

Adequate Silicone Oil Tamponade by Utilizing the Space of Anterior Segment for Complicated Retinal Detachment: Technique, Efficacy, and Safety

Yifan Wang, MD, Zijing Huang, MD, PhD, Dezhi Zheng, MD, Juntao Liu, MD, Dingguo Huang, MD, Jianlong Zheng, MD, Haixia Xie, RN, Peimin Lin, RN, and Weiqi Chen, MD

Purpose: To evaluate the efficacy and safety of adequate silicone oil (SO) tamponade procedure in patients with complicated retinal detachment.

Methods: Thirty-one eyes in 31 patients were enrolled in this prospective case series. Adequate SO tamponade was performed by injecting the SO into the vitreous cavity and the entire anterior chamber, followed by posterior capsulotomy and inferior peripheral iridotomy. Preoperative and follow-up data including retinal anatomic reattachment and SO status, best-corrected visual acuity, intraocular pressure, surgical complications and management were collected and analyzed.

Results: Twenty-nine eyes presented with complete retinal reattachment after subsequent SO removal with a primary success rate of 93.5%. Seventeen patients (54.8%) had complete anterior chamber SO migration to the vitreous cavity within the first postoperative day. The average time for anterior chamber SO migration was 2.3 ± 1.8 days. No oil-fluid interface in the vitreous cavity was observed in all the eyes, indicating a relatively adequate SO tamponade. Acute intraocular pressure elevation occurred in 16 (51.6%) eyes and was controllable under medication ($n = 16$) and anterior chamber paracentesis ($n = 1$). Two patients developed recurrent retinal detachment and received SO removal and a secondary adequate SO tamponade. At final follow-up, all the eyes had SO removal for at least 3 months and retinas maintained completely attached.

Conclusions: The adequate SO tamponade procedure offers a simple, safe, and efficacious treatment alternative for complicated retinal detachment.

Key Words: adequate silicone oil tamponade, inferior peripheral iridotomy, posterior capsulotomy, retinal detachment

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From the Joint Shantou International Eye Center of Shantou University and The Chinese University of Hong Kong, Shantou, Guangdong, China.

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Address correspondence and reprint requests to: Weiqi Chen, Joint Shantou International Eye Center of Shantou University and The Chinese University of Hong Kong, 69 North Dongxia Rd, Shantou 515041, Guangdong, China. E-mail: cwq@jsiec.org.

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Surgical techniques and instruments for retinal detachment (RD) have shown extensive progress in the past few decades.^{1,2} Modern pars plana vitrectomy (PPV) with or without external-route microsurgery reveals a satisfactory primary success rate of over 85%. Nevertheless, more than 10% of RD can still have surgical failure and requires secondary operations, of which a quarter would suffer from another redetachment.³ The main causes for the surgical failure include unsealed or new-onset retinal breaks particularly in the inferior quadrant, proliferative vitreoretinopathy (PVR), and intrinsic retinal contraction.^{4,5}

Silicone oil (SO) is a well-established and effective tamponade in the treatment of severe RD and complex vitreoretinal diseases.⁵ However, the appearance of inferior redetachment following SO tamponade remains surgically challenging. Although the vitreous cavity is filled with SO intraoperatively, an oil-liquid interface can often be observed,⁶ indicating insufficient SO tamponade (Supplementary Digital Content, Figure 1, <http://links.lww.com/APJO/A104>). This is mainly due to absorption of chorioretinal edema and residual subretinal and subchoroidal fluid in postoperative days, which enlarges the vitreous cavity. Regular SO tamponade, therefore, becomes insufficient and fails to support inferior retinal quadrants. Due to its high viscosity and cohesive properties, the SO (especially 5000 centistokes) in the vitreous cavity tends to form a spherical shape. This means that a slightly smaller than an ideal bubble of SO might leave many clock hours of retina uncovered.⁷

In this study, we propose a modified procedure for adequate SO tamponade in the aphakic eyes. Following an active posterior capsulotomy and inferior peripheral iridotomy, the vitreous cavity, as well as the anterior chamber, were filled with SO. After surgery, the aqueous fluid produced from the ciliary epitheliums can move into the anterior chamber through the iridotomy, forcing the anterior chamber SO to migrate to the vitreous cavity through the posterior capsulotomy, leading to an adequate SO tamponade. This study aimed to evaluate the efficacy and safety of this procedure in patients with complicated RD.

SUBJECTS AND METHODS

Subjects

This prospective and interventional case series study conformed to the guidelines of the Declaration of Helsinki. The research was conducted in compliance with a suitable accredited institutional review board from the Ethics Committee of Joint Shantou International Eye Center (JSIEC), and was registered on the Chinese Clinical Trial Registry (ChiCTR 1900028002).

