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CHARACTERISTICS AND MANAGEMENT OF MYOPIC TRACTION MACULOPATHY IN MYOPIC EYES WITH AXIAL LENGTH LESS THAN 26.5 mm

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Purpose: To explore the characteristics and underlying mechanisms of myopic traction maculopathy (MTM) with axial length less than 26.5 mm and to assess the effectiveness of macular buckling for the treatment of MTM.

Methods: Thirty-eight MTM eyes with axial length less than 26.5 mm were prospectively enrolled. Thirty-one eyes received surgery, and they were followed up for at least 6 months. Characteristics of MTM and surgical outcomes were evaluated.

Results: Of the MTM eyes, 92.11% (35/38) showed posterior staphyloma. Narrow macular staphyloma was the most common type (54.29%, 19/35), followed by peripapillary (37.14%, 13/35). Three cases (8.57%) had wide macular staphyloma, and 44.74% of cases (17/38) had vitreoretinal traction. Twenty-two MTM eyes of type T3 underwent macular buckling surgery, and all the cases achieved foveal reattachment after the surgery. The mean best-corrected visual acuity improved significantly at the 6-month follow-up ($P <$ 0.001). Nine MTM eyes of type T4 or T5 received combined surgery, all macular holes recovered, and the best-corrected visual acuity also improved postoperatively ($P =$ 0.008) as of the 6-month visit.

Conclusion: Posterior staphyloma might serve as the initial force of the pathogenesis of MTM in eyes with axial length <26.5 mm. Macular buckling is a productive way to improve the MTM.

RETINA 42:540–547, 2022

Myopic traction maculopathy (MTM), one of the complications of pathologic myopia, is characteristic of retinoschisis, macular hole (MH), and foveal retinal detachment.[1,2] The exact pathogenesis of MTM is not fully understood. Its suspected causes are the opposite tractions of the posterior staphyloma and vitreoretinal interface.[3,4] Although MTM is commonly related to longer axial length (AL), we also observed some nonhighly myopic eyes that presented MTM with an AL less than 26.5 mm in clinical practice. To date, only limited data have been published. No studies have been conducted to analyze characteristics and potential mechanisms in MTM-affected eyes with an AL less than 26.5 mm.

In previous work, we reported that uneven expansion of the ocular globe with posterior staphyloma contributes to MTM.[5] We also observed that eyes with a dome-shaped macula had a weaker possibility of developing MTM, even in cases with preretinal traction,[6] suggesting that posterior staphyloma may play a vital role in the pathogenesis of MTM. However, all

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Supported by the Natural Science Foundation of Guangdong province of China (2018A030310232). The sponsor or funding organization had no role in the design or conduct of this research.

None of the authors have any financial/conflicting interests to disclose.

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these issues were centered on high myopia. Whether MTM eyes with an AL less than 26.5 mm share similar issues remains unclear.

Critically, such MTM eyes may exhibit atrophy of the fundus, posterior staphyloma, and decreased vision. The risks of damaging visual and anatomical functions of these eyes must not be disregarded. Clinicians must focus on the management of this condition. Current treatments for MTM include pars plana vitrectomy (PPV), macular buckling (MB), and combined surgery (PPV/MB).[7–9] PPV enabled a temporary release of the vitreoretinal traction without diminishing the significant risks of posterior staphyloma.[7,10] MB could achieve good anatomical and functional results by releasing both inner traction and stretching force from posterior staphyloma. This method was considered a suitable initial treatment for MTM in high myopia with ALs ≥26.5 mm.[11,12] Nevertheless, there is little evidence regarding the applicability of MB in MTM-affected eyes with ALs less than 26.5 mm.

For this reason, we aimed to investigate the clinical features and underlying mechanisms for those MTM-affected eyes with ALs less than 26.5 mm and its effects of MB on the treatment.

Methods

Study Participants

We studied 38 eyes of 30 myopic patients from the Zhongshan Ophthalmic Center High Myopia Cohort Study between January 2019 and November 2020. The inclusion criteria were myopic patients aged from 18 to 75 years, AL >24 mm and <26.5 mm, the presence of MTM on optical coherence tomography (OCT) image, and evidence of posterior scleral staphyloma detected by three-dimensional magnetic resonance imaging. The exclusion criteria included were history of vitrectomy or scleral buckling, the presence of any other nonmyopia disease, and any opaque media impeding the evaluation of the macula by clinical imaging. This study was approved by the Ethics Committee of the Zhongshan Ophthalmic Center and complied with the tenets of the Declaration of Helsinki. Signed informed consent was obtained from all the patients.

