INTRODUCTION

Pars plana vitrectomy (PPV) combined with fluid-gas exchange has been successful in the management of full thickness macular holes (MH).\(^1\) Vital dye-assisted internal limiting membrane (ILM) peel and/or tamponade with medium- to long-acting gases such as sulfur hexafluoride (SF\(_6\)) and perfluoropropane (C\(_3\)F\(_8\)) contributed to the increase in the success rate of the procedure.\(^2\) Despite remarkable advances in surgical techniques and instruments, a proportion of cases of MH (particularly those with larger or more chronic holes) fails to close after the initial surgery. This issue is important, because without anatomical success, the visual outcome will remain poor.\(^3\)

After MH surgery with gas tamponade, patients are typically instructed to remain in the prone position for several weeks to months, up to months.\(^4\) However, patients may experience discomfort and limited mobility, which can be a reason for delay in returning to their normal activities. Therefore, it is necessary to explore alternative surgical approaches that can achieve similar results without requiring such prolonged postoperative positioning.

In this study, we report the outcomes of redo macular hole surgery using light silicone oil tamponade. We aimed to assess the visual and anatomical outcomes of this approach in patients with persistent macular holes.

Abstract

**Purpose:** To study the outcomes of redo macular hole surgery using light silicone oil tamponade.

**Methods:** In this study, medical charts of consecutive patients who underwent redo pars plana vitrectomy, extended dye-assisted internal limiting membrane peel, and light silicone oil tamponade for failed previous macular hole surgery (from January 2010 to June 2014) were retrospectively reviewed. Best spectacle corrected visual acuity and anatomical closure rates were regarded as outcome measures.

**Results:** Overall, data from 13 patients was recorded and analyzed. The mean (±SD) age of patients was 66 ± 7 years, and four (30.7%) were male. Mean interval between the primary and redo surgeries was 3.7 ± 2.0 months (range, 1 to 8 months). During redo surgeries, 11 (84.6%) subjects underwent additional internal limiting membrane peeling. Mean interval between the redo surgery and silicone oil removal was 5.9 ± 2.1 months (range, 3 to 10 months). After silicone oil removal, patients were followed for 21.8 ± 14.2 months (range, 3 to 51 months). Mean best spectacle corrected visual acuity improved from 20/452 before redo surgery to 20/121 in the last follow-up examination (\(P < 0.001\)). Anatomical success was achieved in 11 (84.6%) patients: nine (69.2%) macular holes were closed and two (15.4%) were flat-open.

**Conclusions:** Redo pars plana vitrectomy with light silicone oil tamponade is an effective method for restoration of macular anatomy and function in patients with persistent macular holes.

Keywords: Internal Limiting Membrane Peeling; Macular Hole, Pars Plana Vitrectomy; Silicone Oil; Surgery

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Silicone Oil Tamponade for Persistent MH; Nowroozzadeh et al

Surgical Technique

The primary surgical technique included a sutureless 23-gauge PPV, membrane peeling (if present), and ILM peeling to at least one disc diameter from the edge of the hole. ILM was stained with Brilliant Blue G (using either Brilliant Peel [Geuder AG, Heidelberg, Germany] or ILM Blue [DORC International, Zuidland, Netherlands]) and peeled with Eckhardt end-gripping ILM forceps (DORC International). Fluid–air exchange was then performed, and the vitreous cavity was replaced with 20% SF6 or 14% C3F8. Phacoemulsification with posterior chamber intraocular lens insertion was performed in all phakic eyes, regardless of the clarity of the lens.

RESULTS

Redo MH surgery consisted of a second PPV (sutureless 23-gauge in 12 eyes and standard 20-gauge in one eye), extended ILM peeling (up to the arcade vessels) using the same method (in 11 eyes), and light SO tamponade (Oxane 5700 or 1300 [Bausch & Lomb, Kingston-upon-Thames, UK]). In this study, light SO 5700 centistokes (cSt) was used in ten eyes and light SO 1300 cSt was used in the remaining three eyes. The choice of different viscosities of the light SO was based on the availability of the light SO type in the operating room. In the setting of 23-gauge PPV, light SO 1300 cSt was preferred (which takes considerably less time to inject); if light SO 1300 cSt was not available, light SO 5700 cSt was used.

