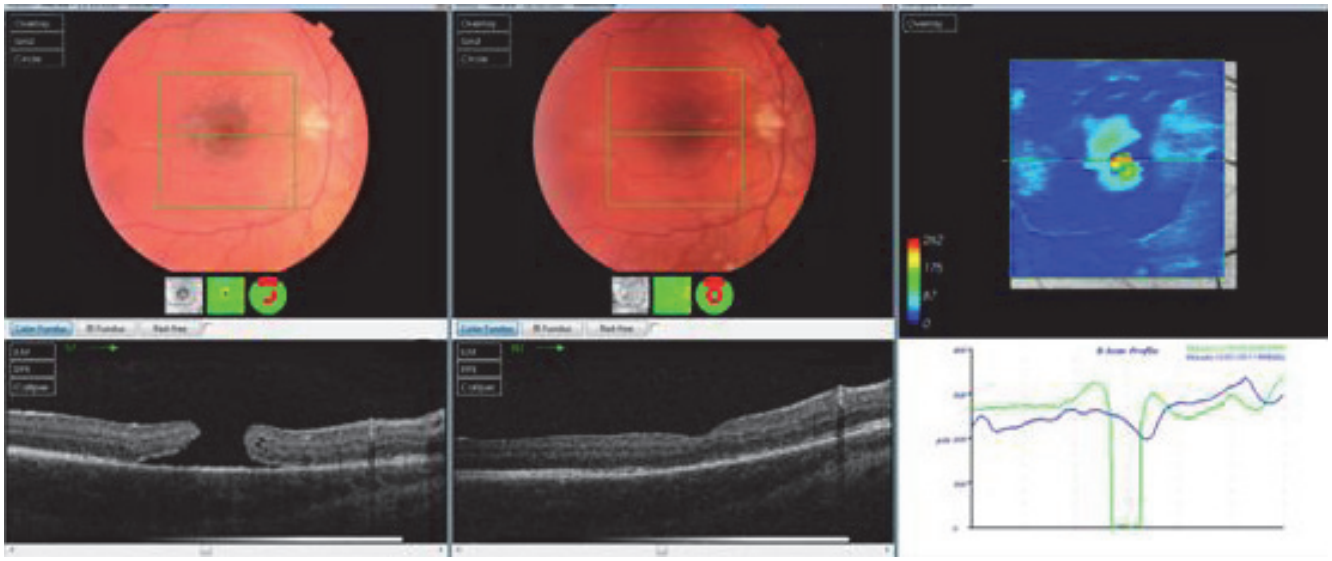

Figure 2: OCT scan of one of the cases in the C_3F_8 group (preoperative and 6 months postoperative).

up for 6 months following the trauma in anticipation of spontaneous closure, which occurred in seven cases that were excluded from the study. The remaining 26 cases (22 males and 4 females) were reviewed, including 10 cases (38.4%) with silicone oil tamponade and 16 cases (61.6%) with 14% C_3F_8 gas tamponade. The age of the patients in the silicone oil group ranged from 9 to 43 years (mean 22.5 ± 12.7 years). The age of the patients in the C_3F_8 group ranged from 17 to 54 years (mean 30 ± 10 years). The mean preoperative LogMAR BCVA in the silicone oil group was 0.8 ± 0.4 (range 1.3 to 0.3). The mean preoperative BCVA in the C_3F_8 group was 1.1 ± 0.2 (range 1.3 to 0.7). The macular hole size in the silicone oil group (measured by Topcon OCT 2000) ranged from 289 μm to 533 μm with a mean of 404 ± 85. The macular hole size in the C_3F_8 group ranged from 354 μm to 490 μm with a mean of 401 ± 35.

3.1. Anatomical Success Rate. Twenty four (92.3%) cases achieved anatomical closure at 6 months while only 2 cases (7.4%) failed to close. Success rate was 90% in the silicone-filled (9/10) and 94% in the gas-filled (15/16) eyes with no statistically significant difference. Only one case in each group failed to close.

3.2. Visual Outcomes. The mean postoperative BCVA at one month in the silicone oil group was 0.5 ± 0.21 (range 1.0 to 0.3) compared to 0.4 ± 0.19 (range 1.0 to 0.3) in the C_3F_8 group. The mean postoperative BCVA at 4 months in the silicone oil group was 0.4 ± 0.22 (range 1.0 to 0.3) compared to 0.3 ± 0.13 (range 0.4 to 0.1) in the C_3F_8 group. The postoperative BCVA at 6 months in the silicone oil group ranged from 1.0 to 0.1 with a mean 0.3 ± 0.25, while in the C_3F_8 group the mean BCVA at 6 months was 0.2 ± 0.13 with a range from 0.5 to 0. The *t*-test was used to compare the preoperative BCVA at 6 months in the 2 groups. The two-tailed *p* value equals 0.0425; this difference is considered to be slightly statistically significant.

Table 1 shows the data from all eyes included in the study.

Confidence interval: The mean of group one minus group two equals −0.129, and the 95% confidence interval of this difference ranges from −0.253 to −0.005.

The intermediate values used in these calculations are as follows: $t = 2.1424$ and the standard error of difference = 0.060.

3.3. Adverse Events. Two cases (7.4%) had permanent nonclosure of the macular hole (one case in each group). Two cases in the gas-treated group had a postoperative day 1 high intraocular pressure that was medically controlled for 2 weeks. None of the cases in the study developed endophthalmitis, choroidal haemorrhage, or retinal detachment. The incidence of cataract was 33% (three of ten) for the silicone oil group and 25% (four of sixteen) in the gas-treated group.

4. Discussion

Thirty-three cases of TMH were reviewed in a retrospective comparative study done from May 2014 to September 2016. After the initial period of 6 months follow-up, 7 cases were excluded due to spontaneous closure. PPV + ILM peeling was performed in all cases. In 16 cases, 14% C_3F_8 was used as a tamponade. For children or adults refusing to adopt the strict facedown position, we used silicone oil as a tamponade (10 cases).

The results showed closure rate for gas-treated eyes (94%: 15 of 16) and closure rate for silicone oil tamponade (90%: 9 of 10) in a single operation. However, the slight difference in the percentage could be due to the different number of eyes included in the 2 studied groups. The primary success rate of traumatic macular holes closure was 92.3% (24 of 26).

The visual results showed that the postoperative LogMAR BCVA at six months in the silicone oil group ranged

Table 1: Shows the data from all patients.

Case	Sex	Age	Pre-BCVA	Macular hole size	BCVA one month	BCVA 4 months	OCT 4 months	BCVA 6 months	OCT 6 months
Silicone									
1	M	19	0.7	378	0.4	0.3	Hole closed	0.3	Hole closed
2	M	14	0.5	289	0.4	0.3	Hole closed	0.1	Hole closed
3	M	43	1.0	478	0.3	0.3	Hole closed	0.2	Hole closed
4	M	26	1.3	503	0.7	0.5	Hole closed	0.4	Hole closed
5	M	16	0.5	291	0.5	0.4	Hole closed	0.3	Hole closed
6	F	32	1.3	415	0.4	0.3	Hole closed	0.2	Hole closed
7	M	14	0.3	433	0.4	0.3	Hole closed	0.3	Hole closed
8	M	10	1.0	390	0.3	0.3	Hole closed	0.3	Hole closed
9	M	9	1.3	330	0.4	0.3	Hole closed	0.3	Hole closed
10	F	42	1.3	533	1.0	1.0	Failure	1.0	Failure
	Mean	22.5	0.8	404	0.5	0.4		0.3	
	MAX	43	0.3	533	0.3	0.3		0.1	
	Min	9	1.3	289	1.0	1.0		1.0	
	SD	12.7	0.4	85.13	0.21	0.22		0.25	
C_3F_8									
1	M	17	0.7	390	0.3	0.3	Hole closed	0.1	Hole closed
2	F	23	1.0	394	0.3	0.3	Hole closed	0.1	Hole closed
3	M	36	1.3	443	0.4	0.1	Hole closed	0	Hole closed
4	M	32	1.0	422	0.5	0.4	Hole closed	0.3	Hole closed
5	M	25	1.0	354	0.5	0.1	Hole closed	0.1	Hole closed
6	M	20	1.0	406	1.0	0.3	Failure	0.5	Failure
7	M	18	0.8	389	0.7	0.4	Hole closed	0.2	Hole closed
8	M	54	1.0	402	0.4	0.1	Hole closed	0.1	Hole closed
9	M	33	1.0	403	0.3	0.3	Hole closed	0.1	Hole closed
10	M	30	1.3	399	0.4	0.1	Hole closed	0.1	Hole closed
11	F	21	1.3	401	0.3	0.1	Hole closed	0.3	Hole closed
12	M	34	1.0	432	0.3	0.1	Hole closed	0.1	Hole closed
13	M	38	1.3	490	0.4	0.4	Hole closed	0.3	Hole closed
14	M	43	1.3	389	0.5	0.3	Hole closed	0.3	Hole closed
15	M	32	1.3	354	0.5	0.4	Hole closed	0.3	Hole closed
16	M	23	1.0	355	0.5	0.5	Hole closed	0.1	Hole closed
	Mean	29.94	1.1	401.44	0.4	0.3		0.2	
	MAX	54	0.7	490	0.3	0.1		0	
	Min	17	1.3	354	1.0	0.4		0.5	
	SD	9.98	0.2	34.8	0.19	0.13		0.13	

from 1.0 to 0.1 with a mean 0.3 ± 0.25, while the postoperative BCVA at six months in the C_3F_8 group ranged from 0.5 to 0 with a mean of 0.2 ± 0.13. Postoperative BCVA was compared at six months in the two groups by *t*-test. There was a statistically significant difference with better BCVA in the gas group. This might be due to the nature of the cases, like silicone oil, being used for larger traumatic macular holes with consequently more photoreceptor and RPE damage. Anatomical closure rates in this study were favorably compared with previous reports of traumatic macular hole 20 as well as myopic [20] or idiopathic hole [21]. This could be attributed to younger patient age, relatively earlier diagnosis, and the fact that overall natural closure rate of traumatic macular hole is higher than that of myopic or idiopathic hole [22–24].

For silicon-filled eyes, the final success rate (90%) is more than that reported by Goldbaum et al. [25] whose success rate was 83% seal rate for idiopathic macular holes, and this may be due to the fact that they operated on their cases and did not instruct the patients to adopt special position in the early postoperative period, and considerably less than the 97% reported previously by Pertile and Claes [26] for idiopathic macular holes.

In this study, the anatomical closure rates for gas-filled eyes (94%) compared to the 58% closure rate were first described by Kelly and Wendel [27] and the 69% seal rate

described by Freeman et al. [28]. This might be because the macular holes in these studies were idiopathic and not traumatic; additionally, younger patients were included in our study with subsequent healthy RPE and ILM peeling was performed in our study.

We also analyzed pre- and postoperative visual acuities. The average preoperative visual acuity was slightly worse in the silicone oil group compared with the gas group. Both groups showed a gradual improvement in LogMAR visual acuities at four weeks, four months, and six months with the silicone oil group improved from 0.8 to 0.3, while the gas-treated group improved from 1.1 to 0.2. Goldbaum et al. [25] reported anatomical closure of idiopathic macular holes with silicone oil which resulted in an improvement of 3-4 lines; however, this result was not reported for traumatic macular holes. The better visual outcome in gas-treated eyes than in silicone-treated eyes may be due to large hole size with consequently more photoreceptor and RPE damage and the potential toxicity of silicone oil when in contact with the bare RPE and photoreceptors [29–32].

5. Conclusions

Spontaneous closure of TMH could occur in a significant percentage of cases, so an initial period of follow-up is advised. In cases treated with PPV with ILM peeling, both silicone oil and C_3F_8 can achieve comparable anatomical and functional results.

Conflicts of Interest

The authors report no conflicts of interest in this work.

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Review Article

Vitreous Substitutes: Old and New Materials in Vitreoretinal Surgery

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Recent developments in vitreoretinal surgery have increased the need for suitable vitreous substitutes. A successful substitute should maintain all the physical and biochemical properties of the original vitreous, be easy to manipulate, and be long lasting. Substitutes can be gaseous or liquid, both of which have associated advantages and disadvantages related to their physical properties and use. Furthermore, new surgical techniques with smaller vitreoretinal instruments have driven the use of more viscous substitutes. In this review, we analyze and discuss the most frequently used vitreous substitutes and look ahead to future alternatives. We classify these compounds based on their composition and structure, discuss their clinical use with respect to their associated advantages and disadvantages, and analyze how new vitreoretinal surgical techniques have modified their use.

1. Introduction

The vitreous body is a clear gel that fills the space between the lens and the retina. It constitutes approximately 80% of the volume of the entire eye [1]. In the recent years, the development of new surgical techniques and intravitreous-release drugs has led to a need for improved vitreous substitutes. The ideal vitreous substitute has all the qualities of the vitreous body (transparency, biocompatibility, volume retention, elasticity, and durability) and lacks negative characteristics such as ageing liquefaction and biodegradation. Intensive research is underway to develop new products that resemble the vitreous as closely as possible. In this review, we describe the positive and negative aspects of current and experimental substitutes and evaluate their use in new surgical techniques to repair retinal detachment.

2. Method of Literature Search

For this review, a literature search was conducted that utilized Medline, Premedline, EMBASE, SCOPUS, and Cochrane. Papers from 1950 onwards were included on vitreous structure and function while review articles from 2011 onwards were included on vitreous substitutes. The following search terms were used: vitreous substitutes, vitreous humour, vitreous body, ideal vitreous substitutes, tamponade in retinal detachment, gas tamponade in retinal detachment, pneumatic retinopexy, silicone oil in retinal detachment, heavy silicone oil in retinal detachment, hydrogel, hydrogel in retinal detachment, microincision vitreoretinal surgery, and vitreous substitutes. References present in relevant articles were used. Only articles in English were considered.

3. Vitreous

3.1. Anatomy. Each eye contains approximately 4 mL of vitreous, a transparent gel-like structure. The vitreous can be subdivided into three anatomical regions: the vitreous core, the vitreous base, and the vitreous cortex. The vitreous cortex is the part closest to the retina; it exhibits a variable thickness and a lamellar structure. It contains hyalocytes and densely packed collagen, similar to the vitreous base which covers the ora serrata [2]. The vitreoretinal interface is composed of the internal limiting membrane (ILM), the innermost part of the retina, and the posterior vitreous. The ILM forms the basement membrane of the Müller cells. It consists of type IV collagen which is associated with glycoproteins and contributes to vitreoretinal adhesion and type

XVIII which binds opticin. Opticin is a class III small leucine-rich repeat protein which binds to heparin sulfate contributing to vitreoretinal adhesion [3]. The strength of vitreous attachment to the surrounding tissue, including lens, differs according to location. The vitreous is known to be most firmly attached at the vitreous base, the optic nerve and macula, and over retinal vessels.

The vitreous body is routed by the Cloquet's canal, a remnant of the hyaloid artery, which arises from the Martegiani's space at the optic disc to the retrolental space known as the Berger's space. Unlike the vitreous base and cortex, the vitreous core does not contain hyalocytes and is usually the area sampled in proteomic studies because it is the simplest to acquire. All vitreous structures undergo characteristic changes with ageing, including progressive liquefaction and, in some cases, posterior vitreous detachment.

3.2. Chemistry. The vitreous is composed of over 98% water. Between 15% and 20% of water is bound to proteins and glycosaminoglycans. Primate studies have demonstrated that the remaining portion is free [4].

3.2.1. Proteins. The average vitreous concentration of proteins is 1200 μg/mL. Albumins (40%) and immunoglobulins are the most prevalent. Iron-binding proteins such as transferrin are synthesized in the vitreous itself and have a protective role in the event of small vitreous haemorrhages via the prevention of iron toxicity [5].

Collagens are insoluble proteins of the vitreous. They form a three-dimensional meshwork within the vitreous gel. Collagen types II, IV, V/XI, VI, and IX are present, with collagen type II to be the most prevalent (65%), followed by type IX (25%), type V/XI (10%), and type IV (<10%) [6]. In vitro studies have demonstrated that Müller cells are able to synthesize collagens, and therefore these cells are thought to generate the vitreous collagens [7].

3.2.2. Glycosaminoglycans. Glycosaminoglycans (GAGs) are important constituents of the vitreous. They are extracellular matrix polysaccharides that contain repeating disaccharide units. Three major groups of GAGs are present: hyaluronic acid (HA), chondroitin sulfate, and heparan sulfate.

(1) Hyaluronic acid. Hyaluronic acid (also called hyaluronan) is unique among the GAGs in that it does not contain sulfate and it is not found covalently attached to proteins forming a proteoglycan. Hyaluronic acid polymers are very large (molecular weights of 100,000–10,000,000 DA) and can displace a large volume of water. The immense size of these molecules makes them excellent lubricators and shock absorbers within the joints and the vitreous. The ageing process creates two structural changes: depolymerization of HA and the subsequent loss of collagen IX. The absence of collagen IX induces aggregation of collagen II fibrils (syneresis) and formation of fluid-filled lacunae (synchisis) [8].

(2) Chondroitin sulfate. Chondroitin sulfate is a sulfated GAG composed of a chain of alternating sugars (N-acetylgalactosamine and glucuronic acid). It is usually attached to proteins as part of a proteoglycan. In the vitreous, it appears in the form of two proteoglycans: versican and type IX collagen [9]. It is important in maintaining the structural integrity of the tissue and provides resistance against compression.

(3) Heparan sulfate. Heparan sulfate has been identified in small amounts in the vitreous, and its role is to maintain adequate spacing between the collagen fibrils. It may also facilitate the regulation of a wide variety of biological processes including development, angiogenesis, and blood coagulation [10], as well as maintaining vitreoretinal adhesion in collaboration with opticin.

3.2.3. Ascorbic acid and cells. Ascorbic acid is found in higher concentrations in the vitreous body than in the plasma [11]. It has an important role in the process of ageing liquefaction and can inhibit neovascularization, as well as increase the proliferation of hyalocytes. Recent studies have shown that the antioxidant properties of ascorbic acid can also reduce early cataract formation [12]. Vitreous body contains three types of cellular element: hyalocytes, fibroblasts/fibrocytes, and macrophages. Fibroblasts and hyalocytes are present on the vitreous surface, and they are also involved in the phagocytosis and/or secretion of collagen.

3.3. Physical Properties. The vitreous is not completely homogeneous, an effect resulting from the presence of so many components. The viscoelastic properties of the vitreous result from the interaction between long collagen fibrils and HA. It is well known that numerous ions in the interior travel from the dense and viscous portions (the vitreous base) to the anterior part. This can affect the release and dissemination of intravitreous drugs.

Although the vitreous has not aroused scientific interest for many years, it has numerous and important roles, with the key functions being to (1) sustain the growth, volume, and elasticity of the eye (structural function); (2) maintain transparency and improve the accommodation (optical function); (3) create a barrier to biochemical substances (barrier function); and (4) provide substances for nutrition and metabolism (nutritional function).

3.3.1. Structural function. Recent studies have shown that the growth of the vitreous may modify the growth of the retinal pigment epithelium (RPE) through the production of HA [13]. The vitreous protects the retina and the other structures from the low-frequency mechanical stress, friction, and vibration that are both common and constant in everyday life. Its viscoelasticity acts as an important shock absorber against physical impact, providing more than a space-filling function, particularly in younger people.

3.3.2. Optical function. The most important role of the vitreous is to maintain transparency, enabling the passage of light rays toward the retina. It transmits visible and near-infrared

light, in a similar manner to the aqueous [14]. Little light scattering occurs in the vitreous due to the large HA molecules that separate collagen fibers. By supporting the lens capsule, it also aids the accommodation process.

3.3.3. Barrier function. The vitreous can protect the eye, acting as a barrier to various biochemical substances and cells. In this manner, it helps prevent bacterial infection, although it can act as a growth surface for some viral agents. In the healthy eye, the vitreous is an important part of the blood-ocular barrier, inhibiting neovascularization and inflammation.

3.3.4. Nutritional function. Other important functions of the vitreous body are metabolism and the regulation of intraocular oxygen through ascorbate concentration [12]. Consuming oxygen via an ascorbate-dependent mechanism protects the lens from oxidative damage and reduces cataract formation.

4. The Ideal Vitreous Substitute

The ideal vitreous substitute is similar to the native vitreous in both structure and function. It should have similar viscoelastic properties and maintain a normal intraocular pressure (IOP) in order to support the ocular structures in their correct position. It should be optically transparent while allowing the circulation of ions and electrolytes. As a substitute, it should be easy to manipulate and self-renewable in order to require a single implantation. It should also be nontoxic to other ocular structures, biocompatible, nonbiodegradable, readily available at reasonable cost, and easy to store [15]. All vitreous substitutes currently have positive and negative characteristics. New research is underway to discover the ideal vitreous substitute.

5. Vitreous Substitutes

There are three major categories of substitute: gases (air, expansile gases), liquids (salt solution, perfluorocarbon liquids, semifluorinated alkanes, silicone oil, etc.), and polymers (hydrogels, smart hydrogels, and thermosetting hydrogels) [15].

5.1. Gases

5.1.1. Air. Air present in the vitreous cavity is colourless and inert. It was first used by Ohm in 1911 to repair retinal detachment [15]. Air is inexpensive and easy to find. It remains in the eye for a few days before being replaced by the aqueous humour, thereby reducing its tamponade effect. It is easily absorbed by red blood cells and therefore diffuses quickly into the blood circulation. This is a negative feature of air as a vitreous substitute. Another negative characteristic is its low refractive index (approximately 1.000293 nanometers), which causes complete light reflection and therefore poor optical function [16]. Its use is limited to pneumatic retinopexy at the end of vitrectomy surgery and as an emergency option.

5.1.2. Other Gases. Intraocular gas tamponades have been an important part of vitreoretinal surgery since 1970. Today, sulfur hexafluoride (SF_6) and perfluoropropane (C_3F_8) are increasingly being used in the treatment of many complicated vitreoretinal diseases. Both these gases are heavier than air, colourless, odourless, and nontoxic. They maintain their tamponade effect due to their high surface tension and the diffusion of other gases from the circulation. In 1993, the U.S. Food and Drug Administration approved their use for pneumatic retinopexy [15]. Sulfur hexafluoride expands to double the injected volume within 1 to 2 days and lasts in the vitreous cavity for 1 to 2 weeks. Perfluoropropane expands to about four times its original volume in 72 to 96 hours and lasts for 6 to 8 weeks. For this reason, patients are usually advised to delay air travel and avoid high altitudes for about 2 weeks and 6 weeks following the administration of sulfur hexafluoride and perfluoropropane, respectively.

Due to their buoyancy, intraocular gas tamponades maintain the position of the retina against the RPE, but this effect is limited on the upper part of the bubble and does not affect the inferior retina. For this reason, awkward face-down positioning is required for several days following administration. Adverse effects include an increase of IOP during surgery and, for a few days after injection, gas-induced cataract formation and corneal endothelial changes [17, 18, 19].

5.2. Liquids

5.2.1. Perfluorocarbon Liquid (PFCL). Perfluorocarbon liquid is a fluorochemical in which all the hydrogen atoms are replaced by fluorine [20]. PFCL has a high specific gravity of between 1.76 and 2.03 g/mL with low surface tension and viscosity and an optical transparency. PFCL was initially used in medicine when it was discovered to carry oxygen atoms in the same manner as the blood [21]. In 1987, Chang et al. used PFCL for the first time in retinal detachment with severe proliferative vitreoretinopathy [22, 23]. During vitrectomy, PFCL flattens the detached retina and displaces the subretinal fluid. Furthermore, its transparency facilitates its ease of use during procedures and intraoperative photocoagulation.

The applications of PFCL are, in part, limited to intraoperative use due to its long-term toxicity. This toxicity begins in the inferior retina with mechanical damage to cells via compression and disorganization of the retinal structure and emulsification six days after surgery [24]. In addition, young patients are at a high risk for developing severe ocular inflammation. Recent developments in PFCL have focused on perfluorocarbon-perfused vitrectomy, in which oxygenated or nonoxygenated PCFL is used instead of balanced salt solutions [20, 25, 26].

5.2.2. Semifluorinated Alkanes (SFAs). Semifluorinated alkanes were identified in 2000 as a new class of compounds with outstanding properties for use in ophthalmology [15]. They have a perfluorocarbon and hydrocarbon segments, and they are soluble in PFCL, hydrocarbons, and silicone oils with a preferred refraction index (1.3). They are physically

inert, colourless, and heavier than water (specific gravity of 1.35 g/mL). The lower specific gravity results in less retinal damage than PCFL, and as such SFAs can be used as a temporary endotamponade for periods from 2 to 3 months [27]. Their collateral effects may include cataract, emulsification, and soft epiretinal membrane [27]. Recently, they have been used in a mixture of silicon oil and SFA.

5.2.3. Silicone Oil (SO). Silicone oil is a liquid polymerized siloxane with organic side chains. It is a hydrophobic polymer with a specific gravity slightly less than water (0.97 g/mL) and a refractive index similar to that of the vitreous [15]. All SO polymers are of commercial interest for their stability, lubricating properties, and as a vitreous substitute, with high surface tension and viscosity, ease of removal, low toxicity, and transparency. For these reasons, they are the only substance currently accepted for long-term vitreous replacement [15, 28]. Due to their buoyancy, SOs have a tamponade force higher at the apex, facilitating the preservation of anatomical integrity. They are used for complicated retinal detachment, when postoperative airplane travel is planned, and in uncooperative patients.

SO is available in several viscosities, but 1000 and 5000 centistokes are used clinically. SO is usually removed after 3 to 6 months once the retina has attached and retinal traction is absent [15].

Although SO is a good vitreous substitute, it has several disadvantages:

(1) Tamponade of the inferior retina is difficult due to its low specific gravity.

(2) Emulsification in small droplets into the aqueous can cause proliferative vitreoretinopathy, failed retinal detachment, inflammation, secondary glaucoma, and keratopathy [29, 30]. With the advent of microincision vitreoretinal surgery (MIVS), less viscous silicone oils are preferred. They can be easily introduced and removed via small instruments, but they are easier to emulsify. For this reason, new silicone oils with an increased extensional viscosity are under investigation [29].

(3) Increased IOP is common after SO implantation. This could be caused by pupillary block glaucoma, overfill of silicone oil, and chronic elevation due to emulsification in the trabecular meshwork and trabeculitis [29].

(4) Decreased choroidal thickness three months following SO implantation [31]. This may be caused by the failure of Müller cells to circulate potassium and the subsequent potassium accumulation, retinal degeneration, and inner retinal and choroidal thinning [32].

(5) Intracranial migration through the optic nerve to the lamina cribrosa and the optic chiasm with the development of central scotoma. This complication is very rare and usually occurs in patients with optic nerve abnormalities and glaucoma [33].

5.2.4. Heavy Silicone Oil (HSO). Heavy silicone oil is a tamponade agent formed from a mixture of SO and partially fluorinated octane (PFA) that is heavier than water. For this reason, it has been used for complex retinal detachment involving the inferior part of the retina complicated by proliferative vitreoretinopathy. In 2011, the heavy silicone oil study [34] compared standard SO with HSO in the treatment of inferior retinal detachment. Although superiority of a heavy tamponade was not shown, the study demonstrated a good intraocular tolerance of HSO and no significant emulsification [15].

Complications of HSO include cataract, anterior segment inflammation, emulsification, and elevated IOP [15, 19, 35, 36].

5.2.5. Hydrogels. Cross-linked hydrogels are synthetic polymer networks that are expanded throughout their volume by water. For this reason, they can melt in water without dissolving. Hydrogels have favourable properties such as transparency, biocompatibility, and mechanical flexibility which have led to their widespread application in ophthalmology as soft contact lenses, intraocular lenses, drug delivery systems, and adhesion for wound repair [37].

Hydrogels can be divided into hydrogels and "smart hydrogels." Smart hydrogels can create a three-dimensional structure in response to a variety of signals including pH variation, temperature, light, pressure, chemicals, and electric fields [38].

To date, these polymers have only been used on an experimental basis. A major disadvantage is their activation of the immune system, resulting in intravitreal inflammation and phagocytosis by macrophages in the vitreous, neuroretina, and subretinal spaces [39]. In addition, they are difficult to sterilize because heat sterilization may cause a degradation of their physical structure. More research is needed to optimize the use of these new molecules as vitreous substitutes.

6. Future Vitreous Substitutes

In the recent years, bioengineering studies using rabbit models have shown promising results in a capsular artificial vitreous body made from elastomer rubber with a valve system full of SO or a balanced solution [40]. However, the biocompatibility of a synthetic implant with the human eye is yet untested.

The properties of new hydrogels make them promising candidates as infill biomaterials for the treatment of retinal detachment. Hayashi et al. reported a new class of hydrogel with extremely low swelling pressure which functioned as an artificial vitreous body for over a year without adverse effects in the eyes of rabbits [41].

Another fascinating possibility for the future is the use of cell culture and gene therapy to artificially synthesize the vitreous via the proliferation of hyalocytes [42]. This research has been aided by the use of reverse transcriptase polymerase chain reaction to analyze and compare the expression profiles of several genes involved in synthesis of the vitreous [43].

7. Microincision Vitreoretinal Surgery and Vitreous Substitutes

Considerable progress has been recently made in the field of vitreoretinal surgery. One of the most important advancements is the development of small-gauge suturless transconjunctival surgery, also known as minimally invasive vitreous surgery (MIVS). This system uses microcannulas and trocars of 23G (0.64 mm), 25G (0.51 mm) and 27G (0.40 mm), and other instrumentation smaller than traditional 20G (0.9 mm) vitrectomy. This new procedure has introduced many benefits, including a reduction of postoperative inflammation at the sclerotomy site, the need for less tissue manipulation, easier recovery, and a decrease in surgical complications.

Tamponades have begun to adapt with this new type of vitreoretinal surgery. The key feature of vitreous substitutes used in MIVS is a low viscosity, in particular for liquids and notably for SO. A less viscous oil would be user-friendly, but an oil with greater viscosity would be less likely to emulsify [44]. New SO has an increasing extensional viscosity with a greater resistance to emulsification and an improved ease of handling.

In accordance with Poiseuille's law, which evaluates the radius and the length of a tube to calculate the flow of a fluid, MIVS uses special devices including a large syringe, a short infusion line, and a nondistensible material to reduce resistance during the injection and removal of SO [44].

The surgical technique used to inject SO into the eye has also changed with MIVS. There is a diffuse consensus to perform air-silicone exchange instead of fluid-silicone exchange (unused due to the high risk of undesired subretinal silicone drops) or PFCL-silicone exchange (direct exchange). This is preferred to the direct exchange usual for uncomplicated retinal detachment with mild periphery or posterior pole break because it is easier to inject SO using a cannula instead of an infusion line.

The removal of SO with MIVS requires more time than the same procedure using a 20G system, but requires less time positioning and removing trocars.

Surgeons have a choice of many tamponades for use with MIVS, each with advantages over the surgical complications associated with 20G vitrectomy, enabling selection appropriate to the underlying disease [45].

8. Conclusion

For many years, it was thought that the vitreous had a marginal role in the anatomy and function of the eye. Only with the advent of new surgical techniques was its importance in maintaining an optimal environment for the retina and the other surrounding tissues recognized.

For this reason, research was originally focused on finding a vitreous substitute with the same physical and biochemical properties of the original vitreous.

In recent years, with the advent of MIVS, it has been necessary to modify the physical structure of the most commonly used vitreous substitutes.

A new generation of vitreous substitutes is under development to satisfy the need for a physiologically equivalent and long-lasting substitute [40, 41, 42, 43].

Future developments based on stem cells and gene therapy may go some way to fulfill the needs of both patients and ophthalmic surgeons.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Clinical Study

Exclusive Use of Air as Gas Tamponade in Rhegmatogenous Retinal Detachment

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Purpose. To investigate outcomes of vitrectomy for rhegmatogenous retinal detachment (RRD) using air exclusively as the gas tamponade. *Methods*. This retrospective, interventional, consecutive case series involved reviewing medical records of patients that underwent vitrectomy and gas tamponade for RRD between January 2013 and December 2015. Patients whose eyes were treated exclusively with air tamponade since July 2014 were assigned to the air group, while those treated with heterogeneous gas agents before June 2014 were assigned to the control group. The primary outcome was the primary reattachment rate. Best-corrected visual acuity (BCVA) and duration to detect redetachments were assigned as the secondary outcomes. *Results*. The air group and the control group included 71 and 72 eyes, respectively. The primary reattachment rate was 94.4% in the air group and there was no significant difference with 94.4% in the control group ($p = 0.951$). BCVA was significantly better in the air group at 1 month ($p = 0.021$) but not at 3 months postoperatively ($p = 0.561$). Redetachments were recognized earlier in the air group (9.3 ± 0.5 days) compared with those in the control group (21.3 ± 7.4 days) ($p = 0.041$). *Conclusions*. In cases of simple RRD with sufficient removal of subretinal fluid, air could be considered for use as gas tamponade. This trial is registered with KCT0002358.

1. Introduction

Pars plana vitrectomy (PPV) with gas tamponade is widely popular for the treatment of rhegmatogenous retinal detachment (RRD). Nonexpansile gases, such as 18% sulfur hexafluoride (SF6), 14% octafluoropropane (C3F8), and room air, are commonly used as gas tamponade at the end of vitrectomy [1, 2]. Of these, 18% SF6 and 14% C3F8 last for at least 1 month and as such are named long-acting gases, whereas room air has a much shorter half-life of only 1 day [3]. Generally, the success rate using long-acting gas as tamponade had been thought to be higher than that using room air in RRD [4].

Due to technical advances, the success rate of vitrectomy for RRD has soared; however, surgeons consider the success rate as well as patient compliance. Recently, a prospective study of inferior RRD by Zhou et al. [5] showed that the results with room air tamponade were not inferior to those with long-acting gas, which agrees with our own retrospective data [6]. On the basis of these results, since July 2014, we have used room air exclusively as gas tamponade at the end of vitrectomy for RRD.