Ophthalmic Examinations

All the patients underwent comprehensive ophthalmic examinations, including color fundus photographs (TRC50LX device, Topcon, Tokyo, Japan), AL measurement (IOLMaster, Carl Zeiss, Oberkochen, Germany), assessment of the refractive error with an autorefractor (KR-8900 1.07, Topcon Corporation, Tokyo, Japan), and OCT images captured with a swept source OCT (DRI OCT Triton, Topcon, Japan). Refractive error was expressed in spherical equivalent refraction. The best-corrected visual acuity (BCVA) was recorded in Snellen value and converted into the logarithm of the minimum angle of resolution (logMAR) for further statistical analysis. Vitreoretinal traction included the epiretinal membrane, posterior vitreoschisis, and vitreomacular tractions detected by swept source OCT.

Identification of Posterior Staphyloma

Posterior staphyloma was defined as an outpouching of a posterior fundus' circumscribed region with a curvature radius less than the surrounding eyewall,[13] confirmed by three-dimensional magnetic resonance imaging scan. Posterior staphylomas were classified into six different types as previously described[14]: wide macular staphylomas, narrow macular staphylomas, peripapillary staphylomas, nasal staphylomas, inferior staphylomas, and other staphylomas. Two independent, well-trained ophthalmologists performed the classification and grading of the myopic maculopathies (CSD and CJ). In cases of disagreement, adjudication was made by a retina specialist (LL).

Definition of Myopic Traction Maculopathy and Myopic Atrophic Maculopathy

We adopted the new classification and grading system (ATN) for myopic maculopathy.[15] In brief, T was graded as T0 to T5 using OCT: T0, no macular schisis; T1, inner or outer foveoschisis; T2, inner and outer foveoschisis; T3, foveal retinal detachment; T4, full-thickness macular hole (FTMH); and T5, MH and retinal detachment. We defined the presence of MTM as the T1 and greater in this study. Myopic atrophic maculopathy was classified into the following types: A0, no fundus change; A1, tessellated fundus only; A2, diffuse chorioretinal atrophy; A3, patchy chorioretinal atrophy; and A4, complete macular atrophy.

Surgical Procedure

We performed MB as previously described.[11] In brief, 360° peritomy of the perilimbal conjunctiva and separation of the Tenon capsule were performed. Then, we isolated the rectus muscle to allow sufficient exposure of the sclera. A T-shaped buckle was designed, consisting of a silicone sponge rod embedded with a perforated titanium plate, a silicone band, and a piece of silicone sponge cushion fixed at the junction site. The silicone sponge cushion was positioned at the

Table 1. Patients and Eye Characteristics With AL Less Than 26.5 mm

Characteristics	
No. of eyes (patients)	38 (30)
Male	12
Female	26
Age (years)	50.76 ± 15.14
Axial length (mm, mean ± SD)	25.89 ± 0.56
BCVA in logMAR (Snellen)	0.91 ± 0.30 (~20/160)
Spherical equivalent refraction (diopter)	−5.93 ± 2.39
Myopic atrophic maculopathy, n (%)	
A0	2 (5.26)
A1	13 (34.21)
A2	23 (60.53)
A3	0
A4	0
MTM, n (%)	
T0	0 (0)
T1	2 (5.26)
T2	5 (13.16)
T3	22 (57.89)
T4	4 (10.53)
T5	5 (13.16)
Vitreoretinal traction, n (%)	
Present	17 (44.74)
Absent	21 (55.26)
Posterior staphyloma, n (%)	
Present	35 (92.11)
Wide macular staphyloma	3 (8.57)
Narrow macular staphyloma	19 (54.29)
Peripapillary staphyloma	13 (37.14)
Nasal staphyloma	0
Inferior staphyloma	0
"Others" staphyloma	0
Absent	3 (7.89)

macula to produce adequate indentation. The two extremities of the silicone band were sutured at the superonasal and temporal sclera, respectively, to ensure the proper location and height of the buckling. Finally, we made a paracentesis of the anterior chamber to drain the fluids and lower the intraocular pressure. Pars plana vitrectomy combined with MB was performed in MTM of T4 and T5 types, as described in our previous study.[16] MTM resolution was defined as a decrease in height or extent at the macula, without development of any inner lamellar MH, macular hole retinal detachment, or a full-thickness MH.

