Progression Patterns of Myopic Traction Maculopathy in the Fellow Eye After Pars Plana Vitrectomy of the Primary Eye

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Purpose. This retrospective study investigated the patterns and risk factors of progression of myopic traction maculopathy (MTM) of fellow eyes after pars plana vitrectomy (PPV) of primary eyes.

Methods. The study population comprised 153 patients with MTM in both myopic eyes who sequentially underwent PPV (2006–2021). Observation periods were from PPV of the primary eye (baseline) to PPV of the fellow (end). MTM was graded based on optical coherence tomography (OCT) images and the ATN (atrophy [A], traction [T], and neovascularization [N]) system. An increase in T grade was considered MTM progression.

Results. MTM progressed in 43.8% of fellow eyes during 34.57 ± 34.08 months. The progression of fellow eyes correlated with T grade of primary eyes ($P < 0.001$). Risk factors for the progression of MTM in fellow eyes were primary eyes in T4–T5, age at baseline <60 years, and fellow eyes with partial posterior vitreous detachment (PVD; $P < 0.001$, $P = 0.042$, and $P = 0.002$, respectively). Fellow eyes in T1/T2 at baseline progressed faster compared with those in T0 ($P < 0.001$); the annual rate of progression to T3–T5 of the T0 (T1–T2) groups was 9.98% (24.59%).

Conclusions. Risk factors for the progression of MTM in fellow eyes included PPV when relatively young, primary eye at high T grade, and partial PVD of the fellow eye. Personalized follow-up for fellow eyes should be based on the severity of MTM of both eyes.

Keywords: ATN classification system, fellow eye, pathologic myopia, myopic traction maculopathy, partial posterior vitreous detachment

Myopia is an ocular disease with increasing worldwide prevalence, and its related macular complications usually lead to visual impairment and blindness.[1] In 2020 globally, about 17% of cases of visual impairment were associated with myopia macular complications, and this rate will rise to 58% by 2050.[2,3]

Myopia is defined as mild, moderate, or high, depending on axial length (AL) and spherical equivalent (SE). The AL and SE of high myopia are >26.5 mm and <–6.0 diopters (D), respectively.[4] Although pathologies may occur at the moderate level, high myopia is more likely to progress to chorioretinopathy, including chorioretinal atrophy, traction lesions, and choroidal neovascularization.[5–8] To classify these maculopathies systematically and comprehensively, many ophthalmologists have adopted the ATN (atrophy [A], traction [T], and neovascularization [N]) system.[9–13]

The traction (T) component of the ATN system has received special focus, because grades T3, T4, and T5 reflect foveoschisis (or myopic traction maculopathy [MTM]), which involves foveal detachment, macular hole (MH), and macular hole retinal detachment (MHRD). Without surgery, the progression of these conditions is irrevocable.[14–16] Progression in the primary eye can be delayed via pars plana vitrectomy (PPV),[17–19] but the fellow eye, in relatively good condition, may also progress and require surgical intervention due to symmetry of refraction and AL elongation.

Previous studies have found that, among patients with bilateral high myopia who underwent PPV in primary eyes for MHRD, 9% to 12.8% of the fellow eyes also progressed to MHRD.[20,21] For this reason, patients with bilateral high myopia who have undergone PPV on the primary eye are usually anxious about the possible progression of the fellow eye. Thus, determining the risk factors for progression of MTM in fellow eyes is an important issue for ophthalmologists, who need a reliable follow-up plan for early detection and treatment of the individual patient.

Previous studies reported that SE, AL, posterior staphyloma, chorioretinal atrophy, and epiretinal traction were risk factors for progression of MTM in Singaporean[22,23] and Chinese people.[24] However, these studies concerned biological parameters of the eyeball and fundus, and associations between MTM and long-term dynamic changes, as in partial posterior vitreous detachment (PVD), remain unknown. In addition, these studies usually regarded the two eyes of the patient as independent research subjects and ignored the interrelationship of the bilateral eyes. Therefore, these findings may not accurately predict the progression of fellow eyes after PPV for primary eyes. It is important to understand the conditions of the primary eye during follow-up after PPV, which may predict problems in the fellow eye.

The present study was designed to avoid the limitations of others. For example, in past studies, MTM progression was observed at scheduled time points, which may have missed the end of natural progression. The present study prevented this omission, using a population comprising patients who underwent PPV in bilateral pathologic myopia eyes and setting the observation period from the time of the PPV of the primary eye to the time of the PPV of the fellow eye. Another advantage of the present study is the application of the ATN classification system, which ensured that changes of the vitreoretinal interface in MTM were investigated precisely and comprehensively.

The present study determined patterns and risk factors of MTM progression in a high-risk population (patients who had already undergone PPV for MTM) via evaluation of the fellow eyes. This analysis should allow ophthalmologists to personalize the duration of follow-up of fellow eyes.

Methods

Patients

This retrospective and observational study adhered to the principles of the Declaration of Helsinki and was approved by the Medical Ethics Committee of Eye and ENT Hospital of Fudan University, Shanghai. All patients provided signed informed consent for this retrospective study and adhered to the follow-up requirements.

The study population consisted of 153 adult patients who visited the Eye and ENT Hospital of Fudan University between June 1, 2006, and February 1, 2021. The observation period of the fellow eye began at the time of the PPV for the primary eye (baseline) and ended with the PPV for the fellow eye (end).

The eligibility criteria for the study were bilateral high myopia with AL >26.5 mm and SE <–6.0 D, underwent sequential PPV of the primary and fellow eye due to MTM, high-quality and complete ocular images suitable for classification, and willing to attend follow-up appointments in the clinic. Patients with any of the following were excluded: unilateral high myopia, history of penetrating ocular trauma, underwent PPV for reasons other than MTM (such as non-MHRD or vitreous hemorrhage), or corneal opacities and dense cataracts.

