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Three-year outcomes of macular buckling for macular holes and foveoschisis in highly myopic eyes

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ABSTRACT.
Background: **To assess the functional and structural outcomes of macular buckling using a silicone sponge-titanium exoplant for the treatment of foveoschisis (FS) and full-thickness macular holes (FTMHs) in highly myopic eyes.**
Methods: **Forty-nine consecutive patients with high myopia who underwent macular buckling for the treatment of FS and FTMHs were included. The outcomes measured included the anatomical success rate with FS resolution, retinal reattachment, MH closure, best corrected visual acuity (BCVA), axial length (AL) and complications of surgery. Moreover, the correlations between the BCVA at year three and series of factors, including age, duration of symptoms, baseline BCVA, AL, surgical type, preoperative macular status and severity of myopic maculopathy, were analysed.**
Results: **This study involved 28 patients (28 eyes) with FS and 21 patients (21 eyes) with FTMHs with macular detachment. Retinal reattachment was achieved in 100% of cases, while MH closure was achieved in 76.19% of cases. The BCVA significantly improved one year after macular buckling in the FS cases and two years after macular buckling in the FTMH cases, and it remained stable throughout the rest of the follow-up period. The mean AL decreased by 2.09 mm postoperatively. No major perioperative complications were observed, although one patient needed to explant the buckling device due to intolerable diplopia.**
Conclusion: **Macular buckling with a silicone sponge-titanium exoplant may represent a safe and effective surgical option for the treatment of FS and FTMH in highly myopic eyes. Macular buckling showed a high closure rate and virtually no tendency to recur.**

Key words: foveoschisis – high myopia – macular buckling – macular hole

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Introduction

High myopia, which is one of the most common ocular abnormalities in Asia, represents a serious public health concern with a prevalence that is increasing significantly (Grosvenor 2003). High myopia is associated with the progressive elongation of the eyeball, which may lead to a variety of retinal and choroidal complications, including lacquer cracks, diffuse and focal chorioretinal atrophy, choroidal neovascularization, foveoschisis (FS), macular holes (MHs) and retinal detachment (Saw et al. 2005).

Vitreoretinal surgeons use a variety of surgical procedures for the treatment of myopia-related complications, including pneumoretinopexy, vitrectomy with gas or silicone oil tamponade, and internal limiting membrane (ILM) peeling (Blankenship & Ibanez-Langlois 1987; Menchini et al. 1988; Ripandelli et al. 2001; Kwok & Lai 2003). Despite the availability of such interventions, MH-related retinal detachment (MHRD) remains one of the most difficult types of RD to treat due to both the high recurrence rate and poor visual prognosis (Kuriyama et al. 1990). Postoperative nonclosure or reopening of the hole, as well as retinal redetachment, may still occur despite interventions, while in some cases, achieving anatomical success may require multiple procedures. When used as the sole treatment modality, vitrectomy can release tangential and centrifugal traction caused by vitreous cortex (Shukla & Dhawan 2009), although it leaves the posterior staphyloma untreated (Nakanishi et al. 2008; Nadal et al. 2012). Furthermore, vitrectomy accompanied by ILM peeling can lead to complications such as MH or extrafoveal retinal hole formation (Panozzo & Mercanti 2007). For these reasons, an additional external procedure is required to support the posterior scleral wall by means of posterior scleral reinforcement, and macular buckles are necessary to release both the anteroposterior traction caused by the posterior staphyloma and the tangential traction exerted by the vitreous cortex (Ripandelli et al. 2001; Theodossiadis & Sasoh 2002; Theodossiadis & Theodossiadis 2005).

We report on our experience using a silicone sponge-titanium exoplant combined with or without pars plana vitrectomy (PPV) for the treatment of FS or MHs with macular detachment (MD). The primary goal of the study was to evaluate the rate of reattachment of the retina, the complete closure of the MH and the resolution of FS.

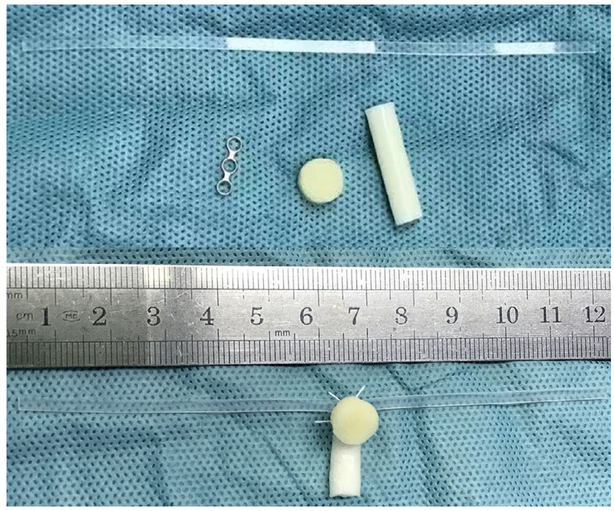

Fig. 1. Silicone sponge-titanium exoplant. Top, the separate components of the exoplant are shown. Bottom, the assembled exoplant with the suture material visible; the titanium plate is hidden within the sponge.

Methods

Patients and study design

This retrospective study was approved by the institutional ethics review board of Zhongshan Ophthalmic Center. All the study procedures adhered to the tenets of the Declaration of Helsinki. Each patient was notified about the risks and benefits associated with the surgery, and informed consent was obtained from all patients.