Statistical Analysis

All the data were processed using SPSS version 24.0 software (IBM Corp). Categorical variables were expressed in frequencies and percentages. Normally distributed continuous variables were compared using paired *t*-tests, whereas nonnormally distributed continuous variables were compared using a Mann–Whitney *U* test. All the tests were two-sided. A value of $P < 0.05$ was considered to be statistically significant.

Results

We included 38 eyes of 30 patients. The features in MTM eyes with ALs less than 26.5 mm were assessed. The clinical characteristics of the MTM eyes are summarized in Table 1. The mean age was 50.76 ± 15.14 years (mean ± SD; range 22–75); the average AL was 25.89 ± 0.56 mm. The mean spherical equivalent was −5.93 ± 2.39 diopters.

Characteristics of Myopic Traction Maculopathy Eyes With AL <26.5 mm

In MTM eyes with AL <26.5 mm, Grade T3 was the most common type of MTM in this cohort, prevailing in 22 of 38 eyes (57.89%), followed by Grade T2 and T5 at both 13.16% (5/38 eyes), Grade T4 at 10.53% (4/38 eyes), and Grade T1 at 5.26% (2/38 eyes). Twenty-three of 38 eyes (60.53%) presented with diffuse chorioretinal atrophy, which resembles pathologic myopic maculopathy; 34.21% (13/38 eyes) showed tessellated fundus and 5.26% (2/38 eyes) with no change in the myopic fundus.

From the three-dimensional magnetic resonance imaging, it was found that 92.11% of MTM eyes (35/38) showed posterior staphyloma. Three main types of posterior staphyloma were identified (Figure 1), of which narrow macular staphyloma was found to be the most common type, accounting for 54.29% (19/35 eyes) (Figure 1B), followed by peripapillary (37.14%, 13/35 eyes) (Figure 1C). The remaining three cases (8.57%) were identified as wide macular staphyloma (Figure 1A). 44.74% of cases (17/38 eyes) had vitreoretinal traction. More than 50% of MTM eyes had no vitreoretinal traction involvement and presented a posterior staphyloma.

Surgical Outcomes

Of the 38 eyes of 30 patients, 31 eyes underwent surgery and seven of them presenting T1 and T2 with relatively superior eyesight declined the surgery and were kept under observation; of the 31 eyes, 22 eyes presenting with macular schisis and foveal detachment underwent the MB procedure and nine MTM-affected eyes presenting with T4 and T5 adopted combined surgery (PPV/MB). After surgery, all patients experienced relief from their macular schisis or foveal detachment, and all macular holes recovered (Figure 2).

