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Original Article

Posterior scleral contraction to treat myopic traction maculopathy at different stages

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Abstract: Objective: We aimed to evaluate anatomical and functional outcomes and determine posterior scleral contraction (PSC) timing in treating myopic traction maculopathy (MTM). Methods: This is a retrospective study of MTM patients undergoing PSC with genipin cross-linked strip at a single hospital site. Differences in demographic and clinical characteristics were compared among three groups defined by the MTM staging system. All patients were followed up for at least one year postoperatively. The best-corrected visual acuity (BCVA), macular hole diameter, axial length (AL), optical coherence tomography findings, and the complications were evaluated. Additionally, regression analyses were performed to account for confounders. Results: Sixty-one MTM patients (24 eyes at stage 2, 22 eyes at stage 3, and 18 eyes at stage 4) were included. The macular holes were closed in 16 eyes (66.7%), 13 eyes (59.0%), and 11 eyes (61.1%) at stage 2, stage 3, and stage 4, respectively. PSC improved the BCVA in patients at each stage (all $P < 0.05$). Postoperative BCVA at stage 2 was significantly better than that at stage 4 ($P = 0.0069$). Preoperative BCVA was associated with postoperative BCVA ($P < 0.001$). Preoperative AL (OR 0.676, 95% CI 0.480 to 0.951, $P = 0.025$), AL shortening amount (OR 5.129, 95% CI 1.974 to 13.327, $P = 0.001$) and macular hole diameter (OR 1.003, 95% CI 1.000 to 1.006, $P = 0.030$) were associated with macular hole closure. Conclusions: PSC is safe and effective in treating MTM at different stages. Early PSC intervention will have more significant visual benefits.

Keywords: High myopia, posterior scleral contraction, maculoschisis, macular hole, myopic traction maculopathy

Introduction

In highly myopic eyes, the axial elongation of the eye and the development of a posterior staphyloma may reduce the thickness of retina and choroid, leading to myopic traction maculopathy (MTM). Shimada et al. [1, 2] showed that foveoschisis could gradually develop as foveal detachment and then progress into a macular hole and macular detachment. A maculoschisis-associated macular hole is one of the severe complications that can potentially cause visual disabilities. It requires surgical treatment to preserve visual function. Pars plana vitrectomy (PPV) alone can release the epiretinal tractions but leave the posterior staphyloma untreated, which is one of the PPV deficiencies. Posterior staphyloma is now considered an established and crucial pathological feature for the onset and progression of MTM [3]. Some studies have shown that macular bucking with posterior scleral contraction can effectively treat MTM in highly myopic eyes [4-10]. However, the choice of the best time to treat MTM is still controversial. Based on our previous results, we performed this study to further determine the proper posterior scleral contraction (PSC) timing for MTM. In the present study, we used genipin cross-linked sclera or endocranium to treat MTM, and the anatomical and structural outcomes of PSC were evaluated for MTM patients at different stages based on the MTM staging system [11]. In addition to the best timing of PSC to treat MTM, we also determined the related factors to improve postoperative visual acuity, and the macular hole closure rate.

Materials and methods

Study design and participants

A consecutive series of MTM patients (stages 2 to 4) undergoing PSC surgery from August 1, 2014 to May 31, 2019 were included in this retrospective study. Patients with missing data were excluded. All patients had at least one year of follow-up after surgery. Based on a new MTM staging system [11], MTM was divided into four stages: stage 1 is the inner macular schisis (I-MS) or inner-outer macular schisis (IO-MS); stage 2 is a predominantly outer macular schisis (O-MS); stage 3 is a macular schisis-detachment (MS-MD); stage 4 is macular detachment without macular schisis (MD). Each stage is subdivided into a, b, and c period: period a is associated with an intact fovea, period b with an inner lamellar macular hole, and period c with a full-thickness macular hole. Some of the patients at an initial stage were regularly followed up and not recommended for surgical intervention. Therefore, patients included in this present study were at stages 2 to 4. Results for PSC in the treatment of macular schisis without macular holes have been published previously [8]. This study followed the tenets of the Declaration of Helsinki and was approved by the Ethics Committee of the Eye Hospital of Wenzhou Medical University (approval number: KYK-2016-40). Signed informed consent was obtained from each participant.