All patients were instructed to maintain a prone position for one week after operation, and to avoid supine position thereafter until SO removal, which was performed by pars plana approach at least 3 months after redo surgery.

Outcome Measures

Best spectacle corrected Snellen visual acuity (BSCVA) was recorded at baseline, after primary surgery (and before redo surgery), and at final examination. The anatomical outcome of redo surgery was classified as flat-closed MH (with apposition of MH edges), flat-open MH (flat edges without apposition), or elevated-open MH (with elevated edges and cuff of retinal detachment around the hole). Flat-closed and flat-open MHs were considered as successful anatomical outcomes.

Statistical Analysis

Data were analyzed using SPSS software version 17 (SPSS Inc., Chicago, IL). For statistical evaluation, BSCVA values were converted into logarithms of the minimum angle of resolution (logMAR) equivalents. The Kolmogorov-Smirnov test confirmed the normality of logMAR BSCVA data. Measurements obtained from different time points were compared using repeated measures analysis of variance (ANOVA) and the Bonferroni multiple comparison test. A P value of <0.05 was considered statistically significant.

for seven to ten days. Prone positioning may be very inconvenient or even impossible for some patients such as elderly, obese, or arthritic patients, or those with lumbar or cervical spine problems. Inaccurate or inadequate positioning in the early postoperative period may contribute to some cases of failure, particularly for larger holes. Optimal tamponade of MH is less compromised by inappropriate postoperative position in cases with silicone oil-filled vitreous cavity than those who receive long-acting gases such as SF6 or C3F8. Hence, silicone oil (SO) may have an advantage over gas in cases of surgery that failed secondary to presumed noncompliance with positioning. In addition, effective long-term tamponade is only possible with SO, which does not lose volume over time. Taken together, SO tamponade may be a useful alternative to gas in MH redo cases. The aim of the present study was to evaluate the anatomical and visual outcome of SO injection in failed MH surgery cases.

METHODS

Study Population

In this single-center retrospective interventional case series, the medical charts of 13 patients who underwent redo surgery with injection of light SO for failed MH surgery from January 2010 to June 2014 were reviewed. Only patients with persistent open idiopathic MH and uncomplicated primary surgery were included. Eyes with re-opening of initially successfully closed MHs were excluded. All included patients had at least 3 months of follow-up after SO removal. Subjects with other types of MH (ex, myopic, or traumatic), or concomitant ocular disorders other than cataract (such as glaucoma, diabetic retinopathy, uveitis, or corneal disorders) were excluded. Patients were operated on by multiple vitreoretinal surgeons in the same hospital. Informed consent was obtained from all subjects before operation. The study protocol was approved by the Ethics Committee at Shiraz University of Medical Sciences.

Data of 13 eyes of 13 patients who underwent redo surgery comprised of phacoemulsification combined
with 23-gauge PPV, ILM peeling and gas injection in ten (76.9%) phakic patients, and 23-gauge PPV, ILM peeling and gas injection in three pseudophakic patients. SF6 and C3F8 were used in seven (53.8%) and six (46.2%) eyes, respectively. The mean logMAR BSCVA was not statistically different at baseline and after primary (failed) surgery (1.21 ± 0.24 and 1.35 ± 0.32, respectively; \( P = 0.126 \)). Mean interval between the primary and redo surgeries was 3.7 ± 2.0 months (range, 1 to 8 months).

Table 2 presents the characteristics and outcome of redo surgery by patient. During redo surgeries, 11 (84.6%) subjects underwent additional ILM peeling. Viscosities of the injected SO were 5700 cSt in ten (76.9%) and 1300 cSt in three (23.1%) eyes. All redo surgeries were performed with the sutureless 23-gauge setting, with the exception of patient number 13 who underwent conventional 20-gauge PPV. SO removal was performed in all patients. The mean interval between the redo surgery and SO removal was 5.9 ± 2.1 months (range, 3 to 10 months).