Ophthalmic Examinations

All patient-related basic information was recorded in detail, including date of birth, gender, duration of symptoms, history of ocular diseases, and surgeries. The ophthalmologic evaluation included a slit-lamp microscope examination for the anterior segment, SE, and best-corrected vision acuity (BCVA). AL was measured using an IOL Master 5.5 (Carl Zeiss Meditec, Dublin, CA, USA). Bilateral optical coherence tomography (OCT; Spectralis OCT, Heidelberg Engineering, Heidelberg, Germany, or Cirrus, Carl Zeiss Meditec) was completed by experienced technicians at the initial presentation and at follow-up visits, including the last. The scan field of the OCT was 30 × 30 degrees centered on the fovea, and the same scanning area was obtained by the integrated follow-up mode. Horizontal and vertical line scans across the fovea were performed at the automatic real-time level of 100 frames.

ATN Classification System

The ATN classification for myopic maculopathy was proposed by Ruiz-Medrano et al.[9] in 2019 (Fig. 1). There are six grades of traction, from T0 to T5, defined as follows: T0, no macular schisis; T1, inner or outer foveoschisis; T2, inner with outer foveoschisis; T3, foveal detachment; T4, full-thickness MH; and T5, MHRD.

In the present study, the grade was evaluated based on OCT images by two experienced residents (KK and SX). Where there was dispute, the results were reevaluated by their superior doctor (YN).

Classification of PVD

Itakura and Kishi[25] defined complete PVD as detachment of the posterior hyaloid of vitreous from the optic disc. Based on this definition and the OCT images, we classified PVD as either partial or complete. Partial PVD was considered when a portion of the posterior hyaloid of vitreous remained attached to the retina or optic disc. Complete PVD is complete detachment of the posterior hyaloid of vitreous.

Statistical Analysis

The data were analyzed with SPSS software (version 22.0; SPSS, Chicago, IL, USA) and GraphPad Prism (version 8.4.0; GraphPad Software, San Diego, CA, USA). All numerical variables are shown as mean ± standard deviation and all categorical variables as number and percentage. Differences in numerical variables with homogeneity of variance among three or more groups were compared using one-way ANOVA and the Bonferroni correction. Differences in numerical variables with heterogeneity of variance among three or more groups were compared with the Kruskal–Wallis test and the Bonferroni correction. Differences in categorical variables among three or more groups were compared using the χ^2 test. Risk factors were first determined via univariate analysis and then tested using binary logistic regression analysis. Survival curves were evaluated with a log-rank test. P values <0.05 were considered statistically significant.

Results

Basic Characteristics of the Patients and Eyes

Overall, 153 patients were included in this study (Table 1). The female-to-male ratio was 3.94. At the time of the PPV procedures, the women were significantly older than the men for both primary eyes ($P = 0.005$) and fellow eyes ($P = 0.003$).