Informed consent was obtained from the subjects after an explanation of the nature and possible consequences of the study. Consecutive patients from January 2017 to August 2020 who met the following criteria were included: 1) diagnosed with complicated primary RD, presenting with one or more of the followings: rhegmatogenous RD with severe PVR (grade C or D according to the Retina Society Classification, $n=21$), posterior polar or inferior retinal breaks ($n=24$), giant retinal breaks ($n=2$), combined RD and choroidal detachment ($n=6$), long-standing (over 6 months) RD ($n=2$), etc; 2) presented with significant cataract or had a history of cataract extraction. Exclusion criteria include: 1) had a history of RD repair; 2) combined with other ocular diseases such as glaucoma, proliferative diabetic retinopathy, optic nerve diseases, etc.

Surgical Procedures

All the surgical procedures were performed by an experienced surgeon. For eyes with significant cataract, phacoemulsification was first conducted. For cases with choroidal detachment, a small drainage sclerotomy was created with a 23-gauge trocar under anterior chamber perfusion. Then a standard 23-gauge PPV was performed. After core vitrectomy, posterior vitreous detachment was induced followed by triamcinolone acetonide injection. Depressed vitreous base shaving was performed. Any visible epiretinal proliferative membranes thought to be contributing to the RD were dissected and removed using the internal limiting membrane forceps and vitrector. For cases with severe PVR, perfluorocarbon liquid was used to stabilize the posterior polar retina and simplify the removal of epiretinal membranes. After that, central posterior capsulotomy with a diameter of approximately 4 mm and inferior peripheral iridotomy with a diameter of approximately 1 mm was performed using the vitrector. After the retina was reattached by fluid-air exchange, endophotocoagulation ($n=30$) or cryotherapy ($n=1$) around the retinal breaks and degeneration was delivered. Repeated and thorough fluid-air exchange was undertaken using a flute needle. The SO (highly purified SO, 5000 cps, RT SIL-OL 5000, Carl Zeiss Meditec AG, Jena, Germany) was subsequently injected into the vitreous cavity as well as the anterior chamber (Fig. 1). Finger tension was done in a real-time manner to maintain the intraocular pressure in the normal-to-slightly high range. Patients were asked to maintain a face-down position for at least 1 week postoperatively. Subsequent SO removal was performed at least 3 months after the primary procedure in patients with retina reattached and retinal breaks sealed. In eyes showing an improvement in best-corrected visual acuity (BCVA), secondary intraocular lens (IOL) implantation in the ciliary sulcus was conducted ($n=27$) followed by SO removal.

Main Outcome Measures

The primary outcome measure was the anatomical success, determined as a complete retinal reattachment with neither patent breaks nor residual subretinal fluid at all the follow-up periods until at least 3 months after SO removal. The retinal reattachment was confirmed using pupil dilated fundus examination, scanning laser ophthalmoscopy (Optos P200T; Optos PLC, Dunfermline, UK), and optical coherence tomography (3D OCT-2000; Topcon Corporation, Tokyo, Japan). Visual function measured by logMAR BCVA was considered as another main outcome measure. According to a previous study, light perception was assigned as 2.60 logMAR, hand motion as 2.30 logMAR, and count finger as 1.85

logMAR.⁸ Other measurements included SO status, intraocular pressure (IOP) using a noncontact tonometer, corneal endothelium cell counting, and postsurgical complications and management. High IOP was defined as a pressure of over 21 mm Hg. Follow-up examinations were scheduled on each day after surgery until discharge, 1-week postdischarge, 1-month postdischarge, and every 1 or 2 months thereafter till the end of the follow-up.

Statistical Analysis

Data were analyzed using SPSS version 25.0 (SPSS Inc, Chicago, IL). Quantitative data were present as mean \pm standard deviation and range. The student *t* test for paired samples and Wilcoxon rank-sum test were used for comparison of BCVA and IOP respectively at baseline and several time points after surgery. *P* values of less than 0.05 were considered statistically significant.

RESULTS

A total of 31 eyes in 31 patients were included (21 males and 10 females, 54.4 ± 13.2 years old). Preoperative PVR was graded as C1 ($n=7$), C2 ($n=7$), C3 ($n=4$), and D1 ($n=3$). Of note, 24 eyes (77.4%) presented with posterior polar and/or inferior retinal breaks. Other cases included RD combined choroidal detachment ($n=6$), long-standing RD ($n=2$), and RD with giant retinal breaks ($n=2$). Twenty-eight eyes presented with clinically significant cataracts and received phacoemulsification before vitreoretinal surgery. Three eyes had a history of cataract extraction, two of them were found with IOL subluxation and another patient was aphakic. The subluxated IOL was removed before PPV. Follow-up data were collected with a follow-up period of 13.9 ± 11.5 months. Baseline characteristics and preoperative data are shown in Table 1. Representative clinical images are shown in Figures 2 and 3.