After SO removal, patients were followed for 21.8 ± 14.2 months (range, 3 to 51 months). At the last follow-up exam, the mean logMAR BSCVA increased to 0.78 ± 0.37, which was a significant improvement from baseline (\( P < 0.001 \)) and after primary (failed) surgery (\( P < 0.001 \)). Figure 1 depicts alterations in logMAR BSCVA at baseline, before redo surgery, and at the last follow-up exam. Mean Snellen equivalent BSCVA was 20/323, 20/452, and 20/121 at baseline, after primary surgery, and at the last follow-up, respectively.

Overall, anatomical success was achieved in 11 (84.6%) patients [nine (69.2%) MHs were closed and two (15.4%) were flat-open]. In three patients, an injection of 0.4 mL undiluted C3F8 was tried about 1 month after failed primary surgery [Table 2], which was unsuccessful in all three eyes, and one patient developed inferior retinal detachment. At the last follow-up (after additional surgeries), one of these MHs remained elevated-open (failed), and two developed into flat-open configuration. One patient (number 10) developed cystoid macular edema after SO removal that responded well to a single intravitreal injection of 1.25 mg bevacizumab. Redo surgery and SO removal were not associated with major complications (such as retinal detachment, vitreous or suprachoroidal hemorrhage, endophthalmitis, or ocular hypertension requiring long-term medication or therapy) in any patients.

**DISCUSSION**

Findings of the present study indicate that redo PPV with light SO injection is associated with a significant improvement in mean BSCVA (20/452 to 20/121) and high closure rate of MH (84.6%). In addition, we found no major intra- or postoperative complications. Taken together, light SO injection seems effective and safe in the context of persistent MH.

Different protocols have been developed to classify failed MH surgery. In this study, we used the clinical classification, which was originally introduced by Tornambe et al. Based on optical coherence tomography (OCT) findings, another article classified MH closures into type 1 closure (closed without foveal neurosensory retinal defect) and type 2 closure (closed with foveal neurosensory retinal defect), which intimately correspond to flat-closed and flat-open configurations, respectively. Currently, the standard approach for MH surgery includes PPV, epiretinal membrane removal (if present), and two (15.4%) were flat-open. In three patients, an injection of 0.4 mL undiluted C3F8 was tried about 1 month after failed primary surgery [Table 2], which was unsuccessful in all three eyes, and one patient developed inferior retinal detachment. At the last follow-up (after additional surgeries), one of these MHs remained elevated-open (failed), and two developed into flat-open configuration. One patient (number 10) developed cystoid macular edema after SO removal that responded well to a single intravitreal injection of 1.25 mg bevacizumab. Redo surgery and SO removal were not associated with major complications (such as retinal detachment, vitreous or suprachoroidal hemorrhage, endophthalmitis, or ocular hypertension requiring long-term medication or therapy) in any patients.

**TABLE 1. Demographic and baseline characteristics of the study cohort**

| Patient | Sex  | Age, y | Eye | MH stage* | Lens status | VA (1) | Gas  | VA (2) | Interval, m³ |
|---------|------|--------|-----|-----------|-------------|--------|------|--------|-------------|
| 1       | Female | 56     | Right | 3       | Phakic       | 20/400 | SF6  | 20/1200 | 6.0         |
| 2       | Male   | 66     | Right | 2       | Phakic       | 20/200 | C3F8 | 20/100  | 4.5         |
| 3       | Male   | 78     | Right | 3       | Pseudophakic | 20/240 | C3F8 | 20/600  | 3.0         |
| 4       | Female | 69     | Right | 3       | Pseudophakic | 20/240 | C3F8 | 20/400  | 2.5         |
| 5       | Male   | 77     | Right | 4       | Phakic       | 20/300 | C3F8 | 20/800  | 8.0         |
| 6       | Female | 65     | Right | 3       | Phakic       | 20/1200| SF6  | 20/800  | 4.0         |
| 7       | Female | 73     | Left  | 4       | Phakic       | 20/600 | C3F8 | 20/600  | 3.5         |
| 8       | Male   | 64     | Left  | 4       | Pseudophakic | 20/600 | SF6  | 20/1200 | 1.0         |
| 9       | Female | 59     | Right | 2       | Phakic       | 20/300 | SF6  | 20/400  | 1.0         |
| 10      | Female | 59     | Left  | 3       | Phakic       | 20/240 | C3F8 | 20/400  | 5.5         |
| 11      | Female | 67     | Left  | 4       | Phakic       | 20/200 | SF6  | 20/200  | 3.5         |
| 12      | Female | 65     | Right | 3       | Phakic       | 20/200 | SF6  | 20/200  | 4.0         |
| 13      | Female | 63     | Left  | 3       | Phakic       | 20/240 | SF6  | 20/400  | 2.0         |