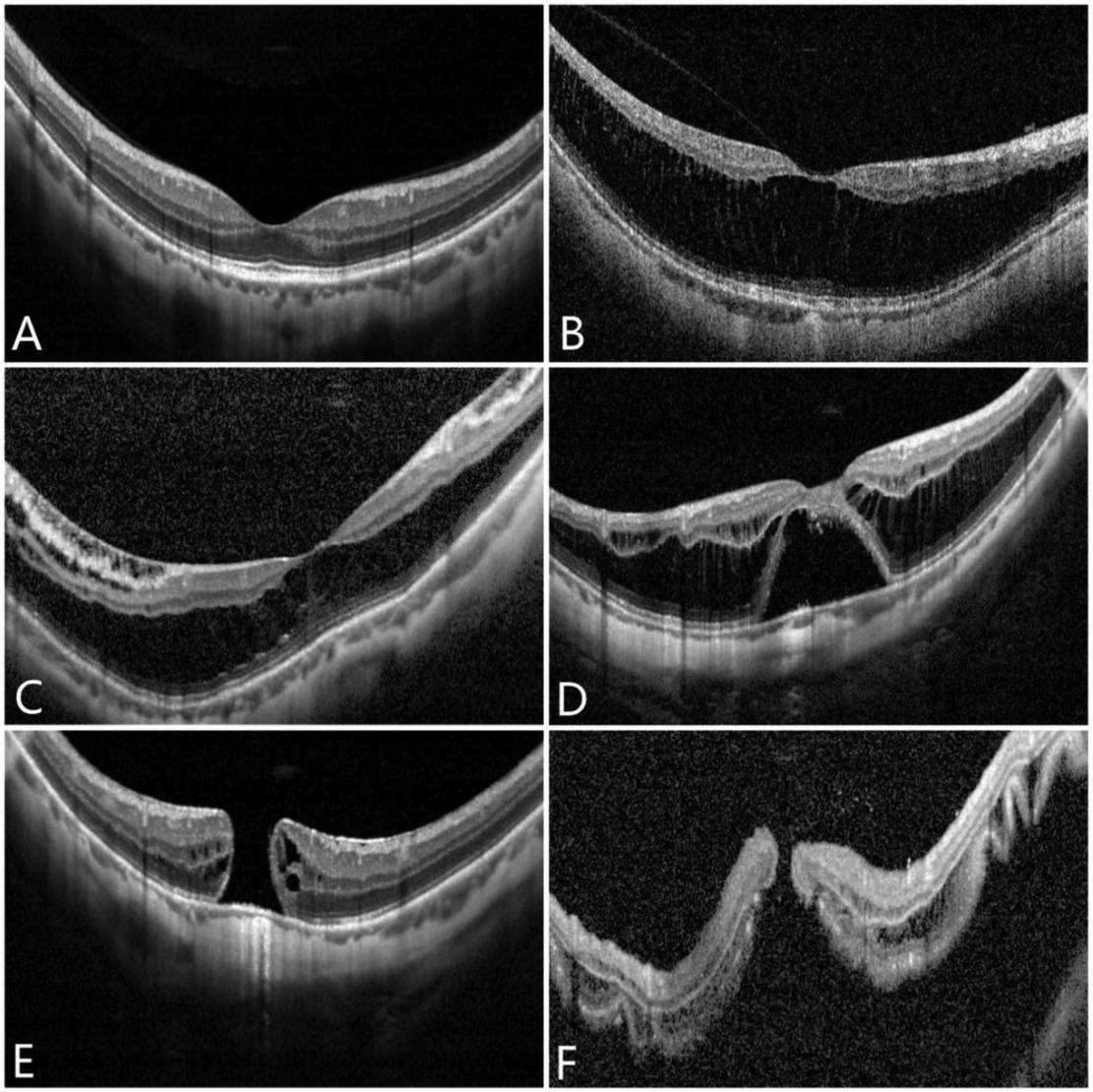

Figure 1. Typical OCT images of the T0–T5 grades. (**A**) T0, no macular schisis. (**B**) T1, inner or outer foveoschisis. (**C**) T2, inner with outer foveoschisis. (**D**) T3, foveal detachment. (**E**) T4, full-thickness MH. (**F**) T5, MHRD.

Table 1. Basic Characteristics of the Study Population ($N = 153$)

Characteristic	Value
Gender, female/male, *n* (%)	122 (79.7)/31 (20.3)
Laterality of primary eyes, right/left, *n* (%)	78 (51)/75 (49)
Surgical interval, mean ± SD (range), mo	23.63 ± 29.68 (1–154)
Age of primary eyes, mean ± SD, y*	
Overall population	55.62 ± 9.78
Women/men†	57.02 ± 8.53/50.09 ± 12.31
Age of fellow eyes, mean ± SD, y*	
Overall population	57.56 ± 9.87
Women/men‡	59.07 ± 8.60/51.65 ± 12.37

* At the time of PPV.
† $P = 0.005$.
‡ $P = 0.003$.

A total of 153 primary eyes (75 left, 78 right) were involved in the study (Table 2). For the population overall, ALs were 29.61 ± 1.73 mm (26.50–34.52 mm), and SEs were –12.52 ± 3.82 D (–6.00 to –24.75 D). Among the primary eyes, 10.5%, 30.7%, 11.1%, and 47.7% were graded T1–2, T3, T4, and T5, respectively.

Table 2. Characteristics of the 153 Primary and 153 Fellow Eyes at the Time of PPV

Characteristic	T1–T2	T3	T4	T5	P*	P†
Primary eyes						
Eyes, *n* (%)	16 (10.5)	47 (30.7)	17 (11.1)	73 (47.7)	—	—
Females, *n* (%)	13 (81.3)	32 (68.1)	9 (52.9)	68 (93.2)	0.001‡	—
Right eyes, *n* (%)	7 (43.8)	29 (61.7)	7 (41.2)	35 (47.9)	0.331	—
Age of PPV, mean ± SD, y	56.95 ± 8.40	51.99 ± 12.11	55.59 ± 10.73	57.65 ± 7.40	0.017‡	0.009‡
AL, mean ± SD, mm	30.08 ± 1.43	29.49 ± 1.47	30.10 ± 2.22	29.47 ± 1.76	0.344	—
SE, mean ± SD, D	–14.23 ± 4.11	–12.23 ± 3.59	–12.32 ± 4.90	–12.12 ± 3.48	0.422	—
Fellow eyes						
Eyes, *n* (%)	46 (30.1)	54 (35.3)	7 (4.5)	46 (30.1)	—	—
Females, *n* (%)	36 (78.3)	39 (72.2)	6 (85.7)	41 (89.1)	0.202	—
Right eyes, *n* (%)	21 (45.7)	30 (55.6)	5 (71.4)	19 (41.3)	0.304	—
Age of PPV, mean ± SD, y	59.60 ± 8.59	54.45 ± 11.07	52.34 ± 12.99	59.97 ± 7.90	0.006‡	0.013‡
AL, mean ± SD, mm	29.82 ± 1.72	29.95 ± 1.82	28.00 ± 1.79	29.73 ± 1.86	0.100	—
SE, mean ± SD, D	–13.51 ± 4.86	–12.89 ± 3.81	–11.00 ± 5.20	–13.55 ± 4.33	0.723	—
SI, mean ± SD, mo	18.65 ± 19.11	14.84 ± 23.83	9.71 ± 10.15	41.04 ± 38.35	0.001‡	—

SI, surgical interval; —, no statistical analysis.
* *P* for groups T1–T2, T3, T4, and T5.
† *P* for T3, T4, and T5 groups.
‡ Significance at $P < 0.05$.

Table 3. Fellow Eyes at Six T Grades According to T Grade of Primary Eyes at Baseline and Last Follow-up

Characteristic	Primary Eye, n		Fellow Eye, *n* (%)							
			FT0	FT1	FT2	FT3	FT4	FT5	Progression	SI, Mean ± SD, mo
PT1–PT2	16	Baseline	0	5 (31.3)	9 (56.3)	2 (12.5)	0	0		
		End	0	5 (31.3)	6 (37.5)	5 (31.3)	0	0	3 (18.8)	10.03 ± 11.98
PT3	47	Baseline	2 (4.3)	7 (14.9)	15 (31.9)	23 (48.9)	0	0		
		End	0	2 (4.3)	13 (27.7)	31 (66)	0	1 (2.1)	12 (25.5)	18.47 ± 21.87
PT4	17	Baseline	2 (11.8)	2 (11.8)	8 (47.1)	2 (11.8)	3 (17.6)	0		
		End	0	1 (5.9)	6 (35.3)	2 (11.8)	5 (29.4)	3 (17.6)	8 (47.1)	14.47 ± 13.32
PT5	73	Baseline	26 (35.6)	9 (12.3)	10 (13.7)	11 (15.1)	8 (11.0)	9 (12.3)		
		End	0	4 (5.5)	9 (12.3)	16 (21.9)	2 (2.7)	42 (57.5)	44 (60.3)*	32.07 ± 36.54†
Sum	153	Baseline	30 (19.6)	23 (15)	42 (27.5)	38 (24.8)	11 (7.2)	9 (5.9)		
		End	0	12 (7.8)	34 (22.2)	54 (35.3)	7 (4.6)	46 (30.1)	67 (43.8)	23.63 ± 29.68