Retinal Reattachment Rate

Twenty-nine of the 31 eyes had complete retinal attachment after the primary procedures and subsequent SO removal, presenting with a primary success rate of 93.5%. One patient developed inferior RD and PVR under SO tamponade in the follow-up. Another patient had an attached retina within 6 months of follow-up but suffered from a redetachment after SO removal due to unsealed breaks. These 2 patients received local retinotomy and another adequate SO tamponade. In the final follow-ups, all the patients had SO removal for over 3 months and retinas remained completely attached. The secondary success rate was 100%.

Visual Outcomes

Twenty-seven (87.1%) cases received secondary IOL implantation in the ciliary sulcus during the follow-ups, of which 20 eyes had combined SO removal and IOL implantation while 7 eyes underwent IOL implantation a couple of months after SO removal. Another 4 eyes remained aphakic due to either super-high myopia that required no IOL ($n=3$) or severe chorioretinal atrophy with no improvement in BCVA ($n=1$). The final logMAR BCVA after SO removal was 0.73 ± 0.39 , which showed significantly improvement compared with that of 1.71 ± 0.68 before surgery ($P < 0.001$). Notably, BCVA improved in 28 eyes (90.3%), maintained stability in 1 eye (3.2%) and deteriorated in 2 eyes (6.5%).

Silicone Oil Status

At the end of PPV, SO was filled with the vitreous cavity and the entire anterior chamber. An average volume of 5.8 ± 1.5 mL