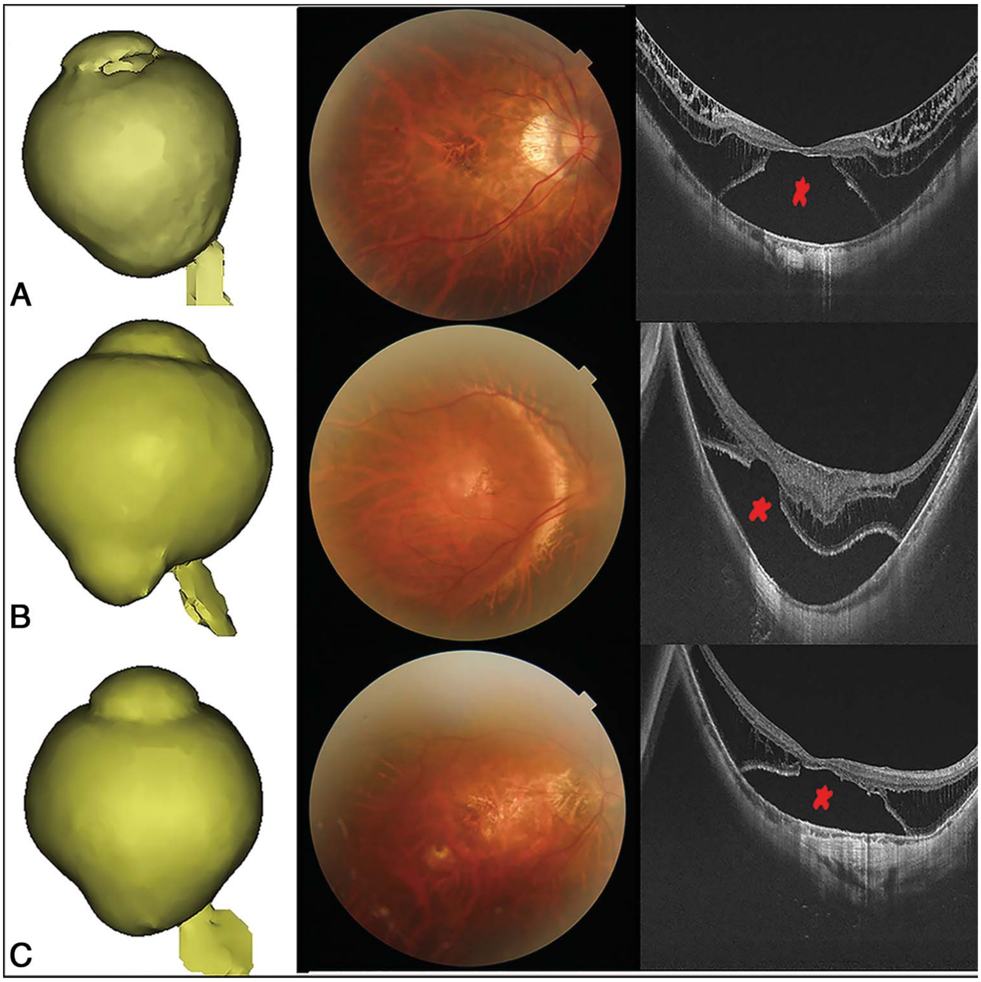

Fig. 1. Representative images of different scleral staphyloma types **A**. A 48-year-old woman with the spherical equivalent of 6.5 diopter and AL of 26.4 mm. Three-dimensional magnetic resonance imaging scan displays wide macular staphyloma (*left lane*). Fundus photography presents slight diffuse atrophy (*middle lane*). Optical coherence tomography shows inner and outer macular retinoschisis with foveal detachment (*right lane*). **B.** A 65-year-old man with a spherical equivalent of 6.25 diopters and AL of 26.2 mm. Three-dimensional magnetic resonance imaging scans showed narrow macular staphyloma with a protrusion in the temporal direction (*left lane*). The fundus presented diffuse fundus atrophy with a remarkable concave line (*middle lane*). OCT presented macular schisis and foveal detachment (*right lane, red asterisk*). **C.** The case of a 61-year-old female patient with a spherical equivalent of 6 diopter and AL of 25.67 mm. Three-dimensional magnetic resonance imaging scan of the globe displays a peripapillary staphyloma (*left lane*). Fundus photography in the middle lane showing diffuse fundus atrophy (*middle lane*). Optical coherence tomography in the right lane showing outer macular retinoschisis with a foveal detachment (*right lane*).

Best-corrected visual acuity improved in 26/31 eyes (83.87%) and remained stable in 5/31 eyes (16.13%). Of the five unimproved eyes, three eyes belong to T4 or T5 type. The difference in BCVA preoperatively and postoperatively was statistically significant ($P <$ 0.001) in both MB surgery and combined surgery during the 6-month follow-up (Figure 3). For those eyes that underwent MB surgery, the mean BCVA values in logMAR (Snellen) at baseline and one, three, and six months after surgery were 1.13 (~20/271), 1.15 (~20/286), 0.84 (~20/140), and 0.74 (~20/110), respectively. Nine eyes underwent combined surgery (PPV/MB). The BCVA improved from 1.14 ± 0.40 logMAR (~20/278) preoperatively to 0.92 ± 0.44 logMAR (~20/167) postoperatively (P = 0.008) as of the 6-month visit.

Changes in AL are shown in Figure 4. Overall, AL was reduced by 2.43 mm (SD = 1.52) on average ($P <$ 0.001) at month six postoperatively. Although there was a slight increase one month later, the AL remained relatively stable during the 6-month follow-up period.

All the patients suffered from metamorphopsia after surgery. However, this symptom significantly improved in the following six months. There were no apparent complications, such as vitreous hemorrhage, binocular diplopia, esotropia, implant exposure, cataract progression, or development of full-thickness MH, as described in our previous study.[11] Transient ocular hypertension occurred in three eyes (9.68%) but gradually decreased within one week.