Herein, we review our case results with room air tamponade and compare them with previous results using heterogeneous gas tamponade.

2. Methods

The current study was a retrospective, interventional, consecutive case series. The medical records of consecutive patients

that underwent vitrectomy and gas tamponade for primary RRD between January 2013 and December 2015 were reviewed. We excluded cases treated by scleral buckling, vitrectomy combined with scleral buckling, or use of silicone oil tamponade. Patients who had a history of intraocular surgery, except for cataract and uveitis or retinal vascular disorders, were excluded. The institutional review board of Pusan National University Hospital approved the study protocol, and the protocol complied with the tenets of the Declaration of Helsinki.

2.1. Choice of Surgical Procedure. Scleral buckling and vitrectomy combined with scleral encircling were usually used in young phakic RRD and severe proliferative vitreoretinopathy cases, respectively. Silicone oil tamponade after vitrectomy was applied in cases with failure to sufficiently remove subretinal fluid or the vitreoretinal proliferative membrane. We deemed vitrectomy with gas tamponade as the best choice in cases other than those described above.

2.2. Surgical Procedures. All patients were operated on by a single surgeon (SW Park), who used the Constellation (Alcon Laboratories Inc., Fort Worth, TX) sutureless 23-gauge (G) or 25 G vitrectomy system and a noncontact wide viewing system, the Resight 700 (Carl Zeiss Meditec AG, Jena, Germany). Phacoemulsification was combined concurrently at the surgeon's discretion. If necessary, to confirm the presence of posterior vitreous detachment or epiretinal membrane, triamcinolone acetonide was applied during the PPV. For shaving the peripheral vitreous, an assistant usually indented the sclera. Prophylactic laser photocoagulation was applied only around retinal breaks or lesions predisposed to retinal detachment, not on the normal-looking retina. During vitrectomy, perfluorocarbon liquid (PFCL) was used if necessary. Patients were instructed to maintain a face-down position for 1 to 3 days after the operation.

2.3. Data Collection. The patients were divided into two groups: the air group and the control group. The air group underwent vitrectomy after July 2014 and received only air tamponade. The control group underwent vitrectomy between January 2013 and June 2014 and received heterogeneous gas tamponade.

The following baseline characteristics were collected: type of gas, age, sex, intraocular pressure (IOP), lens status, axial length, high myopia, involvement of macula, number of retinal breaks, range of retinal detachment, presence of inferior breaks, use of PFCL during operation, and best-corrected visual acuity (BCVA), which was quantified using lines of Snellen visual acuity. The inferior breaks were defined as one or more breaks inside the retinal detachment located between the 4 and 8 o'clock positions.

The primary reattachment was defined as a retina reattached at 3 months after a single operation without any additional procedure. The primary reattachment rate was compared between the two groups. BCVA was compared at 1 and 3 months postoperative. IOP measurements at 1 and 7 days postoperative were analyzed. In the redetached cases, duration to detect the redetached retina, total number of surgeries, final BCVA, and presence of inferior breaks was investigated and compared.

Table 1: Choice of surgical method in each 18-month period.

Surgical methods	Before July 2014 (n, %)	After July 2014 (n, %)	p value
Vitrectomy + gas tamponade	72 (40.0)	71 (40.8)	0.914
Scleral buckling	64 (35.6)	51 (29.3)	0.214
Scleral buckling with vitrectomy	30 (16.7)	29 (16.7)	1.000
Vitrectomy + silicone oil tamponade	14 (7.8)	23 (13.2)	0.118
Total	180 (100)	174 (100)	

2.4. Statistical Analysis. All statistical analyses were performed using SPSS for Windows 21.0 (SPSS Inc., Chicago, IL). BCVA was converted to a logarithm of the minimum angle of resolution (logMAR) for statistical analysis. Differences between the two groups were assessed using an independent Student's t-test (continuous factors) or chi-square test (categorical factors). In the subgroup of redetached cases, differences between the two groups were assessed using the Mann–Whitney U test or Fisher's exact test. p values <0.05 were considered statistically significant.

3. Results

3.1. Baseline Characteristics. The air group comprised 174 eyes in patients with primary RRD who underwent surgery for RRD over an 18-month period beginning in July 2014. Of these 174 eyes, the following were excluded: 51 eyes (29.3%) that received a scleral buckling procedure, 29 eyes (16.7%) that received a combined scleral buckling with vitrectomy, and 23 eyes (13.2%) that were treated with silicone oil as tamponade. Finally, a total of 71 eyes (40.8%) were included in the air group. The control group comprised 180 eyes in patients with primary RRD patients who underwent surgery for RRD for an 18-month period beginning in January 2013. Of these 180 eyes, the following were excluded: 64 eyes (35.6%) that received a scleral buckling procedure, 30 eyes (16.7%) that received a combined scleral buckling with vitrectomy, and 14 eyes (7.8%) that were treated with silicone oil as tamponade. Finally, a total of 72 eyes (40.0%) were included in the control group (Table 1). The air group comprised 34 men and 37 women with a mean age of 58.6 ± 8.8 years, while the control group comprised 40 men and 32 women with a mean age of 56.9 ± 9.8 years. In the air group, air tamponade was used exclusively. In the control group, air was used in 15 eyes, diluted SF6 in 55 eyes, and diluted C3F8 in two eyes. The baseline characteristics of each group are summarized in Table 2. There were no significant differences in terms of age, sex, IOP, lens status, axial length, proportion of high myopia, involvement of macula,

Table 2: Baseline characteristics of each group.

	Control group	Air group	p value
Type of gas (n) Air : SF_6 : C_3F_8	15 : 55 : 2	71 : 0 : 0	<0.001†
Age (mean ± SD, yr)	56.9 ± 9.8	58.6 ± 8.8	0.351*
Sex (M : F)	40 : 32	34 : 37	0.401†
BCVA (mean ± SD, logMAR)	1.38 ± 1.11	1.11 ± 1.05	0.143*
IOP (mean ± SD, mmHg)	13.6 ± 2.7	13.0 ± 3.1	0.237*
Axial length (mean ± SD, mm)	25.14 ± 2.11	24.83 ± 1.65	0.336*
Proportion of high myopia (n, %)	23 (31.9%)	16 (22.5%)	0.282†
Macula On : off	32 : 40	36 : 35	0.614†
Number of retinal breaks (mean ± SD)	1.8 ± 1.3	1.6 ± 1.0	0.315*
Range of retinal detachment (mean ± SD, hours)	4.4 ± 1.7	4.6 ± 1.9	0.357*
Lens state Phakic : pseudophakic	58 : 14	52 : 19	0.422†
Inferior break (n, %)	28 (38.9%)	18 (25.4%)	0.111†
Use of PFCL (n, %)	20 (27.8%)	21 (29.6%)	0.336†

*Independent student's t-test. †Chi-square test. BCVA: best-corrected visual acuity; IOP: intraocular pressure; SD: standard deviation; logMar: logarithm of the minimum angle of resolution; PFCL: perfluorocarbon liquid.

number of retinal breaks, range of retinal detachment, presence of inferior breaks, use of PFCL, and BCVA.

3.2. Surgical and Visual Outcomes. The primary reattachment was observed in 67 of 71 eyes (94.4%) in the air group and 68 of 72 eyes (94.4%) in the control group, with no significant difference between the groups ($p = 0.951$, chi-square test).

In the air group, BCVA improved from 1.11 ± 1.05 logMAR (median, 20/125) at baseline to 0.23 ± 0.25 (median, 20/32) at 1 month and 0.18 ± 0.19 (median, 20/25) at 3 months postoperatively. In the control group, BCVA improved from 1.38 ± 1.11 logMAR (median, 20/300) at baseline to 0.33 ± 0.34 (median, 20/40) at 1 month and 0.20 ± 0.24 (median, 20/25) at 3 months. At 1 month postoperatively, BCVA was significantly better in the air group ($p = 0.021$), but not at 3 months ($p = 0.561$). The IOP of the air group changed from 13.0 ± 3.1 mmHg at baseline to 10.5 ± 3.1 at 1 day and 15.1 ± 4.2 at 7 days postoperatively. In the control group, IOP changed from 13.6 ± 2.7 mmHg to 17.2 ± 7.2 at 1 day and 15.6 ± 5.9 at 7 days. The IOP of the control group was significantly higher at 1 day ($p < 0.001$) but not at 7 days ($p = 0.414$) postoperatively. The postoperative clinical outcomes are summarized in Table 3.

In the subgroup of redetached retina cases, surgical failure was recognized significantly earlier in the air group (9.3 ± 0.5 days) compared with that in the control group (21.3 ± 7.4 days) ($p = 0.041$). The final reattachment was achieved in all cases, requiring 2.3 ± 0.5 and 2.5 ± 0.6 surgeries in total in the air group and control group, respectively. The final BCVA and presence of inferior breaks were not statistically different between the two groups ($p = 0.556$ and $p = 0.465$, resp.) (Table 4).

4. Discussion

In selected RRD cases where air was used as gas tamponade, noninferior results to long-acting gas have been reported [5, 7–10]. To the best of our knowledge, the current study is the first report of exclusive use of air as gas tamponade in vitrectomy for RRD. Our results revealed that air tamponade was noninferior to the heterogeneous gas as tamponade in RRD and had advantages in terms of earlier visual recovery and earlier detection of redetached retinas.

Tamponades serve as a barrier to prevent the movement of fluid between the vitreous cavity and the subretinal space. Once adhesion between the retina and retinal pigment epithelium (RPE) has been established, the barrier is no longer needed. Theoretically, retina-RPE adhesion occurs within 24 hours in situations without subretinal fluid (SRF) [11]. However, remnant SRF around tears can disturb the adhesion, in which cases, the use of tamponade should be extended until the SRF is absorbed. If tears are located in the superior retina, gravity keeps the tears isolated from SRF and use of a long-acting tamponade might be excessive. On the other hand, if tears are located in the inferior retina and viscous SRF remains, a short-acting gas such as room air might be inappropriate as tamponade. Several reports support this theory. Tan et al. [4] said that room air was comparable to long-acting gas not in RRD with inferior breaks but in those with superior breaks. They suggested that air tamponade should be used in cases involving the superior quadrants. Martínez-Castillo et al. conducted three important studies of vitrectomy for RRD with inferior breaks [8–10]. Their results suggested that RRD with inferior breaks could be treated well with vitrectomy even when using air tamponade [9] and that sufficient SRF drainage was an important factor in such cases [10].

Table 3: Clinical outcomes of each group.

	Control group	Air group	p value
Primary reattachment rate (n, %)	68/72 (94.4%)	67/71 (94.4%)	0.951[†]
Final reattachment rate (n, %)	72/72 (100.0%)	71/71 (100.0%)	1.000[†]
BCVA (mean ± SD, logMAR)			
At 1 month	0.33 ± 0.34	0.23 ± 0.25	0.021[*]
At 3 months	0.20 ± 0.24	0.18 ± 0.19	0.561[*]
IOP (mean ± SD, mmHg)			
At 1 day	17.2 ± 7.2	10.5 ± 3.1	<0.001[*]
At 7 days	15.6 ± 5.9	15.1 ± 4.2	0.414[*]

[*]Independent student's t-test. [†]Chi-square test. BCVA: best-corrected visual acuity; IOP: intraocular pressure; logMAR: logarithm of the minimum angle of resolution.

Table 4: Subgroup analysis of the eyes with redetached retinas.

	Control group	Air group	p value
Duration to detect the redetached (days)	21.25 ± 7.44	9.25 ± 0.50	0.041[*]
Total number of surgery	2.25 ± 0.50	2.50 ± 0.58	0.686[†]
Final BCVA (mean ± SD, logMAR)	0.29 ± 0.28	0.22 ± 0.46	0.556[*]
Inferior break (n, %)	2 (50%)	1 (25%)	0.465[†]

[*]Independent student's t-test. [†]Chi-square test. BCVA: best-corrected visual acuity; SD: standard deviation; logMAR: logarithm of the minimum angle of resolution.

The results of primary vitrectomy for RRD were first reported by Escoffery et al. [12]. Air was used as tamponade because no other tamponade was available at that time, and the success rate was 79%. Since then, treatment advances including the use of long-acting gases have led to higher success rates, and these gases have been considered superior to air as tamponade for RRD [4]. Recently, new technologies such as perfluorocarbon liquids, intraocular diathermy, wide-angle viewing systems, and advanced vitreous cutters have contributed to the sufficient removal of SRF and vitreous. Recently, success rates have become over 95% [6, 10, 13, 14], and air tamponades have been reappraised in RRD [5, 6, 10]. The authors retrospectively analyzed 206 cases of RRD using vitrectomy in which the success rate of air tamponade (36 eyes, 100%) was not inferior to that of the others (170 eyes, 95.5%) [6]. A recent randomized comparative prospective trial showed that air was not inferior to diluted C3F8 in RRDs with inferior breaks [5]. But their study designs, procedures, and results seem not to be well controlled; a randomization was failed especially in terms of high myopia. Their method of gas dilution was not general, and although success rates were comparable between the two groups (diluted C3F8: 78.1% and air: 84.4%), those were not comparable to those of other recent reports, 95% or over [6, 10, 13, 14].

Air tamponade has several advantages over long-acting gases, which require additional buying, keeping, and dilution, and it can reduce the cost and surgical time. Dilution and keeping these gases can lead to complications such as elevated IOP, faster absorption than expected, and toxicity due to gas contamination. Additionally, the results of the current study showed that visual recovery and recognition of surgical failure were faster using air. Although we found no significant difference in the final visual outcomes between the groups among the redetached retina cases, an earlier recognition of surgical failure would be expected to offer better outcomes [15, 16].

This study had several limitations. First, there were selective biases due to the retrospective nature. The current study did not include all types of RRD. This study enrolled only simple cases. The cases with insufficient removal of SRF and vitreoretinal proliferative membrane were filled with silicone oil and excluded. The cases treated with scleral buckling or encircling were also excluded. Second, air was compared with heterogeneous gases rather than long-acting gases because we could not find a control group with comparable baseline characteristics who received a long-acting gas. Third, there was a time gap between the surgeries in the two groups, during which technical advances or surgical skill might have had an impact. However, we reasoned that 18 months was too short a time to have a large effect. Finally, while a 3-month follow-up was too short to determine visual outcome, it was enough to evaluate anatomical outcomes and helped to reduce selective biases. In spite of these limitations, the baseline characteristics were quite comparable and a wide spectrum of RRD cases was consecutively enrolled. The current results should be interpreted in consideration of these limitations, and large randomized prospective studies will be needed in the future.

5. Conclusion

Air used exclusively as gas tamponade in vitrectomy for RRD in a consecutive case series spanning 18 months delivered anatomical and visual outcomes that were comparable to

those of the control group receiving heterogeneous gases and also to those described in recent reports [10, 13, 14]. Early visual recovery and early recognition of surgical failure were advantages of air tamponade. In cases of vitrectomy for simple RRD with sufficient removal of SRF, air tamponade can be considered as a substitute for a long-acting gas. A prospective, head-to-head, large-scale comparative study will be necessary in the future to validate the efficacy of air tamponade in RRD.

Conflicts of Interest

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

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Clinical Study

The Combination of Ketorolac with Local Anesthesia for Pain Control in Day Care Retinal Detachment Surgery: A Randomized Controlled Trial

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This study aims to evaluate the efficacy of ketorolac with local anesthesia compared to local anesthesia alone for perioperative pain control in day care retinal detachment surgery. The randomized controlled trial included 59 eyes of 59 participants for retinal detachment surgery who were randomly assigned (1 : 1) into the ketorolac (K) group and control (C) group. All participants underwent conventional local anesthesia while patients in the K group received an extra administration of preoperative ketorolac. Participants in the K group had a statistically significantly lower intraoperative NRS score (median 1.0 versus 3.0, $P = 0.003$), lower postoperative NRS score (median 0 versus 1.0, $P = 0.035$), fewer proportion of rescue analgesic requirement (10% versus 34.5%, $P = 0.023$), and lower incidence of postoperative nausea and vomiting (13.3% versus 41.4%, $P = 0.015$) compared to the C group. Intraocular pressure (IOP) changes ($\triangle$IOP) were significantly reduced in the K group (median 1.9 versus 3.0, $P = 0.038$) compared to the C group 24 hours postoperatively. In conclusion, the combination of local anesthesia with ketorolac provides better pain control in retinal detachment surgery compared to local anesthesia alone. The beneficial effect of ketorolac with local anesthesia may contribute to a wider-spread adoption of day care retinal detachment surgery. This trial is registered with ClinicalTrials.gov NCT02729285.

1. Introduction

Rhegmatogenous retinal detachment (RRD) with a reduction of visual acuity (VA) is an indication for surgical treatment. Although pars plana vitrectomy (PPV) has gained a high popularity and is regarded as the best approach for RRD by the majority of ophthalmologists, scleral buckling (SB) surgery has been proved as effective as PPV in uncomplicated RRD in a meta-analysis of prospective randomized trials by Soni et al. [1]. The authors reported that the postoperative BCVA was better in the eyes treated by SB than those treated by PPV, probably because of a higher rate of cataract formation in the eyes of PPV treatment. Therefore, more attention needs to be paid to SB in the uncomplicated RRD patients [2, 3], especially in those RRD patients without posterior vitreous detachment (PVD) [4].

The practice of local anesthesia (LA) to SB surgery has been increased in recent years [5, 6], especially in the setting of a day care unit. LA is more beneficial to the performance of operations in a day care unit for lower medical cost, lower risks of anesthetic accident, and quicker recovery compared to general anesthesia (GA) [7]. Nevertheless, several reasons may contribute to the perioperative discomfort despite an administration of LA: tissue division [8], repeated ocular muscular traction [9], cryopexy [10], and inflammation [8, 9]. In order to provide a better anesthetic and analgesic environment for surgery, we chose ketorolac as an adjuvant to local anesthesia in day care retinal detachment surgery.

Ketorolac belongs to the family of nonsteroidal anti-inflammatory drugs (NSAIDs) and has been confirmed a short-term analgesic as effective as morphine [11, 12]. Grimsby et al. [11] reported that the continuous infusion of

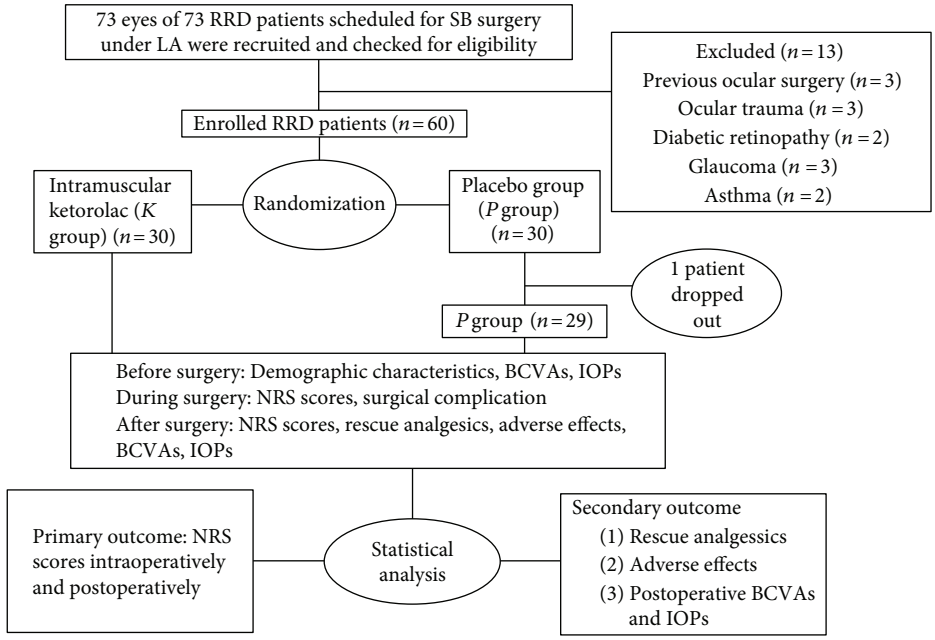

Figure 1: A flow chart showing the enrollment, assignment, procedures, outcome assessments, and data analysis during the whole study. RRD = rhegmatogenous retinal detachment; SB = scleral buckling; LA = local anesthesia; BCVA = best-corrected visual acuity; IOP = intraocular pressure; NRS = Numerical Rating Scales.

ketorolac offered a good pain control after renal surgery. Besides, Yadav et al. [13] reported a significantly improved anesthetic efficacy via preoperative ketorolac with buccal and lingual infiltration combined with articaine inferior alveolar nerve block in mandibular molars with irreversible pulpitis. Moreover, Kim et al. [14] showed that preoperative ketorolac could effectively reduce postoperative pain in laser-assisted subepithelial keratectomy (LASEK). In light of the concept of pain-free anesthesia during the surgery, we designed this trial to evaluate the efficacy of ketorolac with LA compared to LA alone for patients' pain relief in day care retinal detachment surgery.

2. Patients and Methods

This trial was conducted at the Zhongshan Ophthalmic Center, Sun Yat-sen University, Guangzhou, China. Ethical approval for this study (identifier: 2014MEKY042) was obtained by the Ethics Committee of Zhongshan Ophthalmic Center, Sun Yat-sen University, China, and informed consent was obtained from each enrolled subject. The trial was registered with ClinicalTrial.gov NCT02729285 and adhered to the tenets of the Declaration of Helsinki.

2.1. Participants. Our study recruited a total of 73 eyes of 73 adult participants diagnosed with RRD that were scheduled for scleral buckling surgery under a retrobulbar block of LA in a day care unit. The participants included were those 18 years old or above, with a body mass index (BMI) of 18.5–24 kg/m^2 [15], American Society of Anesthesiologists (ASA) physical status I or II, and an understanding of the 11-point Numerical Rating Scales (NRS) [16]. The participants were excluded as follows: history of ocular surgery, trauma, or infection; glaucoma or diabetic retinopathy; diagnosis of renal or liver impairment; diagnosis of asthma, allergy, or coagulopathy; chronic pain syndromes; history of peptic ulceration; history of chronic use of analgesics, sedatives, opioids, or steroids; history of drug or alcohol abuse; history of sexually transmitted disease (STD), including hepatitis B diseases, tuberculosis, syphilis, and acquired immune deficiency syndrome(AIDS); pregnancy or lactation; and cognitive impairment or psychiatric illness. A flow chart is presented for the whole study procedures (Figure 1).

2.2. Randomization and Masking. By using computer-generated randomization, the participants enrolled were allocated (1 : 1) to the ketorolac group (K group) and control group (C group). Both groups received the administration of intramuscular hemocoagulase 30 minutes before surgery for preoperative preparation. Patients in the K group received an intramuscular injection of ketorolac (Lunan Pharmaceutical Group Corporation, Linyi, Shandong Province, China) 30 minutes before surgery. The patients and the outcome evaluators were blind to the randomization.

2.3. Demographic Characteristics and Ophthalmic Examinations. The participants' demographic characteristics including ages and genders were documented. Each participant enrolled in our trial had a comprehensive ophthalmic examination including best-corrected visual acuity (BCVA), intraocular pressure (IOP), and a slit-lamp evaluation preoperatively and 24 hours postoperatively. The BCVA was converted into the logarithm of the minimal angle of resolution (logMAR) for the statistical analysis. The IOP was measured using a noncontact tonometer (Canon) and was calculated as the average value of 3 measurements.

2.4. Surgical Procedures. All participants were fully instructed on the use of the NRS assessments once they were enrolled. On the operation day, standard preoperative preparations were completed including the intramuscular injection of hemocoagulase 30 minutes before surgery. Patients in the K group received a 60 mg of intramuscular ketorolac 30 minutes before surgery.

Upon arrival in the operating room, routine monitoring was implemented, including electrocardiography, heart rate, noninvasive blood pressure, and pulse oximetry. A retrobulbar block was administered with a 3.5 mL injection of lidocaine and bupivacaine (2% lidocaine/0.75% bupivacaine; 50 : 50) into the conical retrobulbar space. We chose this dose for the consideration that the orbital size of Chinese population was generally smaller than the white population, and an overdose of anesthetics into the retrobulbar space may limit the ocular movement, as well as having a risk of toxic reactions [12].

The scleral buckling surgery followed a standard procedure [2, 4]. Briefly, after a 360° peritomy of the conjunctiva and the Tenon's capsule at the limbus, the following procedures were conducted: localization of the break(s), transscleral cryopexy under indirect ophthalmoscopy, drainage of the subretinal fluid (if necessary), and placement of a segmental silicone explant and an encircling band. Any intraoperative complications were recorded. The operations were performed by three professional surgeons (L.L., L.J.Q., and L.T.) with comparable surgical experience. All surgeries were completed within 1 hour.

2.5. Pain Score Assessment. For this trial, we adopted the 11-point (0–10) NRS for pain assessment, with a classification of the pain levels as follows [3, 12]:

(i) Level 0 = no pain

(ii) Levels 1–3 = mild pain

(iii) Levels 4–6 = moderate pain

(iv) Levels 7–10 = severe pain.

The NRS assessment has been confirmed sensitive and reliable for eye pain evaluation in previous studies [3, 17]. Each participant was instructed to report their NRS scores for three times: before surgery, immediately after the operation, and 24 hours postoperatively.

At the baseline, none of the participants reported any pain. On the operation day, the participants were instructed to perceive their pain feelings throughout the whole surgical procedure and reported their intraoperative NRS scores immediately after completing the operation. Then, the participants were asked again to report their NRS scores 24 hours postoperatively, before they received any postoperative eye examinations.

2.6. Supplemental Analgesic Usage and Adverse Effects. During the postoperative period, a participant was given a 0.5 g of oral paracetamol when the postoperative NRS score is either 3 or above or to the demand of participants themselves. The number of patients who required rescue analgesics and the total consumption of paracetamol were recorded.

Any acute adverse events, for example, postoperative nausea and vomiting (PONV), were recorded. The severity of the PONV was evaluated as follows: 0 = none, 1 = nausea once, 2 = vomited once, and 3 = suffered from nausea twice or more or had ≥2 emetic episodes within 2 hours [18]. Metoclopramide was given when the participant's PONV score was 3. Any other adverse events were recorded during the operation and postoperatively.

2.7. Sample Size Calculation and Statistical Analysis. The sample size calculations were based on our pretrial outcome of intraoperative NRS. Given an equal randomization (1 : 1), the probability of type I error (α) is 5%, and the power ($1-\beta$) is 90%, to detect an NRS reduction of 2 or more between the K group and the P group. A total of 56 participants were required for the statistical significance.

Quantitative data were presented as the mean ± standard deviation (SD), confidence interval (CI), range, median, and interquartile range (IQR). Qualitative data were presented as the number of participants and the percentiles. Data of continuous variables were analyzed by the Student t-test or the Mann–Whitney U test, as appropriate. Categorical variables were analyzed by using the chi-square test. A value of $P < 0.05$ was set as the level of significance. All of the analyses were performed by using the SPSS 22.0 version (IBM, Armonk, NY).

3. Results

Beginning in July 2014, 73 eyes of 73 participants with RRD were recruited for this trial in our day care unit, and according to the inclusion and exclusion criteria, only 60 participants were then enrolled. The participants enrolled were randomly assigned (1 : 1) into the ketorolac group (K group) and the control group (C group). One participant in the C group failed to attend the surgery due to a fall accident before the operation. Therefore, there were actually 30 eyes of 30 participants in the K group and 29 eyes of 29 participants in the C group that took part in this clinical trial.

3.1. Demographic Characteristics and Ophthalmic Examinations. In general, the mean age of the participants was 33.5 ± 10.1 years old (95% Cl, 30.9–36.2; range, 18–54). There were 47 male participants (79.7%) and 12 female participants (20.3%), with a male to female ratio of nearly 4 : 1.

Preoperatively, all of the participants were phakic and the median BCVA (logMAR) was 0.92 (IQR, 0.52–1.40). The mean IOP was 12.0 ± 2.5 mmHg (95% Cl, 11.3–12.7; range, 7.0–19.0), and all of the participants' IOPs were within normal criteria.

Overall, the ages, genders, BCVAs, and IOPs were comparable between the K and C groups at the baseline ($P > 0.05$). The participants' demographic and ophthalmic characteristics in both groups are summarized in Table 1.

3.2. Comparison of Perioperative Pain. There was no pain in any of the participants at the baseline. During the operation,

Table 1: Demographic and ophthalmic characteristics of patients.

Variable	K group ($n = 30$)	P group ($n = 29$)	P value
Age (years)			
Mean ± SD	34.5 ± 10.2	32.6 ± 10.2	0.473*
Gender			
Male, number (%)	23 (76.7)	24 (82.8)	0.797**
Educational level, number (%)			0.544**
0	15 (50)	14 (48.3)	—
1	6 (20)	9 (31.0)	—
2	9 (30)	6 (20.7)	—
Preoperative ophthalmic characteristics			
BCVA (logMAR)			
Mean ± SD	1.05 ± 0.65	1.11 ± 0.91	—
Median (IQR)	1.07 (0.48–1.50)	0.82 (0.56–1.40)	0.808***
IOP (mmHg)			
Mean ± SD	12.1 ± 2.7	11.9 ± 2.4	0.819*
Median (IQR)	12.0 (10.2–14.0)	12.0 (10.8–13.0)	—
Postoperative ophthalmic characteristics			
BCVA (logMAR)			
Mean ± SD	1.22 ± 0.52	1.26 ± 0.81	—
Median (IQR)	1.20 (0.88–1.43)	1.00 (0.70–1.45)	—
△BCVA (logMAR), median (IQR)	0.00 (−0.11–0.33)	0.18 (−0.06–0.54)	0.412***
IOP (mmHg)			
Mean ± SD	13.9 ± 4.2	17.1 ± 6.3	—
Median (IQR)	13.0 (10.0–16.3)	16.0 (13.0–18.5)	—
△IOP (mmHg), median (IQR)	1.9 (−1.3–4.0)	3.0 (1.5–6.4)	0.038***

K group: ketorolac group; P group: placebo group; BCVA: best-corrected visual acuity; logMAR: logarithm of the minimum angle of resolution; IOP: intraocular pressure; IQR: interquartile range; SD: standard deviation; △BCVA = postoperative BCVA–preoperative BCVA; △IOP = postoperative IOP–preoperative IOP; *t-test; **Chi-square test; ***Mann–Whitney U test.

75.9% of the participants in the C group compared to 53.3% of those in the K group reported pain ($P = 0.071$) (Figure 2). The NRS score in the C group (median, 3; IQR, 0.5–5.5) was significantly higher than that in the K group (median, 1; IQR, 0.0–2.0; $P = 0.003$) (Figure 3). Thirteen of the participants in the C group (44.8%) compared to 4 participants in the K group (13.3%) reported moderate to severe pain (NRS ≥ 4) during the operation ($P = 0.008$). The highest NRS score in the C group was 8 in one patient lasting for less than 1 minute, while it was 5 in two patients in the K group lasting for less than 1 minute. Among those who reported pain, the most frequently reported NRS score in the C group was 4 (22.7%) and in the K group was 1 (37.5%). Postoperatively, 17 participants (58.6%) in the C group compared to 8 participants (26.7%) in the K group reported pain ($P = 0.013$), and no moderate to severe pain (NRS ≥ 4) was reported (Figure 3).

3.3. Postoperative Analgesic Consumption and Adverse Effect. Statistically significantly fewer participants required rescue analgesics postoperatively in the K group (10.0%) than in the C group (34.5%) ($P = 0.023$). None of the participants took more than once of rescue analgesics during the postoperative 24 hours. The total amount of paracetamol consumption in the K group was 1.5 g, and that in the C group was 5.0 g (Table 2).

The most complained postoperative adverse effects were the incidences of PONV (Table 2). The percentage of participants who reported PONV was significantly lower in the K group (13.3%) than in the C group (41.4%) ($P = 0.015$). Moreover, 100% of the participants who reported PONV scored 1 in the K group, but only 41.7% of those scored 1 in the C group. However, the PONV scores between the two groups were not statistically significant ($P = 0.057$). Besides, 3 participants in the C group had symptoms of dizziness, headache, or chest distress postoperatively, while only 1 participant in the K group reported dizziness. No gastrointestinal bleeding or other postoperative complications were observed.

During the operations, each group reported 1 eye with limited subretinal hemorrhages, and they were controlled by temporary IOP elevations. No other serious complications, such as ocular perforation or severe retrobulbar hemorrhage, were observed intraoperatively.

3.4. Surgical Outcome. The postoperative BCVA (logMAR) in the K group (median, 1.20; IQR, 0.88–1.43) and the C group (median, 1.00; IQR, 0.70–1.45) was slightly higher

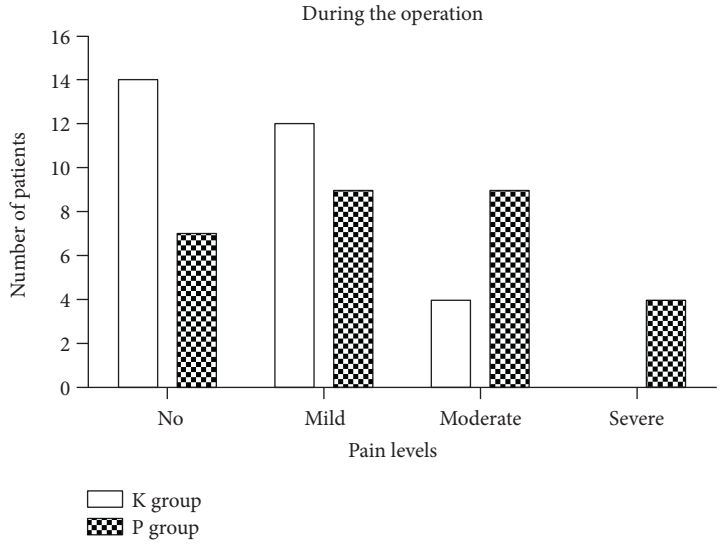

Figure 2: Number of participants with different levels of pain feelings in the K and C groups during the operation. Pain levels were defined by NRS scores: no = 0; mild = 1–3; moderate = 4–6; severe = 7–10.

