Retrospective Study on Changes in Optic Disc Structure, Macular Perfusion, and Ganglion Cell Complex Following Pars Plana Vitrectomy Combined with Silicone Oil Tamponade

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Abstract: Objective: To evaluate the dynamic changes in optic disc structure, macular blood flow perfusion, and ganglion cell complex (GCC) before and after pars plana vitrectomy (PPV) combined with silicone oil (SO) tamponade. Methods: This retrospective study enrolled 35 eyes of patients with rhegmatogenous retinal detachment (RRD) who underwent PPV combined with SO tamponade at Ningbo Eye Hospital between January 2023 and December 2025. Optical coherence tomography angiography (OCTA) examinations were performed preoperatively, during the silicone oil in situ period (3 months postoperatively), and at 3 months after silicone oil removal. Optic disc structural parameters, macular superficial and deep capillary plexus (SCP/DCP) vessel density, and GCC thickness were compared across time points. Results: Best-corrected visual acuity (BCVA) improved continuously from the preoperative period through oil removal (all $P < 0.05$). Intraocular pressure (IOP) increased during the oil-in period and returned to baseline after removal ($P = 0.969$). No statistically significant differences were observed in optic disc cup-to-disc ratio, rim area, or retinal nerve fiber layer (RNFL) thickness between the oil-in period and post-removal (all $P > 0.05$). DCP vessel density decreased significantly after oil removal compared to the oil-in period (37.54% vs. 33.78%, $P = 0.006$), while SCP showed no significant difference. GCC thickness increased significantly after oil removal compared to the oil-in period (85.28 vs. 89.60 μm, $P = 0.014$). Conclusions: Deep retinal microcirculation continued to decline after silicone oil removal, suggesting the presence of persistent deep retinal damage. GCC thickening may reflect correction of measurement bias during the oil-in period and partial structural recovery of ganglion cells. Clinically, vigilant IOP monitoring and evaluation of macular deep perfusion during the oil-in period are warranted, along with timely removal of silicone oil.

***Keywords*:** pars plana vitrectomy; silicone oil tamponade; optical coherence tomography angiography; ganglion cell complex; deep capillary plexus

1. Introduction

Pars plana vitrectomy (PPV) is the standard surgical treatment for rhegmatogenous retinal detachment (RRD) and a variety of other vitreoretinal diseases [1]. Due to its high chemical inertness, large surface tension, and long-term tamponade properties, silicone oil (SO) is widely used in complex cases including proliferative vitreoretinopathy, giant retinal tears, and endophthalmitis [2,3]. Despite high anatomical success rates, some patients continue to experience unexplained visual decline during the silicone oil in situ (SOIS) period or after silicone oil removal (ROSO), with reported incidences ranging from 1% to 33%, and the exact underlying mechanisms remain unclear [2,4].

Previous studies have confirmed that SO tamponade can induce progressive structural changes in the inner retina, including the retinal nerve fiber layer (RNFL) and ganglion cell complex (GCC) [4,5,6]. Proposed mechanisms include direct silicone oil toxicity, disruption of Müller cell potassium siphoning, and accumulation of pro-inflammatory cytokines [2]. In recent years, optical coherence tomography angiography (OCTA) has provided a novel tool for quantitative assessment of retinal microcirculation. Studies have demonstrated that decreased superficial capillary plexus (SCP) vessel density is significantly correlated with GCC loss in patients experiencing silicone oil-related visual loss [7]. Compared with gas tamponade, SO tamponade exerts a more widespread negative impact on vessel density across macular capillary layers and is associated with worse visual outcomes [8,9]. Nevertheless, comprehensive OCTA studies that systematically evaluate the dynamic changes in optic disc structure, macular perfusion, and GCC both during SO tamponade and following its removal remain limited. This study retrospectively analyzed OCTA data from patients who underwent PPV combined with SO tamponade at Ningbo Eye Hospital between 2023 and 2025, aiming to provide clinical evidence for a deeper understanding of silicone oil-related retinal toxicity and the optimization of postoperative follow-up strategies.

