POSTOPERATIVE POSITIONING IN MACULAR HOLE SURGERY

An Objective Evaluation of Nonsupine Positioning and the Effect of the "Tennis Ball Technique"

VEGARD ASGEIR FORSAA, MD,*† JØRGEN KROHN, MD, PhD†‡

Purpose: To objectively evaluate patients' compliance with a nonsupine positioning (NSP) regimen after macular hole surgery and to investigate whether supine positioning time during the first postoperative nights is reduced when a tennis ball is mounted onto the back of the nightshirt.

Methods: A "position monitoring device" capable of recording the time the head is kept in a supine position was attached to the patient's forehead. In a randomized, controlled, crossover study, the accumulated time each patient spent in a supine position was recorded during two consecutive postoperative nights, both when the "tennis ball technique" (TBT) was used and when it was not, respectively.

Results: The study included 40 participants. A mean supine time of 14 minutes and 47 seconds was registered with the NSP regimen. When applying the TBT, the mean supine time was significantly reduced to 4 minutes and 24 seconds ($P = 0.01$). Seven "noncompliant" participants with >30 minutes supine time without TBT had the most marked reduction in supine time from a mean of 63 minutes and 2 seconds, to 3 minutes and 46 seconds, with TBT ($P = 0.02$).

Conclusion: During an NSP regimen, patients generally maintain a high level of compliance after macular hole surgery. The TBT further improves their compliance significantly.

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In full-thickness macular hole (FTMH) surgery, major attention has been paid to the postoperative positioning. In the first decades after the introduction of FTMH surgery with pars plana vitrectomy (PPV) and gas tamponade, strict face-down positioning (FDP) was advocated during the early postoperative weeks.[1] However, FDP remains of unproven benefit,[2,3] and several studies have reported favorable closure rates of FTMH without FDP.[4–7] Recently, we reported no statistically significant difference in the closure rates between patients who applied strict FDP, versus patients whose only restriction was to avoid upward gaze and supine sleeping position.[8] In the latter regimen, which we termed nonsupine positioning (NSP), we also used the so-called "tennis ball technique" (TBT). This technique is intended to improve the patients' compliance by fastening a tennis ball to the back of their nightshirt.[9] It is essential to avoid the supine position in the early postoperative period.

To the best of our knowledge, only two studies have objectively investigated postoperative head positioning after FTMH surgery by means of a positioning monitoring device.[10,11] Verma et al[10] used an electronic device placed in an earpiece equipped with a mercury switch triggered by the angle of tilt. In the setting of an FDP regimen, they found that patients spent, on average, only 38% of the time with their heads facing down. Not surprisingly, it was most difficult to maintain the correct postoperative head positioning between midnight and early morning. It is unlikely that sleeping patients can maintain an ideal

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head position, as they inadvertently may position themselves supine. Recently, Leitritz et al[11] published a pilot study using a gravity- and tilt-compensated sensor, with data-logging function, to measure head positioning after FTMH surgery, based on the recommendation of FDP. Their key finding was that the patients, on average, remained compliant to FDP for only 17% to 18% of the time, during a postoperative period of 24 hours. The aims of this study were to objectively evaluate the postoperative sleeping position in the setting of NSP and to determine the impact of the TBT on the positioning compliance.

Materials and Methods

This prospective, randomized, controlled, crossover trial was conducted at the Departments of Ophthalmology at Stavanger University Hospital and Haukeland University Hospital, between October 2013 and November 2014. The inclusion criteria were maculopathies treated with pars plana vitrectomy, followed by intraocular gas tamponade, that is, FTMH and conditions such as vitreomacular traction, lamellar macular hole, and epiretinal membrane, in which postoperative FTMH formation is a risk. The exclusion criteria were patients aged less than 18 years, conditions that could hinder the patients from maintaining their normal sleeping position, and inability to understand or sign the informed consent form. The maculopathies were classified according to the recently published classification system of the International Vitreomacular Traction Study Group.[12] A meaningful power analysis was not possible because of the absence of data on NSP compliance in the literature. The sample size of 40 participants was therefore a result of practical considerations.

The study was registered and approved by The Regional Committee for Medical and Health Research Ethics, South-East Norway, and followed the official ethical regulations for clinical research and the Declaration of Helsinki. The Clinical Trials Identifier for the study was NCT02011165. All patients gave their written informed consent before participating in the study.

Instrumentation and the Tennis Ball Technique

A head-mounted position monitoring device (PMD) was specifically developed for this study. The device has a sensor, or tilt switch, of the rolling ball type (RBS070310; OncQue Corporation, Taichung, Taiwan), which is electrically connected to a battery and a small, analog watch with a second hand (TW58834A-BA; Club, F. E. Rasmussen AS, Oslo, Norway). These components are mounted inside a box (made of black thermoplastic material) with a partially transparent cover, enabling us to see the watch, and read the exact time. The outer dimensions of the box are 8.5 cm × 4.5 cm × 2.5 cm, with a curved rear side to allow comfortable placement of the PMD on the patients' forehead (Figure 1, A and B). A 25-mm wide adhesive medical tape (3M Durapore; 3M Center, St Paul, MN, USA) is used to attach and secure the device (Figure 2A). The key component of the PMD is the tilt switch, which is placed centrally within the box corresponding to the patient's glabellar region. Once the switch is in the upright position, it will be in a conductive "on" state. When it is tilted more than approximately 45° to any direction (in a full 360° circle), the switch will be in a nonconductive "off" state. Thus, the tilt switch will start the watch when the head of the patient is in the supine position and will stop the watch when the head is turned beyond 45° to either side. In this way, the PMD records the accumulated time the patient has kept the head in supine or near-supine position.

To prevent the patients from sleeping in the supine position, an ordinary tennis ball was attached to the back of a t-shirt by means of a rubber band. The ball

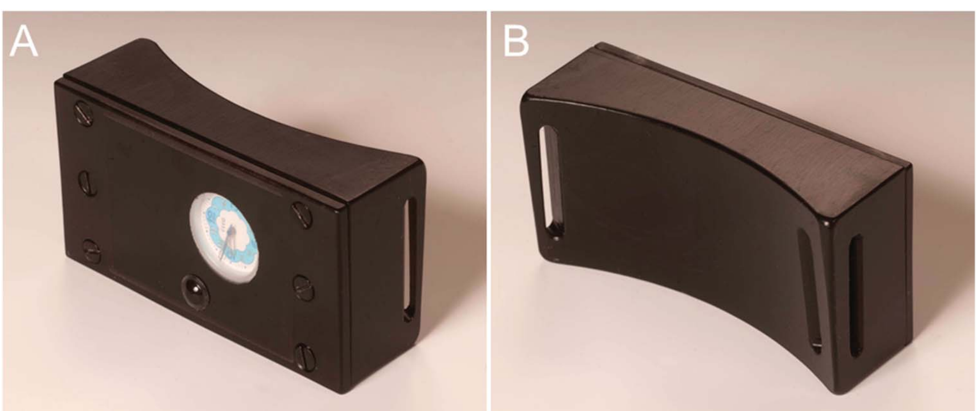

Fig. 1. A. Front view and (**B**) rear view of the head position–monitoring device.