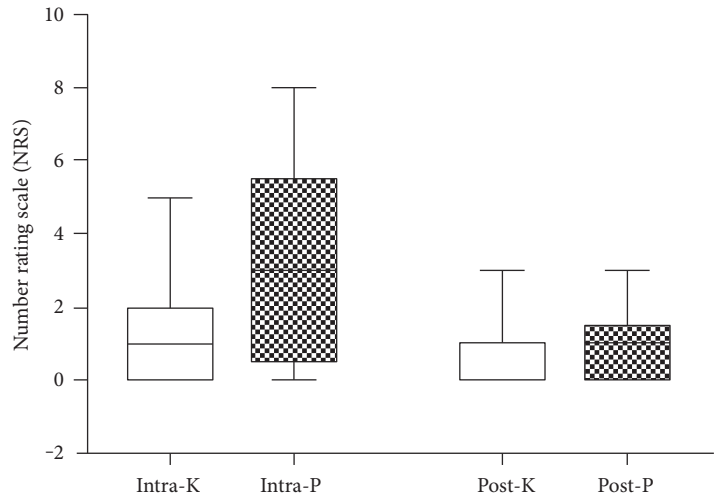

Figure 3: A comparison of NRS scores between the K and C groups both intraoperatively and postoperatively. Intra-K = intraoperative assessment in the ketorolac group; intra-C = intraoperative assessment in the control group; post-K = postoperative assessment in the ketorolac group; post-C = postoperative assessment in the control group.

than those preoperatively (K group: median 1.07, IQR 0.48–1.50; C group: median 0.82; IQR 0.56–1.40) (Table 1). The postoperative BCVA changes (△BCVA) were not statistically different in the two groups ($P = 0.412$).

The postoperative IOP in the K group (median, 16.0 mmHg; IQR, 13.0–18.5 mmHg) was higher than before the surgery (median, 12.0 mmHg; IQR, 10.8–13.0 mmHg). The IOP changes (△IOP = postoperative IOP–preoperative IOP) in the C group were statistically higher than those in the K group ($P = 0.038$). During the postoperative ophthalmic examinations, 2 participants in the C group had ocular hypertension more than 30, and their IOPs were controlled by antiglaucoma drugs.

4. Discussion

According to our clinical trial, the combination of ketorolac with LA exhibited better pain control in day care scleral buckling surgery than LA alone. The administration of ketorolac lowered the incidence of supplementary analgesic consumption, was effective in reducing PONV, and may reduce postoperative elevation of IOP.

In our study, we observed mild to severe pain in 22 participants in the C group (75.9%) and 16 participants in the K group (53.3%). A percentage of 58.6% of participants in the C group and 26.7% in the K group reported pain postoperatively. This is consistent with other studies [3, 9, 19];

Table 2: Comparison of postoperative analgesic consumption and adverse effect between the ketorolac administration group and placebo group.

Variable	K group ($n = 30$)	P group ($n = 29$)	P value
Postoperative analgesic usage			0.023*
None, number (%)	27 (90)	19 (65.5)	—
Analgesic use, number (%)	3 (10)	10 (34.5)	—
Supplemental analgesic consumption			
Paracetamol (g)	1.5	5.0	—
Adverse effect			
PONV, number (%)	4 (13.3)	12 (41.4)	0.015*
PONV score, number			0.057*
1	4	5	—
2	0	5	—
3	0	2	—
Total metoclopramide consumption (mg)	0	20	—

K group: preoperative ketorolac group; P group: preoperative placebo group; PONV: postoperative nausea and vomiting; *chi-square tests.

Marzak et al. [9] reported that 57.5% of their patients had postoperative pain and the greatest pain was during the first 4 hours after scleral buckling surgery. A survey of 100 RRD patients after scleral buckling surgery found that all of them reported eye pain on the first postoperative day [3], and 18% of the patients developed chronic eye pain. The investigators concluded that patients with more intense pain at the onset of the postoperative period tended to develop chronic eye pain.

Several factors contribute to perioperative eye pain. High-intensity noxious stimulation generated by the division of tissues, repeated ocular muscular traction [3, 9], manipulation and trauma to the globe and nearby tissues when planting segment silicone explants and an encircling band [10], cryopexy [10], and drainage of subretinal fluid can be the causes of primary phase injury. The noxious impulses from the surgery-induced tissue trauma reach the spinal cord, thus inducing central neural sensitization that amplifies the subsequent pain feelings [8]. The secondary phase of injury is mainly induced by inflammation [3, 8]. Manipulation of tissues and cryopexy could induce a breakdown of the blood-retinal barriers, thus releasing prostaglandins and other inflammatory mediators [20]. The inflammatory factors and released enzymes reduce the threshold for the activation of nociceptor neurons [8], thus causing feelings of pain. Moreover, an insufficient afferent blockade of local anesthesia may also be a source of pain [21, 22].

Ketorolac is an NSAID with a very strong analgesic effect. Ketorolac can inhibit cyclooxygenase- (COX-) 1 and COX-2 activities, which generate the inflammatory mediators such as prostaglandins [23]. As a result, ketorolac reduces the sensitivities of afferents and finally reduces pain feelings. Like other NSAIDs, ketorolac has side effects such as gastrointestinal hemorrhage, dyspepsia, headache, and so forth However, none of the participants in our trial was found any serious complications. We believe that one injection of ketorolac before surgery is safe to patients in scleral buckle surgery.

Our trial found a marked elevation of IOP in the C group than that in the K group postoperatively, and this was consistent with previous studies. For example, Soni et al. [1] had reported a high postoperative IOP in 21 of 280 patients who underwent scleral buckle surgery; Edmunds and Canning [24] observed that acetazolamide could significantly lower postoperative IOP after scleral buckle surgery. One of the main causes of postoperative IOP elevation was the intraocular inflammation due to massive tissue manipulation [3, 24]. Thus, the anti-inflammatory effect of ketorolac by inhibiting the cyclooxygenases (COXs) may partially lower the postoperative IOP elevation.

The results of our trial contribute to the popularization of day care scleral buckling surgery under LA. The wide spread of day care surgery from in-patient surgery has been taken place in recent decades [25, 26]. A day care surgery meets the patients' requirements by saving medical cost, shortening patients' waiting time, and simplifying the procedures without reducing the service qualities [25]. Besides, the surgical outcome is comparable to that of in-patient surgeries, [26, 27] with no additional risk of complications [28]. Moreover, the adoption of day care units greatly increases the utilization of beds, reduces medical resources waste, and enables surgeons to perform more surgeries at a certain time [25, 26]. The administration of LA contributes to the application of day care surgery by saving operation time, lowering systemic risks of anesthetic accidents, and reducing the potential danger during recovery in comparison to GA [7, 29, 30]. Besides, patients under LA have a quick recovery postoperatively and patient comfort is increased with the use of LA [29, 31]. Moreover, the administration of ketorolac adds to the feasibility and acceptability of day care scleral buckling surgery under LA.

There were some limitations in this study; for example, the participants enrolled were from a single center with a relatively small population. Secondly, the results of our trial cannot be applied to those patients who have contraindications to the drugs.

Our clinical trial does exhibit several strengths; for example, it was a well-designed, prospective, controlled study. Secondly, we adopted the reliable NRS to assess pain. Thirdly, we assess intraoperative eye pain other than the commonly studied postoperative pain for there was a high incidence of pain during the surgery. Finally, we gave our participants oral paracetamol for postoperative pain relief since it does not belong to the NSAIDs and it is easier to administer for an outpatient setting.

5. Conclusions

In conclusion, perioperative ocular pain is a common but often underestimated issue for scleral buckling surgery [3]. The combination of ketorolac with conventional LA is effective in providing better anesthesia, reducing pain, supplementary analgesics, and PONV. Moreover, ketorolac may lower postoperative elevation of IOP. The results of our study are encouraging for the practice of LA in outpatient scleral buckling surgery.

Disclosure

The sponsor or funding organization had no role in the design or conduct of this research.

Conflicts of Interest

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

Authors' Contributions

Xiaohong Chen and Bingqian Liu contributed equally to this article as co-first authors.

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Research Article

Key Factors to Improve the Outcome of Retinal Reattachment Surgery in Proliferative Vitreoretinopathy and Proliferative Diabetic Retinopathy

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Introduction. For management of complicated retinal detachments, a pars plana vitrectomy with temporary silicone oil (SO) fill is the method of choice. According to literature, the retinal redetachment rate varies between <10% and >70% with around 36% in our own group (retrospective data analysis, $n = 119$ eyes). *Methods*. The main goal was to reduce the retinal redetachment rate. Standard operating procedures (SOPs) and evaluation protocols (EVALPs) were developed to prospectively analyse risk factors. Lab analysis of SO was performed, and the role of surgical experience was evaluated and investigated with Eyesi®. *Results*. We achieved a significant reduction of the retinal redetachment rate (to 6.80%, $n = 101$, $p = 0.002$). After surgery with SO injection, neither further membrane peeling (in 16.5%) nor retinal laser coagulation (in 100%) during revision surgery had a significant effect on the reattachment rate ($p = 0.167$, $p = 0.23$), while extensive additional laser coagulation reduced visual acuity ($p = 0.01$). A 3-port approach had to be set up to complete SO removal. A difference in success rate depending on surgical experience was confirmed, and the performance in Eyesi correlated with that in the patients' eye. *Conclusions*. A SOP- and EVALP-based management and new strategies to secure the surgical performance seem to be essential for successful surgery.

1. Introduction

The most common complication of retinal reattachment surgery with a preliminary silicone oil fill is a retinal redetachment after the removal of the silicone oil. In literature, the redetachment rates vary between less than 10% and over 70%.

The cause analysis is "poor" and not sufficient to draw clear-cut conclusions to improve the success rate [1–13]. This poses the question, which parameters should be sought differently and improved upon in order to systematically reduce the rate of redetachments of the retina after the removal of silicone oil and to also check to what extent this is possible.

Goezinne et al. [11] describe the occurrence of a retinal redetachment within the first 3 months after oil removal in two-thirds of all eyes, and only 10% of the redetachments occurred later than 6 months after oil removal.

The immediate assessment of the actual condition of the retina and its environment after primary reattachment service is obviously critical and difficult at the same time. It is otherwise unexplainable, why redetachments after silicone oil removal occur very early if not immediately after [14]. As described by others [15, 16], our own retrospective data showed that in those eyes where redetachments occurred, this complication was not at all expected. Moreover, in two-thirds of the affected eyes, this occurred within the first four weeks after oil removal.

Decisive for the follow-up and the success rate of retinal detachment surgery are concomitant circumstances.

Traditionally, these flow into the so called [17]proliferative vitreoretinopathy [PVR] classification [17–19] and a variety of surgical consequences from this classification. Since in a proliferative diabetic retinopathy (PDR), there are many similarities with the PVR process; Kroll et al. introduced "fPDVR" in 2007 [19] which will be used in this work as P(D)VR from now.

As more damaged retinal tissue has to be removed (retinectomized) to reattach healthier retinal tissue, the risk will be higher that residual retina will also start to shrink and cannot be preserved permanently.

Performing a 360° laser coagulation before draining the silicone oil increases the safety of a permanent retina attachment [20]. The adequately performed laser coagulation reduces the redetachment rate after the removal of oil from 58% to 26%.

In De Silva's work, the probability of poor vision < 20/400 (corresponding to <1/50, threshold of legal blindness) increases with the increase of severity in the P(D)VR classification (by 15% in each of the classification degrees: stages A, B, C, etc.).

In Unlue et al.'s work [14], redetachment risk increases with the increase of severity in the P(D)VR classification; 9.5% with P(D)VR C, 25% with P(D)VR D, over 33% for tractional retinal detachment/trauma, and >37% with giant retinal tears.

The most recent studies of general risk factors fundamentally relevant for the successful establishment of a primary rhegmatogenic ablation retinae include the work published by Jiang et al. [21, 22], Kon et al. [23], and Rodríguez de la Rúa et al. [24]. In a retrospective multicenter study by the European Vitreoretinal Society (EVRS), published under the lead of Adelman et al. [25], substantial general risk factors were concluded from over 7500 eyes: choroidal detachment, significant hypotony, P(D)VR stage C-1, distribution of detached retina over all 4 quadrants, and the size/type of retinal holes (large/giant tears). In the EVRS study in which not only pars plana vitrectomy (PPV) but also buckling surgery was considered, the condition "retinal detachment before or after cataract surgery" was of secondary importance.

In Pavlovic et al.'s work [26], it is quite obvious how essential the assessment of a "clinically stable retinal reattachment" is for the decision whether to remove silicone oil or not (at a certain time) and also for the expected result. Depending on the more or less correct detection of the actual condition of all tissues, a redetachment occurs in 8% to 53%. Pavlovic et al. also stress the importance of laser coagulation.

Gupta and coworkers [27] have followed the progress of treatment options over 10 years in 346 eyes and found that when removing bloody vitreous or vitreous-causing retinal traction, both the anatomical success rate and visual acuity have increased steadily [28–30], most likely because vitreoretinal service was offered promptly (no later than 6 weeks). As many others in literature, they point out the need to meticously remove blood and diseased vitreous in the outermost periphery, particularly when dealing with proliferative tissue activity.

Later, we will discuss that the shift from 20 g to smaller gauges, down to 27 gauge, includes an intrinsic risk-performing surgery less complete during primary service (Figure 1) which implicates different considerations for the revision surgery with intended silicone oil removal.

Since the comparability of known strategies taken from literature about the care and management of complicated retinal detachment as well as a variety of associated parameters was very unsatisfactory, and the results or success and failure rates of existing data were difficult to measure, the aim of this study is to improve the results using standard operation procedures (SOPs) with detailed evaluation protocols (EVALPs) and to show essential steps to achieve this goal.

2. Material and Methods

In the Department of Ophthalmology at the Goethe University in Frankfurt am Main, 119 eyes suffering from a complicated retinal detachment had been serviced with preliminary silicone oil injection at the end of a PPV. Data were retrospectively tracked and stored in an Excel database (Microsoft® Excel® for Windows, 2010; Excel for Mac, 2011). Surgeries performed by 12 vitreoretinal surgeons were included.

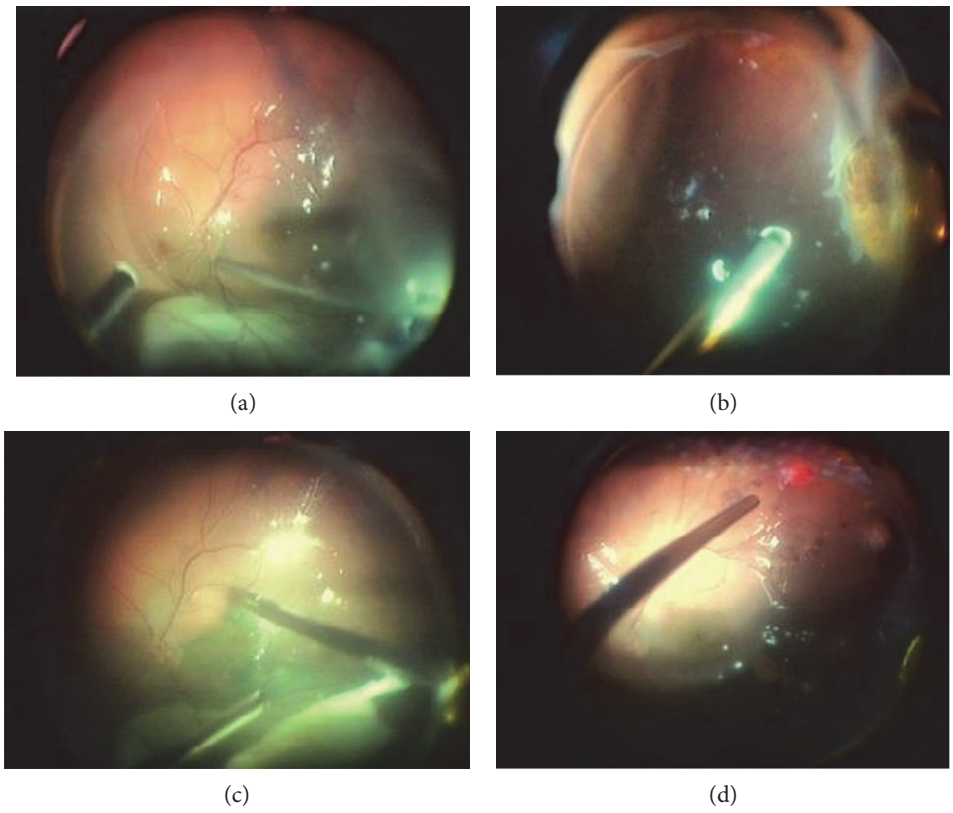
Finally, 101 eyes with sufficiently long follow-up documentation were evaluated and compared with patients prospectively followed up from there. In the majority of these retrospective cases (74 of 101), the silicone oil was drained via 2 channels (passive drainage) once fundoscopy had shown complete reattachment of the retina under the oil fill.

In about 36% of the silicone oil-filled eyes of our patients, a variety of complications after the removal of the oil led to one or more further surgical procedures. There were various reasons found to explain the origin of these complications. We tried to rank their importance: first of all, the quality of documentation of the surgical procedure [31]. Other reasons included the surgeon's choice of primary and secondary care, the surgical experience (years of experience in the vitreoretinal service), the condition (thickness) of the retina, attachment/detachment of the macula/fovea, the number and quality of laser coagulation, the stage of P(D)VR activity, and the quality and completeness of peeling (epiretinal membranes/ILM). After identifying the causes for the development of recurring retinal complications and retinal detachment, a proposal for a standard surgical procedure (SOP) was developed (Figure 2).

It was based on the protocol of a prospective study ($n = 103$ eyes) with an open, controlled study design and the main goal to determine the failure rate. The SOP was revised during the prospective continuation of the study, considering aspects known from literature and those from our own retrospectively collected data.

The study was approved by the ethical review committee, Goethe University in Frankfurt am Main (IRB decision number E 190/11, transaction number 403/11). This study was conducted in accordance with the tenets of the Declaration of Helsinki. Patients' records were pseudonymized and deidentified prior to statistical analysis.

All the analyses were performed using BiAS V10.12 [32] for Windows, IBM SPSS Statistics V22 and the R package V3.1–120 [33].



(a) (b) (c) (d)

Figure 1: Scenes to document essential surgical steps: (a) filling of perfluorocarbon liquids (PFCL); (b) trimming necrotic retina tissue edges; (c) peeling of the inner limiting membrane after staining with indocyanine green; (d) laser coagulation of the retina edges after exchange of the PFCL against air before instillation of silicone oil.

The data were analysed using numerous statistical tests [32–44]. The case count calculation was performed on the basis of the binomial test. A double-sided binomial test (Fisher's F distribution with rejection range $p = 2^*$ (p/2)) was used to test the null hypothesis H0 (theta0 = 0.3564) against the alternative using theta0-thetaA $\leq$ 0.1782 and a 95% binomial confidence interval for the thetaA fraction. The recheck of the null hypothesis was repeated for the operator subgroups. The χ^2-contingency panel test was performed in the presence of categories. The age distribution of the patients was compared using the 2-sample *t*-test in the modified form of the Welch test (for variance inequality). The necessary normal distribution of the values was proven by the Kolmogorov and Smirnov tests. The *F*-test for the comparison of two variances in two-sided questions was used to check the performance fluctuations between the most experienced and the inexperienced surgeon with and without virtual reality training in the Eyesi. In order to investigate which influence criteria were most likely to be responsible for the statistically significant reduction of the retinal detachment rate, a comparison was made by means of multiple regression.

Whether there was a statistically significant difference in the best postoperative visual acuity was tested using the Wilcoxon-Mann–Whitney *U* test. The predictors for the postoperative visual acuity (=dependent variable) were defined according to the above mentioned multiple regression method.

A correlation calculation according to Spearman was carried out to check the correlation between the risk factors which were derived from the retrospective analysis. The evaluation of the correlation coefficient (rho) was made using the effect strength according to Evans as follows: <0.2: poor; 0.2–0.4: weak; −0.4–0.6: moderate; 0.6–0.8: strong; and >0.8: optimal. To check the statistical significance ($p < 0.05$) of the results, a two-page test with Edgeworth approximation was obtained.

Our retrospective study data with $n = 119$ patients showed a retinal redetachment (failure) rate after removing the silicone oil from the vitreous cavity of 34%. The main goal was to reduce the failure rate by at least 50%.

This resulted in the minimum relevant difference of delta0 = −0.17. With the error probabilities of $\alpha = 0.05$ and $\beta = 0.1$ and a power of 90%, a sample size of at least $n = 69$ patients was needed for a 2-sided question.

The following influencing variables were included in the EVALPs of the prospective study and evaluated according to their significance in the course of the observations:

(i) Analysis of visual acuity: visual acuity describes the perception of patterns and contours and is primarily tested for distance (5 m measuring distance) and proximity (30 cm), so that the person concerned can verifiably recognize letters or signs

(ii) Quality of vision: for better measurement of surgical results, we initiated the systematic use of the "Central

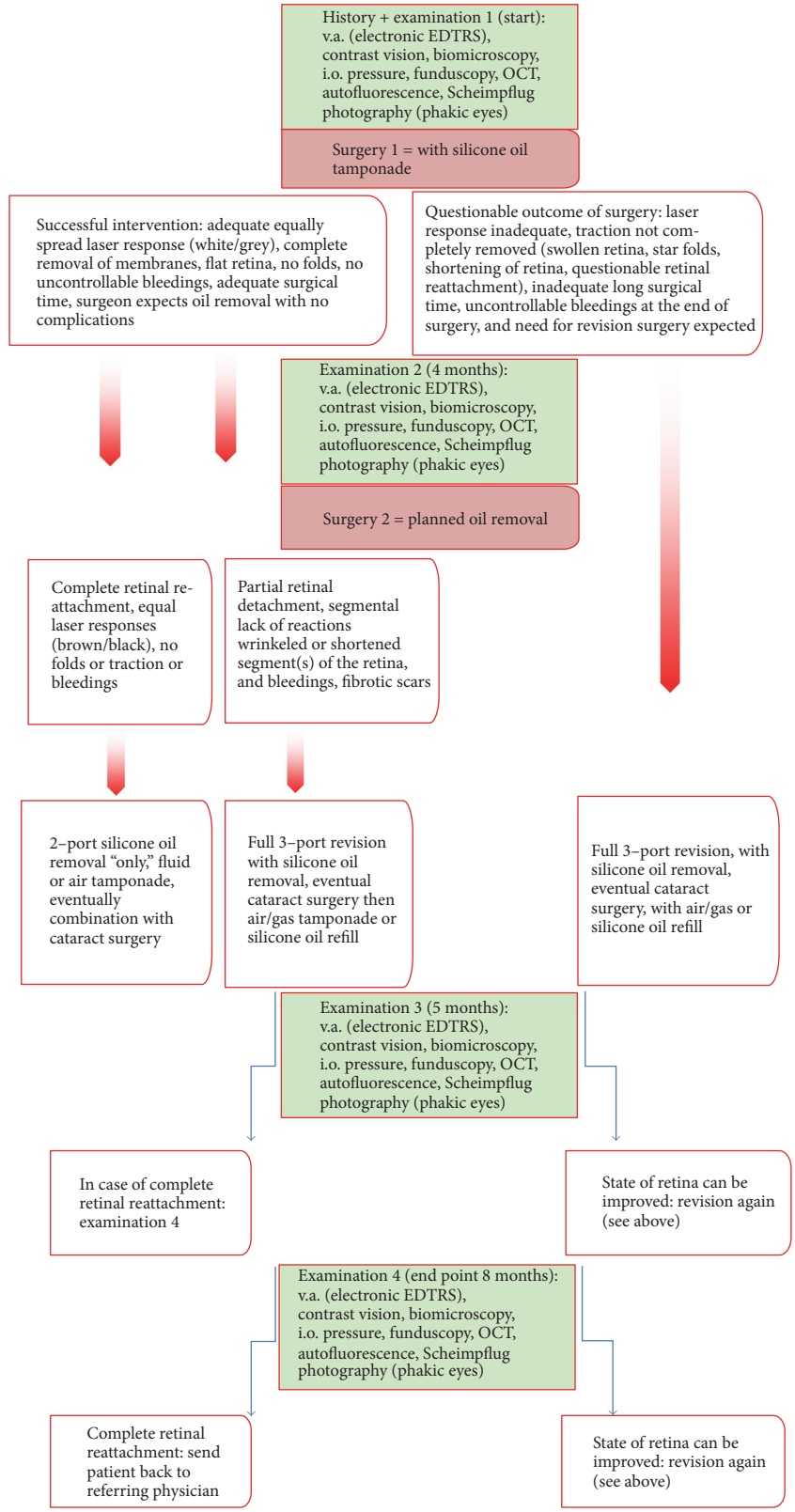


Figure 2: Standard operation procedure for the surgery of complex retinal detachments with preliminary silicone oil tamponade (initial version). EDTRS = international standard to present visual acuity (v.a.) values; biomicroscopy = examination of the anterior segment of the eye, for example, the lens; i.o. pressure = measurement of the pressure in the eye; funduscopy = examination of the retina; OCT: optical coherence tomography = noninvasive "cutting through" the retina using light wavelengths; autofluorescence; special photography of the retina RPE complex; Scheimpflug photography; special measurement of lens changes, related, for example, to aging, diabetes mellitus, inflammation, and trauma.

Vision Analyser (CVA)." The detection of visual quality with the Vimetrics® Central Vision Analyser (CVA) under mesopic and photopic conditions

(iii) Influence of eye length: influence of the deviation from a normal eye length (emmetropia) service documentation: detailed data were collected in an evaluation protocol (EVALP)

(iv) Membrane peeling: staining of membranes and extent of PVD, ERM, and ILM removal

(v) Laser: distribution and intensity

(vi) Structure of the retina/P(D)VR: grading of the retina state according to the classification of the Retina Society

(vii) Total operational supply in one hand: number of surgeons providing service for primary reattachment surgery and revision surgery with silicone oil removal

(viii) Influence of the extent of practical experience (years of experience in the vitreoretinal service): vitreoretinal experience in years and systematically augmented skills (e.g., in Eyesi) are independent important criteria for the success rate

(ix) Degree of retinal detachment: involvement of the macula

(x) Retinal holes: number, size, and condition of retina holes (e.g., enrolled edges and stiffness)

(xi) Retinotomy and retinectomy: removal of retinal tissue; location and extent

(xii) Influence of simulator training on the surgical performance: relation of surgical performance between surgery in the Eyesi surgical simulator and in the patients' eye and role of warming up in the simulator before going to the OR. By randomization, the surgeon either went immediately to the operating room or warmed-up by going through a short simulator training beforehand. Evaluation by two independent observers was performed to guarantee intragrader and intergrader consistency.

3. Results

Both in the retrospectively and prospectively compiled datasets, only the eyes with permanently attached retina after silicone oil removal were considered to be a success. Retrospectively, from 119 patients, 18 patients had to be excluded for the final calculation of the statistical analysis due to inadequate follow-up. 101 patients ($n = 101$) had an adequate observation period of 4 months after the oil drain and could be included in the analysis. There was a failure in $n = 36$ patients, consisting of retinal redetachment ($n = 32$) or a need for permanent oil fill ($n = 4$) of the eye. Overall, the failure rate was 35.64%.

From this, the null hypothesis H0 (theta = 0.3564) was deduced. H0 should be rejected with the aim of reducing the failure rate by at least 50% to 17.82% or less. This resulted in the minimum relevant difference of delta0 = −0.1782.

After evaluating the prospective data, a study inclusion of $n = 113$ patients was possible. $n = 10$ patients did not complete the study (dropouts). Thus, $n = 103$ patients were prospectively evaluated. In this case, a failure rate of $n = 7$, consisting of the number of redetachments of the retina ($n = 3$) and the number of continuous oil tamponades ($n = 4$), was evaluated.

With the aim of achieving a failure rate of <17.82% and the minimal relevant difference of delta0 = −0.1782, the null hypothesis could be rejected with $p = 0.002$ using the double-sided binomial test [36, 41]. The failure rate was reduced to 6.80%.

3.1. Calculation of the Confidence Interval. After rejecting the null hypothesis with $p = 0.002$, a binomial confidence interval for theta (0.07) with $p = 0.95$ was calculated.

This was valid for the proportion theta in $n = 103$ study participants and a failure rate of $k = 7$ patients from 0.027759 to 0.135022. That is, 95% of the failure rate was found to be between a lower limit of 2.77% and an upper limit of 13.50%, and thus a maximum failure rate of 13.50% according to the prospective method SOPs can be expected [41].

3.2. Comparison of Retrospective versus Prospective Study Populations. Prior to evaluating possible impact criteria on the failure rate, the two study groups were tested for homogeneity (Table 1).

A χ^2 contingency panel test [35, 41] was carried out in the analyses concerning the demographics and characteristics of the participants in the course of classes (exception of age distribution).

3.2.1. Age. In order to determine whether the two groups (retrospective versus prospective) were based on the same age distribution, the 2-sample *t*-test was performed.

First, prerequisites for the 2-sample *t*-test were checked. The Kolmogorov-Smirnov test was carried out to test for the normality of distribution. The zero hypothesis was "The age distribution corresponds to a Gaussian distribution." This could be maintained for both groups with $p > 0.10$. As a further assumption for the 2-sample *t*-test, homogeneity of the variances was checked using the *F*-test, which falls below the threshold of $\alpha = 0.10$ with $p = 0.0005$ here, so that equality of the variances cannot be assumed. Thus, the 2-sample *t*-test was applied using the modified form of the Welch test: the p value is 0.0005, so that it could be assumed from different age distributions [41, 45].

3.2.2. Gender. Of the 101 fully evaluable patient eyes of the retrospective study section, 65 (64.36%) eyes were of men and 36 (35.64%) of women. 103 eyes were prospectively evaluated: 66 (64.08%) of men, 37 (35.92%) of women.

This showed no statistically significant difference with $p = 0.99$. Consequently, there was a comparable gender

Table 1: Parameters of population and surgery (retrospective versus prospective) and their statistical relation.

Number of eyes/patients	101 (retro)	103 (pro)	p value
Age, years			0.0005[1]
Mean ± SD	63.35 ± 13.32	57.08 ± 11.81	
Range	26–101	22–86	
Gender, number			0.99*[2]
Male	65	66	
Female	36	37	
Eye, number			0.48*[2]
Right	51	57	
Left	50	46	
Preop. fovea situation			0.94*[2]
Attached	21	22	
Washed up	15	18	
Detached	60	63	
Not specified	5	0	
Redetachment rate			4×10^{-6}*[2]
None	65	96	
Permanent oil fill	4	4	
Redetachment ≥4 months	7	1	
Redetachment 1–4 months	4	1	
Redetachment <1 months	21	1	
Surgeon's skill, years			0.002*[2]
1–7 years	49	25	
≥7 years	36	54	
≥25 years	16	24	
Timing of cataract surgery			0.06*[2]
Primary pseudophakic	29	41	
With silicone oil fill	8	3	
With revision surgery	35	41	
In the course	29	18	
P(D)VR stage			0.71*[2]
AB/A	26	33	
C1/B	12	13	
C2/C1	18	16	
C3/C2	15	20	
D1/C3	9	14	
D2, D3/D1	11	7	
Not specified	10	0	
Viscosity of silicone oil			0.01*[2]
5000 mPa·s	80	69	
4300 mPa·s	4	6	
2000 mPa·s	13	28	
Not specified	4	0	
Laser coagulation (amount and efficiency)			0.11*[2]
Grade 6	10	6	
Grade 5	27	30	
Grade 4	20	33	
Grade 3	21	24	
Grade 2	11	9	

Table 1: Continued.

Number of eyes/patients	101 (retro)	103 (pro)	p value
Grade 1	7	1	
Not rated	5	0	
Amount of membrane peeling			$< 10^{-6*2}$
VB + PVD + ERM + ILM peeling	4	79	
VB + PVD + ERM peeling	22	11	
VB + PVD	72	12	
VB	3	1	
Consistency of surgeon			0.76^{*2}
In one hand	26	30	
2 surgeons	19	16	
>2 surgeons	55	57	
Not specified	1	0	
Kind of revision			10^{-6*2}
2-port	74	0	
3-port	23	103	
Not specified	4	0	
Peeling at the time of revision			0.82^{*2}
Performed	18	17	
Not performed	81	83	
Not specified	2	3	
Axial length			0.0007^{*2}
Patho. myopic	12	19	
Myopic	19	38	
Emmetropic	37	33	
Hyperopic	25	8	
Not specified	8	5	
Number and size of retinal hole area			0.004^{*2}
1 (macula hole, giant tear, 360° tear)	13	15	
2 (>5 holes, <10 hrs)	8	15	
3 (>2 < 5 holes, <8 hrs)	9	22	
4 (=2 holes, <6 hrs)	12	17	
5 (=1 hole, <4 hrs)	32	22	
6 (hidden hole, <2 hrs)	27	11	
Not specified	0	1	
Retino/retinectomy			0.11^{*2}
1 (retinectomy 360°)	0	0	
2 (retinectomy 90–180°, 2 retinot. post. to the equator)	7	5	
3 (retinectomy <90°, 1 retinot. post. to the equator)	18	16	
4 (2 retinot. ant. to the equator)	3	0	
5 (1 retinot. ant. to the equator)	15	8	
6 (not performed)	58	74	

Statistical analysis: [1]two-sample t-test: $^{*2}\chi^2$ contingency table. Number: number of patients; SD: standard deviation; mPa·s: millipascal·second; VB: vitreous body; PVD: posterior vitreous detachment; ERM: epiretinal membrane; ILM: membrana limitans interna; retinot.: retinotomy; post.: posterior; ant.: anterior; preop.: preoperative; patho.: pathological.

distribution with approximately twice as many male than female patients in both groups.