The study included all the patients who presented at our centre with a reduction in their best corrected visual acuity (BCVA) due to MHs or progressive FS with MD in highly myopic eyes with an axial length ≥ 26.5 mm. Forty-nine eyes from 49 patients who underwent surgery between May 2014 and November 2015 were included in the study, and all the surgeries were performed by one surgeon (LL). All the patients underwent macular buckling, either on its own or combined with vitrectomy. Patients with significant vitreous macular traction on optical coherence tomography (OCT) were treated with combined surgery. The patients were evaluated at postoperative day one, week one, month one, month six, year one, year two and year three.

All the patients underwent a regular ophthalmologic examination, including refractometry with the assessment of the BCVA, IOL Master for the measurement of AL, fundus photography (fundus camera TRC-50; Topcon, Tokyo, Japan) and spectral-domain OCT of the macula (Heidelberg Engineering, Heidelberg, Germany). Based on the fundus photography, the severity of the myopic maculopathy was classified using the classification scheme published by Hsiang et al. (2008). During the postoperative follow-up examinations, the measurement of visual acuity, AL and OCT was routinely performed. The patients' anatomical outcomes in terms of retinal reattachment with anatomical success (defined as retinal reattachment with MH closure) were individually analysed. The patients' visual acuity was recorded as decimal values and then converted to the logarithm of the minimal angle of resolution (LogMAR) units for the statistical analysis.

The operative variables recorded in this study included the use of macular buckling in combination with 25-gauge vitrectomy. In cases involving the combination surgery, the macular buckle exoplant was preplaced prior to the vitrectomy. At the end of the vitrectomy, the vitreous cavity was filled with sterile air, and those patients were

Table 1. Clinical characteristics of affected eyes with macular holes and foveoschisis.

	MH	FS
No. of eyes	21	28
Sex (M: F)	1:6	1:3
Age (years)	56.62 ± 7.55 (38.00–66.00)	53.07 ± 11.83 (30.00–72.00)
RE (D)	−13.62 ± 5.94	−10.61 ± 5.52
AL (mm)	29.83 ± 1.56 (27.48–32.29)	29.78 ± 2.17 (26.15–34.39)
BCVA preop (logMAR)	1.30 ± 0.56 (0.52–2.00)	1.12 ± 0.56 (0.22–2.0)
IOP (mmHg)	14.90 ± 2.88	13.90 ± 3.15
Symptom duration (mos)	9.4 ± 14.03 (0.50–60.00)	11.14 ± 9.06 (1–36)
Macular buckling	11	15
Combined with PPV	10	13
MM		
C1	1	2
C2	16	21
C3	3	5
C4	1	0

AL = axial length; BCVA = best corrected visual acuity; C1 = tessellated fundus; C2 = diffuse chorioretinal atrophy; C3 = pathy atrophy; C4 = macular atrophy; FS = foveoschisis; IOP = intraocular pressure; MH = macular hole; MM = myopic maculopathy; PPV = pars plana vitrectomy; RE = refractive error.

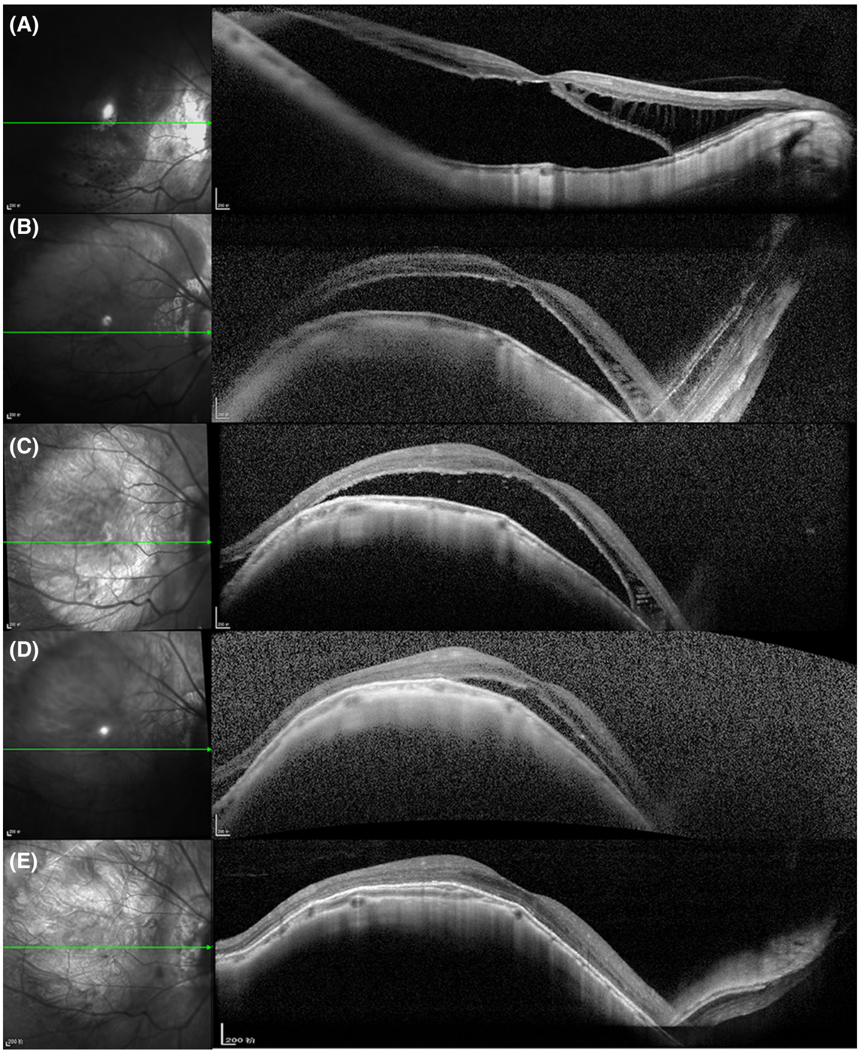

Fig. 2. Preoperative and postoperative OCT scans of a patient with FS and MD. (A) Preoperative image shows FS with MD. (B) Image at the three-month follow-up point after surgery shows the indentation of the macula by the buckle. (C) Six months after surgery, the partial resolution of the MD was seen. (D) One year after surgery, the MD was further resolved. (E) Two years after surgery, the image shows the complete resolution of the FS and MD. FS = foveoschisis; MD = macular detachment; OCT = optical coherence tomography.

asked to maintain a face-down posture for at least 2 days after surgery.