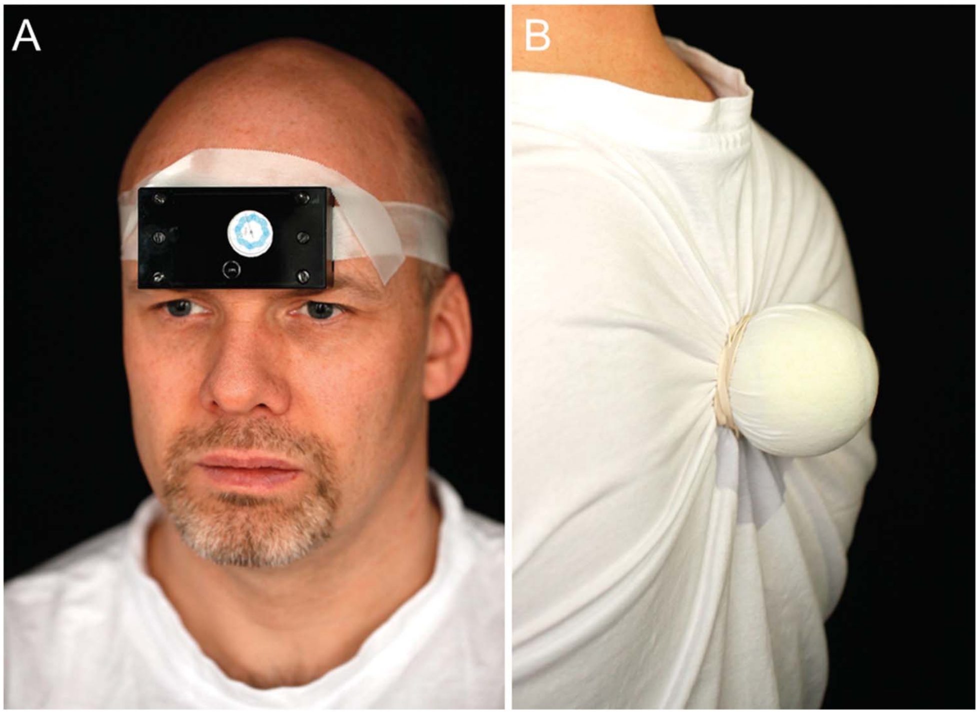

Fig. 2. A. Head position–monitoring device attached to the patient's forehead with medical tape. **B.** Patient demonstrating the tennis ball technique by wearing a t-shirt with a tennis ball attached to the back, by means of a rubber band.

should be placed in the middle of the patient's back, between the shoulder blades, and the shirt has to be rather tight to ensure the location of the tennis ball (Figure 2B).

Procedures

A postoperative NSP regimen was applied, which means that the patients were instructed to maintain their daily activities, but to avoid upward gaze and a supine sleeping position at any time. Each study participant had to wear the PMD on the ward for 12 hours, from 9.00 PM until 9.00 AM, for 2 consecutive nights after surgery. They were assigned to two groups using a restricted randomization technique. One night the patients were assigned to the TBT, that is, they had to wear a nightshirt with a tennis ball fastened to the back, whereas no specific arrangements were made for the other night. The TBT was randomized to either the first or the second postoperative night. When the PMD was removed from the patient's forehead in the morning, the total duration of supine positioning was calculated by determining the exact time difference between the 9.00 PM and 9.00 AM readings.

In addition to these objective data, scoring forms and questionnaires were used to collect some baseline and endpoint parameters. Before surgery, and based on a purely subjective evaluation of the patients' behavior and response during the clinical examination, the investigator scored the expected patient compliance regarding the forthcoming postoperative positioning on a 4-point scale (0 = no compliance; 3 = very high rate of compliance). The patient's preferred sleeping position (lying on the right side, left side, either side alternately, back, or stomach) was also registered. After the second postoperative night, the patients scored the degree of discomfort on a 4-point scale (0 = no discomfort; 3 = severe discomfort) caused by the PMD and the TBT, respectively.

Statistical Analysis

Comparisons between groups were made using the Mann–Whitney *U* test for continuous variables. The Wilcoxon signed-rank test was used to evaluate the efficacy of the TBT. Spearman's correlation was used to evaluate the relationship between the investigators' preoperative scoring of patient compliance, and the patients' actual compliance. Two-tailed *P* values <0.05 were considered statistically significant. The statistical analyses were made by IBM SPSS statistics, software version 21.0 (SPSS, Inc, Chicago, IL).

Results

Forty-three patients were assigned to the study. In two patients, the PMD was displaced during sleep, and a third patient decided to withdraw from the study after the first night. Thus, the final study population included 40 patients (15 men and 25 women). The mean age at the time of surgery was 70.6 years (SD = 6.8 years). Demographic and baseline characteristics are presented in Table 1.

During the night without the use of the TBT, a mean supine time of 14 minutes and 47 seconds (SD = 27:02) was registered, showing compliance to the NSP regimen for 97.9% of the time. When applying the TBT, the mean supine time was reduced to 4 minutes and 24 seconds (SD = 9:28), which means that the patients remained compliant to the NSP regimen for 99.4% of the time. The mean reduction in supine positioning time by the TBT regimen of 10 minutes and 23 seconds (SD = 28:33) was statistically significant (P = 0.01) (Figure 3). Median time in supine position during the night with TBT was 26 seconds (range, 00:00:00–00:42:15), compared with 2 minutes and 20 seconds (range, 00:00:00–01:53:46) during the night without any specific arrangement.

The patients were categorized into 3 different levels of compliance: as "compliant," with less than 1 minute in a supine position; as "moderately compliant," with 1 minute to 30 minutes in a supine position; and as "noncompliant," with more than 30 minutes in a supine position. Without TBT, 17 patients (42.5%) were categorized as "compliant," and the number increased to 25 (62.5%) with TBT. Sixteen patients (40.0%) without TBT were categorized as "moderately compliant," and the number decreased to 13 (32.5%) with TBT. Seven patients (17.5%) were categorized as "noncompliant" without TBT, and the number decreased to 2 (5.0%) with TBT (Figure 4).

In the subgroup of patients classified as "noncompliant" without TBT, the supine time decreased significantly, from a mean of 63 minutes and 2 seconds (SD = 34:33) to a mean of 3 minutes and 46 seconds (SD = 06:34) with TBT (P = 0.02). The supine time in the "moderately compliant" patients decreased significantly from a mean of 9 minutes and 3 seconds (SD = 7:59) without TBT, to a mean of 5 minutes and 59 seconds (SD = 11:02) with TBT (P = 0.03). Finally, the supine time in the "compliant" patients without TBT showed no significant change in supine time from a mean of 20 seconds (SD = 00:16) to a mean of 3 minutes and 10 seconds (SD = 09:08) using TBT (P = 0.61).