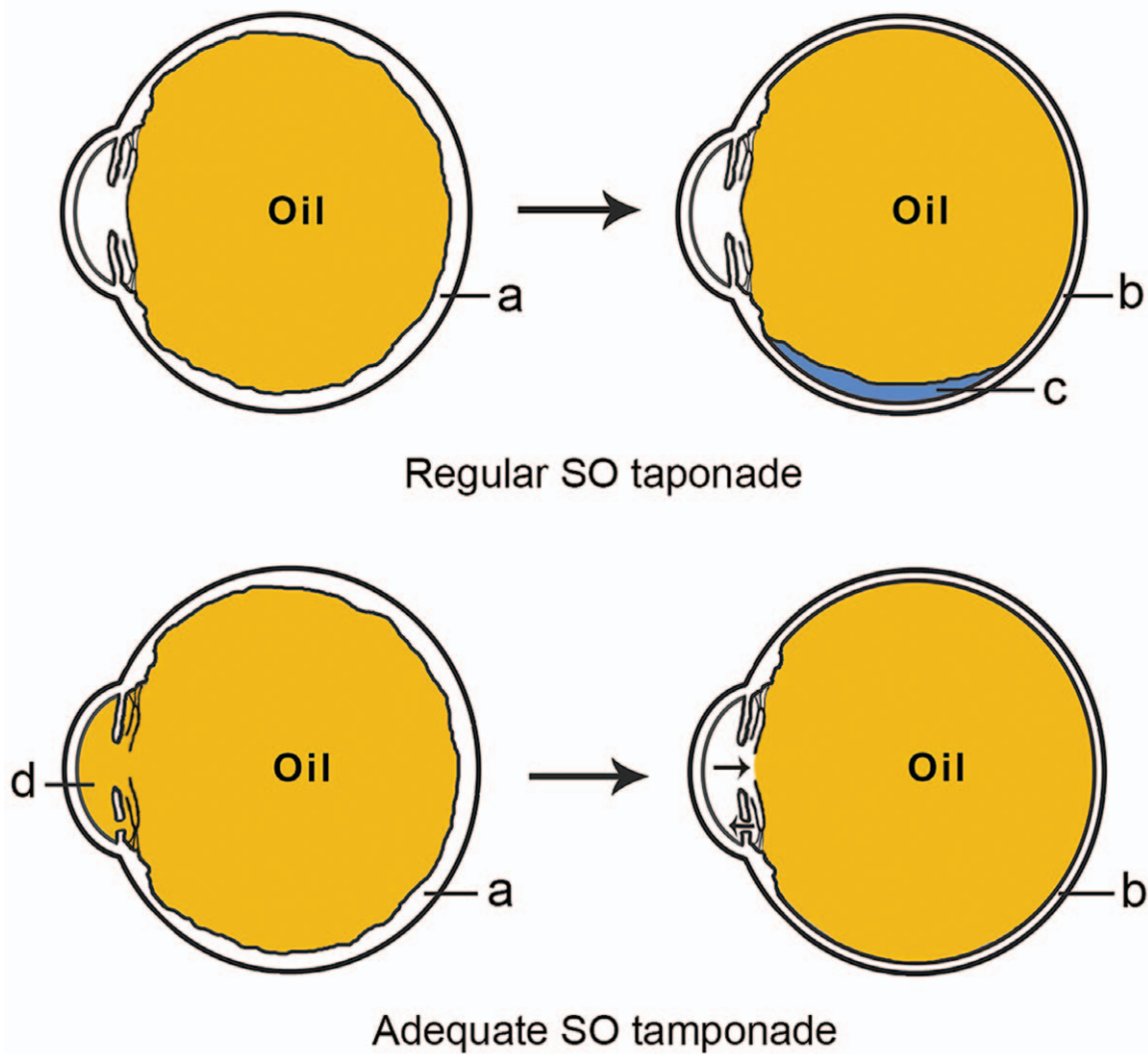


FIGURE 1. A diagram showing the procedure of regular and adequate silicone oil tamponade. (Above) During retinal detachment, liquefied vitreous enters the subretinal space, leading to ocular hypotony and chorioretinal swelling (a). The improvement of chorioretinal swelling and absorption of subretinal fluid (b) increases the volume of vitreous cavity. Regular SO tamponade becomes relatively inadequate and fails to support the inferior retinal breaks. The patent breaks with persistent subretinal fluid (c) leads to proliferation of RPE and glial cells, leading to PVR development. (Below) In aphakic eyes, posterior capsulotomy and inferior peripheral iridotomy are performed following vitrectomy. Then the SO is filled with both the vitreous cavity and the posterior and anterior chamber (d). With a face-down position, the aqueous fluid from the ciliary epithelial cells will move into the anterior chamber through the peripheral iridotomy, forcing the anterior SO to enter the vitreous cavity through the posterior capsulotomy, ensuring an adequate SO tamponade. PVR indicates proliferative vitreoretinopathy; RPE, retinal pigment epithelium; SO, silicone oil.

of SO was used. Seventeen patients (54.8%) presented complete migration of SO from the anterior chamber into the vitreous cavity within the first postoperative day. The average duration for the SO return-flow was 2.3 ± 1.8 (ranged 1 to 6) days. Neither anterior chamber SO nor an oil-fluid interface in the vitreous cavity was observed in all eyes at discharge as well as all the follow-up periods, indicating a relatively adequate SO tamponade. No significant emulsification was observed during the follow-ups. All the eyes had SO removed 6.3 ± 1.9 months after the primary surgery.

Intraocular Pressure

The intraocular pressure (IOP) exhibited an elevation from 11.7 ± 3.7 (range 6 to 19) mm Hg preoperatively to 21.7 ± 13.7 (range 7 to 57) mm Hg on the first postoperative day. Of note, 16 eyes (51.6%) had a high IOP of 35.1 ± 12.7 (range 22 to 57) mm Hg and received antiglaucoma eye drops. Fifteen eyes had controlled IOP while 1 eye had elevated IOP with anterior chamber SO retention until the fourth postoperative day so that

partial SO extraction was performed through anterior chamber paracentesis. The anterior chamber SO showed entire migration to the vitreous cavity at day 6 and IOP was 11 mm Hg. The IOP in all the eyes was well controlled at discharge (15.1 ± 4.8 , range 7 to 24 mm Hg) and maintained normally in the final follow-up (15.5 ± 4.8 mm Hg) except that 2 eyes experienced elevated IOP (25 and 30 mm Hg) and were returned to medication use. Operation data and surgical outcomes are summarized in Table 2.

DISCUSSION

In recent years, continual new tools and techniques have been developed to improve surgical success rates in eyes with complicated RD, including PPV combined inferior retinotomy or retinectomy,^{9,10} additional scleral buckling^{11,12} and two-port revitrectomy¹³ under SO tamponade, high-density tamponade agents,^{14,15} and revitrectomy with 5-FU added infusion fluid^{16,17} (Supplementary Digital Content, Table 1, <http://links.lww.com/>

TABLE 1. Preoperative Data of Patients Undergoing Adequate Silicone Oil Tamponade

Characteristics	No. (percentage)
Gender	
Male	21 (67.7%)
Female	10 (32.3%)
Age, y*	54.4 ± 13.2
BCVA (logMAR)*	1.71 ± 0.68
IOP (mm Hg)*	11.1 ± 3.7
Lens status	
Cataract	28 (90.3%)
Aphakic	1 (3.2%)
IOL subluxation	2 (6.5%)
Complicated RD	
PVR C and D	21 (67.7%)
Inferior/posterior polar breaks	24 (77.4%)
Giant breaks	2 (6.5%)
Combined choroidal detachment	6 (19.4%)
Long-term RD	2 (6.5%)
PVR Grade	
B	10 (32.3%)
C1	7 (22.6%)
C2	7 (22.6%)
C3	4 (12.9%)
D1	3 (9.7%)

BCVA indicates best corrected visual acuity; IOL, intraocular lens; IOP, intraocular pressure; RD, retinal detachment; PVR, proliferative vitreoretinopathy.