FT, T grades of fellow eyes; PT, T grades of primary eyes.
* Significance at $P < 0.001$; comparison of the progression rates of the PT1–PT2, PT3, PT4, and PT5 groups using the χ^2 test.
† Significance at $P = 0.007$, comparison of the SI of PT1–PT2, P3, P4, and PT5 groups using the Kruskal–Wallis test; $P = 0.016$ for PT1–PT2 and PT5 groups, $P = 0.927$ for PT1–PT2 and PT3 groups, $P = 1.000$ for PT1–PT2 and PT4 groups, $P = 1.000$ for PT3 and PT4 groups, $P = 0.151$ for PT3 and PT5 groups, and $P = 0.476$ for PT4 and PT5 groups using Bonferroni correction.

In the current study, at each advancing T grade from T3 to T5, the age of the patients significantly advanced ($P = 0.009$; Table 2). However, among the T1–T2, T3, T4, and T5 groups, the ALs ($P = 0.344$) and SEs ($P = 0.424$) were comparable.

Among the 153 fellow eyes, 30.1%, 35.3%, 4.5%, and 30.1% were graded T1–T2, T3, T4, and T5, respectively (Table 2). The ages of the patients with T5 at the time of PPV for fellow eyes were significantly higher than that of patients with T3 or T4 ($P = 0.013$). Among the T-grade groups, the ALs ($P = 0.100$) and SEs ($P = 0.723$) were similar.

Association Between T Grades of Primary and Fellow Eyes

An association was investigated between the T grade of the primary eye at baseline and the T grade of its fellow at the time of the latter's PPV. The 153 fellow eyes were divided into four groups based on the T grades of the primary eyes at baseline (PT1–PT2, PT3, PT4, PT5), and for each group, the T grades of the fellow eyes were compared at baseline and at the end of observation (Table 3). Relative to the baseline T grades of the fellow eyes, the rates of advancement in T grade of the fellow eyes in groups PT1–PT2, PT3, PT4, and PT5 were, respectively, 18.8%, 25.5%, 47.1%, and 60.3%. Thus, the progression in the fellow eyes appeared significantly associated with the severity of T grade of the primary eyes ($P < 0.001$).

Overall, the baseline T grade of 102 fellow eyes was lower than that of the corresponding primary eye, and of these 102 eyes, the final T grade of 46 (45.1%) fellow eyes matched that of the primary eye at baseline. In the PT3 group, 9 of 24 (37.5%) fellow eyes increased to foveal detachment. In the PT4 group, 3 of 14 (21.4%) fellow eyes increased to MH. In the PT5 group, 34 of 64 (53.1%) fellow eyes increased to MHRD.

The OCT images of two representative patients are shown in Figure 2, in whom the primary eye underwent PPV for T5, and the fellow eye progressed from T0 or T1 to T5.