3.2.3. Right/Left Eyes. A similar distribution of the affected eye was also present: retrospectively, 50 (49.5%) right eyes and 51 (50.5%) left eyes were affected by the retinal detachment, prospectively 57 (55.34%) right eyes and 46 (44.66%) left eye ($p = 0.49$).

3.2.4. Fovea Situation. As more of the macula is affected by the retinal detachment, the more questionable the recovery of visual acuity and vision is. Therefore, macular

Table 2: Failure rate depending on surgical experience.

Surgical experience (years)	Retro: surgery (n)	Failure rate (n)	(%)	Goal (%)	Pro: surgery (n)	Failure rate (n)	(%)	Stat. signific. (p)
Overall	101	36	35.64	<17.82	103	7	6.80	0.002*[1]
1–7 years	49	16	32.65	<16.33	25	1	4.00	0.136*[1]
≥7 years	36	17	47.22	<23.61	54	5	9.26	0.012*[1]
≥25 years	16	3	18.75	<9.38	24	1	4.17	0.655*[1]

Statistical analysis: *[1]two-sided binomial test. n: number of surgeries.

involvement is a critical parameter. OCT technology can assist the assessment.

Retrospectively, there was no adequate data on the condition of the fovea preoperatively in 5 eyes (4.95%). In some cases, the statement was not sufficiently documented; ultimately, there was a detachment of the posterior pole in 60 eyes (59.41%), partial detachment of the fovea in 15 eyes (14.85%), and in 21 eyes (20.79%), the fovea was attached preoperatively.

In the prospective series, all 103 eyes showed definite information on the condition of the fovea: in 63 (61.16%) of the eyes, fovea was detached, in 18 eyes (17.48%), the fovea was underwashed by fluid (washed out), and in 22 eyes (21.36%), the fovea was preoperatively attached.

There was no significant difference between the two studies ($p = 0.94$). In both groups, the fovea was affected from the retinal detachment in four-fifths of all cases.

3.2.5. Retinal Redetachment Rate. In the retrospectively followed group (permanent retinal reattachment in 65 patients = 64.36%), an early retinal redetachment after primary attachment developed within 1 month after the oil drainage in 21 eyes (20.79%), redetachment occurred in 4 eyes (3.96%) after 4 months (3.96%), and later in 7 eyes (6.93%), 4 eyes (3.96%) needed a permanent oil tamponade to stabilize the retina.

After the development and use of the SOP and the evaluation curves in the prospectively followed group, the retina of 96 of 103 eyes (93.21%) stayed permanently attached over the entire period of follow-up. In each group, within 1 month, after 1 to 4 months, and after 4 months, one eye (0.97%) developed a redetachment; a permanent oil fill was needed in 4 eyes (3.88%).

The difference between the retrospective and the prospective study with $p = 4 \times 10^{-6}$ was highly significant.

3.2.6. Surgeons' Skill. In the retrospective group, 16 (15.84%) interventions were performed by the most experienced colleagues (experience > 25 years), in 36 eyes (35.65%) by surgeons with experience of >7 and in 49 eyes (48.51) from surgeons with 1 to 7 years experience.

In the prospective group, 24 eyes (23.30%) were performed by the most experienced surgeons, 54 (52.43%) by surgeons with >7 years of experience and 25 eyes (24.27%) by surgeons with 1 to 7 years of experience.

Between the two studies, there was a significant difference in $p = 0.002$ with regard to operational experience classes. For this reason, we retested the primary parameter "reduction of the failure rate by 50%" for the 3 subgroups with different surgical experience, in order to break down the effect of the experience profile on the main target value "permanently attached retina" (Table 2).

3.2.7. Timing of Cataract Surgery. Retrospectively, 29 eyes (28.71%) were operated after a previous cataract surgery (pseudophakic retinal detachment). In 8 eyes (7.92%), a combined phacoemulsification with implantation of a posterior chamber lens and a 3-port PPV was performed for the retinal reattachment maneuver using a preliminary silicone oil tamponade. In 35 eyes (34.65%), the lens was replaced between initial and revision surgery or during the revision surgery when silicone oil was removed and cataract surgery was performed at a later time in 29 eyes (28.72%). Prospectively, the rate of pseudophakic retinal detachment was 39.8% (41 eyes); in 3 cases, the PPV was combined with cataract surgery, another 41 eyes (39.8%) received a lens exchange together with the removal of silicone oil, and in 18 eyes (17.48%), it was performed later. There was no significant difference between these two groups ($p = 0.06$).

3.2.8. P(D)VR Classifications/Staging. The classification of proliferative (diabetic) vitreoretinopathy (P(D)VR) stages is based on the classification of the Retina Society 1983 and the Kroll classification of 2007 [17–19, 46, 47].

There were no retrospective reports in 10% of the eyes (10 eyes, 9.9%). In the PVR stage D2/D3/PDR stage D1 were 11 eyes (10.89%), in the PVR stage D1/PDR-C3 stage 9 eyes (8.91%), in the PVR-C3 and PDR-C3 (14.8%), in PVR-C2/PDR-C1 stage 18 eyes (17.82%), in PVR-C1/PDR-B stage 12 eyes (11.88%), and in PVR-AB/PDR-A stage had 26 eyes (25.75%).

All eyes were prospectively evaluated with 7 eyes (6.8%) in the most advanced stage PVR D2/D3/PDR D1, 14 eyes (13.59%) in PVR stage D1/PDR-C3 stage, 20 eyes (12.72%) in the PVR-C1/PDR-C2 stage, 16 eyes (15.53%) in the PVR-C2/PDR-C1 stage, and 33 eyes (32.04%) in the PVR-AB/PDR-A stage.

There was no significant difference between the two groups when staging the P(D)VR ($p = 0.71$).

3.2.9. Viscosity of the Silicone oil. Retrospectively, 80 eyes (79.21%) were filled with 5000 mPa·s of silicone oil, 4 eyes (3.96%) with 4300 mPa·s of silicone oil, and 13 eyes (12.87%) with 2000 mPa·s of silicone oil. In 4 eyes (3.96), no data were found on the type of oil used. Prospectively, 5000 mPa·s of oil were used in 69 eyes (66.99%), 4300 mPa·s in 6 eyes (5.83%), and 2000 mPa·s in 28 (27.2%) eyes. Based on the different manufacturing and marketing of silicone oils, the choice of oils differed significantly ($p = 0.01$).

3.2.10. Laser Coagulation. The intra- and postoperative assessment of the quality of the laser coagulation affects the planning of any further procedure.

Does laser coagulation has to be performed after primary retinal detachment service and before revision surgery with oil removal or during revision surgery, directly before or after the removal of oil, and what affects the anatomical outcome and how does visual function respond to it? A thickened (swollen) retina may not be lasered at all during surgery, a thinned retina is also associated with the risk of not being adequately linked to the pigment epithelium, or even being inadvertently penetrated by the laser (iatrogenic laser holes).

The evaluation of the laser coagulation was based on the reasonable number of laser spots as well as their quality (adequate responding). Retrospectively, lasers were classified as very good = grade "6" for 10 eyes (9.9%), grade "5" for 27 eyes (26.73%), grade "4" for 20 eyes (19.8%), grade "3" for 21 eyes (20.79%), grade "2" for 11 eyes (10.89%), and grade "1" for 7 (6.94%) eyes. In 5 eyes (4.95%), no adequate data were found.

Prospectively, grade "6" for 6 eyes (5.82%), grade "5" for 30 eyes (29.13%), grade "4" for 33 (32.04%), grade 3 for 24 (23.3%), grade "2" for 9 eyes (8.74%), and grade "1" for one eye (0.97%). There was no significant difference ($p = 0.11$), and the distribution was approximately the same in both groups.

3.2.11. Membrane Peeling during Primary Surgery. P(D)VR often affects the interface in the macula as well as outside of the macula. During primary service as well as revision surgery, both the removal of macula pucker tissue and all PVR membranes responsible for tissue contraction (e.g. star folds) have to be carefully and repeatedly evaluated.

The extent of membrane peeling performed during the primary retinal reattachment surgery was also classified into categories:

(i) Category 4 = VB + PVD + ERM + ILM peeling

(ii) Category 3 = VB + PVD + ERM peeling

(iii) Category 2 = VB + PVD

(iv) Category 1 = VB.

The measures or points of value are additive.

Retrospective category 1 = vitreous body (VB) removal in 3 eyes (2.97%), category 2 = VB removal plus generation of a posterior vitreous detachment (PVD) in 72 eyes (71.29%), category 3 = in addition to category 2 = peeling of epiretinal membranes (ERM) in 22 eyes (21.78%), and category 4 = in addition to category 3 peeling of the membrana limitans interna (ILM) performed in 4 eyes (3.96%).

Prospective category = comprehensive peeling of category 4 was carried out in 79 eyes (76.69%), while all structures except the ILM were peeled (category 3) in 11 eyes (10.67%) and (category 2) in 12 eyes (11.65%); a VB removal and a PVD were performed, and (category 1) in 1 eye (0.97%), only the removal of vitreous body was mentioned.

In the prospective group, the surgeons performed significantly more membrane peelings ($p < 10^{-6}$).

3.2.12. Consistency of the Surgeon. Retrospectively, initial and follow-up in 26 interventions were carried out by one surgeon (25.74%), 2 different surgeons were involved in 19 eyes (18.81%), and 3 or more surgeons in 55 eyes (54.46%). For one intervention (0.99%), there was no useable data.

Prospectively, in 30 eyes (29.13%), surgeries were in one surgeon's hand; in 16 eyes (15.53%), in the hands of 2 different surgeons; and the remaining surgeries were accomplished by 3 or more surgeons in 57 eyes (55.34%). There was no significant difference ($p = 0.76$).

3.2.13. Revision Type: 2-Port/3-Port. The qualitative changes of the oils (manufacturing/marketing reasons) had significant impact on the prospective protocol of the study, while retrospectively, it was freely chosen between the two approaches (103 eyes), with a 2-port approach in 73.27% (74 eyes) and with a 3-port approach in 21.78% (23 eyes, no data in 5 eyes = 4.95%). Prospectively, a 3-port approach had to be set up for all 103 (100%) eyes because of the necessity for multiple rinsing of the vitreous cavity to guarantee as complete as possible removal of the oil ($p = 1 \times 10^{-6}$).

Once in the eye (3-port approach), additional laser and/or peeling could be considered.

3.2.14. Membrane Peeling in the Revision Surgery. Retrospectively, 18 eyes (17.82%) were peeled in the revision surgery with silicone oil removal from the vitreous cavity, and no membrane peeling was performed in 81 eyes (80.20%). For 2 eyes (1.98%), there was no useable data.

Prospectively, 17 eyes were peeled (16.51%), 83 eyes (80.58%) were not peeled in the revision, and there was no useable data for 3 eyes (2.91%).

There is no statistically significant difference ($p = 0.82$).

3.2.15. Myopia. An increased eye length (high myopia) is often accompanied by limited surgical outcomes, for example, because of pigment deficiencies and consequently less sufficient laser coagulation responses.

The axial length of the eye can become the critical factor for reattaching a detached retina. For our retrospective and prospective patients, we selected a classification based on the literature in which pathologically myopic eyes with −6 dptr or higher negative values were distinguished from myopic eyes (between ≥−0.5 dptr and ≤−6 dptr), emmetropic eyes (between −0.5 dptr and +0.5 dptr), and hyperopic eyes (≥+0.5 dptr.).

While the proportion of pathologically myopic eyes increased from retrospectively 12% to prospectively 18%, proportion of myopic eyes from almost 19% to 37%, number of emmetropic eyes fell from retrospective over 36% to a prospective 32%, and the proportion of hyperopic eyes decreased from around 25% to less than 8%. In both groups, no clear data was available in some eyes, and so that proportion was reduced by a retrospective 8% to a prospective 5%.

In total, there was an increase in the overall risk due to significant shift in the direction of the myopic axis length with $p = 7 \times 10^{-4}$.

3.2.16. Retinal Hole: Total Area. According to their clinical importance, the retinal area and location were weighted into

6 categories. Retrospectively, 27 eyes (26.73%, category 6) did not have any holes or tiny defects preoperatively invisible behind the vitreous body.

A single hole could be presented preoperatively or intraoperatively at just one-third of the interventions (32 eyes/31.68%, category 5), 2 holes in 12 eyes (11.88%, category 4), 2 to 5 holes in 9 eyes (8.92%, category 3), more than 5 holes in 8 eyes (7.92%, category 2), and a giant tear or retinal detachment with macular hole in 13 eyes (12.87%, category 1).

Prospectively, 11 eyes (10.69%) were found in category 6, 22 eyes (21.36%) in category 3, 17 eyes (16.5%) in category 4, 22 eyes (21.36%) in category 3, along with 15 eyes (14.56%) in category 2, and as many in category 1. There was no data available for an intervention (0.97%). The risk profile shifts significantly ($p = 0.004$) with respect to the retinal surface area to "disadvantage" the prospective group. The prospective eyes have a significantly higher risk, especially in the case of risk assessments 2, 3, and 4 (2 to >5 holes, 29% retrospectively versus 53% prospective), whereas only a few eyes in the prospective group have only one or no holes (categories 5 and 6).

3.2.17. Retino/Retinectomies. Small cuts (retinotomies) lead to relaxation of smaller retinal contractions. If larger areas cannot be relaxed by retinotomies, the retina has to be removed (retinectomies).

In the case of a need of retinectomies (removal of a contracted, shortened, functional retina), categories were again created and intended to reflect the clinical risk profile:

(i) Category 1: retinectomy 360°

(ii) Category 2: retinectomy 90–180°, 2 retinotomies posterior of the equator

(iii) Category 3: retinectomy <90°, 1 retinotomy posterior of the equator

(iv) Category 4: 2 retinotomies peripheral to the equator

(v) Category 5: 1 retinotomy peripherally of the equator

(vi) Category 6: no retinectomy performed.

Retrospectively as well as prospectively, 360° retinectomy was not seen in either of the eyes (0% in category 1). 7 (6.93%) versus 5 (4.85%) eyes were classified retrospectively versus prospectively in category 2, 18 (17.82%) versus 16 (15.53%) met the criteria in category 3, 3 (2.97%) versus 0 (0%) met the criteria in category 4, 15 (14.85%) versus 8 (7.76%) met the criteria in category 5, and 58 (57.43%) versus 74 (71.84%) eyes were not retinectomized. With $p = 0.11$, there was no statistically significant difference.

3.3. Reduction of the Failure Rate as a Function of the Surgical Experience (Independent of Simulator Training). A statistically significant difference ($p = 0.002$) between the retrospective and prospective study was found in the χ^2 contingency panel test between the retrospective and prospective study, and the following survey was carried out to determine whether our main goal parameter "failure rate by 50% lower" also applies to the individual operating subgroups with different experience spectra.

This was also checked by means of a binomial test for the comparison of two Poisson frequencies by Fisher's F distribution with a rejection range $p = 2^*$ (p/2).

As shown above, the retrospective failure rate of 35.64% (consisting of redetachment and duration fill) of the whole group was prospectively reduced (marginally relevant difference of delta0 = −0.1782) down to 6.8% with a $p = 0.002$.

Regarding the group of inexperienced surgeons (1 to 7 years of experience), retrospectively, a failure rate of 32.65% was found (Table 2). This resulted in a prospectively minimally relevant difference of delta0 = −0.1633. With a prospective failure rate of 4%, the target could be reduced by 50% with the subgroup of inexperienced surgeons (1 to 7 years) with double-sided questioning with $p = 0.136$.

In the case of the "average" surgeons (>7 years of experience), a retrospective failure rate of 47.22% differed from a prospective rate of 9.26%. This was shown as a highly significant difference by a two-sided test with $p = 0.012$.

The very experienced surgeons (>25 years of experience) retrospectively ended up with a failure rate of 18.75%, prospectively 4.17%. The null hypothesis could not be rejected with statistic significance ($p = 0.655$) in two-sided questions.

3.4. Effect of the Simulation Training on the Actual Operating Performance Depending on Surgical Experience. Whether simulator training just improves surgical confidence or also affects the actual surgical performance was a controversially discussed issue at the beginning of the study at hand. It had to made measurable based on criteria as anatomical success rate, surgical time, and so forth.

The influence of simulation training on the operative performance was obtained by means of the Eyesi surgical simulator. In Deuchler et al. [48], our group related the vitreoretinal surgery performance in Eyesi to that in the operating room and proved a statistical significant effect of VR warmup training to the actual service in the patients' eye.

Our study also showed that the expert typically caused less tissue damage, and score deductions had been limited to "time" and "completeness of the training module."

In the following, we focussed on the deviation from the mean performance value depending on surgical experience and Eyesi training.

3.4.1. Analysis of Total Performance (with and without Warmup Training). All video recordings (assessment scale 1–5) of the VR-to-OR performance (with and without warmup training, $n = 21$) of 4 surgeons who participated selectively in the Eyesi training module were evaluated by two independent observers: The surgeon with 25 years of experience ($n = 7$) achieved an average of 4.60 ± 0.21, while the other three participating surgeons with 2, 3, and 7 years of experience ($n = 14$) had mean values of 3.42 ± 0.76. Regardless of whether they had warmed up or not, the standard deviation of the 3 less experienced surgeons is very high

Table 3: Performance scatter depending on surgical experience.

Surgical experience in years	Mean without warmup	SD without warmup	Mean with warmup	SD with warmup	Mean without + with warmup	SD without + with warmup
25	4.48	0.07	4.91	0.04	4.60	0.21
3	2.96	0.24	3.47	0.86	3.13	0.50
7	3.08	0.89	4.10	0.66	3.59	0.89
2	—	—	3.79	1.11	—	—
2, 3 + 7	3.01	0.54	3.83	0.74	3.42	0.76

SD: standard deviation.

compared to that of the expert with a SD = 0.76 (less experienced surgeons, $n = 14$) versus SD = 0.21 (expert, $n = 7$).

It was shown using the F-test for the comparison of two variances [41] in double-sided questioning with $p = 0.005$ that the variance $s^2 = 0.0441$ of evaluations with the most experienced surgeon is significantly lower than with evaluations of the other participating surgeons with 2, 3, and 7 years of surgical experience with the spread $s^2 = 0.5776$.

3.4.2. Analysis of Video Recordings without "Warmup" Training. The most experienced surgeon was evaluated with a score of 4.48 ± 0.07 ($n = 5$) without "warmup" training in real surgery. For the two surgeons with 3 and 7 years experience ($n = 7$), the mean evaluation score is 3.01 ± 0.54. The surgeon with 2 years of surgical experience was randomized with all his operations "with simulator training" ($n = 2$) and could, therefore, only be evaluated in this subgroup analysis. Using the F-test to compare two variances, the variance $s^2 = 0.0049$ of evaluations in the most experienced surgeon was significantly lower than in evaluations of the other participating surgeons with 3 and 7 years of experience with the spread $s^2 = 0.2916$.

3.4.3. Subgroup Analysis of the Video Recordings with "Warmup" Training. The most experienced surgeon (25 years of experience, $n = 2$ operations) has a mean score of 4.91 ± 0.04 and 3.83 ± 0.74 in the group of surgeons with 2, 3, and 7 years of experience ($n = 7$ operations).

Here, despite the spread of values, $s^2 = 0.0016$ in the scores of the most experienced surgeon versus $s^2 = 0.5476$ in the scores of the other participating surgeons with 2, 3, and 7 years of experience almost no significant difference was achieved in performing the F-test for the comparison of two variances in a two-sided questionnaire with $p = 0.083$. This is most likely explained by the low number of cases.

It can be clearly seen that the surgeon with 25 years of experience with ($s^2 = 0.0016$) and without ($s^2 = 0.0049$) warmup training has only minimal scattering in performance (Table 3). However, the scatter is much higher in the group of inexperienced surgeons.

Looking at the performance of surgeons separately, it was shown that warmup training resulted in a significantly better outcome of evaluations, but the spread of each inexperienced surgeon increased from 0.2916 (without warmup) to 0.5476 (with warmup). This is most likely explained by the fact that the total number is small and the most inexperienced surgeon with the highest standard deviation was randomized to the "warmup group" exclusively.

This shows that warmup training does not alter the performance scatter of the surgeons but the performance level of the surgeons.

3.5. Multiple Regression to Analyse Potential Risk Factors. In order to determine the most important influence factors for retinal redetachment in the retrospective versus prospective group (Table 4), we performed a multiple regression analysis. In this model, the statistical significance niveau is traditionally set at 10%. By combining the most important variables, multiple regression techniques show the overall explanatory power of the variables.

After performing multiple regression analysis with retinal redetachment rate as dependent variable, we could show that the most influential factor for retinal redetachment in the retrospective group was the amount of retino/retinectomies with $p < 10^{-4}$ and the quality of documentation with $p = 0.017$.

After repeating the multiple regression with the same influence factors for the prospective group, all parameters were eliminated except for the amount of retino/retinectomies (Table 5).

The elimination of the constant "quality of documentation" in the prospective group was possibly achieved by our definition of standard operation procedures and evaluation protocols that improved consistency and information transfer between the different surgeons of primary and revision surgery. The surgeon, who took over the revision surgery, could control and if necessary, treat certain "weak" retina structures. The amount of retino/retinectomies plays the most crucial role for the outcome of retinal redetachment surgery with $p < 10^{-4}$.

Both multiple regression analyses show a late elimination of the constant "timing of cataract surgery." This was evaluated in detail in the following. Furthermore, we had to forgo the constant "kind of revision" in the prospective group, because we had to perform 100% 3-port revision surgeries instead of simple 2-port silicone oil removals.

Because of the improved documentation, the multiple regression analysis was repeated for further potential risk factors (Table 6) for retinal redetachment rate in the prospective group. These risk factors were not documented properly retrospectively but should not be neglected according to literature [49, 50].

Although fifteen instead of nine predictors were used, the same risk factors as before remained: the combination of the

Table 4: Multiple regression to analyse potential risk factors for retinal redetachment rate in the retrospective group.

Model		Coefficients[a]				
		Not standardized coefficients		Standardized coefficients	t	Sig.
		B	Standard deviation	Beta		
1	(Constant)	.096	1.573	—	.061	.951
	Emulsification rate	−.040	.097	−.042	−.412	.681
	Surgical experience	.059	.178	.031	.331	.741
	Timing of cataract surgery	.233	.196	.123	1.188	.238
	Med. history/ reop. surgery	−.013	.131	−.010	−.102	.919
	Amount of retino/retinectomies	.504	.125	.394	4.026	.000
	Quality of documentation	.653	.255	.264	2.556	.012
	Quality of laser coagulation	−.140	.144	−.095	−.973	.333
	Amount of membrane peeling	.097	.133	.070	.734	.465
	Consistency of surgeon	.128	.106	.114	1.203	.232
	Kind of revision	.041	.448	.009	.092	.927
9	(Constant)	1.007	.679	—	1.484	.141
	Amount of retino/retinectomies	.515	.115	.402	4.468	.000
	Documentation	.543	.223	.220	2.438	.017

[a]Dependent variable: retinal redetachment rate.

Table 5: Multiple regression to analyse potential risk factors for retinal redetachment rate in the prospective group: in this group, all patients got a 3-port revision surgery, so that "kind of revision" was not a predictor in this model.

Model		Coefficients[a]				
		Not standardized coefficients		Standardized coefficients	t	Sig.
		B	Standard deviation	Beta		
1	(Constant)	3.456	1.008	—	3.427	.001
	Emulsification rate	−.014	.062	−.021	−.218	.828
	Surgical experience	−.015	.128	−.014	−.118	.906
	Timing of cataract surgery	.169	.115	.165	1.474	.144
	Med. history/preop. surgery	−.008	.087	−.011	−.092	.927
	Amount of retino/retinectomies	.238	.069	.347	3.439	.001
	Quality of documentation	.092	.109	.086	844	.401
	Quality of laser coagulation	−.017	.118	−.015	−.143	.886
	Amount of membrane peeling	.062	.059	.105	1.054	.294
	Consistency of surgeon	.014	.068	.024	.205	.838
9	(Constant)	4.474	.331	—	13.524	.000
	Amount of retino/retinectomies	.245	.064	.356	3.831	.000

[a]Dependent variable: retinal redetachment rate.

amount of retino/retinectomies with $p = 0.003$, the amount of membrane peeling with $p = 0.028$, and the timing of cataract surgery with $p = 0.099$ (both were eliminated late before). It indicates that pseudophakic patients or those being operated on the retina and cataract simultaneously less often get a retinal redetachment compared to patients who underwent cataract surgery during revision surgery or afterwards. Furthermore, the prognosis of eyes with retinal detachment surgery is better when a complete vitrectomy with posterior vitreous detachment and epiretinal membrane peeling is carried out, as well as ILM peeling if needed.

3.6. Influence of the Prospective Approach on Postoperative Vision. Apart from the significant reduction of the retinal redetachment rate to 6.80%, the prospective group also got a significant improvement in visual acuity with $p < 10^{-6}$ using Mann–Whitney U test with a probability of $p\{(X|\text{group1}) < (Y|\text{group2})\} = 0.722565$. Patients in the prospective protocol had a better vision outcome in 72.26%, which is important because after a successful retinal reattachment, the postoperative visual function is essential for patients. It certified that a primary reattachment is essential for a gain in vision. The exact correlation of these two parameters can be found below.

To find out if similar influence factors play a role in retinal redetachment as well as for postoperative vision, we repeated the multiple regression analysis with the dependent variable postoperative vision (Table 7).

Table 6: Multiple regression to analyse further potential risk factors for retinal redetachment rate in the prospective group.

Model		Coefficients[a]				
		Not standardized coefficients		Standardized coefficients	t	Sig.
		B	Standard deviation	Beta		
1	(constant)	4.461	.862	—	5.174	.000
	Emulsification rate	.006	.041	.016	.158	.875
	Surgical experience	.028	.082	.041	.345	.731
	Med. history/preop. surgery	.030	.051	.065	.581	.563
	Documentation	.068	.070	.103	.973	.333
	Quality of laser coagulation	−.003	.075	−.004	−.041	.968
	Amount of membrane peeling	.075	.038	.202	1.977	.051
	Consistency of surgeon	.016	.043	.044	.367	.715
	Timing of cataract surgery	.148	.070	.232	2.104	.038
	P(D)VR stage	.048	.058	.101	.822	.413
	Preop. fovea situation	.016	.042	.041	.373	.710
	Amount of retino/retinectomies	.107	.049	.251	2.201	.030
	Number and size of retinal hole area	.013	.053	.026	.243	.809
	Axial length	−.048	.047	−.108	−1.039	.302
	Peeling at the time of revision	−.286	.181	−.154	−1.581	.118
	Laser coagulation at the time of revision	−.266	.212	−.127	−1.255	.213
13	(Constant)	4.329	.366	—	11.830	.000
	Amount of membrane peeling	.078	.035	.210	2.237	.028
	Timing of cataract surgery	.099	.059	.155	1.667	.099
	Amount of retino/retinectomies	.123	.040	.289	3.091	.003

[a]Dependent variable: retinal redetachment rate.

The results show that besides a low P(D)VR stage ($p = 0.001$) and a good preoperative fovea situation ($p = 0.074$), a permanent attachment of the retina ($p = 0.041$) leads to a better prognosis of postoperative vision. Furthermore, the primary and revision surgery should remain in one surgeon's hands ($p = 0.089$).

3.7. Correlations between Risk Factors in the Prospective Study Part. After finding the most important risk factors for retinal detachment and follow-up of vision, we looked for correlations between these individual factors. In the following, the significant correlations are listed.

3.7.1. Factors Associated with the Best Postoperative Visual Acuity. The visual acuity is the most widely used form of performance testing, for example, the reattachment of a formerly detached retina. However, it is by no means suitable to testify actual visual quality. Therefore, a contrast vision test is also requested in the evaluation list for checking the quality of vision.

The detection of visual quality with the Vimetrics® Central Vision Analyser (CVA) impressively enables the evaluation of visual function under the conditions of a retinal detachment with and without macular involvement, before and after retinal reattachment surgery under mesopic and photopic conditions. This helps to determine why the affected person is a subject to other visual limitations than those to which the pure visual test implies.

(1) Best Postoperative Visual Acuity/Course of Visual Development/Retinal Attachment. A Spearman [34, 51] correlation coefficient of rho = 0.26 and a statistical significance of $p = 0.006$ was found for visual acuity gain with retinal attachment, and a correlation coefficient of rho = 0.29 with $p = 0.003$ for retinal attachment and the best postoperative visual acuity.

(2) Best Postoperative Visual Acuity/Preoperative Situtation/Intraoperative Course. Foveal attachment ($p = 0.006$, rho = 0.27) and a low degree of proliferation (P(D)VR stage) were associated with better visual acuity ($p = 4 \times 10^{-4}$, rho = 0.35). Patients with a better postoperative visual outcome ($p = 7 \times 10^{-6}$ and rho = 0.42) also showed more vision gain during the course of the study. If the intraoperative risk profile was low, this initial situation also correlated with better results for the visual acuity ($p = 0.01$, rho = 0.23).

(3) Best Postoperative Visual Acuity/Surgeon Consistency. "Everything in one surgeon's hand" leads to better visual results ($p = 0.04$, rho = 0.20). This is not as trivial as it sounds, because all patients are evaluated in a team of supervisors, surgeons, and assistants.

(4) Best Postoperative Visual Acuity/Gain of Visual Acuity/OCT. There was a highly significant correlation between the best visual acuity and the morphometry measured with the optical coherence tomography (OCT), ($p < 10^{-6}$, rho = 0.57).

Table 7: Multiple regression to analyse essential factors for good postoperative vision in the prospective group.

Model		Coefficients[a]				
		Not standardized coefficients		Standardized coefficients	t	Sig.
		B	Standard deviation	Beta		
1	(Constant)	.038	1.180		.032	.975
	Emulsification	.080	.057	.139	1.402	.165
	Surgical experience	–.050	.114	–.050	–.442	.660
	Preop. surgery	.051	.071	.076	.719	.474
	Med. history in general	–.155	.109	–.135	−1.420	.159
	Med. eye history	.044	.063	.072	.698	.487
	Documentation	.023	.098	.024	.235	.814
	Quality of laser coagulation	.091	.105	.089	.869	.387
	Amount of membrane peeling	.058	.054	.106	1.068	.288
	Consistency of surgeon	.088	.060	.167	1.452	.150
	Timing of cataract surgery	.164	.103	.177	1.598	.114
	P(D)VR stage	.228	.081	.328	2.812	.006
	Preop. fovea situation	.134	.059	.237	2.293	.024
	Amount of retino/retinectomies	.030	.069	.048	.437	.663
	Number and size of retinal hole area	–.094	.073	–.131	−1.287	.202
	Redetachment rate	.207	.150	.142	1.384	.170
	Axial length	.020	.068	.031	.300	.765
13	(Constant)	.952	.768	—	1.240	.218
	Consistency of surgeon	.081	.047	.155	1.717	.089
	P(D)VR stage	.218	.067	.313	3.270	.001
	Preop. fovea situation	.095	.052	.167	1.805	.074
	Redetachment rate	.277	.134	.190	2.071	.041

[a]Dependent variable: postoperative vision.

Correspondingly, the visual acuity gain correlated with the OCT result with $p = 0.026$ and rho = 0.22.

(5) Best Postoperative Visual Acuity/Contrast Vision/Oil Type/Retina Attachment. In principle, 5000 mPa·s and 4300 mPa·s silicone oils had more stability than those with 2000 mPa·s. Differences were not significant, neither regarding the retinal reattachment rate ($p = 0.68$) nor the visual acuity ($p = 0.33$) or the contrast vision ($p = 0.34$).

(6) Best Postoperative Visual Acuity/Contrast Vision/OCT/Fovea Attachment/Risk Profile/P(D)VR/Autofluorescence. Between the best visual acuity and contrast vision, there was a highly significant correlation with $p < 10^{-6}$ and rho = 0.62. The seemingly trivial nature of this is discussed.

Depending on the actual situation immediately before retinal detachment surgery, an even more important aspect emerges in that the actual visual acuity gain is based on the operative care. There is a significant correlation between visual acuity and contrast visual gain ($p = 0.04$, rho of 0.22).

A lower intraoperative risk profile correlates with better visual acuity ($p = 0.01$, rho = 0.23). A homogeneous autofluorescence correlated significantly with a better postoperative visual acuity ($p = 9 \times 10^{-6}$, rho = 0.436) as well as the contrast vision ($p = 2 \times 10^{-6}$, rho = 0.483) and a good OCT result ($p = 3.8 \times 10^{-5}$, rho = 0.406).

3.7.2. Factors Not in Context with Visual Acuity

(1) Increase in Contrast Vision/OCT-Assessment/Autofluorescence/Perioperative Course. There was a statistically highly significant correlation between contrast and OCT with $p = 3 \times 10^{-6}$. The better the clinical contrast that the patient developed during the course of the study, the more homogeneous the structure of the eye with a correlation coefficient of rho = 0.465 in the last visit—with a good receptor layer thickness without swelling or atrophy in the OCT. If the fovea was present during primary retinal detachment surgery, the contrast vision was better ($p = 0.046$, rho = 0.206).

The lower the P(D)VR activity, the more favorable the contrast vision development ($p = 0.04$, rho = 0.21), structural preservation of the retina in OCT ($p = 0.003$, rho = 0.29), and its autofluorescence ($p = 0.09$, rho = 0.17).

Moreover, the lower the intraoperative risk profile ($p = 0.018$, rho = 0.237), the more homogeneous the autofluorescence.

(2) Retinal Attachment/Time of Cataract Surgery. When a correlation between cataract surgery timing and retinal

detachment was performed, a clear trend with $p = 0.06$ showed that the earlier a cataract operation was performed (preoperatively or at least during oil removal), the better the success rate of the retinal detachment (rho = 0.188).

This verifies the results of Fisher-Freeman-Halton's exact contingency panel test [52], comparing the failure rate between the preoperative pseudophakic versus phakic group; a higher success rate among the already pseudophakic patients with a p value with Valz and Thompson's algorithm of $p = 0.039$.