*aAccording to Gass classification. bBest spectacle corrected visual acuity at baseline. cBest spectacle corrected visual acuity after the failed surgery and before silicone oil injection. dThe time between the first surgery and redo surgery. MH, macular hole; m, month; VA, visual acuity; y, year
vital dye-assisted ILM peeling, and fluid-gas exchange using a long-acting gas such as C3F8 or SF6. This approach is successful in >90% of cases. However, some cases still fail after primary intervention. Several factors have been linked to the failure of primary MH surgery, including residual traction from epiretinal membrane or ILM, ineffective tamponade, poor patient compliance with proper positioning, and MH size of >400 µm. However, in some cases, no obvious cause can be found. Two main factors are considered to contribute to MH closure: removing all types of tractional forces on the hole, and limiting the passage of fluid through the hole to promote gliosis at the hole edges. The former goal is accomplished by intraoperative induction of posterior vitreous detachment (removal of vertical traction), epiretinal membrane removal, and ILM peeling (removal of tangential traction). The latter goal is achieved using long-lasting tamponade, and/or intraoperative adjuvants. During redo surgery, adequacy of epiretinal membrane or ILM removal is usually evaluated using vital dyes, and additional peeling is performed if deemed necessary. Currently, there is no consensus about the effect of the extent of ILM peeling on the closure rate of large MHs. In principle, more peeling may provide a more relaxed retina to be closed. A recent study reported less tension on the macula with extended ILM peel. In general, redo surgery is concluded with fluid-air exchange and injection of long-lasting tamponade agents such as gases or SO.

Table 2: Redo operation with light silicone oil injection and its outcome in patients with failed macular hole surgery

| Patient | ILM peel | SO, cSt | Interval, m | Anatomical result | Final VA | FUC, m | Notes |
|---------|----------|---------|-------------|-------------------|---------|--------|-------|
| 1       | Yes      | 5700    | 5.5         | Flat-closed       | 20/200  | 25     |       |
| 2       | Yes      | 5700    | 7.0         | Flat-closed       | 20/200  | 24     |       |
| 3       | Yes      | 5700    | 9.0         | Flat-closed       | 20/50   | 33     |       |
| 4       | Yes      | 5700    | 10.0        | Flat-open         | 20/100  | 27     | C3F8 was injected |
| 5       | Yes      | 5700    | 6.0         | Elevated-open     | 20/400  | 6      | Did not maintain face down position |
| 6       | Yes      | 5700    | 5.0         | Flat-closed       | 20/400  | 9      |       |
| 7       | Yes      | 5700    | 3.0         | Elevated-open     | 20/300  | 25     | C3F8 was injected; Maintained face down position |
| 8       | No       | 5700    | 7.5         | Flat-open         | 20/200  | 36     | C3F8 was injected; Developed inferior retinal detachment after C3F8 injection |
| 9       | Yes      | 5700    | 6.0         | Flat-closed       | 20/100  | 27     |       |
| 10      | No       | 5700    | 5.5         | Flat-closed       | 20/30   | 12     | Developed macular edema after SO removal, which responded to 1 intravitreal injection of bevacizumab |
| 11      | Yes      | 1300    | 4.0         | Flat-closed       | 20/50   | 51     |       |
| 12      | Yes      | 1300    | 5.0         | Flat-closed       | 20/70   | 5      |       |
| 13      | Yes      | 1300    | 3.0         | Flat-closed       | 20/70   | 3      |       |

The time between redo surgery and silicone oil removal. A 0.4 mL undiluted C3F8 was injected into the vitreous cavity about 1 month after the failed primary operation. In these patients, the macular hole remained open after C3F8 injection. Follow up after silicone oil removal. ILM, internal limiting membrane; cSt, centistoke; FU, follow-up; m, month; SO, silicone oil; VA, visual acuity.