Discussion

Myopic traction maculopathy eyes with AL less than 26.5 mm are much less common than those in highly myopic eyes. To the best of our knowledge, this is the first study to center on the characteristics, potential mechanisms, and management of MTM eyes with AL <26.5 mm. Our results showed that posterior

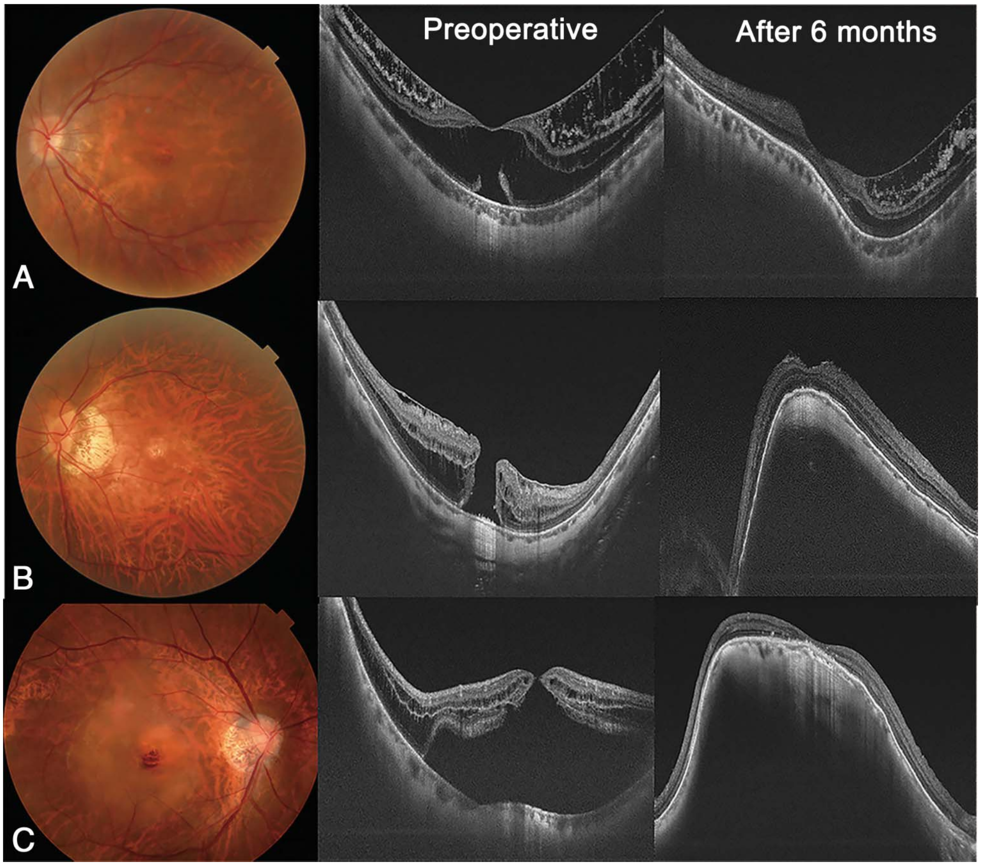

Fig. 2. Preoperative and postoperative characteristic image. **A.** A 37-year-old woman with a spherical equivalent of 6.5 diopter and axial length (AL) of 26.35 mm. Fundus photography showed diffuse atrophy (*left lane*). Optical coherence tomography showed inner and outer macular retinoschisis with foveal detachment preoperatively (*middle lane*). The best-corrected visual acuity was 1.0 logMAR (20/200) at 6 months after MB surgery. Optical coherence tomography showed all the macular schisis, and subretinal fluid disappeared, although paramacular schisis existed (*right lane*). BCVA significantly improved to 0.4 logMAR (20/50); AL was 24.62 mm. **B.** A 57-year-old woman with a spherical equivalent of 5.0 diopter and AL of 25.66 mm. Fundus photography showed diffuse atrophy (*left lane*). Optical coherence tomography showed a macular hole preoperatively (*middle lane*). Best-corrected visual acuity was 1.30 logMAR (20/400). At the 6-month postsurgery follow-up, OCT showed complete closure of the macular hole (*right lane*). BCVA significantly improved to 0.92 logMAR (~20/167); AL was 23.68 mm. **C.** A 66-year-old man with a spherical equivalent of 5.0 diopter and AL of 26.13 mm. Fundus photography showed diffuse atrophy (*left lane*). Optical coherence tomography showed macular hole retinal detachment preoperatively (*middle lane*). Best-corrected visual acuity was 1.22 logMAR (~20/333). After combined surgery (PPV/MB), OCT showed complete closure of the macular hole and foveal reattachment (*right lane*). At the 6-month postsurgery follow-up, BCVA significantly improved to 0.70 logMAR (20/100); AL was 24.04 mm.

staphyloma might be the leading force contributing to the pathogenesis of MTM. Macular buckling or combined (MB/PPV) surgery was recommended as the preferred treatment, which could produce functional and anatomical outcomes.