(3) Degree of Laser Coagulation/Emulsification Rate/P(D)VR Activity. In Spearman's rank correlation, a significantly negative correlation between laser quality (high-scale value = high number laser spots) and emulsification rate (high-scale value = low-emulsification rate) occurred ($p = 0.03$, rho = −0.21). Additional laser was performed once oil filled into the vitreous cavity induces a higher emulsification tendency.

A low rate of emulsification (evaluated by blisters in the VB, AC, or lens capsule) correlated negatively ($p = 0.018$, rho = −0.24) with a more advanced P(D)VR stage. At first glance, this confusing result will be discussed (advancement of severity P(D)VR versus inflammatory activity and emulsification rate).

(4) Documentation/Degree of Laser Coagulation/Intraoperative Risk Profile. The quality of the documentation of the procedure and that of the laser coagulation correlate with a p value = 0.01 and rho = 0.24. If a lot of laser spots have been applied, it was very well documented. The diligence of the documentation was requested by the SOP, with laser documentation being provided in both text form and graphically.

With a clear trend, the quality of the documentation was improved ($p = 0.059$, rho = −0.186) with increasing risk profile (more retino/retinectomies), such as intraoperative insight into the severity and complication of the intervention.

(5) Intraoperative Risk Profile/Severity Degree P(D)VR/Retinal Redetachment. There was a highly significant correlation between intraoperative risk profile and severity of the P(D)VR staging ($p = 9 \times 10^{-4}$, rho = 0.322). This can be explained by the membrane-induced stiffening of the retina with the consecutive tediousness of tissue removal (retinotomy/retinectomy). The more severe the P(D)VR and the higher the intraoperative risk profile ($p = 0.005$ and rho = 0.33), the greater the risk of redetachment of the retina ($p = 0.016$, rho = 0.237).

(6) Patient Age/Eye Disease/Membrane Peeling. When retinal detachment occurred, more severe eye changes were seen in younger patients ($p = 0.017$, rho = 0.235), for example, in uveitis intermedia or infectious eye inflammation (e.g., HIV). Also in younger patients, significantly more membrane peeling ($p = 0.02$, rho = −0.22) was necessary.

(7) Membrane Peeling/Retina Holes. The higher the number and extent of the retina holes in one eye ($p = 0.057$, rho = 0.188), the more intense an ERM and ILM peeling was required.

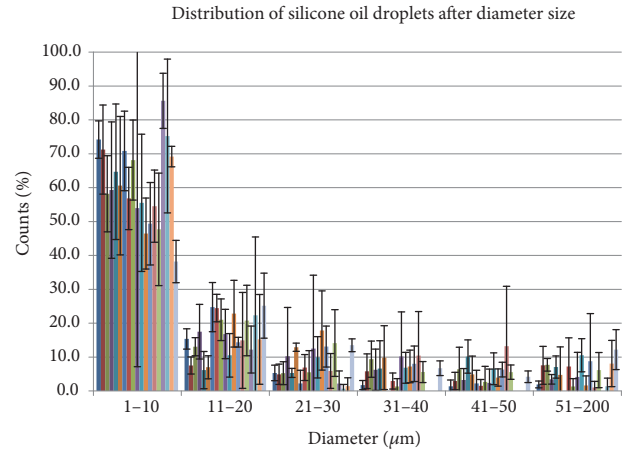


Figure 3: Distribution of silicone oil droplets after diameter size, in % with standard deviation.

3.8. Analysis of Interactions between Silicone Oil and Eye Tissue

3.8.1. Results of Microscopic Oil Analysis in the Laboratory. In Deuchler et al. [52, 53], the focus was on potential connections between different types of silicone oils and their emulsification characteristics [54–60]. As presented, the measurements of the oils were taken with the aid of a Bresser-Trino research field microscope (with the help of alamedics GmbH & Co.KG, Dornstadt, Germany) showing very different distribution densities (0–250, 250–500, 500–750, 750–1000, and >1000 oil bubbles/cm$^{2)}$.

Different bubble diameters are graphically represented here.

With the percentage distribution of the emulsification bubbles by their diameter, it was found that the majority of the emulsification bubbles have a diameter of only 1–10 μm (Figure 3). This greatly increases the risk that emulsification bubbles enter the chamber angle and could potentially lead to secondary glaucoma, justifying our decision for a 3-port oil removal revision surgery in which the vitreous space can be repetitively rinsed.

In the context of the subgroup analysis of completely evaluable samples from 19 eyes, the connection between the type and extent of emulsification and preceding anterior segment operation or retinal preoperations before oil removal (oil analysis) is emphasized, as well as the connection between emulsification, failure rate, and the amount of laser coagulation not before but after filling the silicone oil into the glass body.

3.8.2. Effect of Silicone Oil on the Lens Maturation (Scheimpflug Examination with Pentacam®). In Deuchler et al. [52, 53], we published important correlations between the lens status and the success of retinal reattachment surgery with temporary silicone oil fill.

When analysing the lens transparency loss projecting the reference body through the whole lens, the Wilcoxon test for four age groups (group 1 (mean 69.5 years), group 2 (mean 62 years), group 3 (mean 51 years), and group 4 (mean 36 years) ($p < 0.05$)) proved for all except for the younger ages with significant lens changes ($p \leq 0.05$). The strongest signs of maturation were obvious in the age groups 2 and 3.

When analyzing the sections of the lenses separately, the lenses in group 3 showed significant transparency changes in all parts, and in group 2, changes in the anterior and central part were significant ($p = 0.004$), but not in the posterior part ($p = 0.375$). The lens sections separately analysed showed no significant changes in the oldest group (group1), and most pronounced changes here were found in the anterior part ($p = 0.094$).

Obviously, the lens transparency loss plotted against age does not show a linear function: the lens transparency loss increases from group 4 (youngest group) through group 3 to group 2 but decreases in the oldest group 1. In Deuchler et al. [52], the relationships between temporary silicone oil filling and the individual lens change when performing a PPV with temporary silicon oil filling to manage a complicated retinal detachment was discussed in detail. It was speculated that older patients (group 1) already had a relatively more advanced cataract before surgery with silicone oil instillation.

3.9. EVALP/SOP: Consequences of the Statistical Findings for the Protocols. The current retrospective data record shows the role of insufficiently accurate documentation of individual parameters: for example, the quality of laser coagulation should be specified for individual segments of the retina separately. In the case of an insufficient primary response to laser applied primarily and no proper additional laser where necessary (during revision surgery or in between), redetachments of the retina after silicone oil removal are likely. A better documentation can compensate the negative effect of the visual outcome if more than one surgeon has operated on one eye.

The adaptation of an evaluation protocol and the development of SOPs were a common thread throughout the entire study [53]. It was clear from the beginning that both would be a prerequisite for successful vitreoretinal surgery and the treatment of complicated retinal detachments. The necessary data set was immediately transferred postoperatively to the developed evaluation sheets. For creation of the 6-sided evaluation protocol, known parameters from the literature (e.g., P(D)VR stage and amount of retinectomy) were used as well as parameters which were significantly important in the retrospective analysis (e.g., amount of membrane peeling and quality of laser coagulation).

The careful creation of the initial EVALP took 3 months, and its format was continually revised and adapted during the study. At the end of the study, the final version was optimized in correlation to the ergonomics. The EVALP was finally revised in such a way that this form of evaluation should take, on average, about 10 minutes to complete for each operating unit. Therefore, it can be recommended to the general public as a quality assessment sheet.

The SOP at the end of the study shows two major content-related changes compared to the initial version: the option of removing silicone oil "passively" via a 2-port access from the eye no longer exists because of changes in the manufacturing process. Furthermore, we have to reduce the silicone tamponade time from 4 to 2 months.

Firstly, our analysis shows that a redetachment usually occurs within 4 weeks after oil removal; secondly, it is still an open question to what extend retinal damages can be provoked by long standing silicone oil fill.

4. Discussion

Even if the group of eyes followed up retrospectively versus prospectively were expected to show lots of differences, essential baseline and demographic parameters proved to be homogeneous: gender, distribution of the right and left eyes, fovea involvement, efforts to laser retina or peel membranes, and, last but not the least, there did not exist any noteworthy differences regarding the staging of PVR or PDR (=P(D)VR).

Parameters like "amount of membrane peeling" and "revision strategy (2-port/3-port access)" had changed due to the introduction of our SOP.

That the parameter "axial lengths" shifted more towards a higher degree of myopia (from retrospective towards prospective) underlines our improved retinal reattachments rate because higher myopia in general is expected to have a negative impact onto the success rate.

After analyzing the subgroups with different surgical experience, we found an improved success rate in all groups. The most pronounced effect could be observed in the group with intermediate experience. Obviously SOPs and EVALPS are most effective when a surgeon has overcome starting issues but has not reached expert levels.

The rate of complication "redetachment of the retina after PPV with a temporary silicone oil tamponade" was reduced from about 35% to approx. 7%.

Only the eyes, which after the final removal of silicone oil had a permanent retinal attachment, were classified a success and differentiated from those redetaching and/or requiring a permanent oil fill to stabilize a partial or complete retinal attachment.

Eyes with partially or completely redetached retinas and those permanently filled with oil were considered to be a failure, since the patient does not experience a final morphological or functional rehabilitation.

This result is only helpful if the cause analysis leads to significant explanatory possibilities that allow reproducible results for all. Since the introduction of the 3-port PPV technology by Machemer et al. [61], this PPV procedure has allowed to precisely remove the traction component in the environment of a retinal hole. Meanwhile, there are sufficient long-term observations on representative cases [62–65].

Various authors refer to strong fluctuations in retinal redetachment rates between <10% and >70%.

Whoever tries to analyse the given data from other groups and to compare it with the own outcomes usually does not achieve a satisfactory result in the absence of SOPs and comparable EVALPs [66].

Choudhary et al. [13] have a correspondingly low-complication rate of just under 4% in the retrospective analysis of their pars plana vitrectomies with silicone oil tamponade for the management of so-called complicated retinal detachments.

In their series, retinal redetachments occurred within 6 weeks (in our series, within 4 weeks). Are there connections between their retrospective data collection and data in our study? What conclusions can be drawn, if any?

The measurement parameters "anatomical reattachment rate," "best visual acuity," and "intraocular pressure" appear to be essential but cannot sufficiently explain the overall good result.

An "aggressive approach" with vitrectomy in front of the outer vitreous base makes a lot of sense. In advanced P(D)VR, the need for retinotomies and retinectomies in the outermost periphery is very likely [13, 67]. Where tractions prevent retinal reattachment, the removal of tissue (including retinal tissue) is inevitable in many cases.

An "as complete as possible filling" of the vitreous cavity with silicone oil is an important issue often mentioned in literature, but difficult to measure and hardly comparable between different investigations. Argon laser coagulation is also one of those obviously necessary parameters which should have a positive effect on the outcome. In the study by Choudhary et al. [13], this is achieved in all cases as a 360° laser coagulation. However, one question remains unanswered: What stage of P(D)VR did the authors have to deal with? How extensive were the retinotomies/retinectomies been performed?

The following statements were made: 167 of 173 (96.5%) of the eyes were classified as anatomically successful.

The mean length of stay of the oils was 70 ± 48 weeks, which is significantly higher than in our study. 21% P(D)VR versus 79% PVR are similar to our ratios of 14.6% P(D)VR versus 85.4% PVR. The best visual acuity [13] was 0.2 or higher in 50% of all eyes 3 months after oil removal; in our study, there was no patient completely blind (no light perception); 4 months after oil removal, 10% of patients had a visual acuity between light perception, and 1/50 and a quarter of the patients (26.2%) had visual acuity between 1/50 and 0.1, one third of the patients (34.9%) between 0.1 and 0.3, 17.5% developed vision 0.3 to ≤0.5, and 10.7% saw better than 0.5; in more than a quarter of our patients, no visual aids were needed for reading (visual acuity of at least 0.3).

Chaudhary's working group was able to remove the oils in all cases via a 2-channel access, and postoperative "floaters" (oil bubbles) in almost 10% of all patients seemed tolerable and did not lead to any further complications—if one disregards a potential association with a 7.5% secondary glaucoma rate which required treatment with cyclocryocoagulation. In our prospective work (oil drainage via 3-port access including rinsing of residual oil bubbles), there was no secondary glaucoma. Indeed, we had to flush the vitreous space at least once after removing the main oil bubble to completely remove satellite bubbles which are best accessible during repeated fluid air exchange.

Although Chaudhary's group mentions retino/retinectomies as parameters which are indicated when membrane remedies cannot be removed from the retina, the extent of these tissue removals is not explained in detail.

Prognostic factors for the long-term reattachment of the retina and a positive visual outcome are discussed in various contradictory ways. In principle, Grigoropoulos et al. [68] consider a good visual result to be possible even with heavier pathologies and the possible need for multiple, larger retinectomies.

A smoldering P(D)VR as well as hypotonia is prognostically unfavorable factors, whereas a shorter oil tamponade, the oil removal itself, small retinectomies, only few preoperative surgical interventions, and a good visual acuity are favorable factors as a starting point. It is important to "limit the number/size of retinectomies, but to retinectomize in time."

In our group, we tried to define the requirements for the adequate retinectomy issue as follows: in the areas where the vitreous exerts traction in proximity to a retinal hole, either the tractions must be completely removable or the retinal detachments must be extended until the contracted tissue is stress-free attachable to the underlying choroid RPE complex. The success of this procedure must not only be judged under air or heavy liquid (forced preliminarily) but must also be ensured under physiological fluid (as BSS).

A basic consideration should be as follows: to what extent is the staging of the P(D)VR and/or its smoldering activity, de facto decisive for the outcome prognosis? We do know from extensive research carried out by the group of Charteris: if at all, a combination of fluorouracil and heparin exclusively in the early stages of P(D)VR can (prophylactically) influence this most disastrous event [47, 69]. Decent information which could contribute to a better understanding of this disease can probably only be gained if the removed vitreous is systematically examined for VEGFs and interleukins. Obvious is that the risk for a permanent retinal detachments correlates with the amount of retinectomies and the efforts which have to be taken to repair the retinal detachment by removing retinal tissue can also contribute to further proliferative vitreoretinopathy activity.

De Silva et al. [70] focus on the importance of the etiology of the retinal detachment and on the relevance of the P(D)VR staging, and a 360° laser coagulation considered to be a positive predictor for the anatomical and functional result.

We know that laser coagulation of the freshly applied retina might not be able to be carried out in an equally efficiently and in a low-risk manner (retinal swelling, leakage risk) in many areas; additional coagulation has eventually to be carried out in the free interval between the first and second interventions or during revision surgery later on.

In De Silva's working group [70], adequately performed laser coagulation reduces the retinal redetachment rate from 58% to 26% after silicone oil removal.

Our results supplement these observations in regard to the functional success rate (postoperative visual gain). Here, the visual gain increases with the number of laser coagulation spots. Extensive laser coagulation during the primary supply (final silicone oil filling) has no negative effect on visual acuity and visual quality [71, 72]. However, during revision surgery (silicone oil removal), an additional laser coagulation should be limited to the absolutely necessary diagnostic/therapeutic need. Surgical time and effort, timing of a cataract surgery in view of specific lens changes under silicone oil tamponade [52, 53, 73], torsion instability of thinner instruments, so-called flow dynamics ("fluidics"), estimation of inflammation parameters in the vitreous space, and so forth are only some of the parameters that in the future will have to be worked up from these points of views, especially since we have gained negative experience with preoperative, incompletely vitrectomized eyes within the framework of this work.

Without doubt, the early entry (<4 weeks) into an eye with persistent vitreous hemorrhages has to be preferred due to the reduction of proliferative activities (P(D)VR); however, the supposed "attractiveness" of smaller gauges and the associated need for modification of the procedure should not lead to a "small", incomplete removal of the vitreous when P(D)VR requires a meticulous procedure in the outer vitreous periphery as well as peeling of epiretinal membranes in the macula [74].

Although a "total" removal of the vitreous body cannot be attained purely mechanically, the removal of any vitreous which exhibits tractive effects on the retina during the intervention or at the end of the procedure immediately before the silicone oil filling has to be carried out as completely as possible. Otherwise, it serves as a recruitment area for P(D)VR activity processes. This should be kept in mind when applying low-gauge instruments—although sufficient for removal of an uncomplicated macula pucker or a macula hole, these instruments may not be able to fulfill the requirements for cumbersome removal of pathologically changed vitreous in P(D)VR.

5. Conclusions/Recommendations

Our recommendations for future approaches that we like to sum up here are mainly based on not only the key factors discussed above but also other practical findings with effect onto the outcome of surgery:

(i) We generally recommend using a defined treatment path (SOP) and an EVALP, which should promptly and carefully be considered by all medical staff in attendance. The protocols prepared and revised in the present analysis can serve as a guide for other operating units. According to our literature research, there is no consensus about SOPs and EVALPs which would allow to relate procedures and outcomes of different centers to each other. Only a uniform approach, according to SOPs and EVALPs, make protocol controlled procedures and their results comparable.

(ii) Preferably, in all required interventions, the service for a patient's eye should be provided by one and not by different surgeons because of the ultimately demonstrable positive effect on the development of visual acuity. Once you apply an EVALP and SOP, case- and situation-related exceptions from the "one-surgeon-only-service" are conceivable. Protocolled details about the course of disease and surgery allow a 2nd and 3rd surgeon to improve further steps of treatment of the same eye. Essentially for the effectiveness and safety of the service in a vitreoretinal center also should the option for any surgeon to make use of a more experienced colleague to assist the case or even take over from the less experienced surgeon.

(iii) Once silicone oil has been removed, the follow-ups of the operated eye must be carefully structured during the first four weeks, including the instructions for the patient about how to perform self-monitoring.

(iv) If triamcinolone or ICG-assisted dusting or staining of the vitreoretinal interface demonstrates clinical relevant pathological changes, a peeling of the epiretinal tissue with or without peeling of the ILM should be performed. The nature and extent of peeling-associated retinal hemorrhages suggest to continue peeling, starting from the vascular arcades, working towards the fovea with reduced speed.

(v) The vitreous body must be removed as carefully and completely as possible in the outermost retinal periphery of the present pathologies with tissue proliferation. For this purpose, the choice of the surgical procedure (one-handed, bimanual) and the necessary tools (hand-held light pipe, chandelier, and so forth) must be weighed for this procedure as well as a decision on the status of the eye lens. If desired, a defined amount of the triamcinolone typically used to detect residual vitreous can be left in the eye as a potentially anti-inflammatory agent.

(vi) Due to the particular challenge involved in the treatment of proliferative vitreoretinopathies, instruments and optics should be tailored to both pathological lengths of the eye as well as special requirements in the context of decreasing gauges (instrument design, instrument stability, reduction lenses for different observation systems, light sources, and light guides). To date, the use of 27 g instruments should be reserved for the treatment

of pathologies without heavy secondary response to inflammatory activity.

(vii) The use of PFCL has to be weighed critically. In principle, the heavy liquids and silicone oils available on the market since around 2012 come with more emulsification side effects than those from many years before. Without retinal cracks, the retina can also be reattached via a liquid-air drainage without temporary PFCL instillation. If the use of PFCL in the vitreous cavity is necessary, preferably the heavy liquid should not be filled up beyond the equator of the eyeball, because remnants of this substance can easily stick to the ciliary body tissue. Of the two options, PFCL-silicone oil-direct exchange and PFCL-via air-to-silicone oil-exchange, the latter one should be the preferred for a thorough removal of the PFCL.

(viii) Due to the increasing silicone oil emulsification rate over time, we have now concluded that silicone oil should be preferably removed already after 2 months. This might also help to lower the rate of "visual loss for unknown reasons after temporary silicone oil tamponade." With regard to the final structural outcome, the postoperative visual acuity, or the rate of emulsification, no recommendations for a certain oil or special viscosity can be given.

(ix) Other factors affecting the type and extent of emulsification include the strategy of oil instillation as well as the "timing" of laser (under BSS, air, and oil) when injecting silicone oil through cannulas with small gauges, speed has to be reduced to the threshold where air bubbles will not build up, and laser, in general, should be avoided or limited once oil is filled into the vitreous cavity.

(x) It is necessary to define circumstances when the surgeon—regardless of his experience—has to recall his skill level in the Eyesi and/or run through individually tailored "warmup programs" before providing service in the operating room. Particularly for colleagues "in-training," a short curriculum must be drawn up so that a preoperative training on Eyesi is possible thus decreasing the risk of causing complications.

(xi) Emulsification management including strategies to remove "sticky oil" as well as the management of vitreoretinal diseases in eyes with pathological axis length should be integrated into Eyesi and be trainable.

(xii) It has to be prospectively established when and under which criteria the lens should be operated on, either before or simultaneously with the primary retinal reattachment including silicone oil instillation. As much as leaving the lens in place can have a stabilizing effect when the eye suffers from inflammatory diseases, the lens itself can be "in the way" and make it difficult to allow access to the peripheral vitreous space. When delayed, opening the anterior lens capsule during cataract surgery might be significantly more difficult since after temporary silicone oil tamponade, the lens nucleus and all layers in front of it show significant changes. This affects particularly the middle age groups (50–70 years).

(xiii) The current classification(s) of a P(D)VR do not allow estimation of the actual ratios of endothelial/fibrotic activities for the different stages of P(D)VR (stages A until stages C/D). Since growth factors (VEGFs) and inflammatory mediators (interleukins) play an essential role in the emerging cascade of retinal detachments with P(D)VR, a concept has to be developed to measure these.

(xiv) As long as no significantly improved silicone oil products are offered, it will be necessary to choose a complete 3-port PPV strategy to reliably remove the silicone oils from the eye by repeated rinsing procedures. A modern illumination technique (extraocular, diaphanoscopically) could allow such a procedure to be performed in the future, choosing a 2-port PPV approach.

(xv) The total surface area of all retinectomies should be kept as small as possible: enrolled edges of retinal holes, necrotic tissue, and dispersed pigment epithelial cells which have to be trimmed back, respectively, and removed from the globe as complete as possible (reduction of PVR potential).

(xvi) To evaluate the postoperative success, vision quality assessment tests that provide information for vision under various conditions (e.g., contrast and glare), visual acuity measurements, and OCT documentation of structural changes should be assigned to reflect subjective vision and give a more reliable prognosis for final visual outcome.

(xvii) Less experienced surgeons typically show significant performance fluctuations and benefit most from improved operational documentation and standardized procedures.

(xviii) Only a uniform approach, according to SOPs and EVALPs, makes protocol-controlled procedures and their results comparable.

Abbreviations

AC: Anterior chamber
AHFG: Anterior hyaloid fibrovascular proliferation
ERM: Epiretinal membrane
EVALP: Evaluation protocol
EVRS: European Vitreoretinal Society

Eyesi: Eye simulator (manufactured by VRmagic company)
f/u: Follow-up
g: Gauge
GRT: Great retinal tears
ILM: Inner limiting membrane
mPa·s: Millipascal seconds
med.: Medical
P(D)VR: Proliferative (diabetic) vitreoretinopathy
PFCL: Perfluorocarbon liquids
PPV: Pars plana vitrectomy
PVD: Posterior vitreous detachment
SLP: Scheimpflug lens photography
SO: Silicone oil
SOT: Silicone oil tamponade
SOP: Standard operation procedure
TRD: Tractional retinal detachment
VB: Vitreous body.

Conflicts of Interest

Svenja Deuchler, Hanns Ackermann, Pankaj Singh, Thomas Kohnen, and Frank Koch have no conflict of interests regarding the publication of this paper. Clemens Wagner is employed by VRmagic company, Mannheim, Germany.

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Review Article

Review of Small Gauge Vitrectomy: Progress and Innovations

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Purpose. To summarise the surgical advances and evolution of small gauge vitrectomy and discuss its principles and application in modern vitreoretinal surgery. The advent of microincisional vitrectomy systems (MIVS) has created a paradigm shift away from twenty-gauge vitrectomy systems, which have been the gold standard in the surgical management of vitreoretinal diseases for over thirty years. Advances in biomedical engineering and surgical techniques have overcome the technical hurdles of shifting to smaller gauge instrumentation and sutureless surgery, improving surgical capabilities and expanding the indications for MIVS.

1. Introduction and History of Microincisional Vitrectomy Surgery (MIVS)

Robert Machemer introduced pars plana vitrectomy (PPV) in 1971. Prior to this, Kasner had described vitreous excision removal under an open sky technique, using sponge and scissors [1]. Machemer developed a closed system for vitreous removal with control of intraocular pressure. His vitreous infusion suction cutter (VISC) was 17-gauge (1.42 mm in diameter), multifunctional, and utilized a 2.3 mm scleral incision [2, 3]. O'Malley and Heintz separated the components of vitreous cutting, infusion, and illumination and developed the first three-port 20-gauge(G) vitrectomy system in 1974. Absorbable sutures were used to close the sclerotomies and conjunctiva [4]. Improvements in electric and pneumatic cutters led to 20G three-port vitrectomy becoming the standard technique for vitreoretinal surgery for over thirty years, until the advent of microincisional vitrectomy surgery (MIVS). In 1985, Machemer and Hickingbotham introduced the first 20G trocar/cannula system to be inserted into the sclerotomy, allowing for easier passage of instruments and reduced traction at the vitreous base [5]. In 1990, De Juan developed 25G instrumentation for use in paediatric eyes [6]. Peyman then developed a 23G vitrectomy probe in 1990, primarily intended for vitreous and retinal biopsies [7, 8]. In 2002, Fujii et al. introduced a 25G transconjunctival vitrectomy system using microtrocars and cannulas and popularized the widespread use of small gauge pars plana vitrectomy [9–11]. Eckardt later introduced 23G vitrectomy instrumentation as an alternative to the 25G system [12], and the trend toward yet smaller gauge instruments continued with the development of a 27G sutureless vitrectomy system by Oshima in 2010 [13].

2. Advantages and Disadvantages of Small Gauge Vitrectomy

Small gauge vitrectomy, with its smaller instrumentation intended to be transconjunctival, self-sealing, and sutureless, has theoretical advantages including decreased ocular trauma and inflammation, decreased corneal astigmatism, reduced operating times, faster postoperative recovery, increased patient comfort, reduced conjunctival scarring, and conjunctival preservation, especially in patients with prior or pending glaucoma surgery [14–16]. In addition, smaller gauge vitrectomy instruments are better suited to the narrower spaces of paediatric eyes.

However, miniaturization of instruments limits instrument diameter and lumen, with counterproductive effects on instrument flexibility, efficiency, and performance. Initial indications for small gauge vitrectomy were limited to those not requiring extensive vitrectomy, membrane dissection,

or phacofragmentation, due to initial issues with limited instrument array and increased flexibility. Advances in wound construction, instrumentation, fluidics, cutter technology, illumination, and wide-angle viewing systems (WAVS) have overcome the handicaps of smaller gauge instrument size and are discussed in detail as follows.

3. Trocar/Cannula System

Standard 20G vitrectomy surgery requires conjunctival incisions and sclerotomies of 0.89 mm diameter. Smaller gauge vitrectomy using transconjunctival trocar/cannula systems, have reduced the scleral incision diameter to 0.64 mm for 23G, 0.51 mm for 25G, and 0.4 mm for 27G. The trocar/cannula system theoretically creates less traction on the vitreous base during instrument entry and exit. However, a large retrospective study by Rizzo et al. found similar incidence of retinal detachment after sutureless 23G and 25G vitrectomies and conventional 20G vitrectomy (1.7% versus 1.2%) [17]. The once only placement of the cannulas maintains the alignment between the conjunctiva and sclera and is less traumatic to wound borders than the repeated insertion and withdrawal of instruments through a 20G sclerotomy. It also increases the chances of self-sealing sclerotomy closure and minimizes the risk of suture-related inflammatory reaction, or subsequent atrophy and thinning over the sclerotomy site. Cannulas also allow for interchangeability of instrument and infusion sites, allowing for improved access in certain instances.

However, the cannula sleeve internal diameter limits the radius of curvature of intraocular scissors, resulting in a blunted curve and shorter blades, and renders them less efficient for membrane cutting and dissection than their 20G counterparts, forcing surgeons to use other methods [18]. The cannula sleeve may also slightly affect instrument rotation and flexion during globe manipulation, as well as anterior and peripheral access. Placing the sclerotomies closer to the horizontal meridian reduces the need to rotate instruments significantly for peripheral and superior access and avoids displacement of the infusion as the eye is rotated inferiorly [19].

4. Wound Construction

Wound construction in smaller gauge vitrectomy systems is a critical step and affects whether the sclerotomy seals well at the end of surgery. The thickness of the sclera in the area of the pars plana is 0.8 mm. Early incisions were straight (perpendicular to the sclera) in 25G systems, as better self-sealing was expected with the smaller diameter incisions [11]. This was changed to an angled (oblique) scleral incision after studies showed better wound closure and reduced risk of hypotony compared with straight incisions [20–22]. One- and two-step techniques of angled wound construction have been described.

The original two-step technique for 23G vitrectomy, as described by Eckardt, involves displacement of the conjunctiva and stabilization of the eye with a pressure plate, followed by use of a sharp angled MVR blade to create the initial slit opening in the sclera followed by insertion of the blunt trocar, onto which the cannula is mounted [12]. This technique allows more consistent wound creation, but it may sometimes cause difficulty in finding the initial point of trocar insertion. The modern one-step technique involves entry by a sharp trocar with a mounted cannula. Cannulas are quick to insert and easily removed from the trocars without need for a second instrument, but it may be necessary to apply a slightly higher pressure to insert the microcannula at an oblique angle, which can cause problems in eyes with recent corneal or scleral wounds [19].

Additional modifications have been made to the one-step angled technique to improve wound architecture. In general, the longer (more oblique) the intrascleral path, the better the wound apposition. In Zorro's incision, the blade is inserted obliquely at an angle of 10 to 15 degrees and enters the vitreous without straightening [23]. Pollack improved on this by suggesting a biplanar incision, where the trocar is inserted at a 5-degree angle to the sclera until 50% scleral depth, and then raised to a 30-degree angle to the sclera. Trocar entry at 30 degrees produces a longer tunnel length of 1.414 mm, compared with a tunnel length of 1.154 mm produced by trocar entry at 45 degrees. The 30% increase in tunnel length results in more watertight closure [23]. Alternatively, the trajectory may also be made very tangential to the sclera at about 5 degrees and then tilted up to a more perpendicular angle after the cut is made through the sclera in order to avoid impaling the retina. Moreover, older blades created chevron-shaped incisions with a tendency to gape, but newer blades create flat, linear incisions [18].

The course of angled incisions can run perpendicular or parallel to the limbus. Kwok et al. modified the original perpendicular incision by rotating the sclera tunnel by 90 degrees, making it parallel to the limbus [24]. Due to the orientation of scleral fibres around the cornea, scleral incisions made parallel to the limbus offer a theoretical benefit of displacing the scleral fibres rather than cutting them, as in incisions that run perpendicular to the limbus, facilitating more rapid and superior sclerotomy closure [25, 26]. In addition, scleral tunnels that run parallel to the limbus are less likely to encroach on the lens or retina. Microincisional scleral tunnel entry radial to the limbus leaves more room for future sclerotomies than conventional 20G incisions running parallel to limbus, preventing coalescing of wounds in repeat surgeries.

Conjunctival and scleral vessels should be avoided where possible, to reduce postoperative subconjunctival haemorrhage. Conjunctival displacement from the scleral incision has been proposed in order that the two incisions will not be aligned after cannula withdrawal, and the conjunctiva will cover the sclerotomy. It is intended to reduce the risk of postoperative scleral wound contamination. However, Singh et al. demonstrated that conjunctival displacement did not prevent ocular surface fluid from entering sutureless 25G scleral incisions in cadaver eyes [27]. Avoiding conjunctival displacement in eyes with silicone oil fill may also prevent leaking silicone oil from becoming trapped in the subconjunctival and sub-Tenon's space [28].

5. Valved Cannula System

Newer valved cannula designs remove the need for plugs and consist of a cap-like silicone membrane mounted onto the cannulas (DORC, Dutch Ophthalmic Research Corporation, Zuidland, the Netherlands), or built into the cannula head (Alcon, Fort Worth, Texas, US). They help maintain a closed system, provide more stable intraocular pressure (IOP) control during instrument exchange, and reduce the amount of infusion. High infusion flow can cause turbulence when working with perfluorocarbon liquids, direct mechanical trauma to the retina, ballooning of the retina if the infusion is directed toward a retina break, or increased dehydration if fluid-air exchange has already been performed. Valved cannulas address the problem of high flow from the infusion through open cannulas during instrument exchange due to IOP compensation features, which can lead to a "fountain effect" at the open cannulas and dislodge plugs, or cause vitreous or retinal incarceration at the sclerotomies [29].

However, valved cannulas can lead to increased friction between the instrument and the valve, and difficult entry for soft or flexible tip instruments, such as the soft tip backflush cannula, or the diamond dusted membrane scraper (DDMS). Entry of such instruments requires straight entry at the centre of the valve aligned with the cannula direction, or a second instrument to act as a glider displacing the valve leaflet [30]. Other alternatives are cutting or removing the soft tip and using newer retractable versions of flexible tip instruments, such as the DDMS. A built-in valved cannula design can also create intraocular pressure buildup during air-silicone oil exchange, and venting extensions that allow air to go through the valves have been introduced to prevent this. For DORC valved cannula systems, the silicone caps can be easily popped off to enable passage of soft-tipped instruments, or to allow for venting.