*Data are presented as mean ± standard deviation.

APJO/A105). Nevertheless, recurrence of RD has been reported to be nearly 20%,^{3,18} with some patients requiring multiple surgical procedures and may progress to a final inoperable outcome. In this study, we proposed an adequate SO tamponade procedure for complicated RD with severe PVR and found a satisfactory primary reattachment rate of 93.5%, which was comparable to existing literatures (60%–94.1%) (Supplementary Digital Content, Table 1, <http://links.lww.com/APJO/A105>). Notably, these patients had subsequent SO removal with retinas attached for at least 3 months, indicating that 93.5% was a definite success rate. Meanwhile, over 90% of our cases demonstrated an improvement in BCVA after treatment, which is also comparable to previous literatures. In addition, the current procedure shows superiority such as being easy and simple to handle, taking a shorter operation time, and being able to avoid buckle-associated conjunctiva insults and scarring, suggesting an alternative to the treatment of complicated RD.

Regular SO Tamponade May Be Insufficient When the Vitreous Cavity Enlarges with Improvement of Chorioretinal Edema

Inadequate SO tamponade following vitreoretinal surgery is often observed,⁶ characterized by the presence of an oil-liquid interface under funduscopy (Supplementary Digital Content, Figure 1, <http://links.lww.com/APJO/A104>). One major reason is that with the absorption of residual subretinal/suprachoroidal fluid and the regression of chorioretinal edema, the vitreous cavity is becoming larger than that before surgery. In addition, the 5000 ophthalmic SO has very high viscosity and cohesiveness and tends to form a spherical shape in the vitreous cavity. This means that a slightly smaller than ideal bubble of SO might cause a significant decrease in tamponade effect. In eyes with superior retinal breaks

and mild PVR, inadequate SO tamponade might have good outcomes since the floated SO still supports the breaks. However, for those with inferior breaks and severe PVR, the SO floats above the water, leaving the inferior retina unsupported and eventually leading to recurrent RD.

The improvement of chorioretinal edema seems to be a slow process after surgical repair. Therefore, in RD eyes with severe PVR and chorioretinal folds, even prolonged and repeated fluid-gas exchanges can hardly remove all the residual subretinal fluid. Regular tamponade of SO becomes inadequate after a period when chorioretinal edema absorbs.^{7,19} To our knowledge, this is one major cause for recurrence of RD.

The Anterior Segment SO Compensates for the Lack of SO and Ensures Better Tamponade Effect

The volume of the lens and anterior chamber in adult individuals is about 200 μ L and 260 μ L respectively,²⁰ the sum of which is approximately 10% the vitreous volume in normal eyes (about 4.5 mL). Due to high interfacial tension and cohesiveness, the SO will spontaneously form a spherical shape in the vitreous cavity. Literatures have shown that 90% fill with SO provides a 200-degree angle of tamponade for the model eye. When the sphere was 100% filled with SO, the contact angle of tamponade largely increases to 324 degrees presenting over one and a half times the tamponade effect than a 90% fill. Therefore, the anterior segment SO is essential as it provides much more pronounced tamponade effect, especially in supporting inferior retinal breaks.

In this study, no oil-fluid interface was found in all the eyes during the whole follow-ups, indicating that the anterior segment SO could fairly compensate for the postoperative lack of SO in the vitreous cavity. By achieving an adequate tamponade, this procedure provides complete endotamponade of the retina and better sealing of inferior patent breaks, which plays a pivotal role in the recurrence of RD. Besides, an adequate tamponade reduces the movement of SO in the vitreous cavity as well as its contact with inflammatory liquid, which may slow down SO emulsion and suppress local inflammation and proliferation.^{21,22} However, for severe PVR with a shortened retina, adequate SO tamponade alone might hardly work whereas a combination of retinotomy and/or retinectomy was preferred.

Inferior Iridotomy Should Be Routinely Performed in SO-filled Eyes with Posterior Capsular Rupture

In aphakic and SO-filled eyes, an iridotomy at the 6 o'clock position is the routine procedure in the setting of posterior capsular defect to allow aqueous humor to enter the anterior chamber from behind the iris and forces SO to enter the vitreous cavity through the posterior capsular defect, therefore keeping the anterior chamber free of SO.²³ We are inspired and turn this passive procedure into actively building a passage between the anterior segment and vitreous cavity by performing posterior capsulotomy and peripheral iridotomy. Then the additional SO in the anterior segment can migrate into the vitreous cavity and provides a more pronounced tamponade effect.

