Efficacy of Vitrectomy With Tamponade Versus No Tamponade for Myopic Traction Maculopathy: A Multicenter Study (SCHISIS Report No.1)

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• PURPOSE: **To evaluate the influence of tamponade on the visual and anatomic outcomes of pars plana vitrectomy for myopic traction maculopathy (MTM).**

• DESIGN: **Multicenter, retrospective clinical cohort study.**

• METHODS: **Consecutive eyes that underwent vitrectomy for advanced MTM with tamponade of air, sulfur hexafluoride (SF_6), or perfluoropropane (C_3F_8) or without tamponade with a minimum follow-up of 12 months were included. Main outcome measures included postoperative visual acuity (VA) at 12 months in eyes with vs without tamponade.**

• RESULTS: **We included a total of 193 eyes (193 patients) in this study; 136 eyes (70%) treated with tamponade were compared with 57 eyes (30%) treated without tamponade. Baseline characteristics did not differ significantly between the groups. Both groups showed significant visual improvement at 12 months (both $P < .001$). However, postoperative visual acuity and visual improvement at 12 months were significantly better ($P = .003$ and $P = .028$, respectively) in eyes without tamponade, although the MTM in these eyes without tamponade took longer to resolve ($P = .039$). Retinal thickness and the ellipsoid zone were more preserved in eyes without tamponade ($P < .001$ and $P = .001$, respectively). Complications such as macular holes did not differ between the groups. A novel imaging finding of "schisis bending (accordioning)" was identified during MTM resolution.**

• CONCLUSIONS: **Vitrectomy either with or without tamponade for MTM was effective in improving vision in this study. However, eyes without tamponade experienced even better visual improvement and preserved retinal anatomy, despite a longer schisis resolution time. Surgery without tamponade may achieve better visual outcomes. (Am J Ophthalmol 2023;254: 182–192. © 2023 Elsevier Inc. All rights reserved.)**

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Myopic traction maculopathy (MTM) is a macular complication caused by traction in eyes with high myopia. MTM has a prevalence of 7% to 35% in highly myopic eyes, and this condition itself can decrease visual acuity (VA) due to retinal thickening, lamellar macular hole (MH) formation, and foveal retinal detachment.[1-4] In addition, an advanced form of MTM, also known as myopic macular retinoschisis (MRS), and myopic foveoschisis (MFS) may progress to develop full-thickness MH and MH retinal detachment (MHRD), resulting in significant vision loss.[5-8] The pathogenesis of MTM is multifactorial, involving combined anteroposterior and tangential retinal tractions induced by vitreomacular adhesion, posterior staphyloma, vitreous cortex remnants, and epiretinal membrane (ERM).[5,9] The internal limiting membrane (ILM), retinal vascular microfolds, and paravascular vitreal adhesions may also contribute to the pathogenesis.[10-13] Therefore, the release of retinal traction by surgery has been shown to be effective for resolving MTM and for preventing future MH and MHRD.[14-16]

The current standard of treatment for MTM involves pars plana vitrectomy (PPV), removal of any vitreous

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cortex or epiretinal membrane, and ILM peeling with or without a fovea-sparing technique.[14,17] Tamponade with air, sulfur hexafluoride (SF_6), perfluoropropane (C_3F_8), or silicone oil (SO) has also been used to facilitate repositioning of the retina in patients with MTM.[14,15,18,19] However, MTM can be treated without tamponade (ie, with only fluid) if the traction is adequately removed by surgery; however, the possible effects of tamponade on visual and anatomic outcomes are unclear.[5,20] Two previous studies compared gas vs no-gas tamponade in the treatment of MTM and found no significant differences in postoperative visual acuity; however, both studies included a total of only 17 patients. Therefore, the small study sizes may have limited the power of the statistical analyses.[21,22] Some surgeons have asserted that long-lasting tamponade may prevent the development of postoperative MH formation, but no evidence has been published to support this idea. Thus, the use of tamponade remains controversial in the treatment of MTM.

The purpose of this study was to investigate and to compare the visual and anatomic outcomes and complication rates after vitrectomy with vs without tamponade for the treatment of MTM. We conducted a multicenter study to determine the impact of tamponade on surgical outcomes in MTM.

METHODS

This was a multicenter, retrospective clinical cohort study of consecutive eyes that underwent vitrectomy for MTM between June 2008 and April 2021 at the following 9 institutions in the United States, India, and Japan: Wills Eye Hospital and the offices of Mid Atlantic Retina, University of Pittsburgh Eye Center, Narayana Nethralaya, Osaka University Graduate School of Medicine, Aichi Medical University, Oshima Eye Clinic, Hyogo College of Medicine, Toho University Sakura Medical Center, and Ikuno Eye Center. The Institutional Review Board (IRB) of each institution approved the study, and the IRB of Aichi Medical University approved this multicenter study. The study was compliant with the Health Insurance Portability and Accountability Act of 1996 and adhered to the tenets of the Declaration of Helsinki.