Surgical material

The buckling exoplant was prepared under sterile conditions at the time of surgery using a silicone sponge, silicone band and titanium plate at the time of surgery, which was previously reported (Liu et al. 2016). The silicone sponge was tunnelled using a 19-gauge needle, and the titanium plate was then inserted into the tunnel. The inner titanium allowed for shape customization and bending to achieve optimal positioning. A round sponge was sutured using 5-0 non-absorbable thread (Ethicon, Johnson & Johnson Medical Ltd, China) inside at the end of the titanium plate, while the silicone band was sutured outside the titanium plate to achieve the fixation of the buckle beneath the macula (Fig. 1).

Surgical technique

Under general or retrobulbar anaesthesia, the surgery began with a 360° limbal periotomy. The four rectus muscles and the inferior oblique muscle were separated from the surrounding tendons, and soft tissue, intermuscular septi and adhesions. Then, the rectus muscles were looped using silk ties to allow for the rotation of the eye during placement. The space between the muscles and the globe was exposed to allow for the passage of the buckle. The diameter of the sponge ranged from 6 × 6 mm to 8 × 8 mm according to the AL and the size of the staphyloma. The macular buckle was placed in the supero-temporal quadrant. One of the distal ends of the silicone band was passed under the lateral rectus muscle belly and the inferior oblique muscle, and it was sutured to the sclera on the nasal side of the inferior rectus muscle using a spatulated needle with 5-0 non-absorbable thread (Ethicon, Johnson & Johnson Medical Ltd) approximately 12–14 mm posterior to the limbus. The other end of the band crossed the superior rectus muscle, and it was sutured to the sclera on the nasal side of the superior rectus muscle. The titanium was sutured and temporarily fixated using a slip knot. The positioning and indentation of the macular plate were checked under indirect ophthalmoscopy. Particular care was taken to ensure that the height of the macular buckle was not excessive and that the buckle did not compress the optic nerve. Once the appropriate position had been identified, the slip knot at the end of the titanium was tied into a permanent knot.

The preoperative and postoperative logMAR BCVA and AL were compared using a paired *t*-test. Univariate analyses of the associations between the prognostic factors concerning the final BCVA were performed using the appropriate tests. Multiple linear regression models, which included the patients' age, duration of symptoms, presence of myopic maculopathy, baseline BCVA and baseline AL, were constructed to assess the associations with the final BCVA. A p value of less than 0.05 was considered to be statistically significant. All the statistical analyses were performed using SPSS version 21.0 (SPSS, Inc, Chicago, IL, USA).

Results

In total, 49 eyes from 49 patients (10 male and 39 female) were analysed in this study. The mean age of the patients was 54.59 years (range: 30–72 years), and the majority of patients were female [42 subjects (85.71%)]. The mean spherical equivalent was –11.95 ± 5.85 D (range: –6.0 D to –25.0 D), while the mean AL was