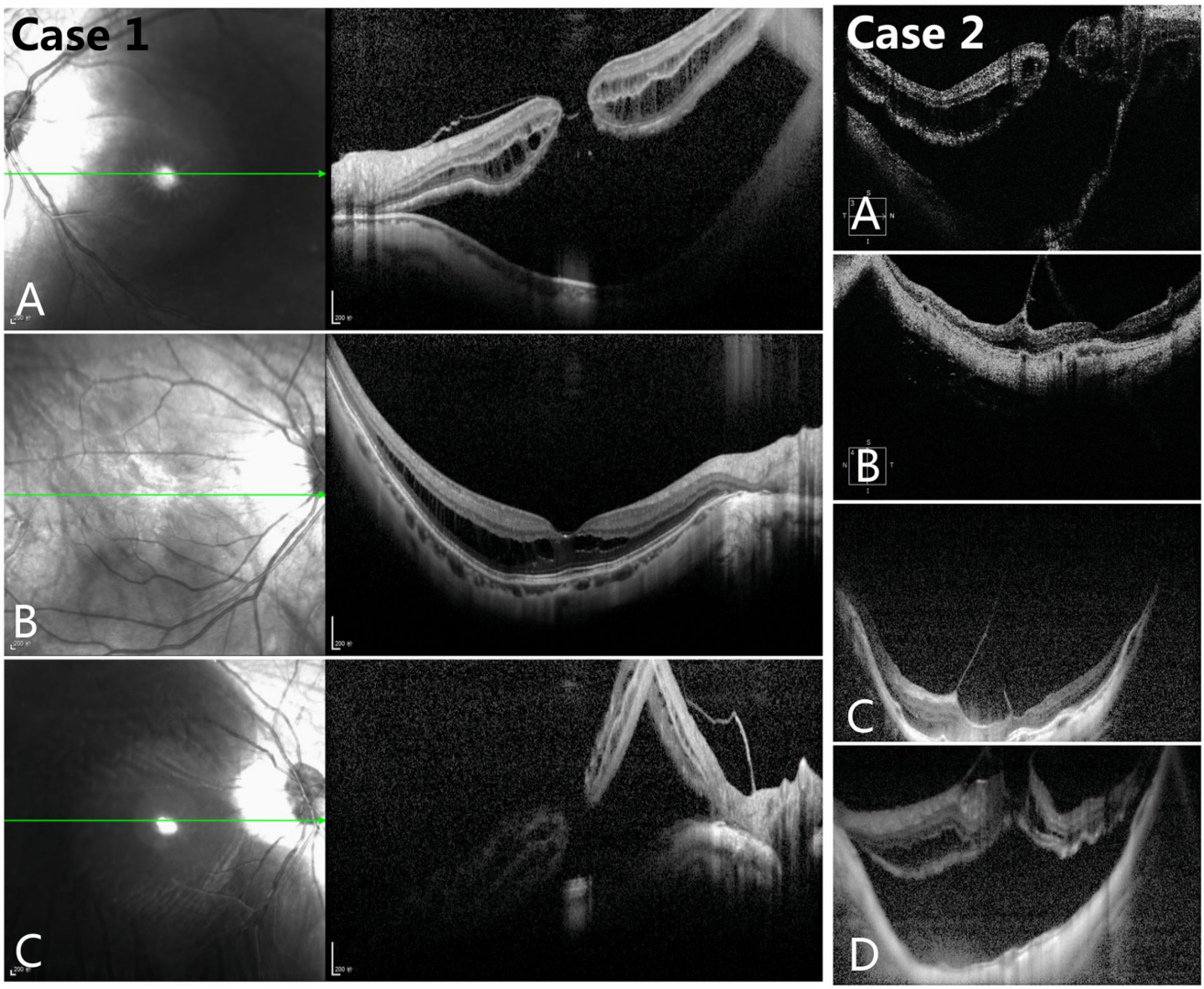

Figure 2. OCT images of representative patients, in whom the primary eye underwent PPV for T5, and the fellow eye progressed from T0 or T1 to T5. Case 1: (**A**, **B**) A 55-year-old woman. At the initial PPV, the left (primary) eye was in T5, and fellow eye was in T1 (outer foveoschisis). (**C**) The right eye progressed to T5 three years later. Case 2: (**A**, **B**) A 55-year-old woman. At the initial PPV, the right (primary) eye was in T5, and the fellow eye was in T0. (**C**) Two years later, her left eye had remained in T0. (**D**) Four years after the initial PPV, the fellow eye had progressed to T5.

Risk Factors of Progression of MTM in Fellow Eyes

At baseline, 9 (of 153) fellow eyes were in T5, indicating the need for emergency surgical treatment. These were excluded for analysis of risk factors in the progression of MTM, because they could rise no further in T grade. The final follow-up results of the remaining 144 fellow eyes showed that 67 (46.5%) increased in T grade, and 77 (53.5%) were unchanged. For analysis, the fellow eyes were classified as progressed or unchanged.

A univariate analysis was conducted to determine the variables that influence progression of MTM. The following were excluded P values >0.1: dome-shaped macula ($P = 0.772$), posterior staphyloma ($P = 0.417$), AL of primary eyes >30 mm ($P = 0.730$), AL of fellow eyes >30 mm ($P = 0.737$), SE of fellow eyes <–12 D ($P = 0.844$), history of phacoemulsification ($P = 0.259$), history of refractive surgery ($P = 1.000$), primary left eyes ($P = 0.322$), and male gender ($P = 0.417$). Potential factors that showed statistical significance in the univariate analysis were further analyzed by multivariate analysis (Fig. 3): partial PVD (66.18%; cf. 39.47%, $P = 0.003$), primary eyes in T4–T5 (76.47%; cf. 38.16%, $P < 0.001$), and age of primary eyes undergoing PPV <60 years (76.47%; cf. 59.21%, $P = 0.05$). After setting the surgical interval at >14 months as a hypothetical risk factor to prevent confounders and adjust the odds ratio (OR), the multivariate analysis showed that each of the following were risk factors for the progression of MTM in fellow eyes (Fig. 3): partial PVD (OR = 3.727; 95% confidence interval [CI], 1.615–8.597; $P = 0.002$), primary eyes in T4–T5 (OR = 6.260; 95% CI, 2.658–14.741; $P < 0.001$), and age of primary eyes undergoing PPV <60 years (OR = 2.517; 95% CI, 1.033–6.136; $P = 0.042$).

The OCT images of two representative patients in the progression group who were younger than 60 years at the time of PPV of the primary eye and who developed partial PVD in the fellow eye are shown in Figure 4.