Figure 1. Mean logMAR visual acuity (central line) with 95% confidence intervals of the mean (error bars) for baseline (1), before redo operation (2), and final (3) measurements. BSCVA, best spectacle corrected visual acuity; LogMAR, logarithm of the minimum angle of resolution.
| Study                          | No. Eye (case) | Age, y | Procedure                        | ILM Peel | Dye | Adjuvant | Tamponade | FU, m | Success, % | Mean Visual Acuity | Notes                                                                 |
|-------------------------------|----------------|--------|----------------------------------|----------|-----|----------|-----------|-------|------------|---------------------|-----------------------------------------------------------------------|
| Ie et al., 1993               | 12 (11)        | 63     | 20-g PPV                         | No       | No  | TGF-β2   | C3F8      | 11    | 100        | 20/265              | 20/108; 0.005 The VA was calculated from available data              |
| Smiddy et al., 1996          | 48 (46)        | 62     | 20-g PPV                         | No       | No  | TGF-β2   | C3F8      | 7.4   | 83 (40/48) | 20/140              | 20/60                                                                  |
| Kozy and Maberley, 1996      | 17             |        |                                   |          |     | TGF-β2   | Gas       | 94    | (16/17)    |                     | 1.76 lines improvement                                                |
| Ezra et al., 1997            | 46             | 66     | 20-g PPV                         | No       | No  | Autologous Serum | C3F8      | 10.3  | 80.0 (37/46) |                     | Median; 20/60 Membranectomy was done in 29/46 eyes. VA was reported for closed holes. |
| Johnson et al., 1997         | 23             | 69±6   | Outpatient fluid-gas exchange (C3F8) | No       | No  | None     | C3F8      | 13.2  | 74 (17/23) | 20/247              | 20/86; <0.001 The VA was calculated from available data               |
| Ikuno et al., 1998           | 13 (12)        | 64±8   | Outpatient fluid-gas exchange (SF6) | No       | No  | Laser (to the hole bed) | SF6       | 10.2±4.2 | 92.3 (12/13) | 20/200              | 20/98; 0.005 The VA was calculated from available data               |
| Kumar et al., 2002           | 8              | 69     | Standard PPV                     | No       | No  | Autologous Serum | LSO       | 7.5   | 87.5 (7/8) |                     | 0.03 logMAR improvement                                               |
| Iwase and Sugiyama, 2007     | 7              | 66±8   | Outpatient fluid-gas exchange (SF6) | No       | No  | None     | SF6       | 100   |            | 20/138              | 20/46                                                                  |
| Hillenkamp et al., 2007      | 28             | 71     | Standard PPV                     | No       | ICG | Platelet: 22 Blood: 1 None: 1 | SF6: 15 | 15.3±8.6 | 68 (19/28) |                     | 0.6±3.3 lines improvement                                              |
| Saeed et al., 2009           | 5              |        |                                   | Yes      | TB  | None     | HSO       | 3     | 60.0 (3/5) | 20/142             | 20/81; 0.109 One of the failed eyes was reported to have flat edges. |
| Rizzo et al., 2009           | 23             | 69     | 20-g PPV                         | No       | ICG | None     | HSO       | 12    | 87.0 (20/23) | 20/276              | 20/81; P<0.001                                                       |

Contd...
Intraocular tamponade in redo surgeries was the only consistent finding in all presented studies, implying its fundamental role in closure of persistent MHs. In fact, several studies demonstrated that intraocular tamponade for an extra period of time without any other intervention was associated with successful closure of MH in the majority of treated eyes. Table 3 also reveals that older studies (before 2007) tended to use intra- or peri-operative adjuvants such as laser, autologous blood, or transforming growth factor-β to increase the overall success of MH surgery, while in recent studies adjuvants were substituted by chromovitrectomy and advancement of ILM removal.