The study included a consecutive series of patients with advanced MTM aged ≥18 years who underwent PPV and had follow-up for at least 12 months and up to 36 months at each institution. Advanced MTM was defined as stage 3 (schisis of the entire fovea) and stage 4 (schisis of the entire macula) based on the classification by Shimada et al.[6] These stages are also known as MFS and MRS. Exclusion criteria included eyes with pre-existing MH, prior PPV, and a postoperative follow-up period of less than 12 months. In patients who underwent bilateral surgery for bilateral MTM, only the eye operated on first was included in this study.

• **SURGERY:** All patients underwent PPV with a 3-port system, using a 23-, 25-, or 27-gauge system. Surgery consisted of core vitrectomy, followed by posterior vitreous detachment (PVD) induction if not already present, and removal of vitreous cortex remnants and ERM if they were present. The ILM peeling, with or without a fovea-sparing technique, was performed in most eyes, although some eyes did not undergo ILM peeling. Triamcinolone acetonide, indocyanine green (ICG), and Brilliant Bllue G (BBG) were used for ILM peeling. The decision to use tamponade was at the discretion of the individual surgeon based on the surgeon's practice patterns. The choice of tamponade included air, SF_6 gas (mostly 20%, but some patients had 22% or partial fills of pure SF_6), or C_3F_8 gas (10%-16%). In this study, patients who had silicone oil tamponade were excluded.

• **OPTICAL COHERENCE TOMOGRAPHY:** Macular optical coherence tomography (OCT) scans were performed with Spectralis (Heidelberg Engineering), Cirrus HD-OCT (4000, 5000, or 6000; Carl Zeiss Meditec Inc), RS-3000 (NIDEK), or DRI OCT Triton (Topcon) units. Preoperatively, 3 parameters were manually measured on the horizontal OCT scans, centered on the fovea, using a caliper tool supplied with each OCT machine. The height of the retina was defined as the distance between the ILM and the inner border of the retinal pigment epithelium (RPE). In eyes with foveal retinal detachment, the thickness of the neurosensory retina was measured as the distance between the ILM and the outer border of the retina at the fovea. In eyes without foveal retinal detachment, the neurosensory retinal thickness was regarded as the same as the height of the retina. The choroidal thickness was defined as the outer border of the RPE line to the hyperreflective line of the choroid–sclera interface. The preoperative morphological MTM pattern (type), such as retinoschisis, lamellar MH, foveal detachment, and combined lamellar MH and retinal detachment, was also assessed using horizontal and vertical OCT. Postoperatively, the following 4 parameters were evaluated: time to resolution of the MTM, central foveal thickness (height of the retina) at 12 months, presence or absence of the ellipsoid zone (EZ) at 12 months, and our novel finding of the bending and accordioning of the elongated columns of neuronal and Müller cells—which we named "schisis bending (accordioning)." The presence of schisis bending was evaluated on early postoperative horizontal and vertical OCT within 2 months after surgery while gas remained in the eye. The resolution of MTM was defined as the complete disappearance of any schisis (intraretinal cysts) and foveal detachment, as evaluated on a horizontal OCT scan 6 mm long and centered on the fovea, which was taken at every postoperative visit. The measurement was conducted by a grader at each institution. Some phakic patients underwent phacovitrectomy.

• **DATA ANALYSIS:** The eyes were divided into 2 groups: a tamponade group (eyes with any tamponade, including air,

SF_6, and C_3F_8) and a non-tamponade group (eyes without any tamponade). The main outcome measures included the postoperative best-corrected VA (BCVA) and visual improvement at 12 months.

We reviewed the medical records, operative reports, and OCT scans of patients for the following parameters: age, sex, ophthalmic history, preoperative and postoperative VA at 12 months, lens status, axial length (if available), preoperative type of MTM (retinoschisis, lamellar MH, and foveal detachment), preoperative height of the MTM of the fovea (distance between the ILM and the RPE), preoperative neurosensory retinal thickness (distance between the ILM and the outer border of outer retina), choroidal thickness, vitrectomy gauge, ILM peeling, fovea-sparing technique, use of dye for ILM peeling (ICG, triamcinolone, and BBG), tamponade, choice of gas tamponade (air, SF_6, and C_3F_8), postoperative central foveal thickness (height of retina) at 12 months, time to resolution of retinoschisis, postoperative schisis bending, postoperative status of EZ at 12 months, and postoperative complications, such as full-thickness MH and RRD.

• **STATISTICAL ANALYSIS:** Snellen VA was converted to logarithm of minimal angle of resolution (logMAR) units for statistical analysis. Baseline, intraoperative, and postoperative variables were compared between eyes with and without tamponade using the Mann–Whitney rank-sum test, Student *t* test, χ^2 test, and Fisher exact test, where appropriate. Univariate linear regression analysis was used to determine the correlation between the postoperative logMAR VA and variables such as the type of tamponade (none: 0, 1: air, 2: SF_6, and 3: C_3F_8, based on the duration of tamponade), age, sex, laterality, preoperative VA, axial length, preoperative lens status, MTM height, neurosensory retinal thickness, choroidal thickness, vitrectomy gauge size, phacovitrectomy, ILM peeling technique, and dye used for ILM peeling. Variables that were significant on univariate analysis were selected to include in multivariable linear regression analysis.