6. Transconjunctival Sutureless 20G Entry

Cannulated and noncannulated transconjunctival sutureless entries for 20G systems have also been developed to allow use of the traditionally more rigid scissors, forceps, and cutters and to allow hybrid 20G/25G or 20G/23G approaches, such as dropped nucleus or intraocular foreign body (IOFB) removal. In 1996, Chen et al. introduced self-sealing sclerotomies using scleral flaps for 20G vitrectomy [31]. Single-step and two-step entry 20G transconjunctival cannulated systems (TCS) are commercially available. Lafeta and Claes described a two-step entry for 20G valved TCS (DORC, Zuidland, the Netherlands) using limbus-parallel 3.5 mm scleral tunnels made at a 10-degree angle to the sclera with a bent stiletto, without conjunctival displacement [32]. None of the eyes required suturing, although it should be noted that 92% of eyes received air tamponade. Only one eye developed hypotony (defined as IOP less than 6 mmHg). Single-step beveled entry nonvalved 20G TCS (Synergetics, O'Fallon, MO) has been reported by Kim et al. and Shah et al. However, 35% to 38% of eyes required suturing [33, 34].

7. Cannula Removal and Wound Closure

The self-sealing ability of a sclerotomy wound is affected by wound architecture, scleral tunnel length, scleral elasticity, wound apposition by residual vitreous, surface tension of a gas bubble, and intraocular pressure. To facilitate approximation of the wound edges, the cannulas should be withdrawn in a tangential trajectory. Infusion pressure can be decreased prior to cannula removal to minimize vitreous prolapse [19]. Infusion pressure may be activated to raise internal pressure while concurrent external pressure on the wound facilitates the angled incision tunnel to collapse and close [32]. Some vitreous remnant may also plug the ports to an extent during cannula removal. However, there is no increased rate of retinal detachment attributable to this [17]. Removal of the cannula over a nonhollow probe such as a light pipe has been proposed as a means to decrease vitreous wick incarceration. However, competency of scleral closure may be affected [35]. Partial fluid-air exchange may help reduce wound leak from the sclerotomies until fibrin seals the wounds, due to the increased surface tension of gas compared to fluid [19]. However, better wound construction has obviated its routine use in MIVS. If a wound leak is still detected at the end of surgery, absorbable sutures can be placed, especially in the setting of leaking silicone oil. Leakage from sclerotomies is more likely in highly myopic eyes with low scleral rigidity, in eyes with scarred conjunctiva or sclera from previous surgery, in Marfan's syndrome [36], and in young children [19].

8. Instrument Rigidity, Functionality, and Array

Rigidity of instruments is dependent on material, thickness, diameter (gauge), and length [37]. As the trend toward smaller gauge continued, problems with instrument array and tool flexure arose. Initially, 25G vitrectomy was primarily utilized in macular surgeries. As the range of instruments for small gauge systems increased, surgeons applied 25G and 27G systems to cases requiring more extensive peripheral vitrectomy, and flexibility of the smaller cutter was a problem, especially when using the instruments to affect eye rotation for peripheral access and visualization. Hubschman et al. demonstrated that 23G and 25G cutters were less stiff than 20G cutters. Even within the same gauge group, cutter stiffness varied due to differences in internal diameter among 25G and 23G vitrector probes [38]. Paradoxical movements at the tip of thinner forceps can also occur since stress on the shaft near the proximal end of the forceps can cause a reverse movement of the distal end during attempted rotation of the eye. Some surgeons stabilize the smaller gauge instruments with an extra finger close to the sclerotomy to reduce bending. Optimal positioning of the sclerotomies close to the horizontal meridian, avoiding the supraorbital rim and bridge of the nose, wide-angle viewing systems, and scleral depression, all minimize the need for eye rotation and problems related to tool flexure.

Newer generation 25G and 27G cutters, endoilluminators, and laser probes are now stiffer, and newer forceps are shorter to increase stiffness. However, shorter instruments

may not be suited for use in highly myopic eyes with long axial lengths. Oshima et al. shortened the 27G cutter from 32 mm to 25 mm, with similar rigidity to the 25G cutter, but were still able to perform core and peripheral vitrectomy in eyes with axial lengths ranging from 22 to 28 mm [13]. Tapered stiffening sleeves have also been developed as another means to increase rigidity of the thinner 27G instruments. Besides shortening, the radius of curvature of curved instruments is also often blunted in order to accommodate passage through the narrower internal diameter of the cannulas. As a result, 25G curved scissors are less efficacious than larger 20G scissors, and dissection of dense membranes may need to be completed by other methods [23].

Due to the improvements in instrument stiffness, instrument array in the smaller gauge systems has expanded accordingly, as well as application to a wider range of surgical indications, including simple and complex retinal detachments, macular surgeries, tractional retinal detachments, and stages 4 and 5 retinopathy of prematurity [39–45]. The 27G vitrectomy platform now has an extensive instrument portfolio including valved trocars, light pipe, cutter, backflush brush, forceps, straight scissors, laser, and diathermy. Phacofragmentomes for removal of dense dropped nuclear fragments have traditionally been limited to 20G, but a 23G fragmentome has recently been introduced (DORC, Zuidland, the Netherlands).

9. Fluidics of Vitrectomy

9.1. Infusion Flow Rates. Reduction in internal diameter of the infusion cannula in smaller gauge systems increases frictional forces and loss of pressure head and decreases volume flow at the infusion tip entry into the eye, as per Poiseuille's law, which states that flow of an incompressible viscous fluid is proportional to the fourth power of radius of the transmitting tubing and inversely proportional to its length [29]. The volume flow rate decreases by a factor of sixteen when the inner tubing radius is reduced by half. In addition, the volume flow rate is directly proportional to the pressure differential and inversely proportional to the fluid viscosity.

Higher infusion pressures in the range of 40–50 mmHg may be a way to compensate for this and allow higher flow rates in smaller gauge systems, but may affect eyes with compromised ocular perfusion [19]. Infusion fluid can be infused into the eye either by a gravity-fed system or a pressurized system. In gravity-fed systems, infusion pressure, measured in centimetres of water, is equivalent to the bottle height above the eye. In vented gas-forced infusion systems, the infusion bottle itself is pressurized and allows for rapid infusion pressure control via console-controlled venting [29]. In the Constellation system (Alcon, Fort Worth, Texas, US), the infusion is pressurized within the console cassette, which should ideally be placed at eye level. The integrated pressurized infusion has internal, noninvasive sensors that constantly measure flow into the eye through the infusion line and cannula and integrate it through the microprocessor of the computer. The resistance is measured during machine priming. Ohm's law for fluids is analogous to Ohm's law for electricity and states that pressure (gradient) is equal to flow rate multiplied by resistance. Vitrectomy creates a pressure gradient that the machine senses and compensates for by increasing infusion. Infusion pressure can therefore be adjusted according to the sensed flow rate to maintain the desired IOP during surgery, and IOP compensation is accurate to within 2 mmHg [37].

9.2. Cutter Flow Rates. Vitreous cutters developed based on the VISC had different drive systems. The electric cutter maintained a constant duty cycle (percentage of time the cutter port is open relative to each cutting cycle) with increased cut rate, but it was heavy and the electric motor in the handpiece led to easy muscle fatigue. The pneumatic cutter was first reported by O'Malley and Heintz in 1975 [4]. Until quite recently, pneumatic cutters employed a single pneumatic pulse from a pneumatic energy source located in the machine to close the cutter guillotine blade and relied on a spring to open it to complete a duty cycle. Pneumatic cutters were smaller and lighter, but as the mechanical properties of the spring remain constant, as the cut rate increased, the inability of the spring to keep up with the pneumatically driven closure increased the time the port is closed, thereby decreasing the duty cycle [46].

Engineering advances led to newer dual pneumatic drive cutters, which replaced the passive spring return phase with a second pneumatic piston that actively pushes the guillotine blade into the open position. This allowed a higher duty cycle at ultrahigh-speed cut rates up to 7500 cuts per minute and allowed surgeons to vary the duty cycle between 50% (50/50), less than 50% (shave mode), or more than 50% (core mode) [18]. The latest twin duty cycle (TDC) cutter design on the Enhancing Visual Acuity (EVA) vitrectomy system (DORC, Zuidland, the Netherlands) has a second port in the internal guillotine blade of the pneumatic cutter. The concept of a double-port cutter was originally patented by Hayafuji more than 20 years ago. With two cutting edges, it cuts both forward and backward, nearly eliminating any port closed time, resulting in a 92% duty cycle independent of cutting speed and allowing cut rates to be doubled to reach 16,000 cuts per minute. With the smaller 27G cutters, increased cutting rate and duty cycle improve cutting efficiency, without unduly increasing tractional forces [47].

Cutter size, speed (cut rate), duty cycle, internal probe diameter, and cutter geometry (including port diameter, distance between the port and tip), all affect its performance. The internal diameter of vitrector probes has decreased from 0.52 mm for 20G, 0.36 to 0.39 mm for 23G, 0.26 to 0.29 mm for 25G, and 0.20 mm for 27G systems. It should be noted that the smaller gauge cutters may show some variability of internal diameters [38]. Larger port diameters, such as in the newer Ultravit 25G+ or 27G+ systems, allow higher flows [29]. While the external diameter of the cutter handpiece has dropped from 0.9 mm for 20G to 0.4 mm for 27G, the port diameter of the 27G cutter still reaches 60% that of the 20G probe. The ports of 23G, 25G, and 27G cutters are also significantly closer to the tip of the probe compared with 20G cutters [18]. Smaller 25G and 27G cutters, with port openings close to the tip, can get extremely close to the retina with

smaller sphere of influence on surrounding tissue [48]. This not only enhances safety during vitreous shaving over mobile retina but also can allow the cutter to serve as a dissection tool by enabling access to the very narrow tissue planes during membrane dissection in diabetic tractional detachments [49].

Flow rate through the cutter is influenced by the infusion pressure, aspiration pressure, port diameter, internal diameter of the probe, drive mechanism of the cutter, duty cycle, and viscosity of the aspirated vitreous [50]. Adding to the complex interactions, the vitreous itself is a heterogenous substance that exhibits viscoelastic properties. It is elastic and deformable, and its attachments to the retina require the vitreous to be cut as it is aspirated in order to reduce traction on the retina. The vitreous is 98% water, and the rest is composed of a matrix of collagen fibrils, hyaluronic acid, proteins, and glycoproteins. Since it does not behave as a liquid, other factors such as aspiration pressures, cut rates, and duty cycle govern cutter flow rates in clinical settings [50]. Efficient surgery requires the ability to control outflow through the cutter to achieve high flow, such as during core vitrectomy or induction of a posterior vitreous detachment, and conversely, to enable low flow, such as during peripheral vitreous shaving over a detached retina. In both situations, high cut rates are desirable to reduce pulsatile traction on the retina.

Higher flow rates in smaller gauge cutter systems can be achieved by higher aspiration vacuums in the range of 400–600 mmHg to counter the higher pressure head loss with the smaller vitrector probe diameters. Duty cycles with a longer port open time also result in higher flow rates for vitreous removal. With pneumatic cutters, the duty cycle converges at 50% with increasing cut rate for both open biased and closed biased duty cycles. However, it is important to note that high cut rates reduce the "bite" size and thus the effective viscosity of non-Newtonian fluids such as vitreous. Flow rates and efficiency of vitreous removal can therefore be maintained at high cut rates, and pulsatile traction is minimized [29]. Watanabe et al. have even recently reported removal of dropped nuclear fragments using a 27G TDC cutter and found that the cutter was able to maintain stable suction power to hold the fragments at high cut rates [47].

Vitrectomy systems, such as Constellation (Alcon, Fort Worth, Texas, US), have traditionally used Venturi pumps to create vacuum because the older peristaltic pump designs were constrained by slower rise times than Venturi pumps due to pump inertia and inherently pulsatile flow resulting from rotary compression of the flexible tubing [29]. However, due to advances in peristaltic pump design, some newer vitrectomy machines offer both venturi and peristaltic pumps. With venturi pump systems, the vacuum is set and flow will vary according to viscosity of substances encountered by the cutter. High maximum vacuum can be set for core vitrectomy and low maximum vacuum for peripheral vitreous shaving. In peristaltic systems, it is the flow that is set and vacuum varies to maintain flow with varying viscosity of substances. Similarly, high flow rates can be set for core vitrectomy and low flow rates for vitreous shaving. EVA (Dorc, Zuidland, the Netherlands) has a flow-control technology called VacuFlow Valve Timing Intelligence (VTI) that combines computer-controlled operating pistons and closure valves working in small-flow chambers to allow the surgeon to have adjustable settings for both peristaltic and venturi controls. There is some debate as to whether a peristaltic pump system gives more control during vitreous shaving over a detached retina [51]. However, low flow settings, and automatic adjustment of vacuum and infusion parameters to maintain constant flow, do minimize surge turbulence at the port and traction on surrounding tissue [29]. Furthermore, newer generation MIVS systems offer a dual dynamic drive (3D) vitrectomy mode or a proportional vitrectomy mode. The 3D vitrectomy mode allows for simultaneous linear control of cutting rate and vacuum pressures to produce the resulting flow rate and enhancing efficiency. As the surgeon presses the footpedal, he can change the settings linearly from a preset start point for cutting and the vacuum to a preset endpoint. The proportional vitrectomy mode allows for high fixed cut rates as the vacuum is varied linearly, thereby reducing pulsatile traction and enhancing safety [18].

"Port-based flow limiting," which describes the flow limitations of cutter gauge size, port size, cut rate, and duty cycle, can be seen as an advantage of smaller gauge systems. A reduced flow rate and high cut rates reduce the average vitreous fibre travel between cuts and therefore limit the traction exerted on the vitreous and retina [29]. A closed biased duty cycle and low flow reduce motion of the detached retina during peripheral vitreous shaving and reduce postocclusion surge after sudden elastic deformation of dense membranes through the cutter port during membrane delamination with the cutter in diabetic tractional detachments [29].

10. Illumination

The first light source for vitrectomy originated from an external slit illuminator. In 1976, Peyman introduced endoillumination for 20G vitrectomy using a fibre optic inserted into the vitreous cavity [52]. Coaxial and slit lamp transcorneal illumination from the operating microscope produce scattered light (glare), while endoillumination minimizes light reflections and light scattering from the viewing system lens, cornea, lens, and vitreous [53]. Modes of endoillumination include light pipes, chandelier lights, and illuminated instruments.

Handheld light pipes allow techniques of focal bright illumination, specular illumination where light shone at a critical angle causes an almost transparent surface to glow, highlighting surface irregularities, as well as retroillumination by reflecting the endoilluminator off the surface of the retina, retinal pigment epithelium, choroid, sclera, or off the cutter [53]. Conventional halogen or metal halide light sources initially caused decreased illumination with the smaller gauge light probes. Compared to 20G light pipes, 23G and 25G endoilluminators had reduced light transmission due to reduced surface area of the fibre optic by 40% and 50%, respectively, and therefore required higher power sources. Initially, high arc lamps (xenon and mercury vapour) provided the high power output required for small gauge endoilluminators [53]. Newer light emitting diode (LED)

light sources provide up to 40 lumens without degradation of light output, can last more than 10,000 hours, and are therefore particularly suited for smaller gauge endoillumination. Moreover, newer light probes have wider cone angles and allow better peripheral viewing with less probe angulation. Some newer generation light probes offer more than 100 degrees divergence angle, compared to older generation endoilluminators with illumination fields ranging from 50 to 80 degrees. Beveled sheath designs on the tips of some help to minimize glare, while providing wide-angle illumination.

Chandelier light and illuminated instruments were developed to allow bimanual surgery. Illuminated picks provide focal bright light at the surgical dissection site, allowing clearer delineation of the surgical dissection planes. Illuminated lasers, scissors, forceps, and infusions are also available. Chandelier illumination is fixed in the sclera and provides wide-angle diffuse lighting. Eckardt developed 25G "twin light" chandelier illumination in 2003, introduced through two sclerotomies to provide more homogenous lighting and minimize shadows seen with single fibres [54]. Other 25G endoilluminators include the Tornambe Torpedo (Insight instruments, Stuart, FL) and the Awh 25G chandelier (Synergetics Inc., St Charles, MO). Much brighter xenon light sources, such as BrightStar (DORC, Zuidland, the Netherlands), Photon Light Source (Synergetics Inc., St Charles, MO), or integrated into vitrectomy machines such as Constellation (Alcon, Fort Worth, Texas, US), allowed the development of smaller gauge chandeliers. Oshima developed a self-retaining 27G chandelier endoilluminator in 2007 [55], and Eckardt then introduced a 27G twinlight chandelier illumination system [56]. A 30G dual fibre chandelier system in 29G cannulas (Synergetics Inc.,St. Charles, MO) is now also available [57].

While chandelier lights produce superior video image quality, the more distant diffuse fixed illumination may be less helpful in identifying dissection planes at the surgical point of interest and cause glare after fluid-air exchange. Excessive use of diffuse illumination also reduces the ability to see transparent structures such as the internal limiting membrane (ILM), clear epiretinal membranes (ERM), and the vitreous, compared to focal illumination from light pipes [53]. Shadows cast by instruments in the path of the light may impede visualization, and thermal buildup has also been known to occur in the steadily illuminated chandelier [58].

Phototoxicity from high intensity light sources can be reduced by starting with low intensities, lowering intensities when switching from 25G to 20G endoilluminators, shortening exposure times to the macula, and maximizing working distances between the tip of the endoilluminator and the retina [53]. Newer LED light sources, used in LEDStar (DORC, Zuidland, the Netherlands) and integrated in EVA (DORC, Zuidland, the Netherlands), have built-in adjustable yellow filters to minimize phototoxicity.

11. Wide-Angle Viewing Systems (WAVS)

In conjunction with developments in MIVS, enhancements in wide-angle viewing systems (WAVS) have improved panoramic viewing of the surgical field and enhanced safety and efficiency. They reduce the need for eye rotation, head repositioning, or scleral indentation and are particularly advantageous when using the smaller gauge cutters. Most WAVS consist of two components: an indirect ophthalmoscope lens placed on or above the cornea and a prismatic stereo reinverter that reinverts the image. WAVS are broadly classified into contact and noncontact viewing systems. Contact WAVS have a fixed field of view depending on the lens dioptric power, whereas the field of view in noncontact systems varies depending on the distance between the ophthalmoscope lens and the cornea [59]. Two contact-based wide-angle lens systems, ClariVit and HRX (Volk Optical Inc), are available. They provide approximately 10 degrees wider field of view than noncontact systems and provide superior image quality as they eliminate corneal aberrations and light reflections by directly placing the lens on the cornea. However, an experienced assistant is needed to hold the lens, and therefore more surgeons prefer to use the noncontact systems. Noncontact systems widely used include BIOM (Binocular Indirect Ophthalmo Microscope; Oculus, Wetzlar, Germany), OFFISS (Optical Fibre Free Intravitreal Surgery System, Topcon Medical Systems, Oakland, NJ), Resight 700 (Carl Zeiss Meditec AG, Jena, Germany), and Peyman-Wessels-Landers vitrectomy lens (Ocular Instruments, Bellevue, WA) [60]. The BIOM system is the most commonly used WAVS, is easily adaptable to most microscopes, and is easily sterilized. The latest version, BIOM 5, offers foot-pedal controlled focusing and automatic image inversion. Newer lenses are wider in diameter, are adapted to compensate for the optical properties of the eye, and have variable back focal length optimized to focus on a curved instead of a flat surface, allowing the concave fundus surface to be in focus for the full extent of the retina from the macula to the periphery with minimal distortion or aberration. However, flat planoconcave contact lenses still have superior axial resolution and lateral resolution over wide-angle systems for macular surgery [53].

12. Complications Associated with MIVS

12.1. Intraoperative. Rise in intraocular pressure to more than 60 mmHg has been measured during insertion of the trocar cannula complex [60], but newer sharper trocar blade designs have improved ease of entry. Increased intraocular pressure and globe deformation can open recent corneal or scleral wounds, and placing sutures prior to port insertion reduces the risk of wound gaping and hypotony [61]. Displacement of the infusion cannula, during scleral indentation and eye rotation, can lead to serous or haemorrhagic choroidal detachment [62]. It can also occur in eyes with choroidal edema, such as in redetachment surgeries [63]. The dislocated infusion can be quickly moved to one of the other two ports to repressurize the eye. Avoiding excessively long scleral tunnels and placing the infusion closer to the horizontal meridian prevent easy dislodgment by the inferior lid or speculum. Cannula dislodgement can occur when instruments are withdrawn from the eye as a result of increased friction between the instrument and cannula wall, such as when removing forceps or scissors without fully closing the jaws [19]. Sclerotomies situated over areas of scleral thinning,

such as in eyes with repeat surgeries, may have reduced friction between the cannula and the sclera and predispose to cannula dislodgement [23]. The dislodged cannula can be mounted onto a trocar and reinserted through the same scleral tunnel, or if it cannot be found, a new sclerotomy can be made. Rarely, breakage and intraocular dislocation of a segment of a cannula tip have also been reported [63]. Use of hybrid 20G/23G or 20G/25G systems, such as during phacofragmentation, can create infusion/outflow mismatch if care is not taken to raise infusion pressures to match egress [64]. Entry site breaks are not common in small gauge vitrectomy [65, 66]. Gentamicin retinal toxicity has also been reported when given subconjunctivally in eyes undergoing small gauge sutureless vitrectomy and should be avoided [67].

12.2. Postoperative. Wound sealing of the sclerotomies was the main problem in the development of sutureless small gauge vitrectomy systems. The hypotony is usually transient, but can sometimes be severe, leading to choroidal detachment or haemorrhage, hypotonous maculopathy, or gas escape, and inadequate tamponade [19, 68]. Furthermore, initial reports suggested higher rates of endophthalmitis. This may be due to contamination from conjunctival flora, ingress associated with postoperative hypotony, and vitreous wick effect at unsutured sclerotomies [69]. India ink passage has been demonstrated in eyes with unsutured 25G, 23G (straight or beveled), and 20G sclerotomies, compared to no entry of India ink in eyes with sutured sclerotomies [21, 70]. Kunimoto et al. reported an endophthalmitis incidence of 0.23% for 25G PPV compared to 0.018% for 20G [71], and Scott et al. identified an endophthalmitis incidence of 0.84% for 25G PPV compared to 0.03% for 20G in their cohort studies [69]. This may have been related to variations in sclerotomy construction, as a straight incision was found to have increased risk of endophthalmitis compared with a beveled approach. A systematic review by Govetto et al. did not find an increased risk of endophthalmitis for microincisional vitectomy systems compared to standard 20G vitrectomy [72].

13. Summary and Future Directions for MIVS

Significant strides in microincisional vitrectomy system fluidics, instrumentation, illumination, and viewing systems have been made in recent years, and MIVS has all but replaced 20G systems for a wide variety of vitreoretinal surgical indications. Retinal specialists have shifted away from 20G systems to smaller sutureless systems that have reduced operative times, surgical trauma, inflammation, astigmatism, and improved patient comfort, postoperative recovery times, and patient satisfaction. This drives the quest toward even smaller gauge systems, although this is tempered by the engineering challenges, instrument tradeoffs, surgical learning curves, availability, and, importantly, the higher costs. Careful case selection and optimisation of surgical techniques for small gauge systems are important for surgical success.

Conflicts of Interest

Dr. Claes is a consultant to Alcon.

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Review Article

A Review of Innovations in Rhegmatogenous Retinal Detachment Surgical Techniques

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Rhegmatogenous retinal detachment (RRD) requires surgical intervention for its repair. There are variable techniques used for this purpose, and they are all being continuously refined. In this review, we detail the recent innovations in surgical management of RRD and proliferative vitreoretinopathy (PVR).

1. Introduction

Rhegmatogenous retinal detachment (RRD) is defined as the separation of the neurosensory retina from the retinal pigment epithelium (RPE) layer due to the presence of retinal breaks. Usually, these breaks are caused by vitreous traction on the retina and allow the accumulation of fluid in the subretinal space [1]. RRD is frequently encountered by ophthalmologists of all subspecialty areas, and its repair is the quintessential procedure of vitreoretinal surgeons worldwide. The prevalence of RRD has been estimated to range from 6.3 to 17.9 per 100,000 people per year and has an overall lifetime risk of approximately 0.06% [1–3].

In the distant past, RRD was an untreatable condition ultimately resulting in irreversible vision loss. This has been dramatically transformed over the past decades, as effective treatments were developed and employed. This began with the invention and popularization of scleral buckling in 1951 by Charles Schepens, which had a high rate of success and became the treatment of choice for this condition [4]. In the 1970s, pars plana vitrectomy (PPV) was introduced by Robert Machemer and proved to be effective as well for the treatment of RRD. Later on, in 1986, pneumatic retinopexy was introduced by Hilton and Grizzard as an outpatient procedure capable of effectively treating select cases of RRD [5].

At the present, all three techniques—scleral buckling, pars plana vitrectomy, and pneumatic retinopexy—are used successfully for the treatment of RRD, with primary success rates of up to 90% [1]. PPV is currently the most common procedure used for the treatment of RRD [6, 7], although it should be noted that it is not necessarily better than scleral buckling. All of these procedures have undergone significant modifications since their original conception and have evolved along with advances in materials, instrumentation, and surgical techniques. These modifications have enabled these techniques to achieve their present potential, making them an armamentarium that allows retinal surgeons to repair almost all cases of RRD, with high rates of success. The purpose of this review is to detail the most recent innovations reported on techniques for RRD repair.

2. Recent Innovations

2.1. Pneumatic Retinopexy. Pneumatic retinopexy consists of intravitreal injection of gas followed by postoperative head positioning that places the gas bubble at the breaks, thus reducing traction and the passage of fluids into the subretinal space. This may be performed along with cryopexy before the gas injection or with laser photocoagulation around the breaks after the retina has been reattached. Not all RDs are

suitable for treatment by pneumatic retinopexy, and soon after its introduction in the 1980s, it has been recommended to be used in cases with one or more retinal breaks within one-clock hour of the retinal arc in the upper two-thirds of the retina and sufficiently clear media to rule out the presence of other retinal breaks [8]. However, it has also been used successfully outside of these indications, for example, in cases with multiple breaks or break in the inferior one-third of the retina, as well as in pediatric patients [9, 10].

Not much has changed in the technique of pneumatic retinopexy since its original description. In cases where cryopexy is not performed, it may be difficult to visualize and localize the retinal breaks after the intravitreal gas injection. A recent series has reported that preoperative laser marking of the ora serrata at the meridians of the breaks made it easy to find them after pneumatic retinopexy has been performed. In a series of 10 such patients, all premarked retinal breaks were found and treated within 48 hours of the intravitreal gas injection [11]. The gas used for pneumatic retinopexy is usually C3F8 or SF6 at 100% expansile concentration, which allows for injection of a relatively small volume of gas that later expands and can cover a greater area of the retinal surface. One study reported on 77 patients who underwent pneumatic retinopexy with intravitreal injection of air, which achieved a long-term retinal reattachment rate of 80.5%, comparable to the reported rates of the conventional technique [12]. The advantage of using air is its faster rate of elimination, which allows the patients to regain good visual acuity sooner (5 days versus 2–4 weeks with the gases).

2.2. Scleral Buckling. Although the frequency of scleral buckling has been gradually declining since the introduction of pars plana vitrectomy, it is still a very effective technique that is still in use today. Scleral buckling originated in the 1950s and has undergone many changes in its materials, instrumentation, and surgical technique. Nevertheless, some innovations are still being reported on its use. Traditionally, identification and treatment of retinal breaks in scleral buckle surgeries were performed by indirect ophthalmoscopy. In recent years, several studies have reported on the use of fiber-optic endoillumination for this purpose, which allowed for the identification and treatment of retinal breaks to be performed with the use of a wide-field viewing apparatus. This was first described in 2008, in a series of 16 patients in whom a torpedo-style chandelier light source was used through an uncannulated sclerotomy [13]. Later refinements of this concept included the use of a fiber-optic chandelier light source through a standard transscleral cannula [14] or twin uncannulated 27-gauge chandeliers [15]. Potential advantages of this technique include improved visualization and the ability of trainees and the entire surgical team to share the intraoperative view of the surgeon [16].

Chandelier-assisted scleral buckling has also led to new techniques of subretinal fluid drainage. In one case, it has been reported to help in the direct visualization of the retina during external subretinal fluid drainage [17]. In another case, the chandelier light microcannula was used to inject balanced salt solution in order to maintain intraocular pressure and push the subretinal fluid through an external transscleral cannula under direct visualization [18].

Classic scleral buckling also typically includes a large or 360-degree peritomy. A recent study reported a technique for segmental buckling through a small conjunctival opening, which was used successfully in 46 patients with uncomplicated rhegmatogenous retinal detachment [19]. This technique includes performing a 5 to 6 mm radial conjunctival incision corresponding to the retinal break without cutting the limbal conjunctiva and Tenon's capsule, followed by cryopexy and implantation of a minimal segmental buckle that was fixed with one to two sutures through the conjunctival opening, which was later closed via layered closure. Cosmetic recovery was rapid and excellent.

An innovative technique has recently been described for suprachoroidal buckling. In this technique, an illuminated catheter is inserted into the suprachoroidal space and navigated to any desired location where peripheral breaks are present, where a long-lasting hyaluronic acid filler can be injected to create internal choroidal indentation. This can be performed without or in combination with vitrectomy and has been used successfully for the treatment of patients with retinal detachment [20, 21].

2.3. Pars Plana Vitrectomy. As mentioned previously, PPV is currently the most commonly used procedure for the repair of RRD [6, 7]. Over recent decades, this surgical procedure has been progressively improved due to technological advances, such as the development of small-gauge instrumentation and the use of intraocular perfluorocarbon liquid, silicone oil, and gases. All of these have played a part in making PPV a highly effective technique for repair of simple and complex RRDs, and new modifications are still being made.

The majority of PPVs performed today are small-gauge (23–27 gauge), allowing for transconjuctival and often sutureless sclerotomies. Leakage from sclerotomies and hypotony is undesirable and was more of a concern when 20-gauge instrumentation was commonly used. 20-gauge transconjunctival PPVs are still performed today, although much less frequently than a decade ago. A recent study reported that hydration of the sclerotomies achieved low rates of hypotony and complications and good final visual outcome [22].

A new technique has recently been suggested for the treatment of macular retinal detachment due to macular holes in highly myopic eyes. Due to the unique anatomy of these eyes, such macular holes are relatively difficult to close. It has been suggested that using the inverted internal limiting membrane (ILM) flap technique may be beneficial in these cases. This technique has previously been reported to improve the closure rates of large and persistent macular holes [23]. In a report of 3 patients with high myopia and macular retinal detachment due to macular holes, the ILM was peeled to the rim of the macular hole and then inverted into it, and following retinal reattachment, intraocular gas or silicone oil was used for tamponade, with retinal reattachment and macular hole closure achieved in all 3 cases [24]. This technique was later compared with standard ILM peeling without flap inversion, in a retrospective study which

included 22 eyes. Higher rates of macular hole closure and retinal reattachment, as well as a small but significant improvement in the final visual acuity, were achieved with this technique [25]. It has been suggested that the inverted ILM flap stimulates the proliferation of glial cells that aid in closing the hole, and this may be a useful technique for the treatment of these challenging cases. A recent comparative study has also investigated the effectiveness of combining a macular buckle with PPV and ILM peeling in eyes with extreme myopia and RD with macular hole. The group of patients who underwent combined surgery with macular buckle had a higher rate of retinal reattachment and macular hole closure than those who did not [26].

Another interesting new technique has been reported for the treatment of macular folds, which can complicate RRD surgery and have significant implication on the visual prognosis. It has been suggested that induced detachment of the macula be performed by the subretinal injection of balanced salt solution, as well as the addition of filtered air. Under these conditions, the action of gravity of the perfluorocarbon liquid in the vitreous cavity combined with an active globe manipulation (i.e., positioning the eye so the perfluorocarbon fluid moves over the area of the detached retina that is to be flattened) has been reported to achieve successful flattening of the macula in 3 patients [27].

One of the most exciting areas of active research is the development of improved retinopexy methods which could produce immediate chorioretinal adhesion of sufficient strength to obviate the need for long-term tamponade and patient positioning. Recent studies have evaluated the potential of high-frequency electric welding (HFEW) for this purpose in a rabbit model of retinal tear. One study reported that the HFEW technique was able to create an immediate retinopexy equal in strength to mature laser retinopexy, which takes about two weeks to achieve maximum adhesion [28]. Previously reported methods to achieve this same purpose include the development of biocompatible glues, analogous to fibrin, for intraoperative use at retinal breaks [29, 30]. The elimination of long-term gas tamponade and elimination of the need for patient positioning may be the next major advance in retinal detachment surgery.

2.4. Management of Proliferative Vitreoretinopathy. Proliferative vitreoretinopathy (PVR) complicates 5–10% of RRD cases and is the main cause of surgical failure [31]. Risk factors for the occurrence of PVR include longer RRD duration, greater extent of the detachment, associated vitreous hemorrhage, presence of intraocular inflammation, and increased retinal tear size, as well as extensive cryopexy and laser retinopexy, failure to close retinal breaks, perioperative scleral perforation, and perioperative vitreous hemorrhage [32]. Surgical management of retinal detachment complicated by PVR is often challenging.

A recent study reported on 36 eyes with active PVR causing retinal detachment and vitreous hemorrhage, which were randomized into two groups—one group received intravitreal conbercept a week prior to surgery and the other was a control group. Administration of conbercept, a recombinant fusion protein with antivascular endothelial growth factor (VEGF) activity, was found to reduce the rate of intraoperative bleeding, which can facilitate the management of these difficult cases [33].

An interesting technique has been suggested to improve retinal flattening and prevent passage of perfluorocarbon liquid into the subretinal space. After performing vitrectomy, ophthalmic viscoelastic devices (OVDs) were injected over areas where confluent retinal folds were formed with possible retinal breaks. This protective layer still allowed the perfluorocarbon liquid placed over it to achieve retinal flattening and prevented it from entering the subretinal space. This innovation has been named "the soft-shell technique" and has been reported to have been used successfully in a series of 5 patients [34].