Surgical procedures

To achieve better therapeutic efficacy for MTM, we improved the procedure by shortening the AL and tightening the strip. The human sclera was obtained from a local eye bank after the cornea had been removed for transplantation. The Red Cross donated human endocranium. The sclera or endocranium strip was cross-linked by 0.1% genipin. All donors had negative serology for HIV and hepatitis B. The strips were randomly selected based on the availability of materials.

The PSC surgery was performed under general anesthesia. The pruned strip was then put on the posterior pole of the eye with its middle part between the inferior oblique and optic nerve. The nasal end of the strip was fixed at around 2.0 mm behind the nasal side of the inferior rectus. The temporal end of the strip was fixed behind the temporal end of the superior rectus. After locating the strip properly, the strip was tightened following releasing some drops of aqueous humor (0.05 to 0.20 ml). The surgical details were described in our previous papers [8-10].

During the operation, the most challenging step was to determine the axial shortening amount. If the MTM patients were at stages 2 to 3, AL shortening would be 1.5 to 2.5 mm. If the MTM patients were at stage 4, the AL might be shortened by 2.0 to 3.5 mm. On the first day after the operation, fundus examinations, OCT imaging, and AL measurements were performed. According to OCT images, if the patient's AL shortening amount did not meet the designed amount (the difference was more than 0.5 mm), or retinal contraction was insufficient or excessive, the strip would be relevantly adjusted under the local anesthesia.

Study outcomes

The preoperative and postoperative examinations included manifest refraction, evaluation of the logMAR best-corrected visual acuity (BCVA), biomicroscopy, intraocular pressure, and dilated funduscopy. The axial length (AL) was also measured via an optical biometer (IOLMaster, Zeiss, Germany), and optical coherence tomography (OCT, Carl Zeiss Meditec, Dublin, CA, USA) was used to obtain high-resolution images of the retina and measure maximum macular hole diameter. The buckling effect was assessed by calculating the AL shortening amount and reviewing the OCT images on the first day after surgery. We measured the highest maculoschisis cavity or macular detachment using OCT scans. Postoperative, we defined the case as MTM recovery if the exact direction measurement or the highest measurement was decreased by more than 80%, and un-recovery otherwise.

Statistical analysis

All statistical analyses were performed using SPSS V.20.0 (SPSS Inc. Chicago, USA). All continuous variables were expressed as the mean ± standard deviation. BCVA of counting fingers and hand motion was arbitrarily assigned an equivalent of 2 and 3 logMAR units. Preoperative and postoperative BCVA and AL at each

Table 1. Demographics and clinical data of included patents

	Stage 2	Stage 3	Stage 4
Eyes	24	22	18
Age (years)	59.12 ± 10.15	58.09 ± 10.22	60.77 ± 8.46
Preoperative BCVA (logMAR)	0.96 ± 0.49	1.21 ± 0.62	1.43 ± 0.44
Axial length (mm)	29.99 ± 1.69	29.80 ± 1.67	31.43 ± 2.33
Macular hole diameter (μm)	504.2 ± 211.8	506.9 ± 166.6	507.9 ± 261.8
Follow-up (months)	22.91 ± 10.43	19.00 ± 7.41	18.11 ± 6.29

BCVA: best-corrected visual acuity.

Table 2. Comparison of preoperative and postoperative BCVA (logMAR)

MTM stage	Preoperative BCVA	Postoperative BCVA	*P*-value
2	0.96 ± 0.49	0.72 ± 0.36	0.010
3	1.21 ± 0.62	0.83 ± 0.43	0.009
4	1.43 ± 0.44	1.12 ± 0.55	0.001

stage were compared using a paired t-test. Preoperative logMAR BCVA, macular hole diameter, age, axial length, and follow-up time of three stages were analyzed by variance. Univariate regression analysis of the associations between the prognostic factors concerning the final BCVA was performed, including the patients' age, preoperative BCVA and AL, cataract surgery, macular hole closure. Logistic regression analyses, which included the patients' age, preoperative AL, macular hole diameter, and AL shortening amount, were constructed to assess the associations with the macular hole closure. Odds ratios (OR) and 95% confidence intervals (CI) were calculated based off the regression model. A *P*-value less than 0.05 was considered statistically significant.