The correlation between the duration of gas tamponade (0: none, 1: air, 2: SF_6, and 3: C_3F_8, based on the duration of tamponade) and central foveal thickness, the integrity of EZ at 12 months, and the schisis resolution time was evaluated by univariate linear regression analysis. The association between postoperative visual acuity at 12 months and the integrity of EZ was also evaluated by univariate linear regression analysis. All statistical analyses were performed using SigmaStat software (version 4.0; SPSS Inc). A *P* value of <.05 was considered statistically significant.

RESULTS

• **PATIENT CHARACTERISTICS:** This study included a total of 193 eyes from 193 patients (151 female and 42 male) who underwent PPV for MTM, after excluding eyes with pre-existing small MH (4 eyes), prior PPV (1 eye), and a postoperative follow-up of <12 months (25 eyes). Baseline characteristics are shown in Table 1. In total, 136 eyes (136 patients) treated with tamponade were compared to 57 eyes (57 patients) treated without tamponade. The surgical techniques and the baseline characteristics, including age, sex, laterality, height of the MTM, sensory retinal thickness, choroidal thickness, proportion of phakic and pseudophakic eyes, axial length, type of MTM, preoperative VA, type of ILM peeling (standard or fovea sparing), dye for ILM peeling, and follow-up length, did not differ significantly between the 2 groups. However, the gauge size used in vitrectomy differed between the groups, as 23-gauge systems were more commonly used in the tamponade group whereas 25-gauge systems were more commonly used in the non-tamponade group.

• **VISUAL OUTCOMES:** The visual outcomes of eyes with vs without tamponade are compared in Table 2. After surgery, both the tamponade and non-tamponade groups gained significant improvement in vision at 12 months ($P < .001$ for both groups) (Figures 1 and 2). However, postoperative logMAR VA was significantly better in the non-tamponade group (0.27 ± 0.32) compared to the tamponade group (0.48 ± 0.49) ($P = .003$). Similarly, improvement in vision at 12 months was significantly better in the non-tamponade group (−0.25 ± 0.31) compared to the tamponade group (−0.13 ± 0.38) ($P = .028$). The longer-acting gas had the least improvement (air: −0.16 ± 0.36, SF6: −0.13 ± 0.37, and C3F8: +0.01 ± 0.49).

In the non-tamponade group, the VA at 12 months improved by 3 or more lines for 27 eyes (47.4%), did not change in 27 eyes (47.4%), and decreased by 3 or more lines in 3 eyes (5.3%). In the tamponade group, the VA at 12 months improved by 3 or more lines in 50 eyes (36.8%), did not change in 67 eyes (49.3%), and decreased by 3 or more lines in 19 eyes (14.0%). The tendency toward a higher incidence of visual improvement and a lower incidence of visual deterioration in the non-tamponade group was not statistically significant ($P = .147$).

A significant improvement in VA was also observed at the final visit for both groups ($P < .001$ for both groups). Postoperative logMAR VA was significantly better in the non-tamponade group (0.28 ± 0.35) than in the tamponade group (0.47 ± 0.48) at the final visit ($P = .010$). Similarly, visual improvement at the final visit was significantly better in the non-tamponade group (−0.23 ± 0.31) than in the tamponade group (−0.13 ± 0.35) ($P = .037$). The proportion of eyes with a visual improvement, no change, or visual deterioration showed no significant between-group differences at the final visit ($P = .102$).

• **FACTORS ASSOCIATED WITH VISUAL OUTCOMES:** Results of the univariate and multivariable linear regression analyses investigating factors associated with logMAR VA

TABLE 1. Baseline Characteristics of Study Subjects

Parameter	Tamponade	No Tamponade	*P* Value
No. of eyes/patients	136/136	57/57	
Age, y mean ± SD (range)[a]	66.1 ± 10.2 (27-86)	67.3 ± 8.3 (45-81)	.471
Sex, female/male, n	109/27	42/15	.423
Eye, right/left, n	79/57	34/23	.968
Preoperative BCVA, logMAR, mean ± SD[a]	0.61 ± 0.38	0.51 ± 0.34	.108
Axial length, mm, mean ± SD (range)[b]	29.3 ± 1.9 (23.9-34.7)	29.0 ± 2.0 (23.6-34.1)	.323
Lens status before surgery, n (%)			
Phakic	82 (60.3)	40 (70.2)	.256
Pseudophakic	54 (39.7)	17 (29.8)	
Type of MTM (Retinoschisis, LMH, FD, Combined LMH/FD), n	33/42/52/9	22/16/15/4	.199
Height of MTM, μm, mean ± SD (range)[a]	369 ± 206 (58-1033)	393 ± 240 (60-1058)	.719
Neurosensory central foveal thickness, μm, mean ± SD (range)[a]	243 ± 184 (10-1001)	270 ± 226 (25-1000)	.633
Choroidal thickness, μm, mean ± SD (range)[a]	73.5 ± 40.7 (0-233)	80.3 ± 49.0 (0-237)	.527
Vitrectomy gauge size, n (%)			
23-gauge	39 (28.7)	3 (5.3)	<.001
25-gauge	94 (69.1)	49 (86.0)	
27-gauge	3 (2.2)	5 (8.8)	
Phacovitrectomy, n (%)	71 (52.2)	37 (64.9)	.143
ILM peeling, n (%)			
Standard	101 (74.3)	44 (77.2)	.276
Fovea-sparing	32 (23.5)	8 (14.0)	
No ILM peeling, n (%)	3 (2.2)	5 (8.8)	.091
ILM dye for ILM peeling, n (%)			
TA	9 (6.8)	5 (9.6)	.451
ICG	48 (36.1)	14 (26.9)	
BBG	76 (57.1)	33 (63.5)	
Intravitreal tamponade during PPV, n (%)			
Air	65 (47.8)	-	-
SF_6	57 (41.9)	-	
C_3F_8	14 (10.3)	-	
Follow-up length, mo, mean ± SD (range)[a]	25.3 ± 10.2 (12-36)	22.0 ± 10.0 (12-36)	.075