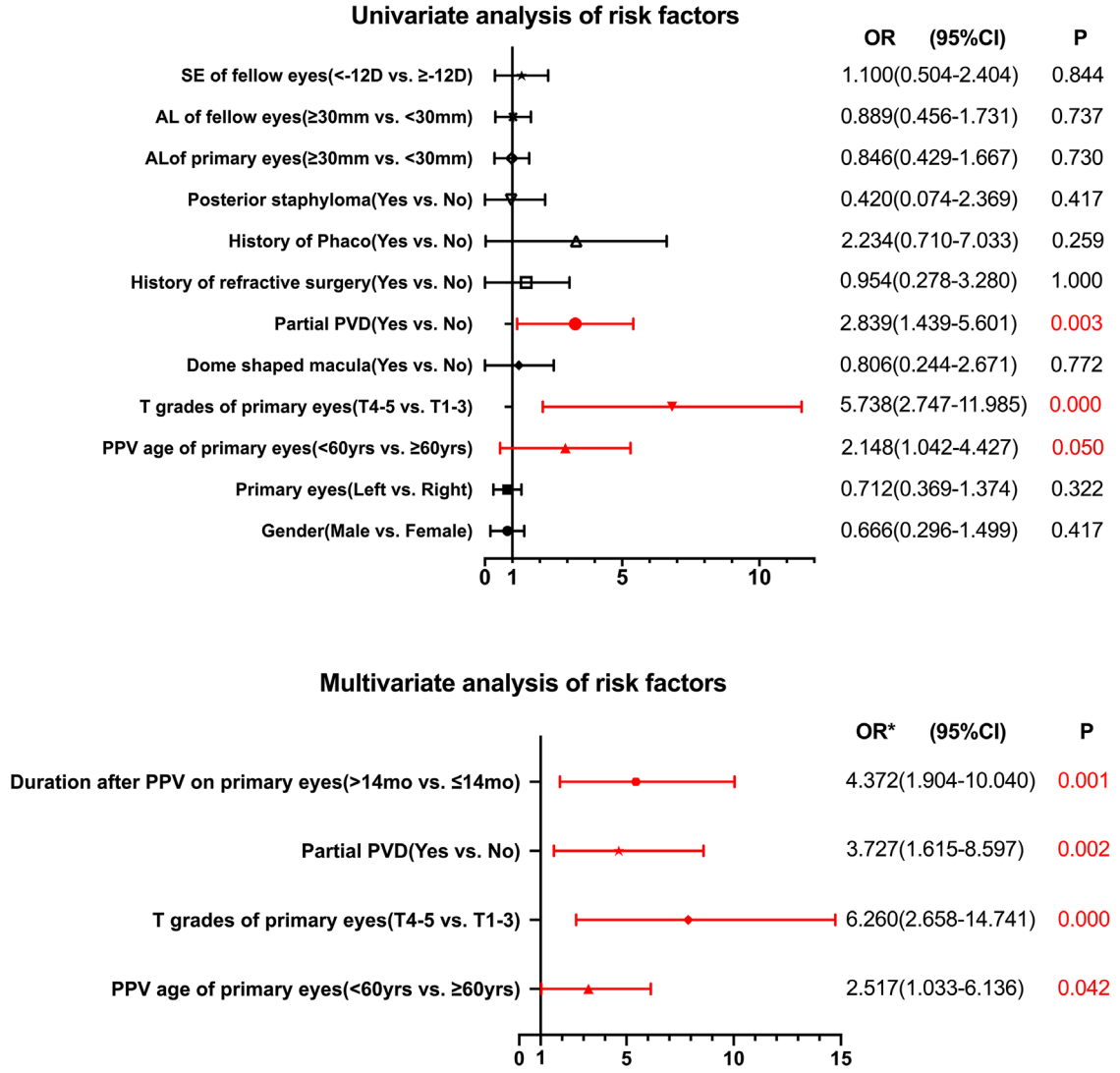

Figure 3. Univariate and multivariate analyses of risk factors of 144 fellow eyes. *Red values* in the univariate analysis indicate $P < 0.1$; *red values* in the multivariate analysis are $P < 0.05$. OR*: OR adjusted according to surgical interval. Note: the surgical interval >14 months was also set as a potential risk factor.

Findings in the Observation of Fellow Eyes in T0–T2

Ninety-five fellow eyes were in T0–T2 at baseline. Of these, 51 (53.68%) increased to T3–T5 during the surgical interval, specifically, 25 (49.02%), 9 (17.65%), and 17 (33.33%) eyes that were in T0, T1, and T2 at baseline, respectively. From the baseline T grade, the time of progression to T3–T5 was significantly longer in fellow eyes at T0 (62.80 ± 40.12 months) compared with those in T1 (22.89 ± 14.37 months) or T2 (17.88 ± 13.01 months; $P < 0.001$, both), although the duration for the T1 and T2 groups was comparable. Within 4 years, 10 (40%) eyes in the T0 group and all eyes in the T1 and T2 groups increased to T3–T5 (Fig. 5).

The log-rank analysis indicated that the progression of the T0 group was significantly slower than that of the T1 and T2 groups ($P < 0.001$), while there was no significant difference between the T1 and T2 groups ($P = 0.615$). The annual rates of increase to T3–T5 of the T0, T1, and T2 groups were 9.98%, 24.65%, and 24.28%, respectively. The semiannual rates of increase to T3–T5 of the T1 and T2 groups were 12.04% and 12.15% (Fig. 6).

Discussion

The foci of this retrospective observational study were the pattern of MTM progression of fellow eyes and risk factors of progression. The high-risk population comprised patients who had undergone PPV for MTM. Structural changes associated with MTM were evaluated based on OCT images, and MTM was judged according to T (traction), using the ATN system of classification. It was found that the MTM progression rate of fellow eyes, reflected by the change in T grade from baseline through the final follow-up, increased with the T-grade severity of the primary eyes at the time of the initial PPV. The logistic regression analysis showed that the significant risk factors for progression of MTM in fellow eyes were all indicated at the initial PPV: primary eyes at T4–T5, the patient younger than 60 years, and fellow eyes with partial PVD. Notably, the duration of progression was determined