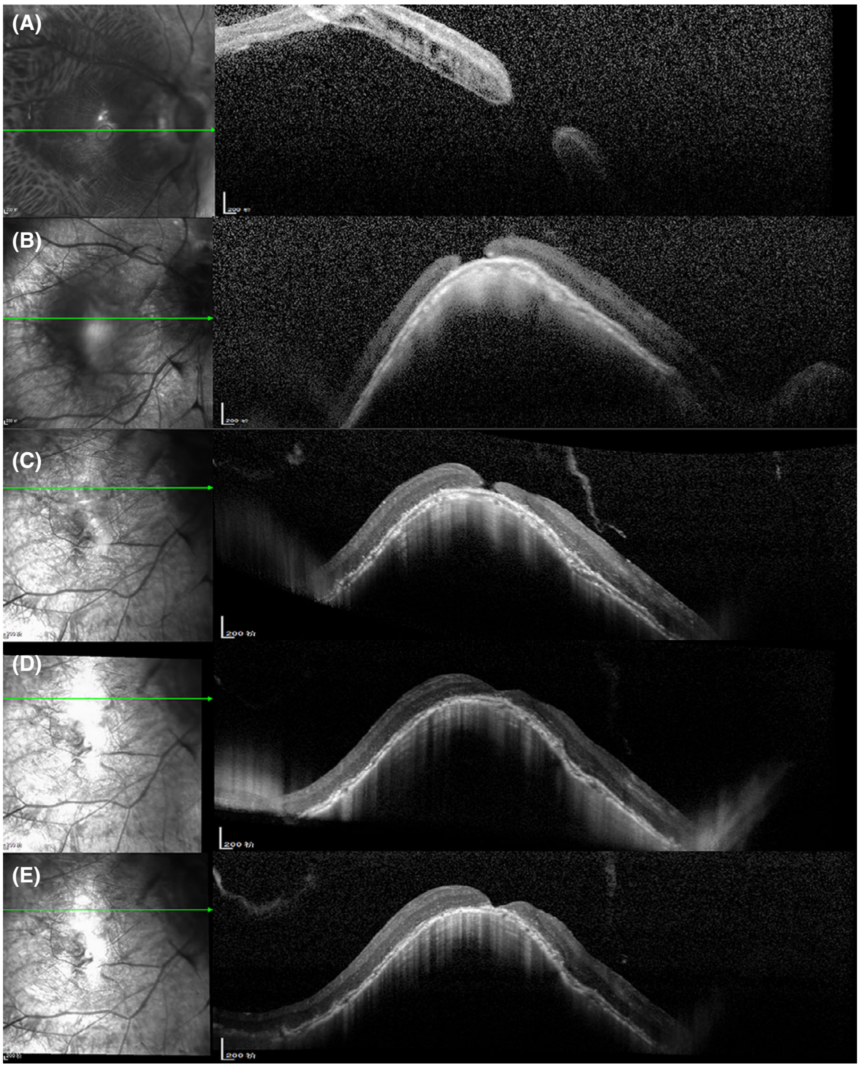

Fig. 3. Preoperative and postoperative OCT scans of a patient with a MH and MD. (A) Preoperative image shows a MH and MD. (B) Image at the three-month follow-up point: the macula was reattached without hole closure. (C) Six months after surgery, the hole was reduced in size. (D) One year after surgery, the macular hole was closed. (E) Two years after surgery, the macular findings remained stable. MD = macular detachment; MH = macular holes; OCT = optical coherence tomography.

29.70 ± 1.90 mm (range: 26.15–34.39 mm). The mean duration of visual symptoms prior to the intervention was 10.47 ± 11.46 months (range: 0.5–60 months). Among these highly myopic eyes, 21 eyes had MHs with MD, while 28 eyes had FS with MD (Table 1).

Following the placement of the MB in all the patients, the concavity of the posterior sclera was inverted. The postoperative OCT showed an attached macula and dome-shaped indentation stemming from the MB. At the 6-month follow-up point, 49 patients (100%) exhibited retinal reattachment. Complete anatomical success was achieved in 26 patients (92.86%) with FS (Fig. 2) and 16 subjects (76.19%) with MHs (Fig. 3) at the 3-year follow-up point. Five patients achieved retinal reattachment without MH closure during the follow-up period (Fig. 4). Throughout the follow-up period, there was a gradual reduction in the surgical indentation, which remained stable after 1 year (Fig. 5). The AL was found to be significantly shortened at the 1-month follow-up point, with the mean decrease in the AL being 2.09 mm at the 3-year follow-up point after surgery. Six eyes showed retinal pigment epithelium (RPE) wrinkles, while hyper-reflective subretinal and intraretinal deposits were observed in eight eyes (Fig. 6).

Overall, the mean BCVA was found to have improved significantly after the surgery. The mean preoperative BCVA was 1.20 ± 0.56, while the mean postoperative BCVA at the 3-year follow-up point was 0.83 ± 0.53, the difference was statistically significant ($p = 0.001$). In the eyes with MHs, the BCVA was found to be significantly improved 2 years after surgery, and it was seen to be further improved at the subsequent follow-up point. In the eyes with FS, the BCVA was noted to have improved significantly at the 1-year follow-up point, and it remained stable throughout the remainder of the follow-up period. The changes in the BCVA observed at each follow-up point are shown in Fig. 7. The patients who achieved complete anatomical success had a better BCVA than those who did not achieve complete success (mean BCVA, 0.75 ± 0.42 versus 1.17 ± 0.75, $p = 0.04$). The final BCVA was not found to be significantly different between macular buckling alone and macular buckling combined with PPV groups (0.71 ± 0.47 versus 0.96 ± 0.58, $p = 0.108$).

No major perioperative complications were observed in this study. One eye with a postoperative vitreous haemorrhage and three eyes with epiretinal haemorrhages were noted, although all the haemorrhages were self-limiting and completely absorbed within one month without the need for any treatment. Almost all the patients exhibited some degree of limitation in terms of their eye movement after the surgery, although their symptoms were found to be either reduced or fully resolved spontaneously at the 6-month follow-up point after surgery. The buckle of one eye had to be readjusted due to improper positioning. One eye required the removal of the buckle due to diplopia and metamorphopsia postoperatively; however, the retina remained attached following the removal of the buckle (Fig. 8). In 16 eyes (32.65%), an elevation in the intraocular pressure (IOP) was observed on the second postoperative day, although the IOP in all the affected eyes returned to normal within one month after the patients received anti-glaucoma medications. Afterwards, no further topical anti-glaucoma agent was necessary in any eye.