Results

Demographics and clinical features

Between August 1, 12014 and May 31, 2019, a consecutive series of 61 eligible MTM patients (64 eyes) were identified. Fifty-four patients (88.5%) were female, and seven patients (11.5%) were male. Based on the MTM staging system, 24 eyes (37.5%, 2b: 11 eyes, 2c: 13 eyes) were at stage 2, 22 eyes (34.4%, 3b: 15 eyes, 3c: 7 eyes) were at stage 3, and 18 eyes (28.1%, 4b: 11 eyes, 4c: 7 eyes) were at stage 4. The mean age of patients at stages 2 to 3 was 59.12 ± 10.15, 58.09 ± 10.22, and 60.77 ± 8.46, respectively. There was no significant difference between ages at each stage (all P > 0.05). Twenty-four eyes underwent uneventful phacoemulsification with intraocular lens (IOL) implantation three to six months after the PSC to address cataract.

Preoperative BCVA (logMAR) of patients at stages 2 to 4 was 0.96 ± 0.49, 1.21 ± 0.62, and 1.43 ± 0.44, respectively. Preoperative BCVA of patients at stage 2 was significantly better than that at stage 4 (P = 0.006). Preoperative AL of patients at stages 2 to 4 was 29.99 ± 1.69 mm, 29.80 ± 1.67 mm, and 31.43 ± 2.33 mm, respectively. Preoperative AL of patients at stage 4 was statistically more extended than that at stage 2 (P = 0.010) and stage 3 (P = 0.009). The preoperative macular hole diameter of patients at stages 2 to 4 was 504.2 ± 211.8 μm, 506.9 ± 166.6 μm, and 507.9 ± 261.8 μm, respectively. No statistical significance was observed among the macular hole diameter at stages 2 to 4 (all P > 0.05, **Table 1**). The results showed that as the disease progressed, stage 4 was significantly more severe than stage 2.

BCVA improvement and AL shorten

At each stage, PSC could significantly improve BCVA (stage 2: P = 0.01; stage 3: P = 0.009; stage 4: P = 0.001, **Table 2**). Same as preoperative, postoperative BCVA at stage 2 was significantly better than that at stage 4 (P = 0.007, **Table 2**). In addition to BCVA, PSC could significantly shorten AL at each stage (all P < 0.001). Although preoperative AL of patients at stage 4 was longer than other patients, due to strict control of scleral construction amount, no statistical difference was found among postoperative AL at different stages (all P > 0.05). The average change of AL was -1.87 ± 0.74 mm, -1.81 ± 0.78 mm, and -2.30 ± 0.95 mm for stages 2 to 4, respectively (**Table 3**).

MTM recovery

For patients at stage 2, the macular schisis recovered in all the cases, and macular holes were closed in 66.7% of the eyes (16/24). For stage 3, the macular schisis-detachment re-

Table 3. Comparison of preoperative and postoperative axial length (mm)

MTM stage	Preoperative axial length	Postoperative axial length	*P*-value
2	29.99 ± 1.69	28.12 ± 1.70	< 0.001
3	29.80 ± 1.67	27.99 ± 1.47	< 0.001
4	31.43 ± 2.33	28.36 ± 1.82	< 0.001

Table 4. Univariate regression analyses of the association between postoperative best-corrected visual acuity (logMAR) and the variables

Variables	Univariate linear regression		
	B (95% CI)	Wald	*P*-value
Cataract surgery	0.079 (-0.200, 0.358)	0.311	0.577
Macular hole closure	-0.067 (-0.329, 0.195)	0.253	0.615
Age	-0.004 (-0.016, 0.008)	0.357	0.550
Preoperative AL	-0.003 (-0.070, 0.064)	0.009	0.926
Preoperative BCVA	-0.499 (-0.677, -0.321)	30.12	< 0.001

AL: axial length; BCVA: best-corrected visual acuity; CI: confidence interval.