2. Methods

2.1 Study Population

This was a single-center retrospective cohort study enrolling patients with RRD who underwent PPV combined with SO tamponade at Ningbo Eye Hospital between January 2023 and December 2025, comprising 35 eyes in total. Inclusion criteria were: surgically confirmed RRD, complete OCTA follow-up data available at both 3 months postoperatively and 3 months after silicone oil removal, and a total follow-up duration of ≥6 months. Exclusion criteria included primary ocular diseases such as diabetic retinopathy or macular degeneration, glaucomatous optic neuropathy, substandard OCTA image quality, and incomplete clinical records. The study protocol was approved by the institutional ethics committee and complied with the principles of the Declaration of Helsinki.

2.2 Surgical Procedure

All surgeries were performed by experienced vitreoretinal surgeons using standard 23-gauge three-port pars plana vitrectomy. Complete core and peripheral vitrectomy was performed, with perfluorocarbon liquid assistance for retinal reattachment when necessary. Endolaser photocoagulation was applied to all retinal breaks and degenerative lesions, and the vitreous cavity was filled with 5000 centistoke silicone oil. Silicone oil removal was performed electively once complete and stable retinal reattachment was confirmed, in the absence of significant emulsification, and when the overall ocular condition was deemed appropriate. A subset of patients underwent concurrent phacoemulsification cataract surgery based on lens status at the time of primary surgery.

2.3 Outcome Measures

Each patient underwent the following examinations preoperatively, at 3 months postoperatively (SOIS period), and at 3 months after silicone oil removal (post-ROSO period): best-corrected visual acuity (BCVA, LogMAR); IOP (mmHg); optic disc parameters assessed by the VG200I swept-source OCTA device (cup-to-disc ratio, rim area, and peripapillary mean RNFL thickness); macular parameters including SCP and DCP vessel density within a 3 mm macular region; and mean macular GCC thickness. Due to the optical properties of silicone oil causing interference with OCTA imaging, the number of available paired measurements varied slightly across different parameters; the actual number of analyzable paired eyes (n) for each analysis is reported accordingly.

2.4 Statistical Analysis

All statistical analyses were performed using SPSS version 26.0. Following Shapiro-Wilk normality testing, normally distributed variables were described as mean ± standard deviation (x¯±s\bar{x} \pm sx¯±s), with paired t-tests and independent samples t-tests used for within-group and between-group comparisons, respectively. Non-normally distributed variables were described as median (interquartile range), with the Wilcoxon signed-rank test and Mann-Whitney U test used for within-group and between-group comparisons, respectively. A two-sided $P < 0.05$ was considered statistically significant.

3. Results

3.1 Baseline Characteristics

A total of 35 eyes were included. The mean age was 57.66 ± 10.08 years; 22 eyes (62.9%) were in male patients; 14 eyes (40.0%) were right eyes; and 16 eyes (45.7%) underwent concurrent cataract surgery. Preoperative LogMAR BCVA was 1.30 ± 0.64, mean IOP was 13.11 ± 2.01 mmHg, and mean axial length was 24.67 ± 2.19 mm.

3.2 Visual Acuity and Intraocular Pressure

LogMAR BCVA improved significantly at 3 months postoperatively compared to baseline (0.58 ± 0.34 vs. 1.30 ± 0.64, $t = -7.915$, $P < 0.001$). Median BCVA further improved at 3 months post-oil-removal compared to the oil-in period (0.30 vs. 0.52, $W = 19.500$, $P = 0.002$). The total improvement from baseline reached 0.92 ± 0.55 LogMAR ($t = -8.783$, $P < 0.001$).

IOP increased significantly during the oil-in period compared to baseline (15.49 ± 3.04 vs. 13.11 ± 2.01 mmHg, $t = 3.636$, $P < 0.001$). After oil removal, IOP declined to a median of 14.00 (11.00, 16.00) mmHg, representing a statistically significant decrease from the oil-in period ($W = 111.000$, $P = 0.012$), with no significant difference from baseline ($W = 246.000$, $P = 0.969$).