For unsuccessful primary MH surgery, light SO has been advocated as a tamponade. Kumar et al. reported that of the eight previously failed MH surgeries, six were closed and two were flat-open after light SO (1300 cSt) tamponade. One of the closed holes re-opened after SO removal. Based on the criteria used in the present study for MH closure, the final success rate reached 87.5% (7/8). Among other methods, Hillenkamp et al. reported 12 cases of persistent MH treated with light SO tamponade, of which eight (66.7%) were successfully closed. In comparison, our data indicates an 84.6% success rate of anatomical closure, corroborating previous evidence about the value of light SO in the context of failed MH surgery.

Long-acting gases as intraocular tamponades in persistent MH have advantages over SO. Gases could be injected in an office-based setting (and are hence more cost-effective), claimed to be less toxic to the retina, and need no additional procedure for removal. In contrast, SO is less position dependent (especially when the vitreous cavity is properly filled), do not limit air travel, and is associated with faster visual rehabilitation. Therefore, SO may be preferred over gases in monocular patients, socially active individuals, or those who are unable or unwilling to restrict their position. In fact, adequate light SO-MH apposition could be achieved in any position except the supine position (Figure 2), while patients with gas-filled eyes should usually be instructed to maintain the prone position for several hours a day for about one week. In addition, unlike gases, SO do not lose volume over time, and can offer longer-term tamponade for complicated cases such as very large MHs that theoretically need longer periods of tamponade to accomplish gliosis around their lengthy edges.

Heavy SO has shown promise in the treatment of persistent MHS. It has the advantage of maximum tamponade effect in the supine position (a more comfortable position for most patients) and offers even less position limitation compared to light SO. Heavy SO may be especially useful in patients who have to maintain strict supine positioning for other medical reasons. However, removal of heavy SO is more

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Table 3. Contd...

| Study | No. Eye Age (case) | Mean Age, y | Procedure | ILM Peel | Dye | Adjuvant | Tamponade | FU, m | Success, % Mean Visual Acuity | Notes |
|-------|-------------------|-------------|------------|----------|------|----------|-----------|------|-----------------------------|-------|
| Lappas et al., 2009 | 12 68±7 Standard PPV | No ICG None | HSO | 4.8±1.4 | 83.3 (10/12) | 20/160 | >0.001 | 83.3 (10/12) | 20/160 | <0.001 | One patient failed after redo surgery and one macular hole reopened after HSO removal. Two of the failed eyes were reported to have flat edges. |
| Moisseiev, et al., 2013 | 29 69±6 3-port PPV | Yes (88.6%) ICG None | SFG/C3F8 | 12.9±10 | 68.9% (20/29) | 20/250 | 20/135 | 68.9% (20/29) | 20/250 | <0.001 | 
| Che et al., 2014 | 13 65±6 23-g PPV | Yes (up to arcades) ICG None | C3F8 | 61.5 (8/13) | 20/214 | 20/126 | 0.021 | 61.5 (8/13) | 20/214 | <0.001 | Two of the failed eyes were reported to have flat edges. |
| Present | 13 66±7 23-g PPV | Yes | BBG None | LSO | 21.8±14.2 | 84.6 | 20/452 | 84.6 | 20/452 | <0.001 | Two of the failed eyes were reported to have flat edges. |
| BBG, brilliant blue G; FU, follow-up; HSO, heavy silicone oil; ICG, indocyanine green; ILM, internal limiting membrane; LSO, light silicone oil; NO., PPV, pars plana vitrectomy; TB, trypan blue; TGF, transforming growth factor; VA, visual acuity; y, year.
In summary, redo surgery with light SO tamponade is an effective and safe procedure for management of persistent MHs. Light SO tamponade may be optimal for very large holes that are supposed to benefit from long-term tamponade, or for individuals who plan to travel, cannot maintain prone positioning, or are monocular. Considering the current scarcity of well-designed studies, multicenter, randomized clinical trials comparing different materials for intraocular tamponade in redo surgery for persistent MHs are warranted.

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Conflicts of Interest
There are no conflicts of interest.

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