In our study of 38 MTM cases, foveal retinal detachment with retinoschisis, defined as T3, was the most frequently observed (57.89%), followed by T2 and T5 (13.16%), T4 (10.53%), and T1 (5.26%). These results were very similar to those reported in previous studies in highly myopic eyes.[1,4] The reason for the high prevalence of category T3 might be attributable to the clinical population's inherent characteristics because decreased vision tends to occur if the lesions involve the macula. In our series, most of the MTM eyes with AL <26.5 mm presented posterior staphyloma. Of the three main types of posterior staphyloma identified in this study, narrow macular staphyloma and the peripapillary staphyloma were the most common types, and the least common was wide macular staphyloma. Our results are consistent with Wakazono's study,[17] showing that sharp-pointed changes in eye shape promote MTM. Limited data could be found regarding those MTM with a short AL. Only one case of MTM in low-to-moderately myopic eyes has been found to have peripapillary staphyloma.[4]

The prevailing views of the mechanism underlying MTM focus on the opposite force arising from both inner vitreoretinal traction and posterior staphyloma.[1] However, in this series, more than 50% of cases showed no involvement of vitreoretinal traction; conversely, more than 90% of the eyes had posterior staphyloma. This suggested that the vitreoretinal traction might not play a pivotal role in the development of MTM. In previous work, we elucidated the role of the nonuniform expansion of the ocular globe with posterior staphyloma in the pathogenesis of MTM in highly myopic eyes.[5] We also observed that MTM was not likely to occur in highly myopic eyes with a dome-shaped macula, although in cases with vitreoretinal traction.[6] Taken together, these findings can be interpreted to indicate that posterior staphyloma is the leading force in the initiation of

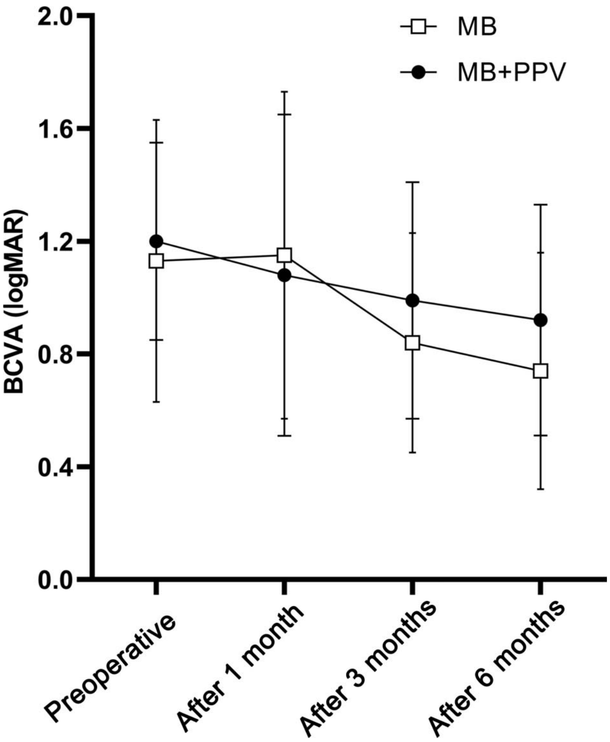

Fig. 3. Changes of BCVA during the 6-month follow-up.

MTM. We speculate that unevenly progressive stretching of the posterior eyeball results in backward stretching of the ocular tissue, including the retina, choroid, and sclera. Then, posterior vitreoschisis or asymmetrical posterior vitreous detachment may take place. Then, vitreal adhesions may work together to induce traction on the retina. Vitreoretinal traction may serve as the secondary factor in the pathogenesis of MTM.

In our experience, if left untreated, these MTM-affected eyes suffer further damage in both visual and anatomical function, arising from progressive stretching of the staphyloma at the posterior hole of the eyeball. There is no doubt that surgery is the best way to treat an MH or MH and retinal detachment. However, the management of foveal detachment has not been ascertained. Previous studies reported a foveal detachment predisposed to develop more frequently into a full-thickness MH during its natural course.[18,19] For all these reasons, prompt intervention is warranted.