BBG = Brilliant Blue G; BCVA = best-corrected visual acuity; C_3F_8 = perfluoropropane; FD = foveal detachment; ICG = indocyanine green; ILM = internal limiting membrane; LMH = lamellar macular hole; logMAR = logarithm of the minimum angle of resolution; MTM = myopic traction maculopathy; SF_6 = sulfur hexafluoride; TA = triamcinolone acetonide; VA = visual acuity.

[a] Mann−Whitney rank sum test.

[b] Student *t* test. Other statistical analyses were conducted with χ^2 test.

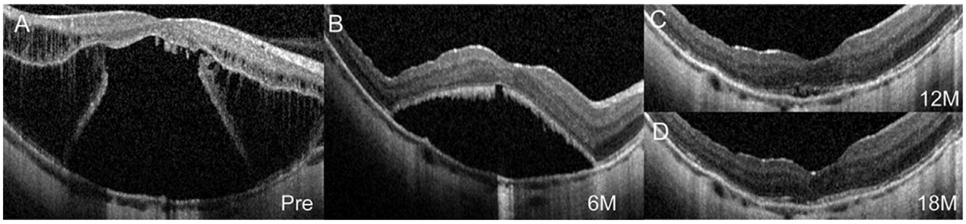

FIGURE 1. Myopic traction maculopathy treated by vitrectomy without tamponade. A. Optical coherence tomography (OCT) image (6 mm) at initial presentation showed foveal retinal detachment in a 45-year-old woman. Visual acuity (VA) was 20/400. B. Six months after surgery. C. Twelve months after surgery. OCT showed residual fluid. Vision improved to 20/50. D. Eighteen months after surgery at the time of schisis resolution.

TABLE 2. Visual Outcomes, Anatomic Outcomes, and Postoperative Complications

Parameter	Tamponade (n = 136)	No Tamponade (n = 57)	*P* Value
Postoperative logMAR BCVA at 12 mo[a]	0.48 ± 0.49	0.27 ± 0.32	.003
Postoperative logMAR BCVA at final visit[a]	0.47 ± 0.48	0.28 ± 0.35	.010
Visual improvement at 12 mo, mean ± SD[a]	–0.13 ± 0.38	–0.25 ± 0.31	.028
Visual improvement at final visit, mean ± SD[a]	–0.13 ± 0.35	–0.23 ± 0.31	.037
Visual change at 12 mo			
Improved 3 lines or more	50 (36.8)	27 (47.4)	.147
No change	67 (49.3)	27 (47.4)	
Deteriorated 3 lines or more	19 (14.0)	3 (5.3)	
Visual change at final follow-up			
Improved 3 lines or more	48 (35.3)	27 (47.4)	.102
No change	68 (50.0)	27 (47.4)	
Deteriorated 3 lines or more	20 (154.7	3 (5.3)	
Eyes that achieved MTM resolution at 12 mo, n (%)	110 (80.9)	39 (68.4)	.090
Eyes that achieved MTM resolution at final visit, n (%)	131 (96.3)	51 (89.5)	.125
Time to MTM resolution, mo, mean ± SD (range)[a]	7.3 ± 5.4 (0.3-24)	9.3 ± 5.8 (0.5-24)	.039
Postoperative CFT at 12 mo, µm, mean ± SD (range)[a]	136.0 ± 63.4 (0-348)	175.0 ± 67.4 (46-348)	<.001
Lens status (phakia/pseudophakia) at 12 mo, n (%)	5/131	2/55	.715
Lens status (phakia/pseudophakia) at final visit, n (%)	3/133	1/56	.724
Eyes with intact photoreceptor EZ at 12 mo, n (%)	57 (41.9)	39 (68.4)	.001
Postoperative complications			
MH, n (%)	16 (11.8)	7 (12.3)	.887
RRD, n (%)	8 (5.9)	4 (7.0)	.977

BCVA = best-corrected visual acuity; CFT = central foveal thickness; EZ = ellipsoid zone; logMAR = logarithm of the minimum angle of resolution; MH = macular hole; RRD = rhegmatogenous retinal detachment.