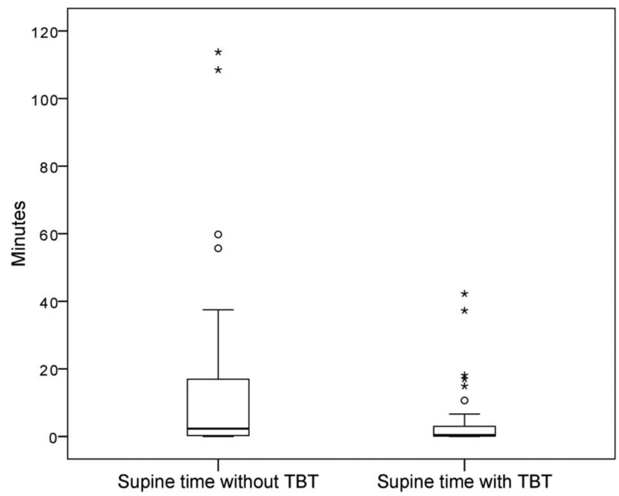

Fig. 3. Box plot of patients' supine positioning time, with and without the use of the tennis ball technique. A line inside the box indicates the median. The length of the box is the interquartile range (IQR). Values more than 1.5 IQR's but less than 3 IQR's from the end of the box are labeled as outliers (o). Values more than 3 IQR's from the end of the box are labeled as extreme, denoted with an asterisk (*).

Table 1. Demographic and Baseline Characteristics

Age, mean (SD), years	70.6 (6.8)
Sex, male/female	15/25
Indication for surgery, n = 40	
Primary FTMH,* n (%)	29 (72.5)
ERM,† n (%)	4 (10.0)
Lamellar MH,‡ n (%)	2 (5.0)
Macular pseudohole, n (%)	2 (5.0)
Secondary FTMH, post-RD,§ n (%)	2 (5.0)
VMT,¶ n (%)	1 (2.5)
Subgroup of primary FTMH with duration less than 36 months, n = 27	
Small FTMH <250 μm, n (%)	2 (7.4)
Medium FTMH ≥250 μm and <400 μm, n (%)	7 (25.9)
Large FTMH ≥400 μm, n (%)	18 (66.7)
VMT, n (%)	9 (33.3)
Mean FTMH diameter, μm (SD)	461 (138)

*Full-thickness macular hole.
†Epiretinal membrane.
‡Macular hole.
§Retinal detachment.
¶Vitreomacular traction.

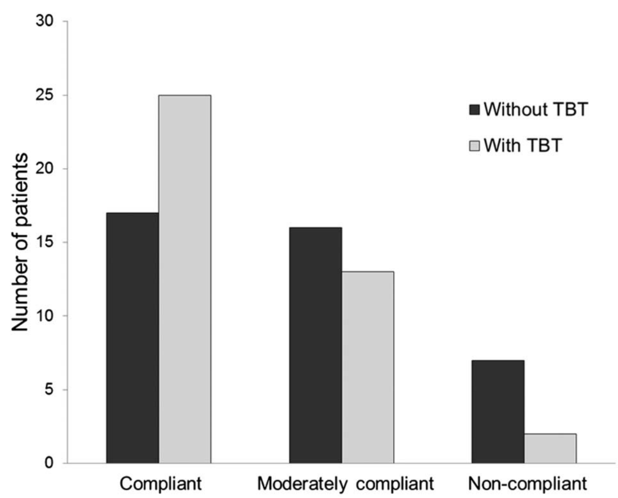

Fig. 4. Number of patients categorized into three different levels of compliance, with and without the use of the tennis ball technique. Compliant: less than 1 minute in a supine position. Moderately compliant: 1 minute to 30 minutes in a supine position. Noncompliant: more than 30 minutes in a supine position.

During the first postoperative night, the patients were positioned supine for a mean of 8 minutes and 40 seconds (SD = 19:45), compared with 10 minutes and 31 seconds (SD = 21:59) during the second postoperative night ($P = 0.86$).

The investigators' preoperative scoring of patient compliance on the 4-point scale did not correlate significantly with the patients' actual compliance (without TBT) ($r = -0.29$, $P = 0.07$).

Twenty-seven participants had a diagnosis of primary FTMH, with a duration of less than 36 months. They all underwent vitrectomy with complete internal limiting membrane peeling after staining with brilliant blue G (Brilliant Peel; Fluoron GmbH, Ulm, Germany). In this group, 25 patients (92.6%) achieved primary FTMH closure. During the first night after surgery, the 2 patients with primary failure had a supine time of 42 minutes and 15 seconds and 16 minutes and 11 seconds, respectively, whereas the mean supine time among the patients with primary closed FTMH was 8 minutes and 30 seconds (SD = 22:52). The FTMH diameter in the 2 patients with primary failures was 533 μm and 699 μm, respectively, whereas the mean diameter of the primary closed MH was 448 μm (SD = 134 μm).

In the questionnaires, the patients were asked to indicate their preferred sleeping position. Thirty-seven patients (92.5%) preferred to sleep in a side position, whereas only 2 (5%) preferred the supine, and 1 (2.5%) preferred the face-down position. The tolerability of PMD and the TBT, explored using a 4-point scale, showed a mean score of 0.25 (SD = 0.49) and 0.65 (SD = 0.66) for TBT and PMD, respectively, which indicated that both were well tolerated.

Discussion

Today the discussion of postoperative positioning after FTMH surgery has come down to the question: How much of a "safety margin" is necessary to protect the closing FTMH against the residual intraocular fluid, without compromising the closure rate? The safety margin is maximized with strict FDP, as the FTMH then has the longest possible distance to the residual intraocular fluid. Increasing evidence supports the view that the large safety margin of FDP is not needed to obtain high closure rates.[5–8] Just avoiding the supine position by following the NSP regimen during the early postoperative phase seems to be sufficient. In this setting, the patients are allowed to walk around, sit, and sleep on either side, as the small amount of intraocular fluid is located inferior to the FTMH. However, the sloshing of residual intraocular fluid causes shear forces that may inhibit the nascent bridging of the FTMH.[13] Tornambe[14] proposes the importance of keeping the macula dry, and thereby allowing the retinal pigment epithelium to remove intramacular fluid. As the swelling resolves, the edges of the FTMH fuse, and the defect closes after 3 hours to 3 days.[15,16] Consequently, the early avoidance of the supine position is essential to achieve FTMH closure.

For 99.4% and 97.9% of the time, patients remained compliant with the NSP regimen with and without TBT, respectively. Such high compliance rates are reasonable as 92.5% of the participants preferred to sleep in a side position. However, as shown by Verma et al and Leitritz et al, it is much more challenging to maintain a high compliance with the FDP regimen.[10,11] Their participants were compliant with FDP for only 38%, and 17% to 18% of the time, respectively. Although an NSP regimen is sufficient for macular hole closure, FDP may be needed after other types of vitreoretinal surgery such as retinal detachment repair with intraocular gas or silicone oil tamponade. Then, the TBT can be modified by attaching two or three tennis balls to the back of the patient's nightshirt.

Previous studies debating the necessity of postoperative FDP have not been based on objective registrations of patient compliance. This study demonstrates that after FTMH surgery, patients spend significantly less time in the supine position during the night when TBT is applied, compared with the night when this technique was not used ($P = 0.01$). Thus, the TBT should be recommended if a supine position is considered potentially harmful to the patient.