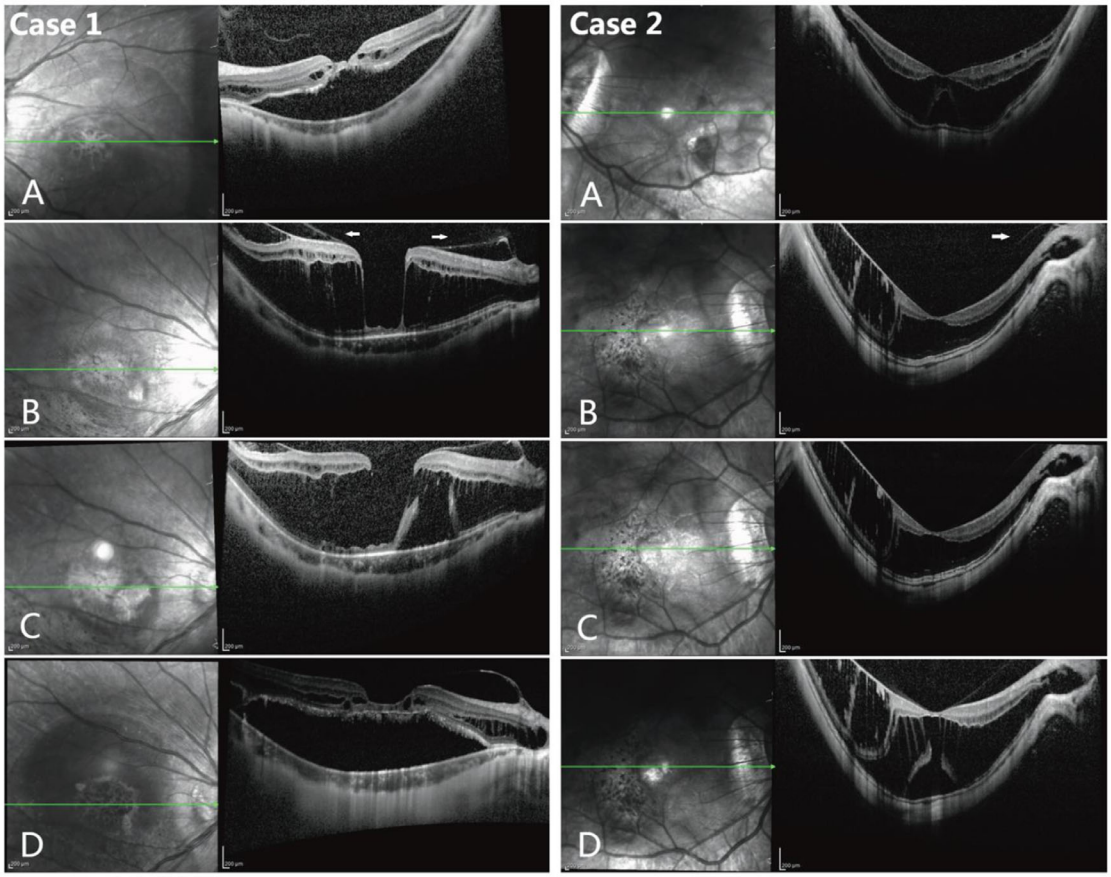

Figure 4. OCT images of representative patients in the progression group who were younger than 60 years at the time of PPV of the primary eye and who developed partial PVD in the fellow eye. Case 1: (**A**, **B**) A 34-year-old woman underwent PPV in her left (primary) eye, which was in T3; her right (fellow) eye was in T2 with partial PVD (*arrows*). (**C**) While mild parafovea detachment occurred, her right eye was still in T2 eight months later. (**D**) Her right eye progressed to T3 and underwent PPV 17 months after her initial PPV on the primary eye. Case 2: (**A**, **B**) A 36-year-old woman underwent PPV in her left (primary) eye, which was in T3; her right (fellow) eye was in T2 with partial PVD (*arrow*). (**C**) Her right eye was still in T2 four months later. (**D**) Fourteen months after the initial PPV, her right eye progressed to T3 and underwent PPV.

by the baseline T grade. The semiannual rate of progression of fellow eyes at T1–T2 was comparable to the annual rate of progression of fellow eyes at T0. Thus, we recommend that assessment of the risk of progression of MTM in fellow eyes, and development of a follow-up plan should be based on comprehensive consideration of the bilateral eyes.

Most patients with pathologic myopia have bilateral lesions and undergo surgeries of each eye sequentially, but researchers have seldom attended to associations of the conditions between the two eyes.[26–28] However, two retrospective studies noted that 10% to 12% of the fellow eyes of patients with bilateral high myopia who had MHRD in the primary eye also progressed to MHRD.[20,21] In the present study, laterality, AL, age at PPV, and T grades of the primary eyes were the assumed potential risk factors of MTM progression in fellow eyes. Analysis of these risk factors determined that patients with primary eyes in T4–T5 of MTM and those who underwent PPV when they were younger than 60 years were more likely to progress in their fellow eyes. The primary eye and the fellow eye of the individual patient usually show symmetric AL elongation and refractive status. This means that similar traction maculopathy will gradually develop in each of the bilateral eyes. Moriyama et al.[29,30] used three-dimensional magnetic resonance images to show that, in 52.1% to 69.8% of patients with bilateral high myopia, the shapes of the posterior segment of the two eyes of the same individual were the same. In the current study, at the last follow-up, the bilateral eyes of about half of the patients were at the same T grade.

The T component of the new ATN classification system proposed in 2019[9] is a better reflection of MTM progression compared with the previous classification system proposed by Shimada et al.[31] Previous studies reported that the severity of MTM increased from T0 to T5 with patient age.[10] In the present study, when the patients were grouped by T grade at the initial PPV, the average ages of groups T1 and T2 were similar, but the ages of groups T3, T4, and T5 were each significantly higher than grade below. In the current analysis, the age of patients with primary eyes undergoing PPV in the T1–T2 group was not entered with the age patterns of the higher-grade groups to prevent potential confounders. Most ophthalmologists consider that MTM in T1–T2 that is without other lesions is not an indication for surgery,[32] and most patients in T1–T2 undergo PPV when MTM is combined with a structural abnormality such as epiretinal membrane or lamellar macular hole, which can induce blurred vision and metamorphopsia.[33,34]