The Current Procedures Should Be Performed in Aphakic Eyes

A premise of the use of this surgical procedure is an aphakic status. In this study, 28 in 31 patients had varying degrees of

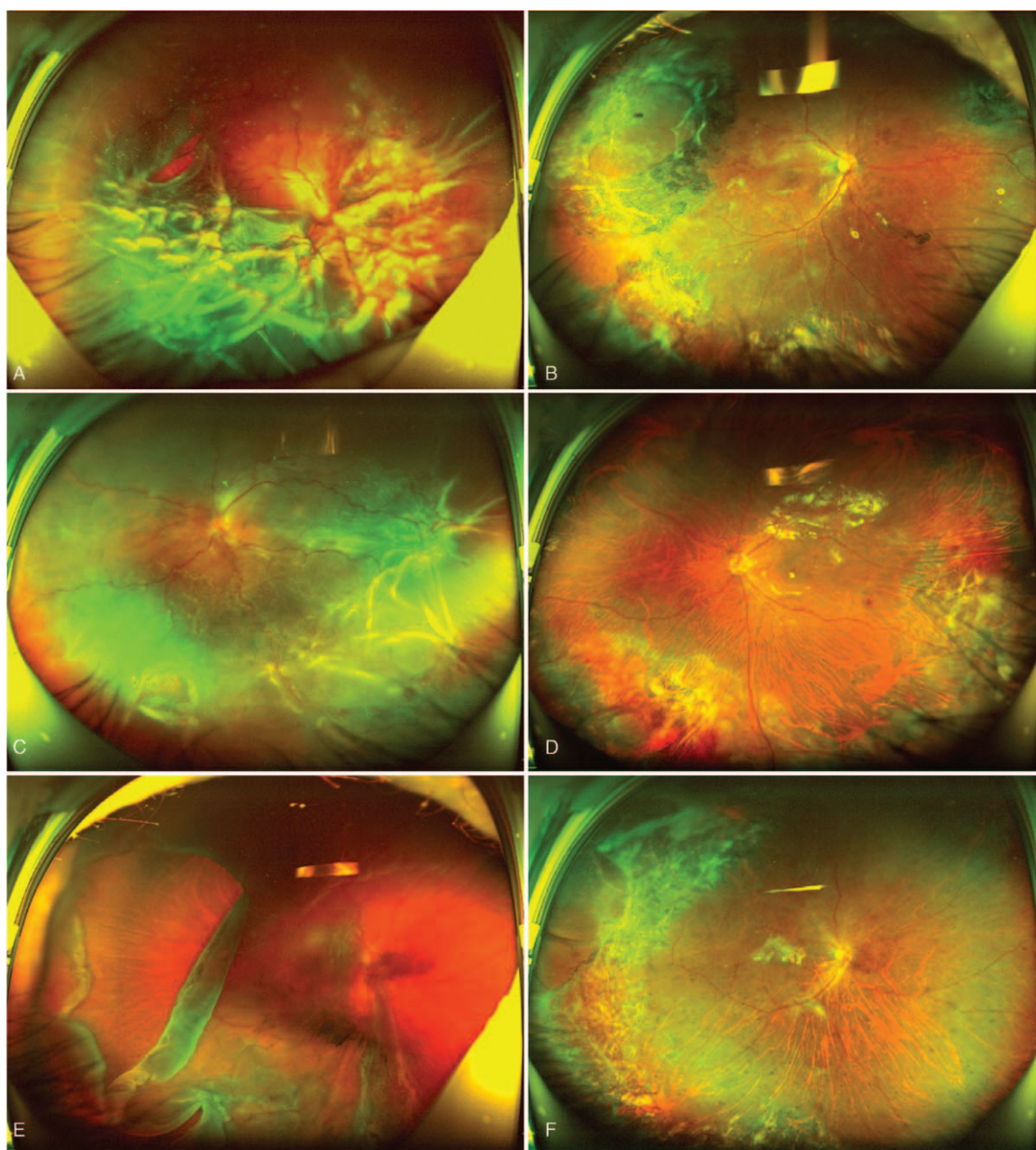


FIGURE 2. Representative fundus images of 3 patients with complicated RD undergoing the surgery of adequate SO tamponade. A and B, Images of a 63-year-old man showing RD with severe PVR (grade C3) and superior breaks (A) and an attached retina at 6-month after surgery (B). C and D, Images of a 55-year-old woman showing RD with inferior breaks and severe PVR (C) and an attached retina at 3-month after surgery (D). E and F, Images of a 55-year-old man showing RD with combined giant retinal breaks and inferior breaks (E) and an attached retina at 6-month after surgery (F). No oil-liquid interface was found in all the affected eyes, indicating a relatively adequate SO tamponade. PVR indicates proliferative vitreoretinopathy; RD, retinal detachment; SO, silicone oil.

cataract at the time of primary RD. Given that most of the patients had significant cataract and were over 50 years old, that the lens opacification could affect PPV procedures in particular a thorough vitreous base shaving, and that SO tamponade would accelerate cataract progression, we performed phacoemulsification before PPV procedures. The rest 3 patients received cataract extraction previously, of which 2 had IOL subluxation so that the IOL was removed and the other one was aphakic.