In recent years, partially fluorinated alkanes (FALKs) were introduced as long-term heavy tamponades, which are heavier than water (in contrast to intraocular gases and silicone oil) and may be of benefit especially in the treatment of inferior RRD or PVR. One of these is F6H8, which is not routinely used due to its early dispersion and emulsification with consequent inflammatory response. A recent study investigated its use in combination with silicone oil, in a series of 22 eyes with inferior RRD with PVR, where F6H8 was used to flatten the retina and was later partially mixed with silicone oil for long-term tamponade. This combination resulted in a clear tamponade allowing postoperative visualization of the retina, with no emulsification, inflammation, or other complications. Several different combinations of F6H8/SO were used in this study—30/70, 40/60, 50/50, 60/40, and 70/30. The best results were reported with F6H8/SO ratios between 50/50 and 30/70 [35].

Surgical management of PVR may require extensive peeling of membranes. Although these are not the tractional membranes encountered in the eyes with diabetic tractional retinal detachment, they may be similarly difficult to peel. Two recent publications have described a four-port approach for bimanual dissection of membranes in patients with diabetic tractional retinal detachment [36, 37]. The suggested technique includes an infusion port, 2 ports used by the surgeon for bimanual manipulation, and a fourth port through which the assistant holds and controls the light source. Although the use of a chandelier light source can also allow for bimanual manipulation of the retina, in this technique, the light source can still be controlled and directed closely at the area of interest. It is possible that this technique may be of use in the management of cases with severe PVR as well.

Another option is planning a staged surgery—an initial surgery to repair the retinal detachment in which tamponade is achieved with perfluorocarbon liquid and left for 2 to 3 weeks, followed by a second procedure in which it is removed. A recent study reported good results with this technique in 44 eyes with retinal detachment complicated by grade C PVR [38].

3. Conclusion

The surgical treatment of RRD has come a long way over the past decades, making the once untreatable condition a very

manageable one. Significant advances have been made, and a variety of techniques are now available, with new instruments and modifications constantly being reported. In this review, we focused on the most recent innovations in the treatment of RRD and PVR; however, as progress continues, further improvements are expected in the future.

Conflicts of Interest

None of the authors have any proprietary interest in this work. Anat Loewenstein is the incumbent of the Sidney Fox Chair of Ophthalmology.

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Clinical Study

The Safety and Efficacy of Adjustable Postoperative Position after Pars Plana Vitrectomy for Rhegmatogenous Retinal Detachment

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Purpose. To report the safety and efficacy of adjustable postoperative position for rhegmatogenous retinal detachment (RRD). *Methods.* Retrospective review of 536 consecutive RRD eyes that underwent vitrectomy surgery for retina repair from year 2008 to 2014. The retinal breaks were divided into superior, lateral (nasal, temporal, and macular), and inferior locations, according to the clock of breaks. Patients with superior and lateral break location were allowed to have facedown position or lateral decubitus position postoperatively, while patients with inferior break location were allowed to have facedown position. *Results.* 403 eyes of 400 patients were included. The mean follow-up interval was 22.7 ± 21.3 months. The overall primary retinal reattachment rate was 93.3%. There were 24 (6.0%), 273 (67.7%), and 106 (26.3%) patients with superior, lateral, and inferior break location, respectively. The primary reattachment rate was 95.8%, 92.3%, and 95.3% accordingly. After further divided the break location into subgroups as a function of duration of symptom, postoperative lens situation, number of retinal breaks, and different vitreous tamponade, the primary reattachment rates were all higher than 82%. *Conclusion.* Adjustable postoperative positioning is effective and safe for RRD repair with different break locations. Choosing postoperative position appropriately according to retinal break locations could be recommended.

1. Introduction

Pars plana vitrectomy (PPV) with different vitreous tamponade, including both gas and silicone oil, followed by facedown positioning for various durations, is still considered as the most standard and effective treatment procedure for rhegmatogenous retinal detachment (RRD) repair in many regions/countries [1–6]. However, the postoperative facedown positioning is an ordeal for almost all patients. Elder patients; young children; or patients with cervical spondylosis, coronary heart disease, pulmonary or bronchial disease, obesity, and other comorbidities have serious difficulties persisting in the facedown positioning. Furthermore, some rare postoperative complications, like ulnar nerve palsies, pulmonary embolism and thrombophlebitis, or decubitus, would develop after a long period of facedown position [7–9].

A decade ago, Sharma et al. reported a high primary retinal reattachment rate (81.3%) for RRD patients with inferior breaks after PPV with gas tamponade with face up or lateral check down postoperative position for 50 minutes in an hour for 7 days [3]. Martinez-Castillo et al. consecutively reported a high primary retinal reattachment rate for pseudophakic RRD patients with inferior breaks after PPV with air/gas tamponade with only 24 hours (93.3%) or even without (90–94%) postoperative facedown position [10–12]. Recently, Chen et al. reported that for RRD repair, the

primary retinal reattachment rate of PPV with gas tamponade with an adjustable postoperative position (alternative upright or lateral recumbent) was as high as traditional strict facedown position (92.3% versus 89.7%) [13]. However, the safety and efficacy of adjustable postoperative position on the outcome of PPV with different ocular diseases, vitreous tamponade, and postoperative lens situation for RRD repair remain unclear. Hence, this study aims to provide further data on the safety and efficacy of adjustable position for RRD repair.

2. Methods

Rhegmatogenous retinal detachment (RRD) patients that underwent pars plana vitrectomy from January 2008 to December 2014 at The Eye Hospital of Wenzhou Medical University were consecutively collected. The exclusion criteria were (1) ocular penetrating trauma history or traumatic RRD, (2) previous retinal detachment repair surgery in the same eye, (3) shorter than 3 months follow-up, and (4) incomplete information on retinal break and retina reattachment postoperation or during follow-up.

A complete ocular examination was performed in each patient, including slit lamp examination, visual acuity converted to logarithm of the angle of minimal resolution (LogMAR), intraocular pressure (IOP) measurement, and fundus and peripheral retinal examination. The number, location, type, and size of retinal detachment and retinal breaks were recorded both before and during surgery. The information of breaks during the surgery was used for further analysis. The visual acuity of finger counter, hand move, light perception, and no light perception was converted to LogMAR 2, 3, 4, and 5, respectively.

All patients underwent similar surgical procedure by the same surgeon (RHW). PPV was performed using either a 23-gauge or a 20-gauge system (Accurus; Alcon Laboratories Inc., Fort Worth, TX) after retrobulbar anesthesia with a 50% mixture of 2% lidocaine and 0.75% bupivacaine. To begin the surgery, three cannulas, that is, the inferior-temporal infusion cannula and the superior-nasal and superior-temporal operation cannulas, were established. Phacoemulsification would be performed for patients with cataract (generally, phacoemulsification would be performed for patients with cataract who are being considered to impede vitrectomy operation). Then, viscoelastic substance was injected into the anterior chamber to maintain its pressure. A core vitrectomy was followed by peripheral vitrectomy using scleral indentation to remove any residual traction around the retinal breaks and anterior vitreous gel at the vitreous base. Perfluorodecalin (Huajieshi Medical Facility Limited Company, Shanghai, YZB 2671-2012) was injected into the vitreous cavity to flatten the retina. A complete fluid-air exchange was performed. Care was taken to ensure that the retina was completely reattached and that all the perfluorodecalin had been removed. Retinal breaks were surrounded by at least two rows of confluent endophotocoagulation or treated endocryotherapy (cryotherapy spot was approximately 1 mm wider than the break area). At the end of the surgery, perfluorocarbon gas (C_3F_8 or C_2F_6, Huajieshi Medical Facility Limited Company, Shanghai, YZB 3394-2011) or silicone oil (Bausch & Lomb, 5000 centistokes) was injected into the vitreous cavity, followed by intraocular lens (IOL) implantation, if needed. The main indications for silicone oil injection were large or multiple retinal breaks, or RRD combined with proliferative vitreoretinopathy, proliferative diabetes retinopathy, choroidal retinal detachment, or pathological myopia.

Patients were allowed to have facedown position or have alternatively facedown or lateral position, according to the location of retinal breaks, when sitting, walking, lying down, or sleeping after the surgery. The following rules were taking the right eye for example, and so on for the left eye. The locations of breaks were divided into superior (11.5 to 12.5 o'clock); lateral, that is, nasal (12.5 to 5 o'clock) and temporal (7 to 11.5 o'clock); and inferior quadrants (5 to 7 o'clock). The macular hole was also considered as a temporal break (Figure 1). The details of rules for postoperative position were as follows. Location 1 (superior break): patients with superior break(s) of either eye could alternatively choose facedown position or lateral position of either side. Location 2 (lateral break): patients with lateral break(s), for example, patients with (1) temporal break(s); (2) temporal and superior break(s); and (3) temporal and nasal with or without superior break(s) (in which the lowest break was in the temporal break; for example, 8 o'clock for the temporal break and 2 and 3 o'clock for the nasal breaks or 8 and 10 o'clock for the temporal breaks and 3 o'clock for the nasal break), could alternatively choose facedown position or left lateral position. However, if the nasal break was as low as the lowest temporal break, the patients could only choose facedown position. Location 3 (inferior break): patients with inferior break(s), with or without lateral break(s), and superior break(s) could have facedown position.

This postoperative position was not required during meals, toilet, or shower. There was no requirement for time distribution of these two alternative positions since it was chosen by the patients' own will. The daily duration and total duration of this adjustable postoperative position mainly depend on the vitreous tamponade. Generally, total duration was required to be approximately 1-2 weeks and 3 months for vitreous tamponade with gas and silicone oil, respectively. The daily duration was required to be approximately 12 hours for gas tamponade, 12 hours for the first week, and 8 hours for the later 3 weeks (if the retina was attached after follow-up examination) for silicone oil tamponade. Patients were explained and required to implement the postoperative position immediately after the surgery. During the admittance, patients were frequently visited and confirmed the postoperative position by the surgeon and other ophthalmologists. However, the patients' compliance of these postoperative positions could not be monitored strictly after discharge.

The vitreous tamponade and its relationship to the retinal breaks were carefully examined using slit lamp and indirect ophthalmoscopy several hours and 1 day after the surgery. The patients were routinely followed up at 1 week, 2 weeks, 1 month, and 3 months and then followed up as necessary. Silicone oil would be routinely removed after vitreous

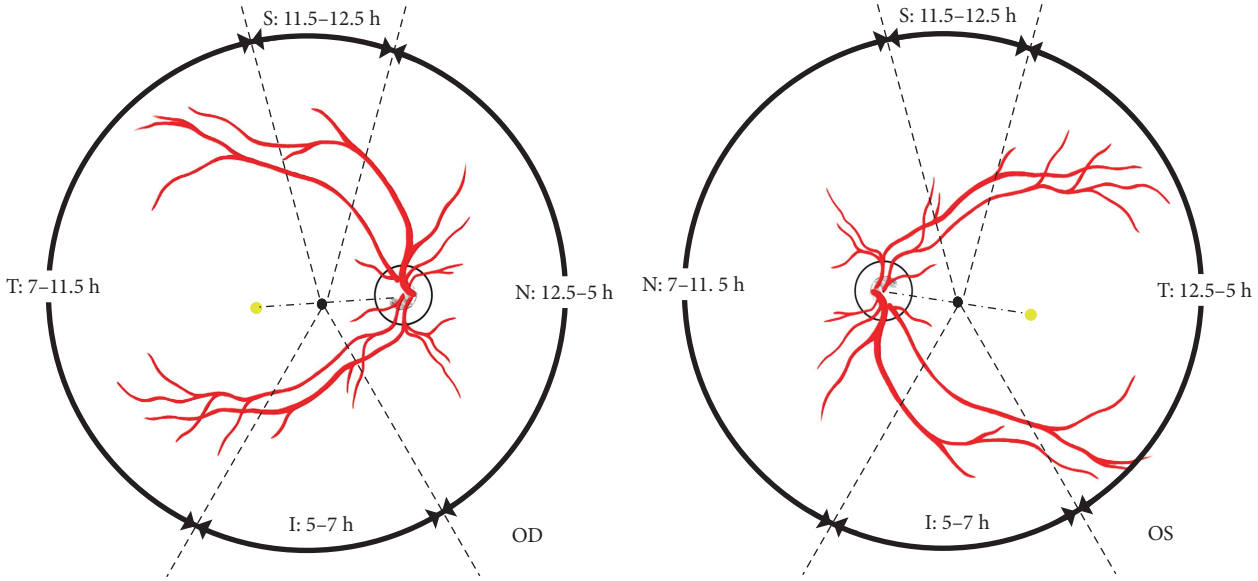

Figure 1: The schematic diagram showing the locations of the retinal breaks. S: superior, T: temporal, I: inferior, N: nasal, h: clock hour.

tamponade for 3–6 months. Additional procedures, such as photocoagulation, membrane peeling, and gas/silicone oil tamponade, would be performed when necessary during the silicone oil removal surgery. Retinal reattachment was accessed after the silicone oil was removed. The old RRD was defined as the RRD with subretinal membrane and/or thick yellowish subretinal fluid. All the information was obtained from the electronic records of the hospital.

Primary retinal reattachment rate among different retinal break locations, vitreous tamponade, and so on were compared using Fisher's exact test. Since the small sample of patients with superior retinal break, they were combined with patients with lateral break for further subgroup comparison of retinal reattachment rate. A p value of <0.05 was considered statistically significant. All statistical analysis was performed with Statistical Analysis System for Windows version 9.1.3 (SAS Inc., Cary, NC).

3. Results

536 eligible rhegmatogenous retinal detachment eyes were reviewed. 48 eyes with ocular-penetrating trauma history or traumatic RRD, 44 eyes with previous RD surgery, and 41 eyes with follow-up shorter than 3 months were excluded. Hence, 403 eyes of 400 patients (222 males, 55.5%) were finally included for further analysis. All patients were Chinese individuals aged 55.0 ± 13.9 (range 19 to 86) years old. The mean follow-up time was 22.7 ± 21.3 months. The mean duration of fresh and old RRD was 18.6 ± 17.6 days and 12.8 ± 9.2 months, respectively. More than half of the eyes (251, 62.3%) had multiple retinal breaks. Single temporal break accounted for most (135, 33.5%) of the breaks, followed by the single nasal break (42, 10.4%). Half of the macula (204, 50.6%) were involved because of the detached retina or macular hole. The retinal break(s) were categorized into 3 locations according to their location (see details in Section 2). There were 24 (6.0%), 273 (67.7%), and 106 (26.3%) eyes in location 1 to location 3, respectively (Table 1).

Single PPV were performed for the majority of the eyes (203, 50.4%), followed by PPV plus phacoemulsification plus IOL implantation (188, 46.6%), and PPV plus phacoemulsification (12, 3.0%). After the surgery, most of the eyes were pseudophakic (55.3%) or phakic (40.7%), while only 4.0% of the eyes were aphakic. The silicone oil was the major vitreous tamponade for RRD repair after the surgery (82.1%) (Table 2).

Table 3 presents the primary retinal reattachment rate in different groups. The overall primary retinal reattachment rate achieved to 93.3% (376/403). The primary reattachment rate was higher than 90% in most of the groups, except for old retinal detachment (89.3%), gas tamponade (87.5%), and macular hole group (86.1%). The primary reattachment rate was 95.8%, 92.3%, and 95.3% for superior, lateral, and inferior retinal break location, respectively. After further dividing the retinal break location into subgroups as a function of patients' gender, retinal duration, postoperative lens situation, vitreous tamponade, number of retinal breaks, and macular involvement, the primary reattachment rates were all higher than 82% (Table 4).

There were 27 out of 403 eyes (6.7%) that had reoccurred retinal detachment after primary retinal detachment repair surgery. The mean time of reoccurred retinal detachment was 108 (lower and upper quartile, 33 and 171) days after primary surgery. A second retinal detachment repair surgery was performed for all 31 eyes. The mean time between secondary surgery and last follow-up was 19.8 (lower and upper quartile, 7.5 and 48.6) months. Seven of the 27 eyes (25.9%) had a retinal reattachment after the second repair, which made the final reattachment rate reach up to 95.0%.

The IOP was increased from 10.8 ± 4.1 preoperatively to 14.3 ± 6.3 mmHg postoperatively ($p < 0.001$). There were 190 eyes (47.1%) that had IOP higher than 25 mmHg postoperatively. Among these eyes, 81.6% (155/190) and

Table 1: Patient's preoperative characteristics.

Variable	
Age (mean ± SD, year)	55.0 ± 13.9
Gender (male/female)	222/178
Follow-up time (month, mean ± SD)	22.7 ± 21.3
Duration of symptoms	
Fresh RD (*n*, mean ± SD, day)	375, 18.6 ± 17.6
Old RD (*n*, mean ± SD, month)	28, 12.8 ± 9.2
Preoperative UCBA	1.72 ± 0.97
IOP (mmHg)	10.8 ± 4.1
Macular involved (on/off)	204/199
Preoperative lens status (aphakic/phakic/pseudophakic)	3/362/38
Number of breaks (single/multiple)	152/251
Pathologic myopia (no/yes)	329/74
Location of retinal breaks	
Location 1	
S	24 (6.0)
Location 2	
T & N	177 (135/42)
T + S & N + S	25 (19/6)
T + N & T + N + S	37 (32/5)
M & M + T & M + T + S	30 (16/11/3)
M + N & M + T + N & M + T + N + S	4 (2/1/1)
Total (*n*, %)	273 (67.7)
Location 3	
I	23
I + S & I + T & I + N & I + T + N	56 (2/33/13/8)
I + T + S & I + N + S & I + T + N + S	18 (9/3/6)
I + M & I + M + T & I + M + T + N + S	9 (3/5/1)
Total (*n*, %)	106 (26.3)

SD: standard deviation; RD: retinal detachment; UCBA: uncorrected visual acuity; IOP: intraocular pressure; S: superior retinal break; T: temporal retinal break; N: nasal retinal break; I: inferior retinal break; M: macular hole.

Table 2: Patient's postoperative characteristics.

Variable	Number (%)
Surgery procedures	
Vitrectomy	203 (50.4)
Vitrectomy + Phaco	12 (3.0)
Vitrectomy + Phaco + IOL	188 (46.6)
Postoperative lens status	
Aphakic*	16 (4.0)
Phakic	164 (40.7)
Pseudophakic	223 (55.3)
Vitreous tamponade	
Gas (C_2F_6 & C_3F_8)	72 (17.9)
Silicone oil	331 (82.1)

Phaco: phacoemulsification; IOL: intraocular lens; *3 eyes were original aphakic, 11 eyes underwent phacoemulsification without IOL implantation, and 2 eyes underwent IOL removal.

Table 3: Primary retinal reattachment rate in different subgroups.

	Number (%)	*p* value*
Total	376 (93.3)	—
Gender		
Male	212 (94.6)	0.24
Female	164 (91.6)	
Duration of symptoms		
Fresh RD	351 (93.6)	0.42
Old RD	25 (89.3)	
Postoperative lens status		
Aphakic	15 (93.8)	0.68
Phakic	151 (92.1)	
Pseudophakic	210 (94.2)	
Vitreous tamponade		
Gas (C_2F_6 & C_3F_8)	63 (87.5)	0.038
Silicone oil	313 (94.6)	
Number of retinal breaks (single/multiple)		
Single	143 (94.1)	0.69
Multiple	233 (92.8)	
Macular hole		
No	339 (94.2)	0.055
Yes	37 (86.1)	
Pathologic myopia		
No	306 (93.0)	0.80
Yes	70 (94.6)	
Retinal break location		
Location 1 (superior)	23 (95.8)	0.65
Location 2 (lateral)	252 (92.3)	
Location 3 (inferior)	101 (95.3)	

RD: retinal detachment.
p value*: tested by Fisher's exact test.

18.4% (35/190) were tamponaded with silicone oil and gas, respectively. Besides, 173 (91.1%) and 6 (3.2%) eyes had anti-IOP eye drops and antiglaucoma surgery, respectively. Until the last follow-up, 14 eyes (14/403, 3.5%) had IOP higher than 25 mmHg. The uncorrected visual acuity (UCVA) improved from LogMAR 1.72 ± 0.97 preoperatively to 1.32 ± 0.76 one week postoperatively and 0.98 ± 0.71 at last follow-up. The best-corrected visual acuity was 1.08 ± 0.90 preoperatively and 0.71 ± 0.70 at last follow-up. However, the BCVA was only obtained in 96 eyes preoperatively and 183 eyes at last follow-up.

4. Discussion

More and more surgeons are trying to reduce or eliminate facedown positioning after macular hole and RRD repair surgery, in order to increase patients' comfort and compliance and decrease the potential systemic complications [3, 10–13]. Recently, Chen et al. reported that for RRD repair, the primary retinal reattachment rate of PPV with gas tamponade with an adjustable postoperative position (alternative upright or lateral recumbent) was as high as traditional strict facedown

Table 4: Primary retinal reattachment rate in different retinal break location subgroups.

	Locations 1 (superior) & 2 (lateral)		Location 3 (inferior)	
	Number (%)	p value*	Number (%)	p value*
Gender				
Male	149 (94.3)	0.27	63 (95.5)	0.99
Female	126 (90.7)		38 (95.0)	
Duration of symptoms				
Fresh RD	256 (92.8)	0.66	95 (96.0)	0.29
Old RD	19 (90.5)		6 (85.7)	
Postoperative lens status				
Aphakic	13 (92.9)	0.24	2 (100.0)	0.68
Phakic	93 (89.4)		58 (96.7)	
Pseudophakic	169 (94.4)		41 (93.2)	
Vitreous tamponade				
Gas (C_2F_6 & C_3F_8)	34 (82.9)	0.02	29 (93.6)	0.63
Silicone oil	241 (94.1)		72 (96.0)	
Number of retinal breaks (single/multiple)				
Single	127 (94.1)	0.51	16 (94.1)	0.99
Multiple	148 (91.4)		85 (95.5)	
Macular hole				
No	246 (93.5)	0.15	93 (95.9)	0.36
Yes	29 (85.3)		8 (88.9)	
Pathologic myopia				
No	223 (92.5)	0.99	83 (94.3)	0.59
Yes	52 (92.9)		18 (100)	

RD: retinal detachment.
p value*: tested by Fisher's exact test.

position (92.3% versus 89.7%) [13]. Furthermore, the final retinal reattachment rate were both 100% in adjustable position and in facedown position [13]. These results were inspiring for retinal surgeons and patients. However, that study excluded patients with documented previous ocular disease (other than acute RRD, previous cataract surgery, and/or refractive error), patients younger than 18 years or older than 80 years, giant retinal tear, proliferative vitreoretinopathy (PVR) of Grade C or greater, retinal detachment accompanied by choroidal detachment and/or RRD caused by macular hole in the eyes with high degree myopia (−6.00 diopter or above), duration of symptoms longer than 4 weeks, incomplete intraoperative drainage of subretinal fluid, and hypotony on the 1st day visit. Hence, the safety and efficacy of this adjustable position may be limited to certain RD patients.

The advantage of this study was that the exclusion criteria were only limited to patients with ocular penetrating trauma history or traumatic RRD, with previous retinal detachment repair surgery. To our knowledge, this study included the largest sample and most risk factors on the postoperative position after RRD repair. Hence, this study not only confirmed previous studies that postoperative facedown position was not the only choice but also indicated to popularize to more kinds of retinal detachment patients, such as retinal detachment patients with long duration, different postoperative lens statuses, silicone oil tamponade, and pathologic myopia. However, it should be mentioned that different with Chen et al., though strict facedown positions was not the only choice, the upright postoperative position which seemed to be more comfortable was not recommended. This warranted further studies.

There were several important findings in this study. First, the overall primary and secondary retinal reattachment rates were high (93% and 95%, respectively) in patients with adjustable postoperative position. The primary rate was comparable with previous reports with traditional postoperative facedown position (75–89.7%) [13–15] or adjustable position (81–94%) [3, 10–13]. In this study, though we found that the primary retinal reattachment rate was lower for the eyes with gas tamponade compared to the eyes with silicone oil tamponade (87.5% versus 94.5%), the rate was still comparable with previous studies on the eyes with gas tamponade (81–94%) [3, 10–13]. Second, more retinal breaks were categorized as superior or lateral breaks and would have more comfortable postoperative positions subsequently. Based on clinic observation, when the eyes rotated appropriately, the silicone oil or gas could give certain pressure to the retina. Hence, we shrank the inferior retinal break from the previous 4 to 8 o'clock [3, 10–12] to the current 5 to 7 o'clock. Importantly, we found that the primary retinal reattachment rate of each location was higher than 90%. Third, after further dividing the retinal break location into subgroups, the primary

retinal reattachment rate was still satisfactory (higher than 80%), even in patients with inferior retinal breaks. This further improved the safety and efficacy of the adjustable postoperative position.

The IOP increased from approximately 11 mmHg preoperatively to 14 mmHg postoperatively. It was known that the IOP was generally lower in retinal detachment eyes and usually elevates in the early postoperative period after retinal detachment repair [16, 17]. However, whether this repair increases the risk of glaucoma remains controversial [17–19]. Overall, nearly half of the eyes had IOP higher than 25 mmHg postoperatively. Similar with previous reports [17], the eyes with silicone oil tamponade had a high risk to increase IOP than gas tamponade in this study (81.6% versus 18.4%). At the last follow-up, less than 5% of the eyes had IOP controlled higher than 25 mmHg. It should also be mentioned that, though only UCVA was obtained in this study, it generally increased postoperatively.

Important limitations remained in this study. First, recall bias was inevitable since this was a retrospective study. Hence, important information, such as best-corrected visual acuity and the actual postoperative position, could not be obtained completely. Second, there was no controlled group (strict facedown position). However, since the primary retinal reattachment rate was higher than 90%, and comparable with previous studies, this limitation did not seem to produce significant bias. Third, some combinations of the retinal break (such as breaks at inferior plus macular plus nasal or inferior plus macular plus superior) did not exist in this study. However, these combinations were speculated with very low incidence; this may also not have significant bias. Last, discomfort was still inevitable even with alternative postoperative positions since upright position was not recommended. Hence, further prospective, randomized, controlled studies with reduced time for facedown/lateral position even with upright positions were warranted.

In summary, choosing postoperative position appropriately according to retinal break locations could be recommended after sufficient surgery treatment, such as complete remove of vitreous traction, and sufficient endophotocoagulation. This adjustable position could improve patient compliance while it does not reduce the surgery success rate.

Conflicts of Interest

The authors have no proprietary or commercial interest in any materials discussed in this article.

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Clinical Study

Comparative Study of 27-Gauge versus 25-Gauge Vitrectomy for the Treatment of Primary Rhegmatogenous Retinal Detachment

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Purpose. To compare the vitrectomy time, clinical outcomes, and complications between 27-gauge (27-G) and 25-gauge (25-G) vitrectomy in patients with primary rhegmatogenous retinal detachment (PRRD). *Methods*. Prospective, nonrandomized, comparative, interventional study. Forty consecutive patients with PRRD were recruited. Twenty patients underwent the 27-gauge procedure and twenty patients had the 25-gauge procedure. The main outcome measure of the study was the actual vitrectomy time. *Results*. The mean duration of vitreous removal was 23.2 min (SD 6.5) with 27-G vitrectomy and 19.6 min (SD 7.3) with 25-G vitrectomy, resulting in a difference of 3.6 min (95% confidence interval (95%CI): −8.0 to 0.8 mins, $p = 0.11$). Mean logMAR visual acuity improved from 1.70 ± 1.18 preoperatively to 0.12 ± 0.14 at final postoperative visit ($p < 0.001$) in the 27-G group and from 1.52 ± 1.15 preoperatively to 0.22 ± 0.30 at final postoperative visit ($p < 0.001$) in the 25-G group. The anatomical success rate after a single operation was 90.0% and 85.0% in the 27-G and in the 25-G groups ($p = 0.63$), respectively. Intraoperative iatrogenic retinal breaks (IRBs) occurred in 2 eyes in the 27-G group and 1 eye in the 25-G group. *Conclusions*. Twenty-seven-gauge vitrectomy may be a safe and effective surgery for the treatment of PRRD.

1. Introduction

The introduction of pars plana vitrectomy (PPV) in the early 1970s by Machemer et al. [1] represented a milestone in ophthalmic progress because for the first time, it allowed for the removal of the vitreous through a closed system rather than through an open-sky technique. Since that moment, the evolution of vitrectomy instrumentation has been driven by the desire for smaller instruments and greater functionality. One of the main aims has been to make smaller and smaller wounds to reduce the surgical trauma, recovery times, and postoperative complications. Over the past several years, recent innovations, such as the advent of powerful light sources, stronger instruments, and high-performance vitrectomy machines, have led to the development of a 27-gauge (27-G) transconjunctival sutureless vitrectomy (TSV) system [2]. The feasibility of this new microincision vitrectomy surgery (MIVS) has been recently demonstrated for various vitreoretinal diseases [2–10], including rhegmatogenous retinal detachment (RRD) [4–6, 8–10]. However, to our knowledge, to date, there is only one comparative study between 27-G and 25-G vitrectomy systems for RRD [10]. The purpose of this study was to compare the surgical time, clinical outcomes, and complications between 27-G and 25-G vitrectomy surgery in patients with primary rhegmatogenous retinal detachment (PRRD).

2. Materials and Methods

A prospective, nonrandomized, comparative study was performed on 40 consecutive patients with PRRD undergoing 27- or 25-gauge TSV. Twenty patients (50%) were treated with the 27-gauge procedure and twenty (50%) with the 25-gauge procedure. All surgeries were carried out by two surgeons at a single center between July 2015 and October 2015. Each surgeon operated on a similar number of patients

in both groups. Inclusion criteria were PRRDs with one or more retinal breaks and the ability to give informed consent. Exclusion criteria included a follow-up period of less than 6 months, patients judged to be incapable of postoperative posturing, a history of any previous vitreoretinal surgical procedures or penetrating ocular trauma, proliferative vitreoretinopathy (PVR) of grade C or greater, and significant ocular comorbidities such as uveitis, uncontrolled glaucoma, and severe or proliferative diabetic retinopathy. Preoperative evaluation consisted of a complete medical, surgical, and ophthalmic history followed by a thorough ophthalmic examination. Preoperative data included age, sex, the eye's axis length, the best-corrected visual acuity (BCVA), intraocular pressure (IOP), lens status, extent of retinal detachment, and location of breaks. At the end of every surgery, the vitrectomy time and intraoperative complications were recorded. Postoperative examination was carried out on 1 day; 1 week; and 1, 2, 3, and 6 months. Postoperative data collected included the retinal status, postoperative complications, and BCVA at 1, 2, 3, and 6 months. Intraocular pressure (IOP) was measured using Goldmann applanation tonometry, and severe postoperative hypotony and hypertony were, respectively, defined as IOP < 6 mmHg and IOP > 30 mmHg. The main outcome measure of the study was the actual vitrectomy time. It was defined as the time required for the complete removal of the vitreous or rather the time period when the cutter was activated for removing the vitreous. To evaluate it, we have recorded the cutting time reported by the instrument. The secondary outcome measures were primary anatomical success rate, postoperative BCVA, and intra- and postoperative complications. BCVA was recorded as a Snellen visual acuity and converted to logarithm of minimal angle of resolution (logMAR) units for statistical analysis. Counting finger (CF) vision was defined as 2.0 logMAR and hand movements (HM) were defined as 3.0 logMAR. For visual outcome comparisons, we excluded patients with amblyopia or retinal redetachment. A primary anatomical success was defined as a complete reattachment of the retina following the initial surgery, when all the gases in the eye had disappeared or silicone oil was removed. The study followed the tenets of the Declaration of Helsinki and was approved by the institution's review board. Written informed consent was obtained from all patients.

2.1. Surgical Technique. All surgeries were performed under a retrobulbar block, using the Constellation vitrectomy system (Alcon, Fort Worth, TX, USA). For this study, the machine was set with an initial aspiration of 0 mmHg moving linearly to 650 mmHg when the foot pedal is fully depressed, maintaining a fixed cut rate of 7500 cuts per minute (cpm) in both vitrectomy systems (27 + and 25 + Total Plus Pak). During surgery, IOP was controlled to 25 mmHg. For posterior visualization, Resight 700 (Carl Zeiss Meditec AG, Oberkochen, Germany) was used. Both the 27- and 25-gauge procedures were performed using a four-port pars plana technique (the fourth port was for a 25-gauge chandelier illuminator). Before starting the surgery, the eyelid and periorbital skin and the ocular surface were prepared with 5% povidone-iodine. After the conjunctiva was displaced slightly, the trocars were placed through the conjunctiva and the sclera 3.5 mm from the limbus. The sclerotomy was created using the trocar cannula with a biplanar entry, tangential to the sclera at first, and then perpendicularly thereafter to create a self-sealing incision, as much as was possible. Phacoemulsification was performed in all phakic eyes to help in the complete removal of the anteroperipheral vitreous. Complete removal of the vitreous gel was performed. Triamcinolone acetonide was routinely injected to facilitate visualization of the vitreous base which was meticulously shaved circumferentially. Scleral indentation was performed with a metal scleral depressor. Any tears or suspicious retinal lesions were treated with endolaser photocoagulation or transscleral cryopexy. Intraoperative use of perfluorocarbon liquids (PFCL) was at the discretion of the operating surgeon. After air-fluid exchange, 20% sulfur hexafluoride (SF6) gas, 12% perfluoropropane (C3F8) gas, or 1000 centistoke silicone oil was used as the tamponade. Silicone oil was given at the discretion of the operating surgeon, or to patients who had to take an aeroplane or who needed to have early visual rehabilitation. After vitrectomy, the microcannulas were removed and a gentle massage of the sclerotomy with a cotton-tipped applicator was performed to avoid leakage; otherwise, bipolar diathermy was performed. If any site showed persistent leakage, 8-0 vicryl sutures were placed in the wound and the overlying conjunctiva. At the completion of the surgery, peribulbar injections of antibiotics and dexamethasone were given. Patients were asked to pose for 7 days, either face down or on one side depending on break position. In both groups, patients received eye drops containing antibiotics and dexamethasone with tapered frequency during the 4 weeks after surgery. During the follow-up period, antiglaucoma eye drops, such as beta-blockers, carbonic anhydrase inhibitors, or prostaglandin analogues, were prescribed when IOP was higher than 24 mmHg. The patients who received silicone oil tamponade underwent a second surgical procedure to remove the oil within 4 months of the initial surgery.