We observed distinct, individual differences in the patients' general positioning compliance and the effect of the TBT. The "noncompliant" patients with more than 30 minutes in the supine position reduced their supine time significantly using TBT. Those were the ones who benefitted most from the TBT regimen. The "moderately compliant" patients, with 1 minutes to 30 minutes in the supine position, also reduced their supine time significantly when applying the TBT. As expected, the already "compliant" patients with less than 1 minute supine positioning without TBT did not improve the compliance significantly using TBT.

It would have been helpful if the vitreoretinal surgeons were able to predict the patients' compliance regarding the forthcoming postoperative positioning. The investigators' preoperative scoring showed a weak, but not significant, correlation with the actual compliance. Therefore, such subjective assessments are not reliable.

The main strength of this study is its design as a prospective, randomized, controlled, crossover trial. A limitation is the construction of the PMD, which only records the accumulated time the patient has kept the head in a supine position. Thus, whether the measured supine time is the sum of many short or a few longer supine periods remains unknown. To answer this question, a position sensor with near-continuous logging of the head position is necessary.

Among the primary FTMH with a duration of less than 36 months, the closure rate of 92.6% is in accordance with previous studies of NSP.[5–8] Although the two failures were characterized by relatively large macular hole diameters, it is tempting to speculate that the surgical outcome may have been influenced by longer periods of supine positioning during the first postoperative night. However, a sufficiently powered, prospective study is needed to investigate the relationship between supine time and closure rate. A PMD, such as the one described in this study, can be used to explore the effects of postoperative positioning on the outcome of FTMH surgery.

Key words: face-down positioning, macular hole, prone positioning, retina, vitrectomy, vitreoretinal surgery.

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References

1. Kelly NE, Wendel RT. Vitreous surgery for idiopathic macular holes. Results of a pilot study. Arch Ophthalmol 1991;109:654–659.
2. Solebo AL, Lange CA, Bunce C, et al. Face-down positioning or posturing after macular hole surgery. Cochrane Database Syste Rev 2011:CD008228.
3. Tatham A, Banerjee S. Face-down posturing after macular hole surgery: a meta-analysis. Br J Ophthalmol 2010;94:626–631.
4. Tornambe PE, Poliner LS, Grote K. Macular hole surgery without face-down positioning. A pilot study. Retina 1997;17:179–185.
5. Simcock PR, Scalia S. Phacovitrectomy without prone posture for full thickness macular holes. Br J Ophthalmol 2001;85:1316–1319.
6. Tranos PG, Peter NM, Nath R, et al. Macular hole surgery without prone positioning. Eye 2007;21:802–806.
7. Alberti M, la Cour M. Face-down positioning versus non-supine positioning in macular hole surgery. Br J Ophthalmol 2015;99:236–239.
8. Forsaa VA, Raeder S, Hashemi LT, et al. Short-term postoperative non-supine positioning versus strict face-down positioning in macular hole surgery. Acta Ophthalmol 2013;91:547–551.
9. Oksenberg A, Silverberg D, Offenbach D, et al. Positional therapy for obstructive sleep apnea patients: a 6-month follow-up study. Laryngoscope 2006;116:1995–2000.
10. Verma D, Jalabi MW, Watts WG, et al. Evaluation of posturing in macular hole surgery. Eye 2002;16:701–704.
11. Leitritz MA, Ziemssen F, Voykov B, et al. Usability of a gravity- and tilt-compensated sensor with data logging function to measure posturing compliance in patients after macular hole surgery: a pilot study. Graefes Arch Clin Exp Ophthalmol 2014;252:739–744.
12. Duker JS, Kaiser PK, Binder S, et al. The international vitreomacular traction study group classification of vitreomacular adhesion, traction, and macular hole. Ophthalmol 2013;120:2611–2619.
13. Angunawela RI, Azarbadegan A, Aylward GW, et al. Intraocular fluid dynamics and retinal shear stress after vitrectomy and gas tamponade. Invest Ophthalmol Vis Sci 2011;52:7046–7051.
14. Tornambe PE. Macular hole genesis: the hydration theory. Retina 2003;23:421–424.
15. Eckardt C, Eckert T, Eckardt U, et al. Macular hole surgery with air tamponade and optical coherence tomography-based duration of face-down positioning. Retina 2008;28:1087–1096.
16. Masuyama K, Yamakiri K, Arimura N, et al. Posturing time after macular hole surgery modified by optical coherence tomography images: a pilot study. Am J Ophthalmol 2009;147:481–488.

AIR TAMPONADE COMBINED WITH NONSUPINE POSITIONING IN MACULAR HOLE SURGERY FOR PSEUDOPHAKIC EYES

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Purpose: To investigate the closure rate of primary full-thickness macular hole, following intraocular air tamponade combined with a nonsupine positioning regimen.

Methods: A prospective study of patients with full-thickness macular hole, who underwent pars plana vitrectomy with internal limiting membrane peeling and intraocular air tamponade followed by 3 days of nonsupine positioning. Outcome measures were primary full-thickness macular hole closure and improvement in best-corrected visual acuity after 6 months.

Results: A total of 34 eyes were included. In the group of full-thickness macular hole ≤400 μm, primary closure occurred in 95% (19/20), whereas only 57% (8/14) of those >400 μm closed (P = 0.01). The mean gain in best-corrected visual acuity was 3.5 ETDRS (Early Treatment Diabetic Retinopathy Study) lines (SD = 1.5) ($P < 0.01$). The air bubble meniscus height at the first postoperative day was estimated to a mean of 59% (range, 50–70%), at the second postoperative day it was 46% (range, 40–55%), and the third day it was 39% (range, 30–45%). Mean intraocular air bubble duration was 10 days (range, 8–13 days).

Conclusion: The combination of air tamponade and nonsupine positioning regimen leads to high closure rates for small/medium macular holes (≤400 μm), but not for large macular holes (>400 μm).

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Ever since the introduction of macular hole surgery in the early 1990s,[1] the use of pars plana vitrectomy followed by gas tamponade and face-down positioning (FDP) has been considered as the standard treatment for full-thickness macular holes (FTMH). The main effect of the gas bubble is to keep the macula dry and isolated from the vitreous fluid. This allows the retinal pigment epithelium to absorb the subfoveal fluid and reduce the intraretinal edema, facilitating fusion of the retinal edges and sealing of the FTMH.[2]

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Both the FDP and the intraocular gas tamponade contribute to patients' discomfort. The necessity of a postoperative FDP regimen is under continuing debate, and several studies where FDP has been abandoned report closure rates above 90%.[3–9] Recently, the authors have shown that a nonsupine positioning (NSP) regimen is sufficient to achieve high rates of macular hole closure.[5,10] In these studies, we also introduced the so-called "tennis ball technique" by fastening a tennis ball to the back of the patients' nightshirt. This technique significantly improved the patients' compliance with the positioning requirements, such that the patients were adherent to the NSP regimen 99% of the time.[10]

Intraocular gas tamponade has a duration of 4 weeks to 8 weeks, depending on the type and concentration of gas used. During this period, the patients were restricted from driving and air travel. In addition, if a patient requires surgery with general anesthesia, nitrous oxide must not be used as long as intraocular gas or air is present.[11] Air tamponade has a considerable shorter duration. In phakic eyes, the intraocular half-life of air is shown to be 1.3 days.[12] When a postoperative FDP is applied, the air tamponade sufficiently isolates the macula from the vitreous fluid, and closure rates between 91% and 100% have been achieved.[13–17] To date, we have found 8 published studies that have aimed to verify the FTMH closure by optical coherence tomography (OCT) 24 hours after surgery (Table 1).[17–24] Pooled together, these studies included 260 patients. In 163 of the cases (63%), the macula could be reliably assessed by OCT at 24 hours postoperatively, and this subset had an FTMH closure rate of 82%. Consequently, in most cases, the decisive morphologic process of FTMH closure takes place during the first 24 hours.