Intraocular Pressure Should Be Monitored in Perioperative Period

Eyes with RD usually present low IOP due to abnormal aqueous outflow through the retinal breaks across the retinal

pigment epithelium.²⁴ Transient IOP elevation is a common event after surgery because of obstruction of the outflow tract as well as other possible mechanisms including inflammation insults, swelling of trabecular meshwork, and breakdown of the blood-aqueous barrier.²⁵ Previous studies reported a high IOP rate of 40% to 56.5% in eyes with complicated RD that received PPV and SO tamponade.^{26,27} In this study, IOP elevation occurred in 51.6% of eyes on the first postoperative day, similar as previous studies.²⁵ In addition, 54.8% of patients had completed SO migration from the anterior chamber to the vitreous cavity, indicating a less correlation between IOP elevation and obstruction of the anterior chamber angle with the SO. Importantly, the IOP was controllable under

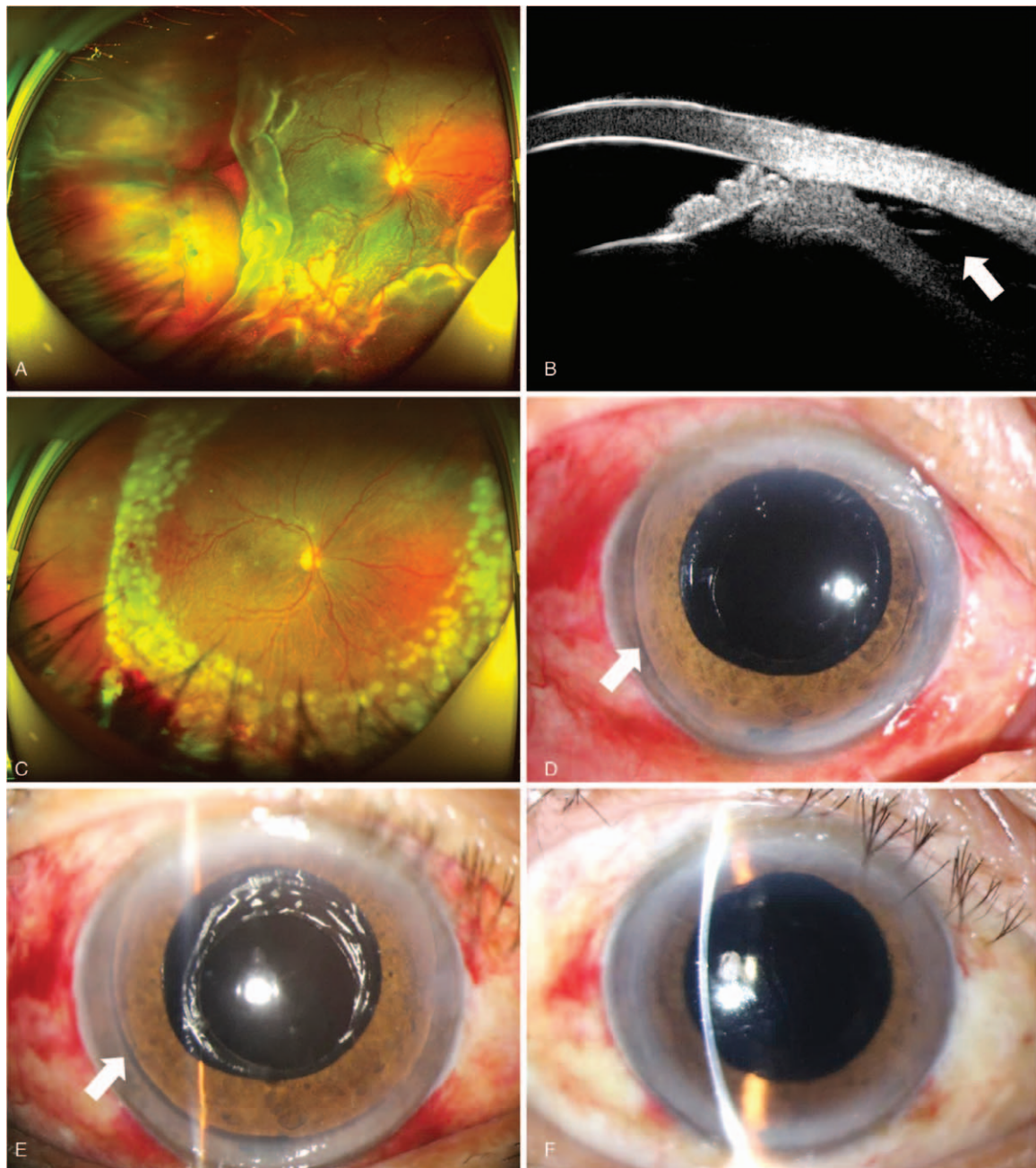


FIGURE 3. Clinical findings of a patient with complicated RD undergoing the surgery of adequate SO tamponade. A 65-year-old man presented with visual loss in his right eye for 1 month. Slitlamp examination revealed a normal anterior segment except for lens opacification. A, Scanning laser ophthalmoscopy showed pan-retinal detachment with giant breaks and retinal folds. B, Ultrasound biomicroscopy showed cyclodialysis and anterior choroidal detachment. C, The retina was completely attached after phacovitrectomy and adequate SO tamponade. D to F, Anterior segment photography showed the migration of SO after surgery. D, On the first postoperative day, the SO was almost filled with the anterior chamber (arrow indicated) and IOP was 18 mm Hg. E, On the second postoperative day, the SO showed partial migration (arrow indicated). IOP was 25 mm Hg and antiglaucoma agents were applied. F, On the fifth postoperative day, complete SO migration was observed with an IOP of 11 mm Hg. IOP indicates intraocular pressure; SO, silicone oil.

medication and without a need for antiglaucoma surgery in the follow-ups.

In eyes with SO remaining in the anterior chamber for over 4 days or an IOP of over 45 mm Hg, anterior SO or fluid extraction through paracentesis should be considered. Because of a direct anteroposterior connection, a small amount of extraction can be easily done under the slit lamp using aseptic techniques instead of entering an operating room.

Would the SO Remigrate into the Anterior Chamber?

In this study, we did not observe any SO remigration to the anterior chamber in all the eyes. Several reasons may account for this phenomenon: 1) patients were warned not to keep supine position until SO removal; 2) inferior iridotomy should be large enough to ensure the drainage of aqueous humor, even in cases of pupil dilation; 3) the aqueous flow towards the anterior chamber