In the multiple linear regression analysis (Table 2), both the duration

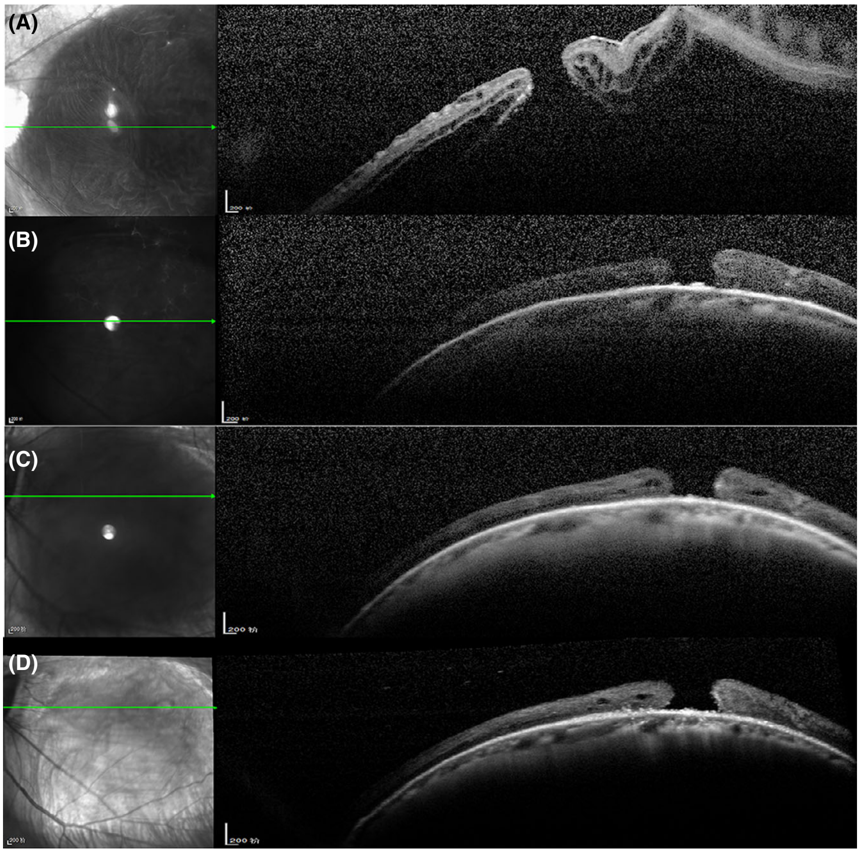

Fig. 4. Preoperative and postoperative OCT scans of a patient with a MH and MD. (A) Preoperative image shows a MH and MD. (B) One month postoperatively, the macula was reattached without hole closure. (C) One year after surgery, the macula remained attached, although the MH was still not closed. (D) Three years after surgery, the macular findings were stable, albeit with the persistence of an open MH. MD = macular detachment; MH = macular holes; OCT = optical coherence tomography.

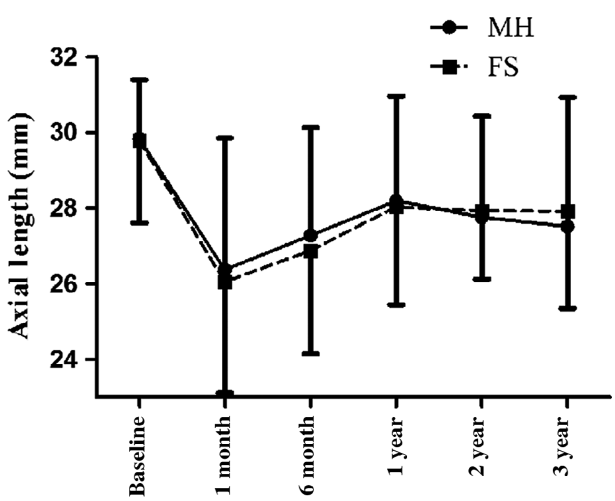

Fig. 5. The AL change following macular buckling. The postoperative AL was initially reduced by 2.5–3.5 mm at the one-month follow-up point. It then gradually elongated and was stabilized one year postoperatively. The effect of the indentation was well maintained from one year postoperatively to the final follow-up point. AL, axial length.

of symptoms and the baseline BCVA were found to be significantly associated with the BCVA at the 3-year follow-up point. The patients' age, the AL, combination with vitrectomy, the preoperative status of the macula and the severity of myopic maculopathy were not found to be significantly associated with the final BCVA at the 3-year follow-up point. A shorter duration of symptoms (r = 0.430, p = 0.006) and a better baseline BCVA (r = 0.359, p = 0.016) were associated with a greater likelihood of exhibiting a better BCVA at the 3-year follow-up point (Fig. 9).

Discussion

We report on the 3-year outcomes of treatment with a modified MB in highly myopic eyes. It showed higher anatomical and functional success rate in comparison to PPV alone (Alkabes & Mateo 2018) and proved to be a safe method of intervention. The results support the use of silicone sponge-titanium as a suitable material in relation to macular buckling, and we propose macular buckling as the first-line treatment for MHs or FS in highly myopic eyes.

Macular holes and FS represent the most challenging problems associated with high myopia. Vitrectomy is currently the most commonly used surgical treatment method for such problems due to its relatively high success rate and widespread popularity among vitreoretinal surgeons. However, the macular complications that arise in cases of high myopia originate from the elongation of the eyeball due to the continuous stretching and thinning of the sclera. The management of complications stemming from high myopia from inside the eyeball might only have a transient effect, since it does not address the underlying pathophysiological cause. Macular buckling has hence been considered a better treatment choice for highly myopic MD, especially for those eyes with posterior staphyloma (Ortisi et al. 2012). The use of several surgical materials for macular buckling has been reported in prior studies, and they demonstrated better outcomes than those reported in relation to PPV (Baba et al. 2006; Stirpe et al. 2012; Parolini et al. 2015; Mura et al. 2017). Macular buckling not only releases the internal surface vitreous traction, but also addresses the global cause of traction, thereby bringing the RPE closer to the neurosensory retina.