Compared with conventional FTMH surgery, the use of intraocular air tamponade and an NSP regimen reduces the patients' burden in the postoperative period. The main objective of this prospective study was to investigate the FTMH closure rate when air tamponade is combined with postoperative NSP in macular hole surgery.

Materials and Methods

Study Design and Patients

The study was conducted at the Department of Ophthalmology, Stavanger University Hospital, from September 2012 to March 2016. It adhered to the tenets of the Declaration of Helsinki and was performed after approval by the Regional Committee for Medical and Health Research Ethics, South East Norway. All patients gave their written informed consent before participating in the study. The study was registered at ClinicalTrials.gov with the registration numbers NCT01680068 and NCT02028481.

The study was planned to include a total of 50 patients, with an interim analysis being performed after enrollment of 20 participants. This sample size was based on practical considerations. The inclusion criteria were primary FTMH with a duration of symptoms of less than 36 months and pseudophakia. Phakic patients were informed about the study and asked to undergo a cataract operation before inclusion in the study. The exclusion criteria were high myopia ($\geq$6 diopters), previous vitreoretinal surgery, ocular trauma, and other diseases that affected visual function. The primary outcome measure was anatomical closure of the FTMH, defined as complete closure of the inner retinal layers assessed by spectral-domain OCT (SD-OCT).

Ophthalmologic Examination and Surgical Procedures

All patients underwent preoperative and postoperative ophthalmic examinations including best-corrected visual acuity (BCVA) using the Early Treatment Diabetic Retinopathy Study (ETDRS) chart, expressed as ETDRS letter score, measurement of intraocular pressure (IOP) by Goldmann applanation tonometry, slit-lamp biomicroscopy, indirect ophthalmoscopy, and SD-OCT (Topcon 3D OCT 2000; Topcon Corp., Tokyo, Japan) imaging of the macula. The classification of the FTMH was done according to the International Vitreomacular Traction Study Group classification.[25] All surgeries were performed in retrobulbar anesthesia by the first author. The surgery consisted of a standard 3-port 23-gauge pars plana vitrectomy with triamcinolone-assisted induction of posterior hyaloid separation. The peripheral vitreous was removed as completely as possible without peripheral indentation. Peeling of the internal limiting membrane was assisted with brilliant blue G (ILM-Blue; Dutch Ophthalmic Research Center, Zuidland, the Netherlands). No additional manipulation of the macular hole edges was done. Finally, a fluid–air exchange was performed, which was completed by keeping the soft-tip of the extrusion cannula at the

Table 1. Closure Rates of FTMH Confirmed 24 Hours After Surgery

	n	OCT Verification at 24 Hours, n/N (%)	Closure Rate at 24 Hours, n/N (%)	Tamponade	Positioning
Jumper et al, 2000[18]	14	5/14 (36)	3/5 (60)	Silicone oil	No FDP
Kasuga et al, 2000[19]	7	4/7 (57)	4/4 (100)	SF6	FDP
Eckardt et al, 2008[17]	33	22/33 (67)	18/22 (82)	Air	FDP
Masuyama et al, 2008[20]	16	13/16 (81)	10/13 (77)	SF6	FDP
Gesser et al, 2010[21]	112	54/112 (48)	48/54 (89)	Air	FDP
Sano et al, 2011[22]	37	28/37 (76)	27/28 (96)	Air, SF6, C3F8	FDP
Yamashita et al, 2013[23]	21	21/21 (100)	12/21 (57)	SF6	FDP
Kikushima et al, 2015[24]	20	16/20 (80)	11/16 (69)	SF6	FDP
Pooled data	260	163/260 (63)	133/163 (82)	—	—

optic disc for a few seconds after the fluid removal. After surgery, the patients followed an NSP regimen for the first three postoperative days.[5] With this regimen, they were encouraged to maintain their daily activities, as long as upward gaze and a supine sleeping position were avoided at any time. The patients were instructed to sleep on either side, and it was pointed out that FDP was unnecessary. To prevent the patients from sleeping in the supine position, an ordinary tennis ball was attached to the back of their nightshirt by means of a rubber band.[5,10]

The patients were scheduled for daily postoperative visits, which included SD-OCT imaging of the macula, slit-lamp evaluation of the air bubble meniscus height, and detailed indirect ophthalmoscopy until it was possible to determine the definite macular hole status by serial SD-OCT scans through the intraocular fluid. The air bubble meniscus height was defined according to Thompson et al,[26] as the percentage of the vertical diameter of the eye; where a meniscus level at the inferior limbus corresponds to a 75% air bubble and a meniscus level at the superior limbus corresponds to a 25% air bubble. To investigate the intraocular air bubble duration, the patients were asked to provide feedback either by phone or text message as soon as they noticed that the air bubble had completely resolved. The final follow-up examination for the purpose of the study was performed after 6 months from surgery.

Statistical Analysis

Comparisons between groups were made by Mann–Whitney *U* test for continuous variables and by chi-Square exact test or Fisher's exact test for categorical variables. Binary logistic regression was applied to evaluate the association between FTMH diameter and closure rate. Goodness of fit was verified with the Hosmer and Lemeshow test. Wilcoxon signed rank test was used to evaluate the efficacy of the treatment. Two-tailed $P < 0.05$ were considered statistically significant. The statistical analyses were made by IBM SPSS statistics, software version 22.0 (SPSS Inc, Chicago, IL).

Results

Anatomical and Functional Outcomes

After inclusion of the first 20 patients, the planned interim analysis was conducted. This analysis revealed a closure rate following primary surgery of 70%. In the subgroup of patients with small and medium FTMH (≤400 μm), a closure rate of 100% was found, whereas only 57% closure was recorded in the subgroup of patients with large FTMH (>400 μm). It was therefore decided to stop the inclusion of patients with FTMH larger than 400 μm, and to only include FTMH equal to or smaller than 400 μm until a total number of 20 patients were reached in this subgroup. This resulted in a total number of 34

Table 2. Demographics, Baseline Characteristics, and Functional and Anatomical Results