[a]Mann–Whitney rank sum test. Other statistical analyses were conducted by χ^2 test.

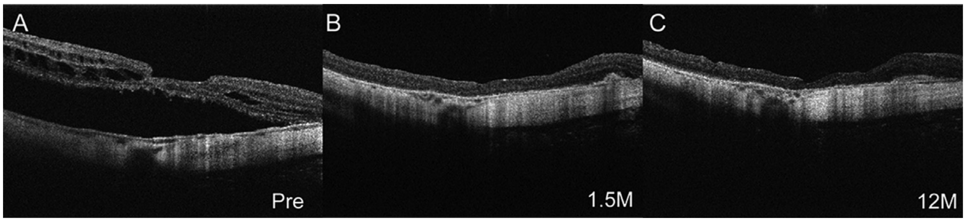

FIGURE 2. Myopic traction maculopathy treated by vitrectomy with tamponade. A. Optical coherence tomography (OCT) image at the initial presentation showed foveal retinal detachment with lamellar hole in a 77-year-old woman. Visual acuity (VA) was 20/100. (B) One and a half months after surgery with air tamponade. Schisis resolved. (C) Twelve months after surgery, VA was 20/250.

at 12 months are shown in Table 3. On univariate analysis, better VA at 12 months was significantly associated with younger age (P = .015), better preoperative VA (P < .001), preoperative phakic lens status (P = .005), thicker choroidal thickness (P < .001), smaller gauge size (P = .002), phacovitrectomy (P < .001), BBG rather than ICG use for ILM peeling (P = .007), and no tamponade use (P < .001). Factors that remained statistically significant in multivariable analysis were better preoperative VA (P < .001), preoperative phakic lens status (P = .041), phacovitrectomy (P < .001), and no tamponade (P = .004).

Results of the univariate and multivariable linear regression analyses investigating factors associated with visual changes at 12 months are shown in Table 4. On univariate analysis, greater visual improvement at 12 months was significantly associated with worse preoperative VA (P = .002), preoperative phakic lens status (P < .001), smaller gauge size (P = .009), phacovitrectomy (P < .001), BBG rather than ICG use for ILM peeling (P = .047), and no tamponade (P = .013). Factors that remained statistically significant on multivariable analysis were worse preoperative VA (P < .001), phacovitrectomy (P < .001), and no tamponade (P = .007).

TABLE 3. Preoperative and Intraoperative Factors Associated With logMAR Visual Acuity at 12 Months

Variable	Univariate Linear Regression			Multivariable Linear Regression
	Regression Coefficient	R^2	*P* Value	*P* Value
Age, y	0.008	0.031	.015	.077
Sex (male: 0, female: 1)	–0.050	0.002	.524	
Laterality of the eye (right: 0, left: 1)	–0.023	0.0006	.724	
Preoperative logMAR visual acuity	0.780	0.400	<.001	<.001
Axial length	0.009	0.002	.604	
Lens status (phakia: 1, pseudophakia: 2)	0.190	0.041	.005	.041
Preoperative MTM height	0.0002	0.007	.260	
Preoperative neurosensory retinal thickness	–0.0001	0.002	.511	
Preoperative choroidal thickness	–0.003	0.088	<.001	.242
Vitrectomy gauge size (23: 1, 25: 2, 27: 3)	–0.214	0.051	.002	.526
Phacovitrectomy (yes: 1)	–0.297	0.106	<.001	<.001
ILM peeling (standard: 0, fovea-sparing: 1)	–0.052	0.003	.431	
Dye for ILM peeling (BBG: 0, ICG: 1)	0.194	0.042	.007	.942
Tamponade type (none: 0, air: 1, SF6: 2, C3F8: 3)	0.147	0.092	<.001	.004

BBG = Brilliant Blue G; C_3F_8 = perfluoropropane; ICG = indocyanine green; ILM = internal limiting membrane; MTM = myopic traction maculopathy; logMAR = logarithm of the minimum angle of resolution; SF_6 = sulfur hexafluoride.

TABLE 4. Preoperative and Intraoperative Factors Associated With logMAR Visual Change at 12 Months

Variable	Univariate Linear Regression			Multivariable Linear Regression
	Regression Coefficient	R^2	*P* Value	*P* Value
Age, y	–0.002	0.002	.493	
Sex (male: 0, female: 1)	0.080	0.009	.202	
Laterality of the eye (right: 0, left: 1)	–0.053	0.005	.315	
Preoperative logMAR visual acuity	0.220	0.050	.002	<.001
Axial length	0.021	0.016	.127	
Lens status (phakia: 1, pseudophakia: 2)	–0.183	0.061	<.001	.106
Preoperative MTM height	–0.00004	0.0006	.748	
Preoperative neurosensory retinal thickness	–0.00007	0.001	.620	
Preoperative choroidal thickness	0.0004	0.002	.545	
Vitrectomy gauge size (23: 1, 25: 2, 27: 3)	0.142	0.036	.009	.522
Phacovitrectomy (yes: 1)	0.265	0.135	<.001	<.001
ILM peeling (standard: 0, fovea-sparing: 1)	0.087	0.006	.307	
Dye for ILM peeling (BBG: 0, ICG: 1)	–0.115	0.023	.047	.961
Tamponade type (none: 0, air: 1, SF6: 2, C3F8: 3)	–0.069	0.032	.013	.007

BBG = Brilliant Blue G; C_3F_8 = perfluoropropane; ICG = indocyanine green; ILM = internal limiting membrane; MTM = myopic traction maculopathy; logMAR = logarithm of the minimum angle of resolution; SF_6 = sulfur hexafluoride.