Table 5. Logistic regression analyses of the association between macular hole closure and the variables

Variables	Logistic regression		
	OR (95% CI)	Wald	*P*-value
Age	0.975 (0.927, 1.026)	0.920	0.337
Preoperative AL	0.676 (0.480, 0.951)	5.051	0.025
AL shortening amount	5.129 (1.974, 13.327)	11.259	0.001
Macular hole diameter	1.003 (1.000, 1.006)	4.697	0.030

AL: axial length; OR: odds ratio; CI: confidence interval.

covery rate was 95.4%, and macular holes were closed in 59.1% of the eyes (13/22). Macular was reattached in all patients at stage 4, and macular holes were closed in 61.1% of the eyes (11/18).

Multivariate analysis

In the univariate regression analysis, the preoperative BCVA was found to be significantly associated with the final BCVA ($P < 0.001$, **Table 4**). Furthermore, as the logistic regression analysis results showed, preoperative AL (OR 0.676, 95% CI 0.480 to 0.951, $P = 0.025$), AL shortening amount (OR 5.129, 95% CI 1.974 to 13.327, $P = 0.001$) and macular hole diameter (OR 1.003, 95% CI 1.000 to 1.006, $P = 0.030$) were associated with macular hole closure (**Table 5**).

Discussion

This study reported anatomical and functional surgical outcomes of 61 MTM patients (64 eyes) after PSC and risk factors for postoperative visual acuity and macular hole closure using multivariate analysis. With the development of the disease from stages 2 to 4, the average visual acuity gradually decreased, and the AL became longer. As previously reported, it takes a year or more to progress from stage 1 to stage 2 [11]. Preoperative mean BCVA was better in stage 2 than stages 3 and 4. The initial stage of MTM, stage 1a, is a compensatory state because patients with macular schisis could maintain a good visual function. Our results revealed that PSC surgery could statistically improve the average visual acuity and benefit retinal repair of patients at each stage. More importantly, the postoperative BCVA was even better in stage 2 than stages 3 and 4, indicating that MTM patients are recommended to receive PSC at an early stage. These results can help guide management in MTM patients with a macular hole.

Consistent with previous studies, the BCVA after macular hole surgery was related to preoperative visual acuity [12, 13]. In the current study, univariate regression analysis revealed that postoperative BCVA was significantly associated with preoperative BCVA. However, age, AL, cataract surgery, and postoperatively macular hole condition did not influence postoperative BCVA. With the recovery of postoperative anatomy after surgery, the visual acuity improved in all three stages of MTM. In stage 4, the posterior pole and the choroid were significantly thinned and atrophied. The increase of the extent of macular detachment is always accompanied by long-term insufficiency of local blood circulation and nutrient supply between the neuroepithelial layer and pigment epithelial layer. Therefore, both the preoperative and postoperative visual acuity was unsatisfied due to the persistent damage. According to the progress of the MTM and the recovery of postoperative visual acuity, it is also recommended that early surgical intervention, such as PSC, be performed at early MTM stage.

PSC shortens the AL to relieve the retinal plane's perpendicular directions and achieve macular schisis or detachment repair. Based on the findings of this study, preoperative AL of patients at stage 4 was longer than patients at stages 2 and 3. After maneuvering sclera shortening, there was no statistical difference in AL between the groups. We found that the AL remained stable during the follow-up, and the macular schisis and detachments gradually improved, suggesting that maintained AL shortening may benefit anatomical recovery. Although the underlying mechanism remains unclear, several studies have revealed the involvement of vector forces acting at the macula, in other words, tangential traction on the inner retinal surface (e.g., rigid internal limiting membrane, stretched retinal vessels, and epiretinal membrane), and posterior scleral ectasia (staphyloma) [6, 14, 15]. The mismatch between the retina and the outer choroid-sclera complex associated with posterior staphyloma and axial elongation is considered a significant cause of MTM. Some studies showed that the centrifugal forces cause MTM, including perpendicular and tangential directions to the retinal plane [16]. The scleral elongation and anteroposterior vitreous traction exert a perpendicular force, which causes macular schisis and detachment. Tangential force is exerted by scleral lateral enlargement and vitreoretinal interface tractions, which cause the inner lamellar macular hole and the full-thickness macular hole. Thus, PSC was designed to shorten AL and relieve retinal traction fundamentally.