	FTMH,* μm					
	≤400					
	≤250	>250≤400	*P*		>400	*P*
Patients, n	6	14		20	14	
Age, mean (SD), years	72 (9)	72 (5)	0.90	72 (6)	67 (9)	0.17
Gender, male/female	4/2	5/9	0.34	9/11	7/7	0.77
Mean FTMH diameter, μm (SD)	201 (35)	307 (37)	<0.01	276 (61)	612 (224)	<0.01
Duration of symptoms, months (SD)	8.8 (8.8)	4.7 (3.4)	0.27	6.0 (5.7)	7.1 (5.6)	0.62
ERM,† n (%)	2 (33)	8 (57)	0.63	10 (50)	7 (50)	1.00
VMT,‡ n (%)	4 (67)	5 (36)	0.34	9 (45)	8 (57)	0.49
Mean preoperative BCVA,§ ETDRS¶ letters (SD)	**59 (12)**	**58 (5)**	0.49	**58 (7)**	**49 (5)**	<0.01
Mean 6 month BCVA, ETDRS letters (SD)	**74 (12)**	**76 (7)**	0.35	**76 (9)**	**66 (8)**	<0.01
Mean ETDRS line gain (SD)	3.0 (1.3)	3.6 (1.5)	0.35	3.5 (1.4)	3.5 (1.6)	0.59
2 ≥ ETDRS line gain, n (%)	6 (100)	13 (93)	1.00	19 (95)	12 (86)	0.55
3 ≥ ETDRS line gain, n (%)	3 (50)	12 (86)	0.13	15 (75)	12 (86)	0.67
Primary FTMH closure, n (%)	6 (100)	13 (93)	1.00	19 (95)	8 (57)	0.01

*Full-thickness macular hole.
†Epiretinal membrane.
‡Vitreomacular traction.
§Best corrected visual acuity.
¶Early Treatment of Diabetic Retinopathy Study.

patients (16 men and 18 women) being included in the study. The mean age at the time of surgery was 70 years (range, 47–83 years). The patients in the group with small/medium FTMH had a mean hole diameter of 276 μm (range, 152–352 μm), whereas the mean hole diameter in the 14 patients with large FTMH was 612 μm (range, 412–1,072 μm). The demographic and baseline characteristics of the participants are presented in Table 2.

The mean follow-up time was 185 days (range, 165–203 days) and no patients were lost to follow-up. The closure rates for the small/medium FTMH and the large FTMH were 19/20 (95%) and 8/14 (57%), respectively. The difference in closure rate between the small/medium and large FTMH was statistical significant ($P = 0.01$). Binary logistic regression revealed a positive and significant relation between increasing FTMH diameter and the event of nonclosure ($P = 0.01$) with an odds ratio of 0.53 (CI 0.33–0.87) per 100-μm increase in diameter. No cases of macular hole reopening occurred during the study period. At the 6-month follow-up visit, the mean overall BCVA had improved from 20/80 to 20/40, which was consistent with a statistically significant mean gain of 3.5 (SD = 1.5) ETDRS lines ($P < 0.01$). The mean ETDRS line gain for the small/medium FTMH and the large FTMH were 3.5 ($P < 0.01$) and 3.5 ($P < 0.01$) ETDRS lines, respectively (Figure 1). Overall, 31 of 34 patients (91.2%) gained 2 or more ETDRS lines.

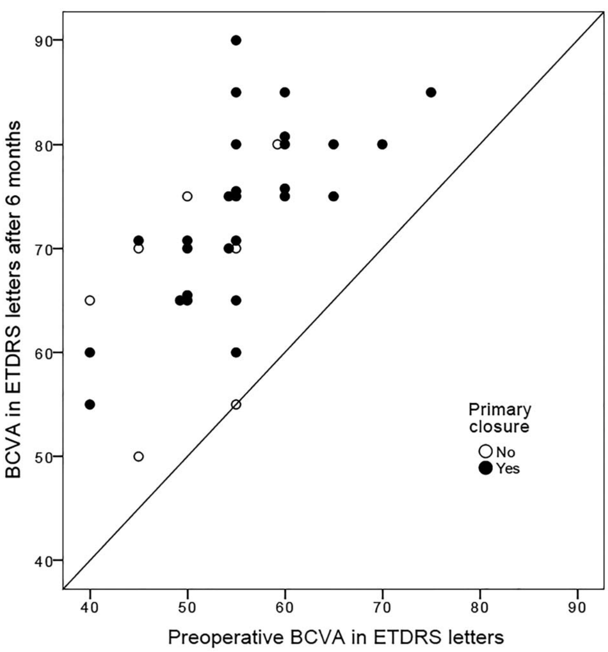

Fig. 1. Preoperative and 6 months postoperative best-corrected visual acuity (BCVA) in eyes with (black circles) and without (open circles) primary closure of full-thickness macular hole.

Patients with epiretinal membrane (n = 17) had a closure rate of 77% and gained 3.6 ETDRS lines compared with 82% ($P = 0.67$) and 3.4 ETDRS lines ($P = 0.66$) for those with no epiretinal membrane. Patients with vitreomacular traction (n = 17) had a closure rate of 77% and gained 3.1 ETDRS lines compared with 82% ($P = 0.67$) and 3.8 ETDRS lines ($P = 0.31$) for those without vitreomacular traction. The functional and anatomical results are summarized in Table 2.

The first postoperative SD-OCT examinations of the macular area were performed through air, but the final SD-OCT imaging had to be performed through the intraocular fluid to verify the status of the macula. The assessment of SD-OCT images taken through the

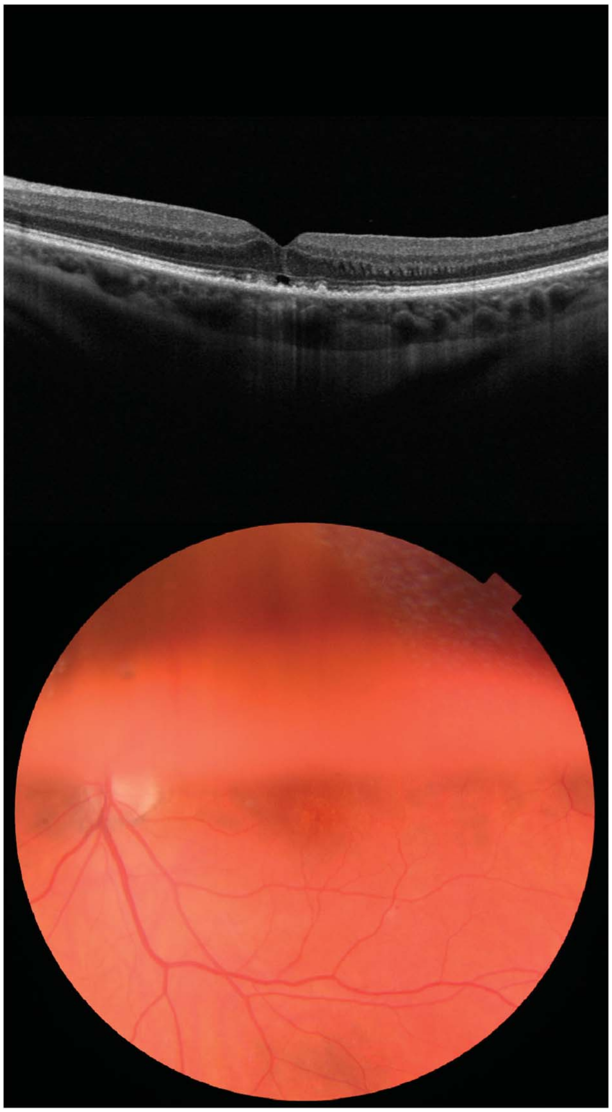

Fig. 2. The SD-OCT image and fundus photograph of one of the study patients taken at the third postoperative day, demonstrating the remaining air bubble and the high quality of the macular scan.

aqueous humor were possible after a mean of 3.2 days (range, 2–4 days), as the air bubble no longer interfered with the optical axis of the eye (Figure 2). Two patients with a slight intraocular hemorrhage precluding satisfactory SD-OCT imaging were excluded from this calculation. Their macular status could be confirmed on Day 7 and 8 postoperatively.