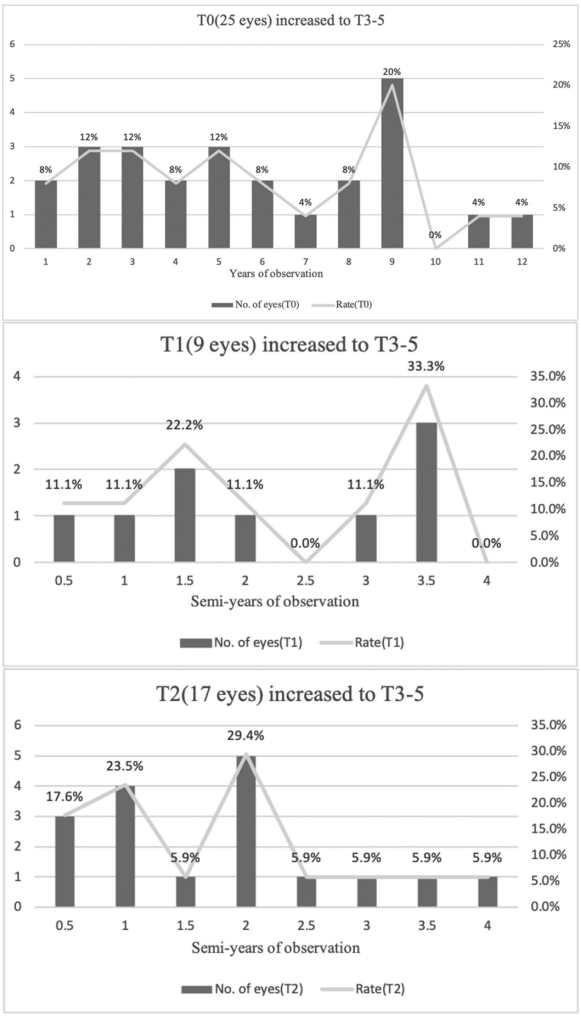

Figure 5. Years of observation of fellow eyes in T0 (25 eyes), T1 (9 eyes), and T2 (17 eyes) at baseline.

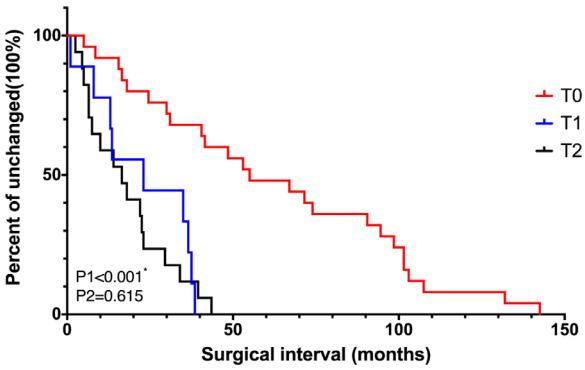

Figure 6. Kaplan–Meier curves of fellow eyes in T0–T2 at baseline. Progression to T3–T5 was set as the end of the unchanged condition. *P1* for groups of T0, T1, T2; *P2* for groups of T1, T2. *Significance at $P < 0.05$.

Using the ATN classification system also revealed that, without surgical intervention, foveoschisis (T1–T2) can gradually progress to foveoschisis with fovea detachment (T3), MH (T4), and MHRD (T5). It is important to determine the related risk factors and analyze the probability of progression of MTM. Previous studies have mainly evaluated biological parameters such as AL and SE as risk factors in the myopic eyeball. For example, Matsumura et al.[23] revealed that greater myopic SE and longer AL were risk factors of progression of MTM. Cai et al.[35] and Xia et al.[24] also reported that highly myopic eyes with longer AL were more likely to progress. However, the roles of AL and SE in the progression of MTM are controversial. Li et al.[10] found that different grades of MTM were not associated with AL or SE. In the present study, AL and SE were initially considered potential risk factors but were excluded by the univariate analysis.

PVD in pathologic myopic eyes develops at a young age, and the prevalence increases with age.[36,37] The vitreous supports the eyeball and maintains the structural and functional normality of the retina.[38] However, vitreous liquefaction may cause PVD, which applies continuous traction to tightly connected interfaces between the vitreous and the retina, before forming complete PVD.[39,40] During this process, the retina may tear, causing foveoschisis, macular hole, and retinal detachment. In the present study, the rate of partial PVD in the fellow eyes of patients in whom T grade increased from baseline was 66.18%, while the rate in patients with unchanged T grade was 39.47%. This indicates that MTM is more likely to progress in the pathologic myopic eye with partial PVD.

In addition to the three risk factors for MTM progression in fellow eyes discussed above, the present study found that the key factor that influenced the duration of progression was the T grade at baseline. The longest duration of progression of the fellow eye from T0 (at baseline) to T3–T5 was 142.5 months, and the annual rate of increase from T0 to T3–T5 was 9.98%. This indicates that most fellow eyes at T0 are relatively stable and progression is slow; the annual and semiannual rates of increase to T3–T5 in the T1 and T2 groups were 24% and 12%, respectively. Li et al.[10] preferred to categorize eyes with outer foveoschisis as T2, rather than T1, because T1 with outer foveoschisis and T2 were similar in BCVA, AL, SE, and posterior staphyloma rate. In the present study, eight of nine eyes in the T1 group had outer foveoschisis, which may be the reason that the T1 and T2 groups showed similar progression rates.

The strengths of this study are as follows. This study investigated the progression of MTM in pathologic myopia eyes based on the ATN classification system and determined three risk factors in fellow eyes after PPV of the primary: partial PVD of the fellow, primary eye in T4–T5, and age younger than 60 years at the initial PPV. The results indicate that T grade and age at the time of the initial PPV (primary eye) may have a promoting effect on the progression of MTM in fellow eyes, which also suggests connections between eyes with pathologic myopia. This study analyzed the T-grade progression patterns and rates of increase of fellow eyes according to T grades at baseline and showed the results with Kaplan–Meier curves.

Limitations of this study include, first, that it was difficult to determine the precise times for appearance and changes in tractional lesions. Second, the duration of progression to T3, T4, and T5 may not be entirely accurate; highly myopic eyes with foveoschisis and fovea detachment are at a risk of progression to macular hole and MHRD, and thus we set the time of fellow eyes progressing to T3 or greater as the end of observation. Third, the surgical interval was the result of progression due to multiple factors, and fellow eyes with longer observation periods had more chance to progress. However, the cause–effect association was not clear. Finally, this was a retrospective study, with

a single institution participating. A prospective multicenter study may be more convincing and accurate.

Conclusion

Risk factors for the progression of MTM in fellow eyes include primary eyes in higher T grades, age younger than 60 years at the time of primary eyes undergoing PPV, and fellow eyes with partial PVD. A personalized patient follow-up should be based on the T grade at the time of the initial PPV. Patients with both eyes at higher T grades should be examined more frequently.

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