• **ANATOMIC OUTCOMES:**

Resolution of schisis

Schisis resolved in 110 eyes (80.9%) in the tamponade group and 39 eyes (68.4%) in the non-tamponade group at 12 months ($P = .090$), and in 131 eyes (96.3%) in the tamponade group and 51 eyes (89.5%) in the non-tamponade group at the final follow-up ($P = .125$). The mean time to the resolution of MTM (both schisis and foveal retinal detachment) was significantly shorter in the tamponade group (7.3 ± 5.4 months) compared to the non-tamponade group (9.3 ± 5.8 months) ($P = .039$) (Figures 1 and 2). Longer-acting gas such as C_3F_8 and SF_6 was significantly associated with a faster resolution of schisis compared with air ($R^2 = 0.044$, $P = .005$).

Retinal thickness

The postoperative central foveal thickness at 12 months was significantly thinner in the tamponade group (136.0 ± 63.4 μm) than in the non-tamponade group (175.0 ± 67.4 μm) ($P < .001$). The postoperative central foveal thickness at 12 months in eyes that achieved resolution of schisis was also significantly thinner in the tamponade group

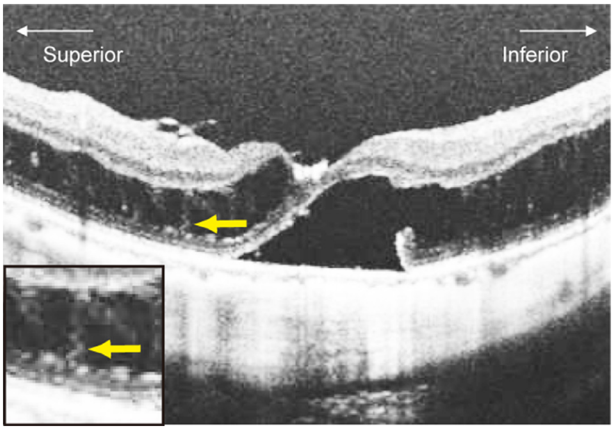

FIGURE 3. A vertical optical coherence tomography showing schisis bending (accordioning) (yellow arrow) in the early postoperative period after vitrectomy with air tamponade. Superior retina (left) where tamponade acts more than the inferior retina (right) shows schisis bending.

(128.4 ± 54.8 μm) compared to the non-tamponade group (164.6 ± 55.6 μm) ($P < .001$). Longer-acting gas was significantly associated with a thinner foveal thickness at 12 months ($R^2 = 0.096$, $P < .001$).

Status of the ellipsoid zone

Spectral-domain or swept-source OCT at 12 months revealed an intact EZ in 57 eyes (41.9%) in the tamponade group and 39 eyes (68.4%) in the non-tamponade group ($P = .001$). Intact EZ was significantly associated with better postoperative VA at 12 months ($R^2 = 0.305$, $P < .001$).

Schisis bending

In the first 2 months after surgery, 37 eyes (27.2%) in the tamponade group and 4 eyes (7.0%) in the non-tamponade group showed schisis bending ($P = .003$) (Figure 3). The presence of schisis bending was not associated with postoperative logMAR VA at 12 months ($P = .648$).

• **POSTOPERATIVE COMPLICATIONS:** Postoperative full thickness MHs developed in 11.8% of eyes (16 of 136) in the tamponade group and 12.3% of eyes (7 of 57) in the non-tamponade group ($P = .887$). Rhegmatogenous retinal detachment developed in 5.9% of eyes (8 of 136) in the tamponade group and 7.0% of eyes (4 of 57) in the non-tamponade group ($P = .977$).

DISCUSSION

This is the first large-scale study to investigate the effects of tamponade on visual and anatomic outcomes in patients with MTM. Our multicenter study revealed that vitrectomy was effective in both eyes with or without the use of tamponade, and resulted in significant improvement in postoperative VA at 12 months and at the final follow-up visit. However, eyes with tamponade had significantly worse postoperative VA and less visual improvement, despite the similar baseline characteristics in the tamponade and non-tamponade groups. These results indicated that tamponade may have a negative impact on visual outcomes in the treatment of MTM. Eyes treated with tamponade had significantly faster resolution of the schisis; however, the retina was thinner at 12 months in the tamponade group compared to the non-tamponade group. In addition, longer-acting gases increased the likelihood of worse visual outcomes and a thinner retina. Tamponades, and especially long-acting gases, may potentially place mechanical stress on the retina and may promote retinal thinning because of the preexisting vulnerability of the retina in highly myopic eyes. The development of postoperative complications, such as MH and RRD, did not differ between the tamponade and non-tamponade groups (12% vs 12%, $P = .887$, and 6% vs 7%, $P = .977$, respectively). Based on our study, surgery without tamponade is possible and may even be recommended for treating patients with MTM, although complete resolution of schisis may take longer.