Pars plana vitrectomy and MB are the primary approaches to the management of MTM with foveal detachment. Although PPV with or without internal limiting membrane peeling was reported to eliminate the tangential and centripetal traction force attributed to vitreoretinal tractions, this method still presents some issues. First, a full-thickness MH might occur after PPV with or without internal limiting membrane peeling. The reported incidence of this complication is 0%–30% for highly myopic eyes.[9,18,20–22] Second, a late recurrence of foveoschisis might exist, owing to the unsolved traction from posterior staphyloma.[14,23] Third, the safety of PPV plus fovea-sparing internal limiting membrane peeling has also been questioned because a late contraction of the remaining internal limiting membrane might lead to complications such as the formation of an epiretinal membrane.[9] Furthermore, the PPV surgery itself is not free of complications, such as iatrogenic injury of the macular structure and subsequent cataract progression.[11,21]

MB has been reported to relieve both inner tractions and posterior staphyloma by reshaping the posterior scleral wall with an inward buckle at the posterior of the eyeball and achieves better results than PPV, particularly in cases with a thin foveal roof or severe foveal detachment.[24,25] Our previous study also revealed the superiority of MB compared with PPV for surgical treatment of macular schisis and foveal detachment in high myopia.[11] Because posterior staphyloma is one potential mechanism underlying the issues in the MTM eyes in our study, as shown in the schematic diagram (Figure 5), we used MB to treat MTM eyes of the subtype T3. Our results showed promising outcomes, similar to those reported in highly myopic eyes.[8,11] In a prospective study

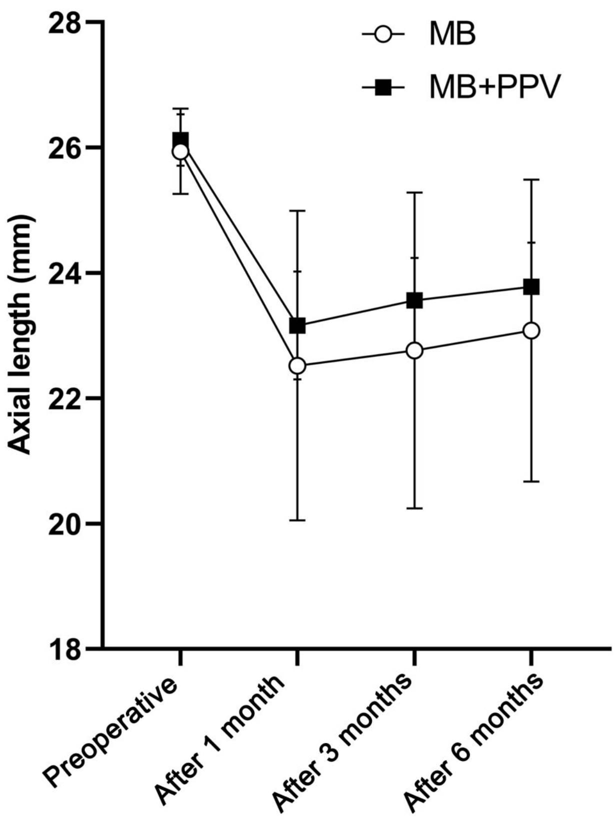

Fig. 4. Changes of axial lengths during the 6-month follow-up.