2.2. Statistical Analysis. A linear mixed model was used to compare the continuous measures in the two groups. Anatomic success at 6 months as a dichotomous measure was compared using a chi-square test. A p value of <0.05 was defined as statistically significant.

3. Results

3.1. Preoperative Characteristics. The mean age of the patients was 64.7 ± 9.7 years (range: 46–78 years) and 62.4 ± 9.8 years (range: 48–83 years) in the 27-G and 25-G groups, respectively. There were 15 men (75%) and 5 women (25%) in the 27-G group and 14 men (70%) and 6 women (30%) in the 25-G group. Mean duration of visual loss was 6.1 ± 5.9 days (range: 1–20 days) in the 27-G group and 8.15 ± 8.77 days (range: 1–30 days) in the 25-G group. Baseline logMAR visual acuity (mean ± SD) was 1.70 ± 1.18 (range: 3.0 to 0.1) in the 27-G group and 1.52 ± 1.15 (range: 3.0 to 0.1) in the 25-G group. Clinical data of the patients are given in Table 1. There were no statistically significant

Table 1: Clinical data of patients.

	27-G group	25-G group
Axial length (mm)	25.07	25.33
Lens status (phakic), number (%)	6 (30%)	9 (45%)
Lens status (pseudophakic), number (%)	14 (70%)	11 (55%)
Clock hours of retinal detachment, mean	6.35	7.1
Number of retinal breaks/holes, mean	3.2	2.85
Giant tears, number (%)	1 (5%)	3 (15%)
Macula-off, number (%)	15 (75%)	17 (85%)
PVR, number (%)	0 (0%)	1 (5%) (PVR of grade B)

PVR: proliferative vitreoretinopathy.

differences in the patients' preoperative characteristics between the 27-G and 25-G groups.

3.2. Surgical Time and Results. All phakic eyes in each group had simultaneous phacoemulsification with intraocular lens implantation to help in the complete removal of the antero-peripheral vitreous. No complications occurred related to phacoemulsification such as posterior capsule rupture or zonular dialysis. The mean duration of vitreous removal was 23.2 min (SD 6.5) with 27-G vitrectomy and 19.6 min (SD 7.3) with 25-G vitrectomy, resulting in a difference of 3.6 min (95% confidence interval (95%CI): −8.0 to 0.8 mins, $p = 0.11$). PFCL was given in 18 eyes (90%) in each group. In the 27-G group, 14 eyes (70%) received endolaser and 6 eyes (30%) external cryoapplication, while in the 25-G group, 15 eyes (75%) received endolaser and 5 eyes (25%) external cryoapplication. In the 27-G group, 10 eyes (50%) had SF6 gas tamponade, 8 eyes (40%) had C3F8 gas tamponade, and 2 eyes (10%) were treated with silicone oil. The oil was given through the port for the chandelier illuminator. In the 25-G group, 7 eyes (35%) had SF6 gas tamponade, 7 eyes (35%) had C3F8 gas tamponade, and 6 eyes (30%) had silicone oil tamponade. After removal of the microcannulas, one sclerotomy site in 2 eyes (3.33% of sclerotomies) was sutured because of leakage in the 27-G group, while in the 25-G group, an average of two sclerotomy sites in 4 different eyes (20% of eyes, 13.3% of sclerotomies) were sutured for wound closure. In this calculation, we had excluded sclerotomy sites for the chandelier light source because we used a 25-G chandelier in the 27-G group, too. Silicone oil was removed after an average of 86.5 days (range: 78–95 days) after the first surgery in the 27-G group and after 66.6 days (range: 51–89 days) in the 25-G group. In both groups, this surgery was performed using the 25-G TSV system.

3.3. Anatomical Results. The primary anatomical success rate after a single operation was 90.0% and 85.0% in the 27-G and in the 25-G groups ($p = 0.63$), respectively. In the 27-G group, 2 eyes developed a retinal redetachment within 1 month of the initial surgery. In the 25-G group, 2 cases detached within 1 month of primary vitrectomy, while 1 case of redetachment occurred within 2 months of surgery. The redetachments were due to proliferative vitreoretinopathy (PVR) in 3 eyes (1 eye in the 27-G group and 2 in the 25-G group), a new retinal break in 1 eye (in the 25-G group), and an opening of an original retinal break in 1 eye (in the 27-G group). All these eyes were reoperated using 25-G instruments. Two cases of PVR were treated with peeling and gas as the tamponade agent, while 1 case required membrane peeling, a relaxing retinotomy, and long-term tamponade with 5700 silicone oil. The eye with the new break received gas as the tamponade agent, while the one with the opening of an original break required a third surgical procedure in which silicone oil tamponade was used. The final attachment rate was 100% in both groups.

Table 2: Changes of visual acuity in patients with primary anatomical success.

	27-G group LogMAR	25-G group LogMAR
Baseline visual acuity	1.65	1.31
Postoperative 1 month	0.23	0.36
Postoperative 2 months	0.15	0.25
Postoperative 3 months	0.13	0.22
Final visual acuity	0.09	0.16

3.4. Changes of Visual Acuity. Baseline and final visual acuity were 1.70 ± 1.18 and 0.12 ± 0.14 and 1.52 ± 1.15 and 0.22 ± 0.30 in the 27-G and 25-G groups, respectively ($p < 0.001$ for each comparison). However, visual recovery could not be assessed in 5 patients undergoing reintervention for redetachment, since the use of intraocular gas, and in general, the postsurgical condition, prevented us from measuring potential visual functioning. Therefore, the change of postoperative visual acuity was compared in the two groups of 18 and 17 patients with primary anatomical success and is given in Table 2. Postoperative BCVA increased significantly in both groups between 1 and 6 months postoperatively ($p < 0.001$) for all comparisons. The mean difference between 27-G and 25-G vitrectomy was −0.095 logMAR (95%CI: −0.231 to 0.042 logMAR), favouring the 27-G vitrectomy, which was not significant ($p = 0.174$).

3.5. Intraoperative Complications. Iatrogenic retinal breaks (IRBs) occurred in 2 eyes (10%) in the 27-G group and 1 eye (5%) in the 25-G group during the vitreous base shaving. Intraoperative laser photocoagulation was carried out around the retinal breaks, and no IRB resulted in postoperative

rhegmatogenous retinal detachment. In the 27-G group, we also experienced one case (5%) of choroidal detachment by infusion cannula slippage into the suprachoroidal space because of a sudden movement of the patient during scleral depression. The infusion line was disconnected from the partially disinserted cannula and was reconnected to another fully inserted cannula. The surgery then proceeded without complications.

3.6. Postoperative Complications. Severe hypertension (IOP > 30 mmHg) was detected in 1 eye (5%) in the 27-G group at 1 month postoperatively and in 2 eyes (10%) in the 25-G at 1 week postoperatively. All the eyes with an elevated IOP were treated with antihypertensive eye drops, and the IOPs returned to normal levels without glaucoma surgery. No other postoperative complications, such as severe hypotony (IOP < 6 mmHg), intraocular bleeding, choroidal detachment, or endophthalmitis, were noted in the follow-up period in either group.

4. Discussions

In this study, we have compared the actual vitrectomy time, clinical outcomes, and complications between 27-G and 25-G vitrectomy surgery in patients with PRRD.

The actual vitrectomy time was slightly longer in the 27-G group compared to the 25-G group (23.2 ± 6.5 versus 19.6 ± 7.3 min, resp.). The difference that was found between the 2 groups was attributed to the different internal diameters of the vitrectomy probe of the two vitrectomy systems used. Indeed, it is known that aspiration and flow rate are regulated by Poiseuille's law, which states that the velocity of the flow of a fluid through a tube is directly proportional to the pressure difference and to the fourth power of the radius of the tube and inversely proportional to the length of the tube and to the coefficient of viscosity, so that the 27-G system had a reduction of flow and consequently, a slightly longer time for the removal of the vitreous as compared to those of the 25-G. In a recent comparative study between 27-G and 25-G microincision vitrectomy for epiretinal membrane (ERM), Mitsui et al. [7] also reported a mean vitrectomy time longer in the 27-G group than in the 25-G group (9.9 ± 3.5 versus 6.2 ± 2.7 min, resp.). However, a comparison between the two studies is difficult as they differ for the vitreoretinal diseases treated and surgical parameters used (in the 27-G, vacuum of 0–600 mmHg and cut rate of 1000–2500 cpm). Indeed, flow rate of viscous materials, such as the vitreous humor, is influenced by the cut rates. High cut rates result in smaller vitreous pieces that are more easily aspirated through the probe for a reduced resistance to flow; thus, vitreous flow rates increased with the increasing cut rate [11].

In both groups, the anatomical success rate was similar to the one described in earlier reports which reported an anatomic success rate with a single procedure ranging from 74% to 95% using 25-G PPV [10, 12–16]. Therefore, although definitive comparisons between studies are usually difficult, as they differ in many parameters, our results showed that 27-G TSV was as effective as 25-G in reattaching the retina after initial surgery.

Postoperative BCVA increased significantly in both groups between 1 and 6 months postoperatively. Studies using 25-G PPV to repair pseudophakic RDs have reported postoperative visual acuities of 20/40 or better in 50–53% of eyes [12–14]. In two of these studies [13, 14], the mean duration of visual loss was approximately 15 days, preoperative VA was 20/50 or less in 82–83% of the eyes, and a macular detachment was found in 77–78% of the eyes. In the present study, final visual acuity was 20/40 or better in 16 eyes (80%) in the 27-G group and in 15 eyes (75%) in the 25-G group, respectively. This can be explained in part by the shorter mean duration of visual loss (approximately, 6 days in the 27-G group and 8 in the 25-G group), because preoperative VA was 20/50 or less in 16 eyes (80%) in the 27-G group and 17 eyes (85%) in the 25-G group, and a macular detachment was found in 75% in the 27-G group and 85% in the 25-G group of eyes. In the study by Horozoglu et al. [12], the mean duration of macular detachment was approximately 6 days, but preoperative VA was 20/50 or less in 100% of the eyes.

Intra- and postoperative complications were similar in both 27-G and 25-G groups. No eyes required conversion to larger-gauge instrumentation during surgery. The 27-G instruments were found to be of sufficient strength to perform all surgical maneuvers in all eyes by both surgeons.

5. Conclusion

There are limitations to our study, including the small number and a nonrandomization of the patients. Nevertheless, in our series, 27-G vitrectomy seems to be as safe and effective as 25-G vitrectomy in PRRD surgery. A randomized, controlled trial with a larger number of patients is needed to confirm the results obtained in this study.

Disclosure

Part of this paper was submitted and accepted as poster presentation to the "FLOREtina 2015 International Congress."

Conflicts of Interest

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

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Clinical Study

Navigated Pattern Laser System versus Single-Spot Laser System for Postoperative 360-Degree Laser Retinopexy

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Purpose. To compare three 360°-laser retinopexy (LRP) approaches (using navigated pattern laser system, single-spot slit-lamp (SL) laser delivery, and single-spot indirect ophthalmoscope (IO) laser delivery) in regard to procedure duration, procedural pain score, technical difficulties, and the ability to achieve surgical goals. *Material and Methods*. Eighty-six rhegmatogenous retinal detachment patients (86 eyes) were included in this prospective randomized study. The mean procedural time, procedural pain score (using 4-point Verbal Rating Scale), number of laser burns, and achievement of the surgical goals were compared between three groups (pattern LRP (Navilas® laser system), 36 patients; SL-LRP, 28 patients; and IO-LRP, 22 patients). *Results*. In the pattern LRP group, the amount of time needed for LRP and pain level were statistically significantly lower, whereas the number of applied laser burns was higher compared to those in the SL-LRP group and in the IO-LRP group. In the pattern LRP, SL-LRP, and IO-LRP groups, surgical goals were fully achieved in 28 (77.8%), 17 (60.7%), and 13 patients (59.1%), respectively ($p > 0.05$). *Conclusion*. The navigated pattern approach allows improving the treatment time and pain in postoperative 360° LRP. Moreover, 360° pattern LRP is at least as effective in achieving the surgical goal as the conventional (slit-lamp or indirect ophthalmoscope) approaches with a single-spot laser.

1. Introduction

Three hundred sixty-degree laser retinopexy (360°-LRP) is an essential element in the treatment of complicated retinal detachment. The incidence of retinal redetachment has been shown to be reduced more than twofold (from as high as 26% to 14%) [1, 2] with prophylactic intraoperative 360°-LRP after removal of silicone oil. In addition, the rate of postvitrectomy RRD due to iatrogenic breaks has been significantly reduced (from 5.7% to 0%) with 360°-LRP [3]. Koh and colleagues have reported that intraoperative 360°-LRP following vitrectomy shows an encouraging reduction (approximately 74%) in the rate of postoperative retinal detachment [4]. A number of studies have demonstrated improved outcomes with the use of 360°-LRP in combined surgery for a giant retinal tear [5–7], with a reduction from 26% to 7% [7] in the rate of postoperative retinal detachment.

The 360° laser retinopexy is most commonly performed at the end of the vitrectomy with the endolaser probe [2–6, 8]. The drawbacks of intraoperative 360°-LRP are increased total operating time and the need for scleral depression to coagulate superior retinal locations which are hard to access. The use of intraoperative 360°-LRP technique may be additionally limited by cases of vitrectomy-related failures and complications, when it is not possible to achieve a complete retinal reattachment intraoperatively. Therefore, when used before the surgical procedure [9] or postponed completely for some time after this procedure, 360°-LRP may provide some advantages over intraoperative 360°-LRP. Moreover, 360°-LRP sometimes cannot be performed (in required cases) during the scleral buckling due to failure to achieve complete retinal reattachment caused by residual subretinal fluid.

Various modifications of conventional postoperative 360°-LRP with a single-spot laser attached to indirect ophthalmoscope or slit-lamp are laborious (since they involve the application of numerous laser burns around the entire fundus periphery) and painful due to postoperative ocular irritation.

Currently, the need for massive laser photocoagulation sessions is satisfied by using the pattern laser photocoagulation techniques. The laser parameter range available with the navigated pattern technology contributes to decreased pain and duration of laser photocoagulation procedure [10, 11]. Therefore, the pattern approach may make postoperative 360°-LRP less laborious and better tolerated by the patient.

The study purpose was to compare three 360°-LRP approaches (using navigated pattern laser system, single-spot slit-lamp laser delivery, and single-spot indirect ophthalmoscope laser delivery) in regard to (1) procedure duration, (2) procedural pain score, and (3) technical difficulties and the ability to achieve surgical goals.

2. Materials and Methods

The study was approved by the Ethics Committee of the Military Medical Academy and followed the tenets of the Declaration of Helsinki. All patients gave written informed consent both for participation in the study and for LRP.

Rhegmatogenous retinal detachment patients with clinical indications for laser retinopexy were included in this single-center prospective randomized longitudinal interventional study. LRP was indicated to prevent retinal redetachment after the surgical procedures specified in Table 1. In vitrectomy cases, 360°-LRP was performed to reduce the risk of retinal redetachment due to iatrogenic breaks [3, 4, 8]. In silicone tamponade cases, 360°-LRP was performed to reduce the risk of retinal redetachment after removal of silicone oil [2]. Some of these vitrectomy cases and silicone tamponade cases also underwent circular scleral buckling (CSB). In patients who underwent CSB only, 360°-LRP was performed due to a giant (>90°) tear, multiple retinal tears (with a total extension of 90° or more), or retinal dialysis. Previously, LRP has been reported to be effective in CSB for a giant retinal tear [5–7]. Since retinal dialysis and multiple retinal tears (with a total extension of 90° or more) are the two pathologies similar to the above, we used LRP also in relevant cases. All these cases correspond to the patients included in the study for a "circular scleral buckling-" relevant indication (Table 1).

Exclusion criteria were (1) incomplete performance of intraoperative LRP (excluding the cases when endolaser photocoagulation was applied outside the 360°-LRP site); (2) acute infections of the posterior segment; (3) postoperative inflammatory response; or (4) use of nonsteroidal anti-inflammatory, antihistamine, sedative, or other drugs which can potentially influence pain self-assessment.

2.1. Surgical Technique. Pattern laser retinopexy was performed using Navilas 532 laser system (OD-OS, Berlin, Germany) incorporating navigated Rapid PRP technology to produce 30 ms pulses, with square pattern from 3 × 3 to 5 × 5 laser spots (spot size, 450 μm; spot spacing, 1 spot size). The Navilas wide-field Rapid PRP (Ocular Instruments, Inc., Bellevue, WA, USA) contact lens was used to deliver laser energy to the posterior segment.

Table 1: Indications for postoperative laser retinopexy (and proportion of patients included in the study).

	Indications for postoperative laser retinopexy	Number of cases		
		Pattern LRP	SL-LRP	IO-LRP
(1)	Vitrectomy for rhegmatogenous retinal detachment (RRD) [4, 7, 8]	10	5	2
(2)	Silicone oil tamponade for RRD [9]	12	11	9
(3)	Circular scleral buckling for RRD [5]	14	12	11

LRP: laser retinopexy; SL-LRP: laser retinopexy using single-spot slit-lamp laser delivery; IO-LRP: laser retinopexy using single-spot indirect ophthalmoscope laser delivery.

Slit-lamp LRP (SL-LRP) was performed with the 532 nm GYC-1000 laser (NIDEK, Japan) attached to ophthalmic YAG laser system YC-1800 (NIDEK). A wide-field contact lens, Mainster PRP 165 (Ocular Instruments, Inc., Bellevue, WA) and/or G-3 Three-Mirror Glass Gonio Fundus Lens (Volk Optical, Inc., Mentor, OH) were used for laser delivery. Given the laser spot magnification of the lens, the actual retinal laser spot size was 350 μm. A 1.0 burn-width spot spacing was used for all SL-LRP cases.

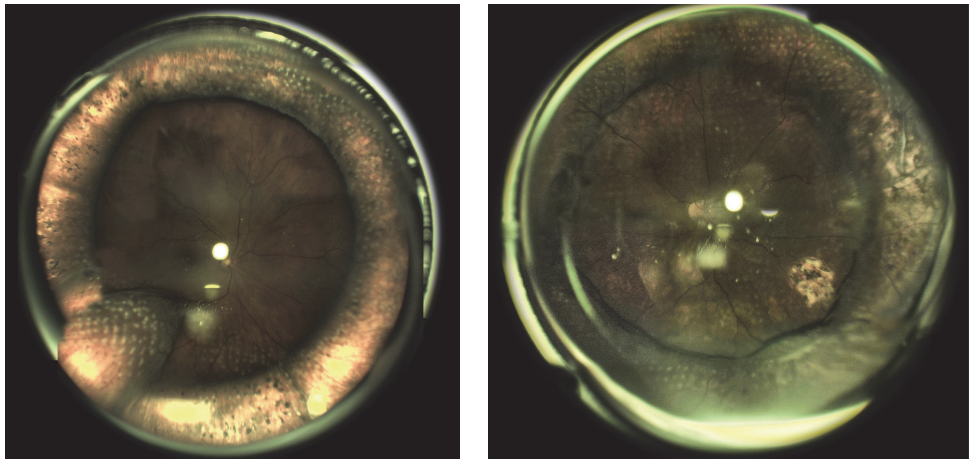
Indirect ophthalmoscope LRP (IO-LRP) was performed with the binocular indirect ophthalmoscope NBO-3-01 (ZOMZ, Sergiev Posad, Russia) and 532 nm GYC-1000 laser (NIDEK). A 20-dioptre noncontact aspheric lens (Ocular Instruments) was used for laser delivery. Given the laser spot magnification of the lens, the actual retinal laser spot size was 800 to 1000 μm. A 1.0 burn-width spot spacing was used for all SL-LRP cases.

Patients were randomly assigned to the pattern LRP, SL-LRP, or IO-LRP.

2.2. Primary and Secondary Endpoints. Primary endpoints were amount of time needed for LRP, number of sessions, pain level, number of applied laser burns, and rate of surgical goal achievement. Retinal redetachment rate after silicone oil removal or after vitrectomy and/or buckling surgery was a secondary endpoint.

The procedural time was measured as the time that elapsed between the initial placement of the contact lens onto the eye (visualization of the fundus with the help of the 20-D aspheric lens in the IO-LRP group) and the final laser burn application, irrespective of the number of placements of the contact lens.

A session was defined as the LRP procedure performed during a patient's visit to the clinic. At the end of each session, the ophthalmologist made a decision whether the next session was required. If the next session was required, the date was scheduled based on the cause of a failure to complete



(a) (b)

Figure 1: (a) Fundus image of the patient with a circular scleral buckle (CSB) and a meridional scleral buckle for multiple retinal tears, after two LRP sessions, with the surgical goal fully achieved. (b) Fundus image of the patient with a CSB and silicone oil tamponade of the vitreous cavity, after a single "pattern LRP" session, with the surgical goal fully achieved (LRP at a single tear was performed intraoperatively).

a 360°-LRP within the first session (cases requiring resorption of subretinal fluid or improvement in vitreous clarity were given increased session-to-session intervals compared to those with difficulties associated with apparent pain, narrow pupil, fibrosis of the capsular bag, or decentration of the intraocular lens).

The total number of laser spots delivered in each patient during all LRP sessions was determined after completion of each session.

The 4-point Verbal Rating Scale (VRS; 0, no pain; 1, mild pain; 2, moderate pain; and 3, severe pain) was used to self-assess the procedural pain immediately following the procedure, with the patient being explained that the pain sensation was caused not by mechanical effects of the lens, but by exposure to laser irradiation [12].

In each case, irrespective of the presence or absence of a tamponade of the vitreous cavity, the single surgical goal was to achieve either coagulation of the extreme and midperipheral fundus (with retinal tear photocoagulation) over 360 degrees or coagulation spread over the entire posterior slope of the buckle and anteriorly of it (with retinal tear photocoagulation) (Figure 1). In retinal tear photocoagulation a 0.5 burn-width spot spacing was used. The goal was considered not achieved if laser spots were not placed at a part of the retinal site planned for treatment with 360°-LRP.

Medical records were retrospectively reviewed to determine the times between the retinal detachment surgery and LRP separately for cases with and without silicone tamponade.

The technical difficulties encountered during each of the LRP session were assessed to explain the causes of possible difference in success rate of surgical goals among the study groups. Technical difficulty was defined as the presence of any condition (e.g., subretinal fluid and IOL decentration) hampering the placement and visual assessment of laser burns at a fundus site during its sequential photocoagulation in a clockwise fashion.

2.3. Follow-Up. Patients underwent fundus examinations at week 2 (following either silicone oil removal from the vitreous cavity or LRP after vitrectomy and/or buckling surgery) and then every month thereafter to exclude retinal redetachment after LRP. Minimum follow-up time was 6 weeks (with 2 consecutive visits). The presence of subretinal fluid posteriorly of the laser coagulation area was considered as retinal redetachment and was checked visually; OCT was done in doubtful cases.

2.4. Statistics. All data are presented as mean ± standard deviation. A one-way analysis of variance (ANOVA) with Bonferroni-adjusted post hoc comparisons was used to assess between-group differences in age and qualitative and quantitative characteristics of LRP. A chi-square test was used to assess between-group differences in male-to-female ratio, rate of surgical goal achievement, technical difficulty rate, and retinal redetachment rate.

3. Results

3.1. Demographics and Basic Characteristics of Subgroups. Eighty-six individuals (44 men and 41 women) were included in the study. There was no statistically significant difference in age and male-to-female ratio among the groups (Table 2).

3.2. Primary Endpoints Analysis. In the pattern LRP group, the amount of time needed for LRP, number of sessions, and pain level were statistically significantly lower, whereas the number of applied laser burns was higher compared to those in the SL-LRP group and in the IO-LRP group ($p < 0.05$) (Table 3). No statistically significant difference

Table 2: Characteristics of the study population.

	Pattern LRP	SL-LRP	IO-LRP
Patients, total	36	28	22
Age, years	50.8 ± 8.8	61.9 ± 12.4	55.1 ± 11.0
Sex, male/female	22/14	13/15	9/12
Patients with IOL	22	17	16

LRP: laser retinopexy; SL-LRP: laser retinopexy using single-spot slit-lamp laser delivery; IO-LRP: laser retinopexy using single-spot indirect ophthalmoscope laser delivery.

Table 3: Comparison of primary endpoints between pattern LRP, SL-LRP, and IO-LRP groups.

	Pattern LRP	SL-LRP	IO-LRP
Procedural time, minutes	12.4 ± 5.4	21.7 ± 7.6	17.0 ± 10.1
Procedural pain score	1.1 ± 0.5	1.8 ± 0.5	1.9 ± 0.5
Total number of laser burns applied	1108.7 ± 345.5	714.5 ± 219.8	408.1 ± 95.5
Number of LRP sessions	1.2 ± 0.4	2.0 ± 0.6	1.9 ± 0.7
Days after circular scleral buckling or vitrectomy	2.0 ± 1.4	3.9 ± 3.1	2.4 ± 1.9
Days after initiation of tamponade	119.8 ± 67.0	103.1 ± 54.3	88.5 ± 61.4

LRP: laser retinopexy; SL-LRP: laser retinopexy using single-spot slit-lamp laser delivery; IO-LRP: laser retinopexy using single-spot indirect ophthalmoscope laser delivery.

was found in these variables between the SL-LRP group and the IO-LRP group. In the pattern LRP group, SL-LRP group, and IO-LRP group, surgical goals were fully achieved in 28 patients (77.8%), 17 patients (60.7%), and 13 patients (59.1%), respectively, and not achieved (due to technical difficulties) in 12 patients, 11 patients, and 9 patients, respectively. There was no statistically significant difference in the rate of surgical goal achievement among the groups.

There was no statistically significant difference in mean time after retinal detachment surgery (in case of silicone oil tamponade, after silicone oil injection) among the groups (Table 3).

3.3. Technical Difficulties. In the pattern LRP group, technical difficulties were encountered in 18 cases (50.0%), with the most common difficulty being residual retinal detachment (11 cases), followed by the rigid pupil (which hampered visualization of the peripheral fundus; 5 cases), fibrosis of the capsular bag and/or decentered IOL (5 cases), irregularly placed CSB (anteriorly displaced; 2 cases), and media opacification (partial vitreous hemorrhage) early following retinal detachment surgery (1 case). The pattern LRP was aborted due to high pain levels in one patient.

In the SL-LRP group, technical difficulties occurred in 15 cases (53.6%) and included residual retinal detachment (6 cases), narrow and/or decentered pupil (5 cases), fibrosis of the capsular bag (2 cases), and posttraumatic corneal scar (1 case). In addition, the SL-LRP was aborted due to high pain levels and significant procedural time needed to fully achieve the surgical goal in 9 patients.

Technical difficulties were encountered in 12 cases (54.6%) of the IO-LRP group and included residual retinal detachment (5 cases), narrow pupil (4 cases), and fibrosis of the capsular bag and/or decentered IOL (3 cases). In addition, the IO-LRP was aborted due to high pain levels and significant procedural time needed to fully achieve the surgical goal in 5 patients.

There was no statistically significant difference in technical difficulty rate among the groups.

If a residual detachment was present at the extreme peripheral fundus, LRP was performed posterior of the detachment. These cases corresponded to "failure to achieve surgical goal." Performing photocoagulation posterior of the area initially planned for photocoagulation was not included into the definition of the achievement of surgical goal, since it does not correspond to the definition of classical LRP.

3.4. Reasons for Failures to Achieve Surgical Goals. In the pattern LRP group, failures to achieve surgical goals were associated with residual retinal detachment (9 patients) or narrow pupil with fibrosis of the capsular bag and decentration of the intraocular lens (3 patients). In the SL-LRP group, these failures were associated with residual retinal detachment (6 patients), narrow pupil and fibrosis of the capsular bag (4 patients), or corneal scar (1 patient). In the IO-LRP group, failures to achieve surgical goals were associated with residual retinal detachment (5 patients) or narrow pupil with fibrosis of the capsular bag and decentration of the intraocular lens (4 patients).

3.5. Follow-Up after Silicone Oil Removal. In the pattern LRP, SL-LRP, and IO-LRP groups, the mean duration of follow-up after silicone oil removal was 6.6 ± 3.1 months, 8.1 ± 4.5 months, and 7.1 ± 4.1 months, respectively (ANOVA3x, $p = 0.35$), with redetachment found in 1 case (8.3%), 2 cases (18.2%), and 1 case (11.1%), respectively. No statistically significant difference was found in retinal redetachment rate after silicone oil removal among the groups (chi-square test, $p = 0.77$).

3.6. Follow-Up after Vitrectomy and/or Buckling Surgery. In the pattern LRP, SL-LRP, and IO-LRP groups, the mean duration of follow-up after vitrectomy and/or buckling surgery was 6.6 ± 3.4 months, 5.9 ± 4.0 months, and 6.3 ± 3.4 months, respectively (ANOVA3x, $p = 0.44$), with redetachment found in 1 case (4.2%), 1 case (5.9%), and no cases, respectively. No statistically significant difference was found in retinal redetachment rate after vitrectomy and/or buckling surgery among the groups (chi-square test, $p = 0.70$).

4. Discussion

The present study shows that 360°-LRP performed using the navigated pattern laser (Navilas) is less time-consuming and less painful than that performed with a single-spot laser

coupled with a slit-lamp or indirect ophthalmoscope laser delivery system. In addition, there was no statistically significant difference in rate of full achievement of the surgical goal and in retinal redetachment rate between the pattern LRP and conventional 360° LRP techniques. The absence of significant difference in goal achievement rate can be explained by similar number and configuration of the technical difficulties (e.g., rigid pupil and residual detachment) resulting from the anatomic status of the eye after retinal detachment surgery and hampering photocoagulation irrespective of the method of laser delivery. However, the rate of achievement of the surgical goal in the pattern LRP was higher than in comparison groups, although not statistically significantly.

The effect of 360° LRP (i.e., the reduction in the rate of postoperative retinal detachment) has been demonstrated for vitrectomy with and without silicone oil tamponade [4] and giant retinal tear surgery [5, 6]. The work presented shows that 360° LRP can be performed using the Navilas laser system in cases where it is indicated (Table 1). Three hundred sixty-degree LRP is mostly required in conjunction with vitreoretinal procedures; in these cases, LRP is performed intraoperatively. Although using LRP in an intraoperative fashion substantially improves patient procedural tolerance, it also extends the operating time (including anesthetic time) required and not always intraoperative LRP can be done over 360°.

Sometimes postoperative, 360° LRP is not well enough tolerated by patients, since retinal photocoagulation itself is painful, and is done in the early postoperative period, thus potentially contributing to increased pain sensation (e.g., following lens contact with conjunctival sutures). However, postoperative LRP can be performed over 360° (in one or more sessions) as the subretinal fluid resolves, with no anesthetic except some topical. The use of a single-spot laser for 360° LRP is more time-consuming than other approaches, which affects tolerability of the procedure; unfortunately, there are no available data on the use of the navigated pattern laser technology for this purpose.

In the study presented, we found that the use of 360°-pattern LRP has the advantages of (1) reduced time required for achievement of the surgical goal due to reduced number and duration of LRP sessions and (2) less pain due to numerous short duration laser burns and reduced need for lens manipulation on the eye because of a wide field of view. Moreover, no additional technical difficulties were found, and the navigated pattern laser technology allows performing LRP in the amount as great as required and at any reasonable time after various retinal detachment surgeries.

We found this approach to postoperative 360°-LRP at least as effective as the two other approaches, with similar rate of redetachment in the early period after silicone oil removal. Moreover, the mean number of laser spots in postoperative 360°-pattern LRP was higher than those relevant to other methods, which can be explained by improved tolerability and treatment speed. The clinical significance of these differences in regard to prevention of retinal redetachment deserves further study.

The so-called Rapid PRP is a special feature of the navigated pattern laser (Navilas), and, with the laser pulse duration and separation as short as of 30 ms and 10 ms, respectively, the time required for the application of a 25-spot pattern is no more than 1 s, allowing to cut the laser treatment time (in panretinal laser photocoagulation) a half [10, 11]. This was further confirmed by the findings of this study, since the 360°-LRP using the slit-lamp or indirect ophthalmoscope required twice as much time (in spite of a lower total number of applied laser burns) compared to the navigated pattern laser approach. In the SL-LRP, a narrow wide field of view necessitates frequent slit-lamp and lens movements for coagulation of the next retinal location, which, along with a rather slow application of laser burns, results in a low number of placed spots and necessity for additional LRP sessions. We found patients of the IO-LRP group to have comparatively high pain scores; it was probably caused by large laser spots on the retina, since a 20-D lens was used. However, the use of a smaller laser spot in the IO-LRP group would increase the procedural time, which is already larger than that in the pattern LRP. The advantages of IO-LRP are the possibility of performing scleral depression (however, this is not necessary in the presence of CESB) and the possibility of performing the procedure in patients incapable of taking a sitting position.

A limitation of this study is the absence of data for comparison of postoperative 360° pattern LRP and intraoperative 360° LRP, with the latter being a widely used typical procedure [2–6, 8]. However, the retinal detachment rate after silicone oil removal in the pattern LRP group was similar to those reported in patients who had received intraoperative 360-degree laser retinopexy [4, 9].

Potentially, the navigated pattern approach may be used not only for 360° LRP, but also for other versions of postoperative LRP, including the LRP at the retinal tear site in meridional or circular extrascleral buckling and the LRP under conditions of pneumatic retinopexy or short-term perfluorocarbon fluid tamponade.

In conclusion, the navigated pattern approach (Navilas) to 360° LRP (a) allows improving the treatment time and pain in postoperative 360° LRP and presents no technical difficulties additional to the conventional (slit-lamp or indirect ophthalmoscope) approaches with a single-spot laser and (b) is at least as effective in achieving the surgical goal as these approaches.

Disclosure

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

Competing Interests

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

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