To date, MTM has been treated both with and without tamponading agents.[5,14-16,18,20-25] Historically, after the first description of retinoschisis and foveal retinal detachment on OCT in 1999, MTM was initially treated in the early 2000s with long-acting gas tamponades.[26] Kuhn and Kobayashi et al separately reported the treatment of foveal detachment by vitrectomy, ILM peeling, and 20% to 30% SF_6.[15,16] Kawano et al and Ikuno et al also treated MTM with vitrectomy, ILM peeling, and 13% to 16% C_3F_8.[18] These studies were conducted as pilot studies aimed at determining the potential efficacy and safety profiles of PPV for MTM. Later, Hirakata et al reported the successful treatment of the retinoschisis type of MTM without tamponade.[27] Gaucher et al and Panozzo et al subsequently reported the successful resolution of schisis and foveal retinal detachment without tamponade also.[5,20] However, the potential benefits or disadvantages of tamponading agents have not been confirmed before this study.

Some surgeons have hypothesized that gas tamponade may break the thinnest foveal area in MTM, potentially leading to MH formation.[27] Others have suggested that gas tamponade may accelerate retinal reattachment, thereby benefiting the retina by restoration of oxygen delivery, and that gas tamponade may also prevent MH formation, as gas is an essential component for the treatment of MH.[22] A few comparative studies reported comparable preoperative and postoperative visual acuity in MTM patients treated with or without tamponade.[21,22] However, Kim et al observed a trend toward a greater proportion of patients experiencing a visual improvement of 3 lines or more in the group without tamponade (63% vs 56% for no tamponade and gas-treated groups, respectively).[21] Postoperative MH developed in 22% of eyes in the gas-treated group. By contrast, Zheng et al showed a greater visual improvement in the gas-treated group compared to the group without tamponade, potentially attributed to the worse baseline visual acuity in the gas-treated group, providing a larger margin for potential improvement.[21,22] MH did not develop in either group. The small sample sizes in these studies due to the relatively rare prevalence of MTM may have contributed to the inconsistency in the previous studies.[21,22] Our findings presented here indicate that tamponade at least does not appear to increase the risk of postoperative MH, although it may have adverse effects on visual outcomes.

The reason why gas tamponade may have an adverse effect on visual outcomes is unclear; however, as the postoperative central foveal thickness 12 months after surgery was significantly thinner in eyes that received tamponade, the tamponade may have mechanically over-pressurized the vulnerable retina. In addition, eyes treated with tamponade had higher chances of EZ disruption. Preserved retinal thickness is associated with better VA in healthy retinas without macular edema, and the EZ is a biomarker of favorable retinal function.[28,29] Therefore, the preservation of retinal thickness and the EZ in the non-tamponade group may have had a positive impact on vision. However, this study is not designed to determine the mechanisms of why EZ disruption was more common with tamponading agents. Macular atrophy soon after surgery has been reported in highly myopic eyes that have undergone vitrectomy with tamponade for MTM or MH retinal detachment.[30] There is a chance that eyes with more attenuated EZ preoperatively were more likely to have undergone surgery with air and gas tamponades, but the preoperative metrics were similar between the 2 groups. Further studies are needed to investigate whether tamponade may more likely to induce macular atrophy than treatment without tamponade.

The worse visual outcomes and thinner postoperative retinal thickness with tamponade in the current study may be related to the specific underlying anatomy in high myopia. The vitreous cavity is enlarged, and the axial length is elongated in high myopia. Tanaka et al reported that the majority of highly myopic eyes had vitreous volumes greater than 7 mL and up to 10.2 mL, whereas eyes without high myopia had vitreous volumes of 4 to 5 mL, indicating that some highly myopic eyes have twice as large a vitreous volume,[31,32] as the vitreous volume is significantly correlated with the axial length.[32,33] The larger volume of the vitreous cavity allows a larger amount of tamponade to fill the eye than would occur in emmetropic eyes, and this extra amount could potentially result in higher pressure toward the retina when the patient is in the face-down position after surgery. Some studies have also indicated that the shear stress received by the retina from eye movement appears to be greater in high myopia because of the larger vitreous space, with a maximum shear stress 1.5 times greater than in emmetropic eyes.[34] In addition, the scleral, choroidal, and retinal volumes are generally low in high myopia.[35-37] This preexisting thinness may make the highly myopic eye more prone to damage from tamponading agents. The high elasticity of the sclera in highly myopic eyes and the reduced rigidity of the retina following ILM peeling may further contribute to a greater stretching force on the retina, resulting in retinal thinning.[38,39] Thus, we speculate that the higher pressure exerted by a larger amount of tamponade and a lower resistance to pressure in eyes with high myopia compared to emmetropic eyes may act synergistically in retinal thinning and may result in worse vision in eyes treated with tamponade. However, as there was no significant association between the axial length and visual outcomes in our study, our speculation should be validated and other potential reasons should be explored in future studies.