In this study, we designed a new surgical technique for macular

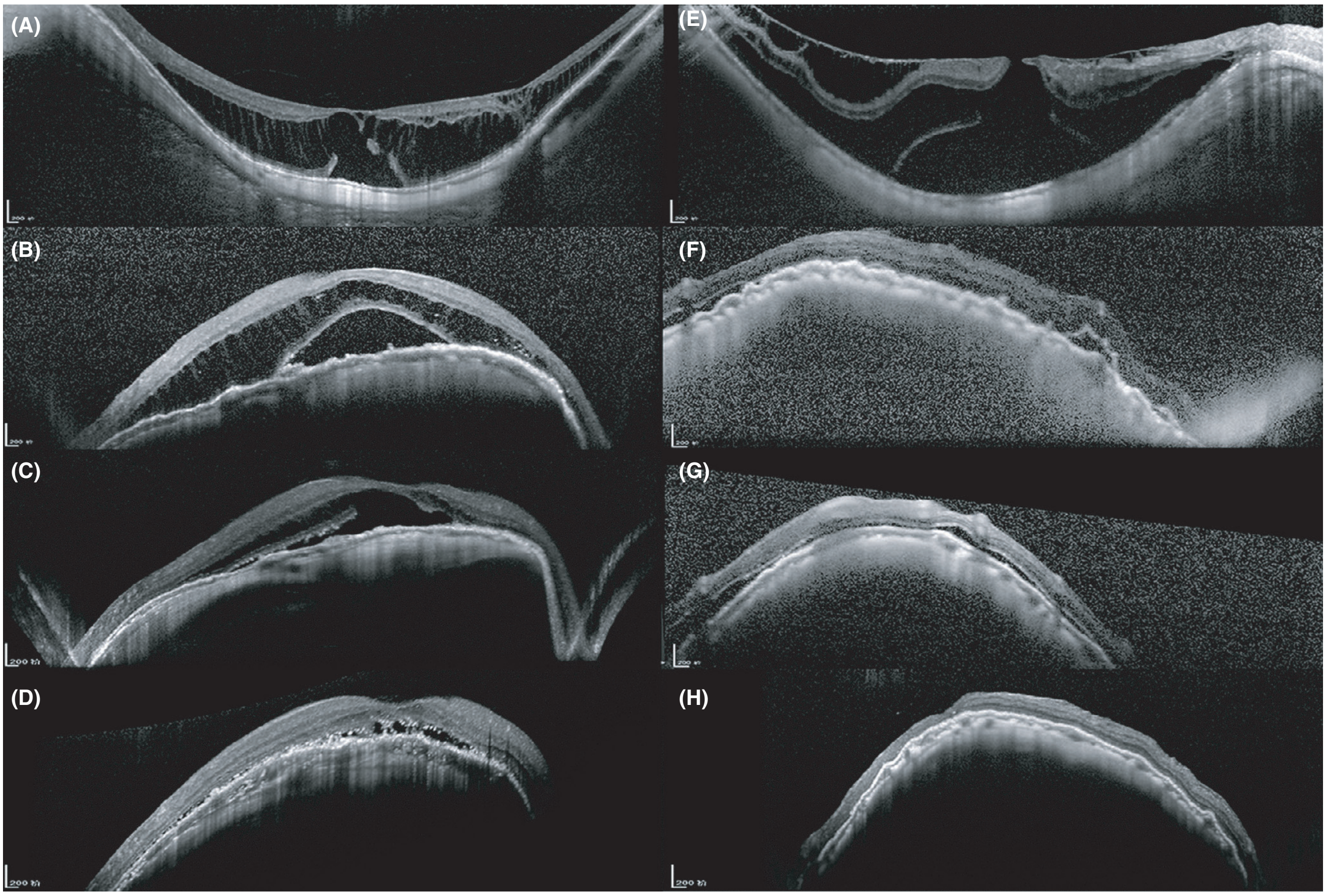

Fig. 6. Subretinal hyper-reflective deposits and wave-like RPE following surgery. (A) Preoperative image of an eye with FS and MD. (B) The RPE showed an irregular contour one month after surgery. (C) Six months after surgery, the FS was partly resolved and the MD remained. (D) Two years after surgery, subretinal hyper-reflective deposits were seen. (E) Preoperative image of a different eye with a MH and MD. (F) The MH was closed, and the MD was resolved at 6 months after surgery, although the RPE exhibited a wrinkle-like change. (G) One year after surgery, the wrinkle-like change was reduced, and the MD remained. (H) The wrinkle-like change remained at the two-year follow-up point after surgery. FS = foveoschisis; MD = macular detachment; MH = macular holes; RPE = retinal pigment epithelium.

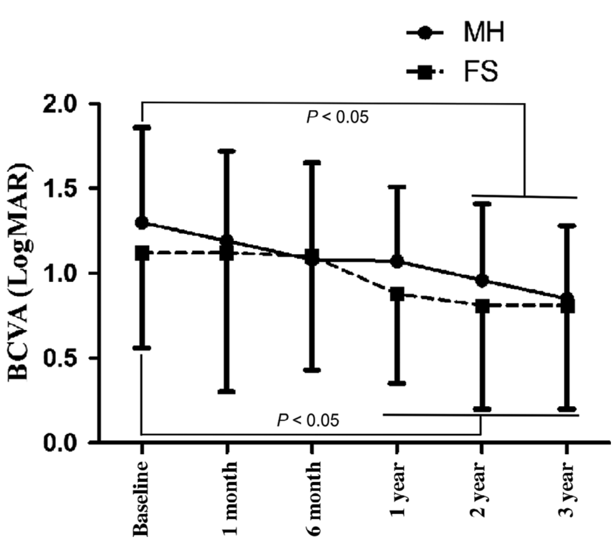

Fig. 7. The BCVA change following macular buckling. The greatest improvement in the BCVA was reported one year after surgery in those eyes with FS, and it remained stable throughout the remainder of the follow-up period. However, the BCVA was improved significantly two years after surgery in those eyes with MHs, and the visual acuity further improved in further follow-up. FS = foveoschisis; MH = macular holes; BCVA = best corrected visual acuity.