Of the 7 patients whose FTMH did not close after the primary surgery, 6 patients were directly subjected to a repeated procedure, which consisted of a fluid–air exchange followed by air–gas exchange with 30% sulfur hexafluoride (SF6) and NSP for 5 postoperative days. This procedure was performed on an average 4.5 days (range, 3–8 days) after the first operation. One patient was not offered reoperation within the first postoperative days. He had a flat and open FTMH without any edema at the edges of the hole, which was considered unsuitable for repeated surgery. After 1 month, however, intraretinal cysts occurred and the patient was successfully retreated. Thus, all the 7 persistent FTMH closed after 1 reoperation, so that a final closure rate of 100% was achieved.

Complete FTMH closure of all the retinal layers, without any subfoveal elevation or outer retinal defects, was found in 22% patients (6/27) within the first postoperative 8 days, in 55% (18/33) after 1 month, and in 88% (30/34) after 6 months. In 9 patients (27%), intraoperative iatrogenic retinal tears occurred, which were all treated with endolaser photocoagulation. Postoperatively, 2 patients (6%) experienced a small intravitreal hemorrhage and 1 patient (3%) had a limited choroidal hemorrhage and leakage of intraocular air. One patient (3%) had a slight cystoid macular edema at the last follow-up visit. No cases of retinal detachment or other complications were observed during the follow-up period.

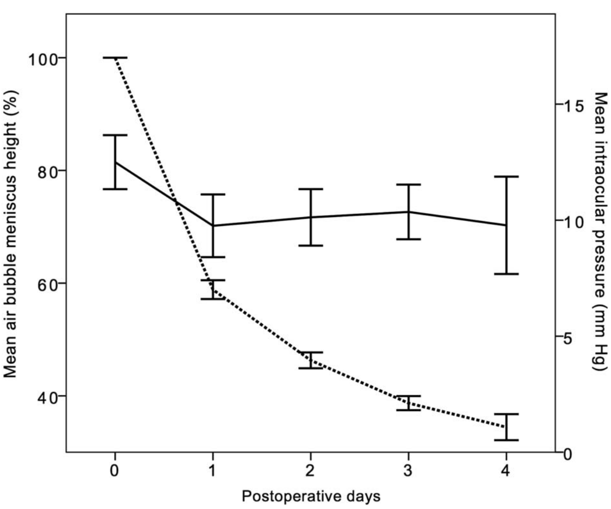

Fig. 3. Line graphs showing the change in mean air bubble meniscus height (dashed line) and mean intraocular pressure (solid line) during the first 4 postoperative days. Error bars indicate 95% confidence interval.

Air Tamponade Duration and Intraocular Pressure

At the first postoperative day, the mean air bubble meniscus height was 59% (range, 50–70%), at the second postoperative day it was 46% (range, 40–55%), and at the third postoperative day it was 39% (range, 30–45%) (Figure 3). Twenty-one patients (78%) with primary closed FTMH provided feedback on the air bubble duration, and the mean duration of the bubble was 10 days (range, 8–13 days). The patient who experienced some air leakage from the eye was excluded from this analysis.

The mean preoperative IOP was 12.5 mmHg (SD = 3.3). Twenty-four hours after the primary surgery, the mean IOP was 9.5 mmHg (SD = 4.1), on the second postoperative day it was 10.0 mmHg (SD = 3.5), and the on third postoperative day the mean IOP was 10.5 mmHg (SD = 3.2) (Figure 3). The highest IOP recorded among all the patients during this time period was 18 mmHg.

Discussion

The combination of air tamponade and postoperative NSP presented in this study is an alternative approach to conventional FTMH surgery. The treatment protocol resulted in a closure rate of 95% for FTMH equal to or smaller than 400 μm, showing that it is possible to treat FTMH with less discomfort for the patients and excellent results. As reported in the study by Alberti et al,[8] approximately 60% of patients consider intraocular gas tamponade as "uncomfortable" or "very uncomfortable." In the present study, the air bubble no longer interfered with the optical axis after an average of only 3.2 days, and the mean time from surgery until the air bubble was completely absorbed was 10 days. Thus, the use of intraocular air tamponade significantly accelerates visual recovery and shortens the period of driving and air travel restrictions. The abandonment of FDP makes FTMH surgery possible for many patients who would otherwise not tolerate this regimen; like obese persons and those with different physical or mental disorders. Additionally, the discomfort and risk of potential complications associated with FDP, like pulmonary embolism and ulnar nerve palsies, are reduced.[27,28]

Twenty-four hours after surgery, the air bubble meniscus height was estimated to a mean of 59%, which apparently is sufficient to close FTMH equal to or smaller than 400 μm. Most likely, small FTMH will close faster than larger ones and be sealed within 24 hours; thus, a tamponade effect is no longer necessary.

The speed of the hole closure is further outlined by the pooled 24-hour closure rate of 82% in the literature (Table 1).[17–24] In the very early postoperative period, however, the healing process may be hindered by the presence of fluid in the macular area. It is probably critical to keep the macula dry for a certain time span, which can be achieved by a high patient compliance to the NSP regimen. This will allow the retinal pigment epithelium pump to absorb the perifoveal intraretinal edema and thereby contribute to a fusion of the FTMH edges. In the present study, we used the "tennis ball technique," which has proven to significantly enhance the patients' compliance to the NSP regimen.[10]

In the group of FTMH larger than 400 μm, the primary closure rate of 57% was considered unacceptable. At the third postoperative day, we estimated the air bubble meniscus height to be only 39%, which means that the foveal area is immersed in aqueous humor unless a strict FDP regimen is applied. The significant relation between increasing FTMH diameter and the event of nonclosure suggests that FTMH larger than 400 μm need more time isolated from the vitreous fluid to heal. This is supported by observations of FTMH closure up to postoperative 3 days.[17,24] It is therefore likely that, in this group, gas tamponade combined with postoperative NSP, or the use of air tamponade in combination with 3 days FDP, will result in a higher closure rate.

In all patients, the macular hole status could be assessed from the SD-OCT scans obtained through the intraocular fluid within 4 days postoperatively, as long as no vitreous hemorrhage was present. This enables potential reoperations to be carried out within 4 days instead of being postponed for weeks, if intraocular gas tamponade is used. We believe that a shorter interval between the primary surgery and the revision procedure is beneficial for the macular recovery, which is in agreement with the good functional results obtained in the present study. Ninety-one percent and 79% of the patients finally gained 2 or more ETDRS lines and 3 or more ETDRS lines, respectively, which compares well with the literature.[5,8,29,30]

Air tamponade is considerably safer than gas tamponade, when it comes to the risk of postoperative IOP rise. As reported by Han et al,[31] 30.6% of patients experience IOP elevations above 30 mmHg following vitreoretinal surgery with gas tamponade. Studying different types of endotamponades, Framme et al[32] found that eyes receiving air filling had the lowest risk of postoperative IOP elevation (with a cumulative hazard of 11.5% to reach an IOP $\geq$ 30 mmHg after 48 hours). In the present study, the mean IOP after 24 hours was 9.5 mmHg, whereas the highest measured IOP among all patients during the first 3 to 4 postoperative days was 18 mmHg. Particularly in patients with preexisting glaucoma, the use of air tamponade offers a possibility to treat FTMH with a lower risk of complications.