We also observed a new finding of "schisis bending (accordioning)" in the early postoperative period, especially in patients treated with tamponade. Although the schisis bending in the early period did not predict the postoperative visual outcomes and although its clinical relevance remains unclear, the higher incidence of schisis bending in the tamponade group suggests that tamponade caused structural changes within the retina due to the pressure it exerts, although a few eyes without tamponade also had this finding, possibly due to the removal of traction by surgery. Bending, or accordioning, of the intraretinal structures was observed at the bridging columns of the schitic retina, which likely corresponds to elongated Müller cells between the inner and outer layers of the split retina.[40] Thus, the removal of traction and tamponade may leave abnormal organization and alignment of the intraretinal structures. It may be possible that in eyes with very early resolution of schisis with tamponade, the elongated Müller cells or neurons may remain bent within the retina. Future studies are needed to determine whether retinal function in such cases may be reduced.

Our results confirmed that schisis resolution is possible without tamponade, as suggested by previous studies.[20,21,27] The disadvantage of not using tamponade is that the schisis takes longer to resolve than when the surgery includes tamponade. Treatment without tamponade leads to gradual and gentle resolution of the schisis without imposing mechanical stress on the intraretinal structure, thereby preserving the retinal architecture. We assume that the slow schisis resolution and the associated gradual retinal repositioning without tamponade seem more physiological than the active and forceful retinal repositioning promoted by tamponade. Both patients and surgeons may feel a sense of reassurance when complete resolution of schisis is achieved quickly. However, waiting for a more gradual resolution seems to be beneficial for obtaining more favorable visual outcomes as long as the traction is removed during surgery. Complete resolution was achieved in 96.3% of the eyes with tamponade and in 89.5% of the eyes without tamponade, with no significant differences at the mean follow-up length of approximately 2 years.

In this study, the use of tamponade did not increase the frequencies of postoperative complications, such as MH and rhegmatogenous retinal detachment. However, tamponade had no beneficial role in preventing MH and retinal detachment. Appropriate treatments, such as gas injection or reoperation with PPV, are necessary when complications develop regardless of the use of tamponade in the initial surgery.

The strength of the present study is its large-scale multicenter approach. However, this study has several limitations. First, a major limitation is the retrospective nature of this study. We understand that the best design to confirm the impact of tamponade would be a randomized prospective study. However, as MTMs requiring surgery are not encountered frequently, a randomized prospective study would require the participation of many institutions over several years, and this is not practical. Second, the OCT measurements were conducted by graders from each institution, although blinded graders at a reading center would be ideal for these measurements. Third, potential differences may have existed in the retinal and choroidal thickness measurements because of the different OCT machines used in this study. Thus, ideally, the same OCT machine should have been used. However, the same OCT machines were used for each eye before and after surgery at each institution, and this reduces the bias regarding longitudinal measurements of the same eyes. Fourth, because this was a multicenter study, different surgeons performed the surgeries, with nonstandardized surgical approaches. Thus, some biases may not be quantitatively evaluated. However, more than half of the surgeons performed surgery in both the tamponade and non-tamponade groups. We also compared many aspects of the surgical approaches, such as concurrent cataract surgery, ILM peeling with or without a fovea-sparing technique, and use of dye for ILM peeling. Although the 23-gauge systems were more commonly used in the tamponade group, this was not significantly associated with visual outcomes based on multivariable analysis, consistent with the previous study that showed no differences in visual and anatomic outcomes between 25-gauge and 23-gauge vitrectomy for myopic foveoschisis.[41] Fifth, because of the retrospective design of this study, we lack the protocol for postoperative follow-up schedules to determine the exact timing of MTM resolution. Sixth, we included only advanced MTM that required vitrectomy and did not include more routine ERMs or vitreomacular traction (VMT) without obvious schisis. Therefore, we could not investigate the potential impact of tamponade on typical ERM or VMT cases without high myopia in general. Finally, eyes with preexisting MH associated with the progression of MTM were also excluded from our study, as we believe that these eyes require tamponade to close the MH. Preoperative evaluation with serial OCT scans is important when choosing the need for tamponade. In the future, prospective studies with larger datasets are needed to validate our results.

In summary, our study represents the first large-scale study to examine the impact of tamponade on postoperative visual and anatomic outcomes. Vitrectomy both with and without tamponade was effective. However, the most notable finding was that eyes without tamponade had even better visual outcomes and more preserved retinal architecture, albeit with a significantly longer schisis resolution time compared with eyes treated with tamponade. Surgery without the use of tamponade may be recommended to improve the visual outcomes of MTM. Future prospective studies that incorporate imaging analysis may be warranted to validate our results and to provide deeper insights into the role of tamponade in retinal morphology to further improve the prognosis of MTM.

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