buckling combined with or without PPV in patients with high myopia. Based on the 3-year follow-up period, the results were similar to those previously reported in relation to L-shaped (Parolini et al. 2015), T-shaped (Devin et al. 2011) and Ando prombe (Bures-Jelstrup et al. 2014) macular buckles. The authors of such studies concluded that macular buckling should be the first choice treatment in FS associated with FTMHs. Alkabes et al.(Alkabes et al. 2014) reviewed different approaches for treating highly myopic FTMHs, concluding that when FS is present, a higher success rate can be achieved by combining PPV and macular buckling. However, in the present study, the anatomical success rate and the final BCVA were not significantly different between the macular buckling alone and macular buckling combined with PPV groups. The possible reason

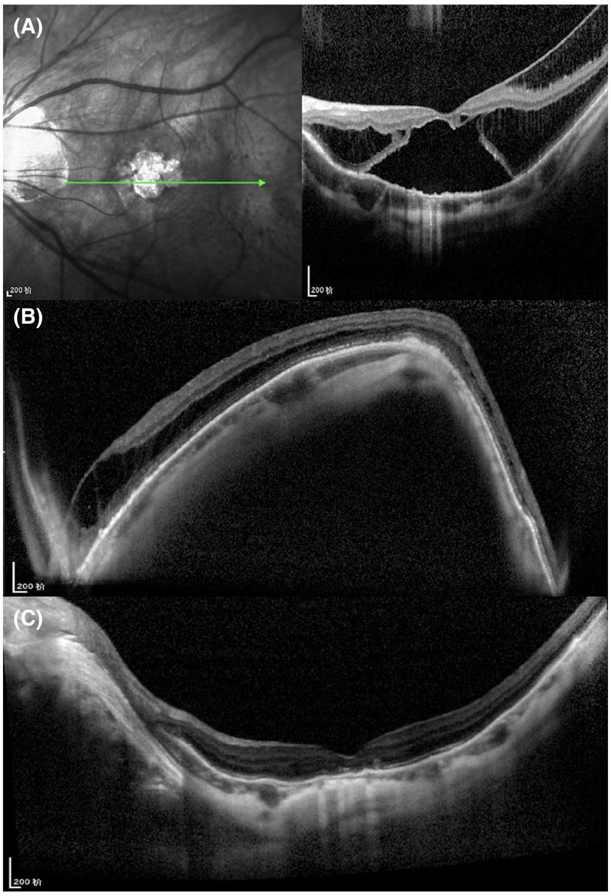

Fig. 8. A patient who underwent the removal of the buckle. (A) Preoperative image showing FS and MD. (B) Three months after the surgery, the retina was attached, and the FS had resolved. (C) The buckle was removed 6 months after the surgery, leading to the disappearance of the macular indentation, and the retina remained in place. FS = foveoschisis; MD = macular detachment.

Table 2. Multiple linear regression of the factors predicting BCVA at 3-year follow-up.

	Standardized coefficients	95% confidence interval	p Value
Age	0.175	(−0.004, 0.014)	0.277
AL	0.180	(−0.021, 0.083)	0.234
Symptom duration	0.430	(0.003, 0.019)	0.006
MB alone or combined with PPV	0.192	(−0.062, 0.287)	0.198
MH	0.036	(−0.148, 0.190)	0.799
MM	−0.208	(−0.285, 0.061)	0.198
BCVA at baseline	0.359	(0.037, 0.334)	0.016

AL = axial length; BCVA = best corrected visual acuity; MH = macular hole; MM = myopic maculopathy; PPV = pars plana vitrectomy.

may be that ILM peeling was not performed in our study. On the other hand, the results of this study demonstrated that the posterior staphyloma and the anteroposterior traction both play a vital role in the pathogenesis of the myopic traction maculopathy, and the macular buckling procedure could confront the outward expansion of the eyeball. It could also explain why the combined surgery showed a better outcome than the PPV alone in extremely myopic eyes (Qi et al. 2015). Furthermore, in cases of FS, macular buckling alone can prevent the formation of an iatrogenic MH (Ikuno et al. 2004; Panozzo & Mercanti 2007) and postoperative MHs (Panozzo & Mercanti 2007), which can occur following PPV with ILM peeling.

The AL was found to be significantly shortened postoperatively; however, the surgical indentation gradually decreased during the follow-up period and then remained stable after 1 year. The possible reason may due to long-term effect of IOP and suture loosen on the very thin sclera. The height of the surgical indentation depended on the adjustment of the buckle and the titanium plate. The increase in the BCVA observed at the 3-year follow-up point was consistent with the complete anatomical success, which was in line with the results of previous studies (Alkabes et al. 2014). The BCVA was found to be stable at the 1-year follow-up point in the patients with FS; however, the BCVA was noted to have further improved in the patients with MHs at the 2-year follow-up point. A possible reason for this may be that complete anatomical success was achieved earlier in the FS patients than in the MH patients. An elevation in the IOP was found to be common following macular buckling surgery. This may stem from the indentation made by the buckle, as well as from the postoperative swelling and inflammation of the soft tissue surrounding the eyeball. In the present study, we observed a transient increase in the IOP on the second day after surgery, although it returned to a normal range within one month following pharmacological therapy combining two or three topical anti-glaucoma and corticosteroid eye drops.