3.3 Optic Disc Structural Parameters

Comparing the oil-in period with 3 months post-oil-removal ($n = 24$), no statistically significant differences were observed in cup-to-disc ratio (0.47 vs. 0.47, $P = 0.343$), rim area (1.49 vs. 1.48 mm^2, $P = 1.000$), or mean RNFL thickness

(110.50 vs. 112.50 μm, P = 0.174). No definitive optic disc structural changes were identified between the two time points.

3.4 Macular Blood Flow Perfusion

Among the 23 eyes with available paired data, SCP vessel density changed from 40.33 ± 9.85% during the oil-in period to 38.25 ± 12.17% after oil removal, with no statistically significant difference (t = −1.531, P = 0.140). In contrast, DCP vessel density decreased significantly from 37.54 ± 9.15% to 33.78 ± 9.41%, a reduction of 3.76 ± 5.98 percentage points, which was statistically significant (t = −3.017, P = 0.006).

3.5 Macular GCC Changes

Among the 21 eyes with available paired data, mean GCC thickness increased significantly from 85.28 (76.25, 90.67) μm during the oil-in period to 89.60 (81.92, 104.90) μm after oil removal (W = 46.000, P = 0.014).

3.6 Summary of Key Parameters and Effect of Concurrent Cataract Surgery

Table 1. Comparison of Key Parameters Between 3 Months Postoperatively (Oil-in Period) and 3 Months After Silicone Oil Removal

Parameter	Oil-in Period (3 months postop)	3 Months Post-Oil-Removal	n	Statistic	P value
LogMAR BCVA	0.52 (0.30, 0.70)	0.30 (0.28, 0.52)	28	W = 19.500	0.002
IOP (mmHg)	15.00 (13.50, 17.00)	14.00 (11.00, 16.00)	35	W = 111.000	0.012
Cup-to-disc ratio	0.47 (0.29, 0.66)	0.47 (0.26, 0.66)	24	W = 4.000	0.343
Rim area (mm²)	1.49 (1.15, 1.80)	1.48 (1.15, 1.79)	24	W = 14.000	1.000
Mean RNFL thickness (μm)	110.50 (100.50, 115.25)	112.50 (100.50, 116.00)	24	W = 6.000	0.174
SCP vessel density (%)	40.33 ± 9.85	38.25 ± 12.17	23	t = −1.531	0.140
DCP vessel density (%)	37.54 ± 9.15	33.78 ± 9.41	23	t = −3.017	0.006
Mean GCC thickness (μm)	85.28 (76.25, 90.67)	89.60 (81.92, 104.90)	21	W = 46.000	0.014

Using the change from the oil-in period to post-removal as the outcome variable for each parameter, no statistically significant differences were identified between the concurrent cataract surgery group and the non-concurrent group for any parameter (all P > 0.05), indicating that concurrent cataract surgery did not significantly influence the major imaging changes.

4. Discussion

This study found that BCVA improved continuously following PPV combined with SO tamponade, while IOP showed mild elevation during the oil-in period and returned to baseline after oil removal. Optic disc structural parameters showed no statistically significant differences between the two postoperative time points. DCP vessel density decreased significantly at 3 months after oil removal compared to the oil-in period. GCC thickness increased significantly after oil removal. None of these findings were materially affected by concurrent cataract surgery.

(1) Visual acuity and intraocular pressure. In this study, BCVA improved continuously from the preoperative period through post-oil-removal, with a total improvement of approximately 0.92 LogMAR, consistent with reports by Chikmah et al. [4] and Ozsaygili et al. [8]. The further improvement in BCVA following oil removal (P = 0.002) supports the clinical decision to remove silicone oil in a timely manner once stable retinal reattachment has been achieved [2]. The pattern of IOP elevation during the oil-in period with subsequent return to baseline after removal is consistent with previously described mechanisms such as obstruction of the trabecular meshwork by emulsified silicone oil droplets [4,10], underscoring the clinical necessity of vigilant IOP monitoring throughout the oil-in period.