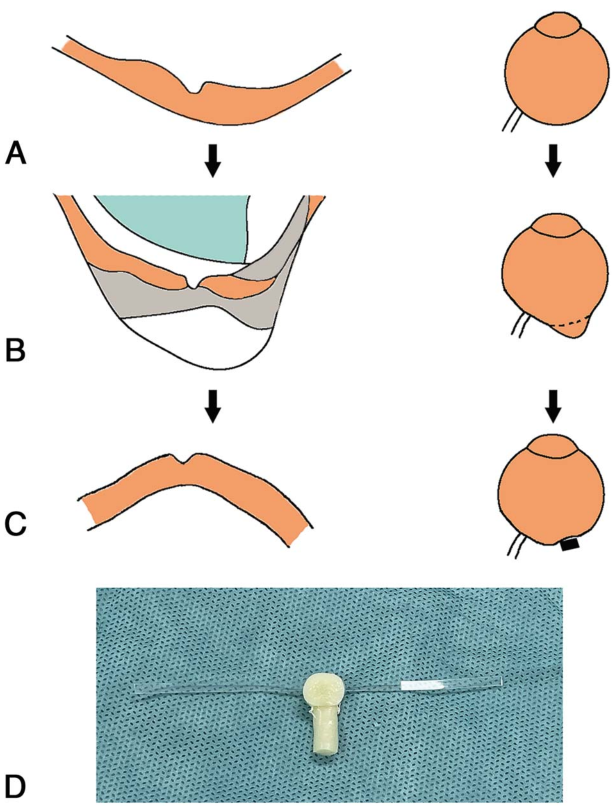

Fig. 5. Schematic diagram of pathogenesis and management of MTM. **A.** Showing normal retinal structure (orange) and eye shape. **B.** Eye shape deforms with posterior staphyloma, resulting in stretching backward of ocular tissue. Subsequently, posterior vitreoschisis or asymmetrical posterior vitreous detachment (green) may occur, then induce macular schisis (gray) and foveal detachment (blank). **C.** Macular buckling releases the traction force from the posterior staphyloma and inner force by an inward buckle (black). **D.** The T-shaped buckle comprises a silicone sponge rod embedded with a perforated titanium plate, an encircling silicone belt, and a circular silicone sponge cushion 8 mm in diameter fixed at the junction site. The silicone belt was adjusted according to the eyeball size during the surgery.

published by Figueroa et al,[8] PPV was used to treat MTM eyes with T3, and this method achieved MTM resolution at a 93% rate (28/30), but complications, including macular hole and a rhegmatogenous retinal detachment, occurred in two patients. Altogether, these studies suggest better outcomes after MB surgery relative to PPV for the treatment of foveal detachment.

MB can achieve a higher success rate in retinal reattachment than PPV on the macular hole and macular detachment.[26,27] In another study on macular holes and foveoschisis treated by MB, retinal reattachment was achieved in 100% of cases, while MH closure was 76.19%.[28] Despite the success rate, MB alone cannot achieve a promising outcome in the macular hole closure. Given the closure of MH, combined surgery (PPV/MB) was performed to treat those MTM eyes with T4 or T5, which could address both the tangential force at vitreoretinal interface and the eye stretching from posterior staphyloma. We observed that all the nine eyes achieved closure of the macular hole within 6 months. Thus, we recommend combined surgery (MB/PPV) to treat macular holes with macular detachment.

Our results showed that BCVA was statistically improved postoperatively and remained well or slightly increased during the follow-up period, consistent with the published literature.[29] 83.87% of eyes (26/31) achieved improvement in BCVA; five eyes (16.13%) remained unchanged compared with the preoperative visual acuity. The reason for the five unimproved eyes in BCVA is possibly because of the chronic condition. Macular buckling brings the retinal pigment epithelium closer to the retina and restores the macular architecture,[7] which might be critical in improving BCVA. The average AL was significantly reduced one month postoperatively and remained relatively stable during the follow-up visits, although there was a slight increase in AL over time. This finding indicates that MB might slow AL elongation, thereby delaying macular atrophy progression and vision deterioration.

Metamorphopsia is commonly seen in patients with macular schisis, macular detachment, or macular holes before and after MB surgery in our previous studies.[11,26] In this study, although all the patients still experienced metamorphopsia postoperatively, all of them presented a gradual improvement of metamorphopsia as of the six-month visit, possibly because of the gradual relieving of macular schisis and foveal detachment.

The strengths of our study stem from the fact that it was a prospective collection of data and added data concerning MTM eyes with ALs less than 26.5 mm to foster a better understanding of the pathogenesis of MTM. It also brought new evidence of the beneficial effects of MB on the treatment of MTM eyes with ALs of $<$26.5 mm. However, several limitations also exist. First, the number of patients was limited. Second, although the patients were prospectively enrolled, no randomized control group was involved. Third, the follow-ups were short, and long-term effects should be investigated with an extended prospective cohort.

In conclusion, this report has added data concerning MTM eyes with ALs less than 26.5 mm to improve our understanding of the pathogenesis of MTM. We concluded that posterior staphyloma might serve as the initial force of the pathogenesis of MTM. For those MTM-affected eyes with posterior staphyloma, MB provides favorable anatomical and visual improvement, and we recommend it as the preferred surgery.

Key words: myopic traction maculopathy, posterior staphyloma, macular buckling.

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