The limitations of this study include the small sample size and the lack of controls. In addition, the visual and anatomical results are only valid for pseudophakic patients. In phakic eyes, the surgical outcomes may be less favorable because of cataract progression and less complete vitrectomy and air tamponade. There was no objective verification of the patients actual positioning during the postoperative period. The daily postoperative examinations and contact with the study staff may have enhanced the patients' responsiveness to the positioning instructions. In a real-world situation, the compliance may thus be lower and the results less favorable. The main strength of this study is the prospective design. We conclude that pars plana vitrectomy with internal limiting membrane peeling, air tamponade, and an NSP regimen for 3 days represent a safe and patient-friendly way to treat small and medium FTMH with high closure rates.

Key words: air tamponade, face-down positioning, macular hole, prone positioning, retina, vitrectomy, vitreoretinal surgery.

References

1. Kelly NE, Wendel RT. Vitreous surgery for idiopathic macular holes. Results of a pilot study. Arch Ophthalmol 1991;109:654–659.
2. Tornambe PE. Macular hole genesis: the hydration theory. Retina 2003;23:421–424.
3. Tornambe PE, Poliner LS, Grote K. Macular hole surgery without face-down positioning. A pilot study. Retina 1997;17:179–185.
4. Tadayoni R, Vicaut E, Devin F, et al. A randomized controlled trial of alleviated positioning after small macular hole surgery. Ophthalmology 2011;118:150–155.
5. Forsaa VA, Raeder S, Hashemi LT, et al. Short-term postoperative non-supine positioning versus strict face-down positioning in macular hole surgery. Acta Ophthalmol 2013;91:547–551.
6. Simcock PR, Scalia S. Phacovitrectomy without prone posture for full thickness macular holes. Br J Ophthalmol 2001;85:1316–1319.
7. Tranos PG, Peter NM, Nath R, et al. Macular hole surgery without prone positioning. Eye (Lond) 2007;21:802–806.
8. Alberti M, la Cour M. Face-down positioning versus non-supine positioning in macular hole surgery. Br J Ophthalmol 2015;99:236–239.
9. Alberti M, la Cour M. Nonsupine positioning in macular hole surgery: a noninferiority randomized clinical trial. Retina 2016;36:2072–2079.
10. Forsaa VA, Krohn J. Postoperative positioning in macular hole surgery: an objective evaluation of nonsupine positioning and the effect of the "tennis ball technique". Retina 2016;36:1081–1086.

11. Wolf GL, Capuano C, Hartung J. Nitrous oxide increases intraocular pressure after intravitreal sulfur hexafluoride injection. Anesthesiology 1983;59:547–548.
12. Thompson JT. The absorption of mixtures of air and perfluoropropane after pars plana vitrectomy. Arch Ophthalmol 1992; 110:1594–1597.
13. Sato Y, Isomae T. Macular hole surgery with internal limiting membrane removal, air tamponade, and 1-day prone positioning. Jpn J Ophthalmol 2003;47:503–506.
14. Park DW, Sipperley JO, Sneed SR et al. Macular hole surgery with internal-limiting membrane peeling and intravitreous air. Ophthalmology 1999; 106:1392–1397; discussion 1397–1398.
15. Hasegawa Y, Hata Y, Mochizuki Y, et al. Equivalent tamponade by room air as compared with SF(6) after macular hole surgery. Graefes Arch Clin Exp Ophthalmol 2009;247: 1455–1459.
16. Hikichi T, Kosaka S, Takami K, et al. 23- and 20-gauge vitrectomy with air tamponade with combined phacoemulsification for idiopathic macular hole: a single-surgeon study. Am J Ophthalmol 2011;152:114–121.
17. Eckardt C, Eckert T, Eckardt U, et al. Macular hole surgery with air tamponade and optical coherence tomography-based duration of face-down positioning. Retina 2008;28: 1087–1096.
18. Jumper JM, Gallemore RP, McCuen BW II, et al. Features of macular hole closure in the early postoperative period using optical coherence tomography. Retina 2000;20:232–237.
19. Kasuga Y, Arai J, Akimoto M, et al. Optical coherence tomography to confirm early closure of macular holes. Am J Ophthalmol 2000;130:675–676.
20. Masuyama K, Yamakiri K, Arimura N, et al. Posturing time after macular hole surgery modified by optical coherence tomography images: a pilot study. Am J Ophthalmol 2009; 147:481–488.
21. Gesser C, Eckert T, Eckardt U, et al. Macular hole surgery with air tamponade. Does air suffice for short-term tamponade? Ophthalmologe 2010;107:1043–1050.
22. Sano M, Inoue M, Taniuchi S, et al. Ability to determine postoperative status of macular hole in gas-filled eyes by spectral-domain optical coherence tomography. Clin Exp Ophthalmol 2011;39:885–892.
23. Yamashita T, Yamashita T, Kawano H, et al. Early imaging of macular hole closure: a diagnostic technique and its quality for gas-filled eyes with spectral domain optical coherence tomography. Ophthalmologica 2013;229:43–49.
24. Kikushima W, Imai A, Toriyama Y, et al. Dynamics of macular hole closure in gas-filled eyes within 24 h of surgery observed with swept source optical coherence tomography. Ophthalmic Res 2015;53:48–54.
25. Duker JS, Kaiser PK, Binder S, et al. The international vitreomacular traction study group classification of vitreomacular adhesion, traction, and macular hole. Ophthalmology 2013; 120:2611–2619.
26. Thompson JT. Kinetics of intraocular gases. Disappearance of air, sulfur hexafluoride, and perfluoropropane after pars plana vitrectomy. Arch Ophthalmol 1989;107:687–691.
27. Holekamp NM, Meredith TA, Landers MB, et al. Ulnar neuropathy as a complication of macular hole surgery. Arch Ophthalmol 1999;117:1607–1610.
28. Au Eong KG, Beatty S, Thomas W, et al. Pulmonary embolism following head positioning for retinal reattachment surgery in a young patient with factor V leiden mutation. Arch Ophthalmol 2000;118:1300–1301.
29. Hasler PW, Prunte C. Early foveal recovery after macular hole surgery. Br J Ophthalmol 2008;92:645–649.
30. Sheidow TG, Blinder KJ, Holekamp N, et al. Outcome results in macular hole surgery: an evaluation of internal limiting membrane peeling with and without indocyanine green. Ophthalmology 2003;110:1697–1701.
31. Han DP, Lewis H, Lambrou FH Jr, et al. Mechanisms of intraocular pressure elevation after pars plana vitrectomy. Ophthalmology 1989;96:1357–1362.
32. Framme C, Klotz S, Wolf-Schnurrbusch UE, et al. Intraocular pressure changes following 20G pars-plana vitrectomy. Acta Ophthalmol 2012;90:744–749.