Six cases exhibited RPE wrinkles after the macular buckling surgery. This might stem from choroid congestion due to the indentation of the sclera. Additionally, hyper-reflective subretinal deposits were observed in nine eyes, which indicated photoreceptor phagocytosis, suggesting that the MD of these highly myopic eyes had occurred a long time prior to the surgical intervention. The elongation of the outer segments of the photoreceptors observed in these patients may stem from a lack of photoreceptor phagocytosis on the part of the RPE (Matsumoto et al. 2008). Furthermore, the duration of this phenomenon affects the simultaneous initiation of photoreceptor apoptosis. Hence, the longer the progression of the FS or MH, the poorer the visual prognosis, which is evidenced by the significant correlation between the BCVA and the

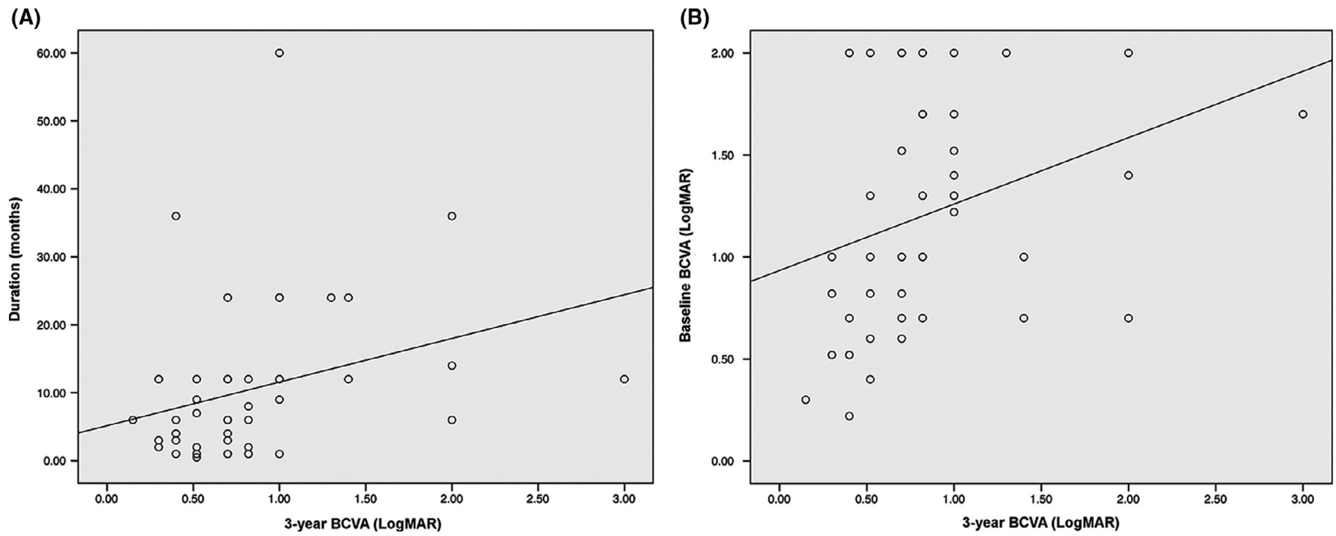

Fig. 9. Scatter plots of the coefficient of the variation in the BCVA at the 3-year follow-up point after surgery in terms of the duration of symptoms (A) and the BCVA at baseline (B). These show a positive correlation between the BCVA (LogMAR) and the duration of symptoms ($r = 0.342$, $p = 0.019$), as well as between the BCVA three years after surgery and the BCVA at baseline ($r = 0.352$, $p = 0.016$). BCVA, best corrected visual acuity.

duration of symptoms prior to surgery. Most of the cases with subretinal fluid can be absorbed within half a year, and a few cases with subretinal fluid was absorbed slowly. The possible reason may be the compression of choroid and the retinal outflow mechanisms fail (Mateo & Bures-Jelstrup 2016). Almost all of the patients suffered restricted eye movement and diplopia during the early period after surgery, although the majority of them reported their symptoms to be relieved or resolved at 6 months after surgery. A possible reason for this may be the oedema of the extraocular muscles caused by both traction and inflammation, as well as the immunological reaction to the implantation of the buckle. Therefore, the length of the titanium plate should be kept as short as possible to avoid postoperative conjunctival erosion and the limitation of eye movement. This proved to be a significant surgical challenge, and necessitating a longer learning curve and additional surgical experience. Even though, there are several advantages of our implant. The three-point suture fixation facilitated stable placement of the buckle. The buckling height could be adjusted by relaxing or pulling the silicone bands. The silicone sponge is soft and seems safe for macular buckling.

There were some limitations to this study. First, the variability of the indentation, in terms of the relative height and shape, was judged subjectively by the surgeon by means of indirect ophthalmoscopy. Second, the final BCVA was not correlated with the severity of myopic maculopathy. A possible reason for this might be due to the small sample size, that is, the low number of those with C1 and C4. Further longitudinal studies including a more balanced severity of myopic maculopathy spectrum are thus warranted. Third, not all patients underwent cataract surgery, so the BCVA in those patients with phakia may be undervalued to a certain extent.

In summary, this study demonstrated the long-term safety and efficacy of macular buckling with silicone sponge-titanium in highly myopic eyes. Based on the favourable results, we suggest that the macular buckling should be considered for MH and FS in highly myopic axially elongated eyes.

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