As observed during follow-up, macular schisis or detachment resolution was achieved in 63 of 64 eyes; more than half of the macular holes were closed. In our study, the total macular hole closure rate was about 60%, consistent with a previous study using an L-shaped macular buckle [6]. However, other studies reported a closure rate between 90% and 100% [7, 17]. The closure rate varies with the sample size, surgical method, MTM progression, and patients' clinical characteristics. We speculated one possible reason for unclosed cases: the PSC did not relieve the tractions in the tangential direction (e.g., epiretinal membranes and vitreoretinal interface tractions). In agreement with some studies that the persistent macular hole rarely progresses to retinal detachment when supported by macular buckling [4], our results showed no aggravation of the macular hole or inducing the retinal detachment during the follow-up for unclosed cases. Within three months after the operation, some patients felt vision deformation due to the retinal fold. With the flattening of the retina, the symptoms generally relieved or disappeared six months postoperative.

Consistent with previous studies [18-20], the multivariate analysis revealed that the macular hole closure rate was related to the axial length, macular hole diameter, and the AL shortening. It is worth noting that the surgical approach is a significant factor influencing macular hole closure. PPV is one of the current mainstream methods for treating myopic traction lesions. PPV directly removes the vitreous to relieve the vitreous traction, also provides convenience for haemorrhage removal, retinal reattachment, photocoagulation, and intraocular drug treatment [21-24]. PPV combined surgery can relieve vitreous traction, increase retinal extension, reattach the retina, and repair retinal and macular tears; however, PPV presents a limited efficacy mainly because of retinal detachment recurrence, hole closure failure, iatrogenic macular hole formation, and other reasons [25, 26]. PPV and internal limiting membrane (ILM) peeling with gas tamponade have been used for treating MTM; however, the closure rate remains at a low level and variable. Since a new method, the ILM flap technique was introduced for macular hole treatment, and the closure rate was increased to about 90% [27, 28].

Interestingly, inconsistency between the relatively low visual acuity improvement rate and the high closure rate was observed. There are several theories behind this discrepancy. In most studies of PPV treating myopic macular holes, the baseline visual acuity of patients was already poor (equivalent to stages 3 or 4 of our study), accompanied by many intraocular disorders, which is because patients are not recommended to receive PPV surgery in the early stage of MTM. A later PPV timing results in more time for unrecoverable anatomical lesions (e.g., chorioretinal atrophy and the foveal photoreceptor layer destruction) [29]. Additionally, PPV may bring neural stimulus and retinal toxic. Therefore, even if the closure rate is high in some PPV cases, the postoperative vision is likely to be unsatisfactory due to the later intervention. These reflect the advantages and importance of an early PSC treatment.

We acknowledge the limitations that our study follows a retrospective design without a group of PPV as the control. In this study, the sample size was small and not equal. Additionally, we did not analyze the severity of posterior scleral staphyloma and other potential factors, which could be the interactions or confounders. Therefore, a longer follow-up time with a larger sample size and more included factors is necessary for future studies. A head-to-head comparative trial is needed to compare PSC and PPV in treating MTM at different stages.

In conclusion, as the disease progresses, MTM aggravates from stage 2 to stage 4; consistent with our results, the AL elongated, and the vision deteriorated. Accordingly, PSC could improve retinal repair and visual functions for each stage. Furthermore, preoperative AL, AL shortening amount, and macular hole diameter are significantly associated with macular hole closure, and preoperative is a crucial factor for determining postoperative BCVA. Notably, patients at stage 2 obtained the best BCVA after PSC operation, suggesting the importance of early PSC intervention for MTM. Therefore, PSC with genipin cross-linked strip is safe and effective in treating MTM at different stages; early intervention will benefit.

Disclosure of conflict of interest

None.

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