TABLE 2. Operation Data and Surgical Outcomes of Adequate Silicone Oil Tamponade

Characteristics	No. (percentage)
Volume of SO (mL)*	5.8 ± 1.5
Follow-up duration (months)*	13.9 ± 11.5
Primary reattachment rate	93.5%
Secondary reattachment rate	100%
Final BCVA (logMAR)*	0.73 ± 0.39
IOP (mm Hg)*	
First postoperative day	21.7 ± 13.7
First postoperative week	15.1 ± 4.8
First postoperative month	17.5 ± 8.1
Sixth postoperative month	19.0 ± 9.0
Final follow-up	15.5 ± 4.8
Anterior chamber SO migration	
Within first postoperative day	17 (54.8%)
Average time (days)*	2.3 ± 1.8

BCVA indicates best-corrected visual acuity; IOP, intraocular pressure; SO, silicone oil.

*Data are presented as mean ± standard deviation.

through iridotomy can prevent SO from re-entering the anterior chamber; 4) due to its high viscosity and cohesion, the SO bubble tends to retract towards spherical shape rather than disintegrating into droplets.

The Current Procedure Causes No Additional Damage to Corneal Endothelium

Potential corneal endothelium damage following SO exposure was once investigated. In this study, the average corneal endothelium density showed a decrease between ($2678.6 \pm 416.1/\text{mm}^2$) at preoperation to ($2139.5 \pm 413.4/\text{mm}^2$) at the time of SO removal (6.3 ± 1.9 months interval). The endothelial loss rate was 19.1%, which was comparable to previous studies showing the cell loss rate of 19.2% and 39.2% in pseudophakic eyes and aphakic eyes respectively following regular PPV and SO tamponade.²⁸ The exposure of SO was transient (several days or less) and our data suggest no additional damage to the corneal endothelium by short-term SO exposure.

The present study is limited by its relatively small sample size due to specific application of the present procedures in complicated RD instead of uncomplicated ones, as well as the lack of a control group in which regular SO tamponade was used. Further investigation is needed to elucidate the safety and efficacy of this surgical technique. In addition, as most of the patients had cataract and underwent phacoemulsification during surgery, the improvement of BCVA cannot merely be attributed to the SO tamponade procedure. A control group without cataract is needed to approve this finding.

In summary, we propose a procedure for adequate SO tamponade, which is preliminarily proved to be feasible and efficacious. By adding an important 10% of SO, this procedure provides more pronounced tamponade effect and offers an alternative treatment strategy for complicated RD.

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