(2) Optic disc structural parameters. No statistically significant differences in cup-to-disc ratio, rim area, or RNFL thickness were observed between the oil-in and post-removal periods in this study. This may be attributable to several factors. The high refractive index of silicone oil can cause light signal scattering and segmentation algorithm bias in OCTA, thereby compromising the reliability of measurements obtained during the oil-in period [5,6]. Furthermore, the follow-up time points selected in this study may not have coincided with the window of greatest RNFL change, and the limited sample size may have resulted in insufficient statistical power. Zoric Geber et al. [5] prospectively demonstrated that RNFL thickness in silicone oil-filled eyes remained consistently greater than that of fellow eyes within the first 6 months, suggesting that different results might be obtained with a fellow-eye control design, extended follow-up, or a larger sample size. Overall, optic disc OCTA parameters acquired during the oil-in period should be interpreted with considerable caution.

(3) Macular blood flow perfusion. The continued decline in DCP vessel density after oil removal (P = 0.006) represents one of the more notable findings of this study. The DCP is located within the inner nuclear layer, a region that constitutes

a relative "watershed zone" of retinal vascular perfusion and is highly susceptible to ischemia and hypoxia [1,9]. Ozal et al. [9] demonstrated that in patients with macula-off RRD, silicone oil-filled eyes exhibited significantly lower vessel density in the SCP, DCP, and choriocapillaris compared to gas-filled eyes. Ma et al. [7] similarly reported that decreased SCP perfusion was significantly associated with GCC loss. The persistence of DCP decline after oil removal observed in the present study suggests that deep microcirculatory damage does not recover immediately following oil removal, and may involve multiple mechanisms, including persistent ischemic injury sustained during the period of retinal detachment, vascular remodeling during retinal reconstruction, and ongoing inflammatory responses. It is important to emphasize that, in the absence of a gas tamponade control group and preoperative macular OCTA baseline data, the observed DCP changes cannot be attributed solely to the direct toxicity of silicone oil, and more rigorously controlled study designs are required for definitive verification [1,8].

(4) GCC changes. The significant increase in GCC thickness after oil removal ($P = 0.014$) can be understood from two perspectives. From a technical standpoint, optical interference from silicone oil may have led to underestimation of true GCC thickness during the oil-in period, and measurement accuracy is expected to improve following oil removal. From a biological standpoint, there may be a degree of reversible structural recovery of the GCC, consistent with observations by Caramoy et al. [6] that silicone oil predominantly damages the inner retinal layers while the outer retina is relatively preserved. The integrative hypothesis proposed by Ma et al. [7] suggests that superficial capillary ischemia, in conjunction with phototoxicity arising from silicone oil-mediated dissolution of macular pigment, jointly drives ganglion cell apoptosis. The resolution of phototoxicity and mechanical compression following oil removal may thereby contribute to partial GCC recovery [2,7]. However, the long-term prognosis of GCC recovery remains to be established by prospective studies with extended follow-up, particularly in cases with special etiologies such as acute retinal necrosis, where complex postoperative complications after oil removal — including recurrent retinal detachment, persistent macular edema, and hypotony — may further complicate both visual and structural outcomes [10].

The principal limitations of this study include its retrospective design, limited sample size, absence of a gas tamponade control group and preoperative macular OCTA baseline, the confounding effect of silicone oil on OCTA image quality during the oil-in period, and the use of single follow-up time points for each measurement phase. Future studies should adopt a prospective design incorporating appropriate control groups, longer follow-up durations, and complementary functional assessments such as microperimetry and electrophysiology, in order to more systematically elucidate the comprehensive effects of silicone oil on retinal microcirculation and ganglion cells and their clinical implications.

Acknowledgments

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