Am J Transl Res 2024;16(8):4134-4143
www.ajtr.org /ISSN:1943-8141/AJTR0156792

Original Article

Relationship between visual function and macular microstructure in highly myopic patients undergoing surgery for rhegmatogenous retinal detachment

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Received March 25, 2024; Accepted July 5, 2024; Epub August 15, 2024; Published August 30, 2024

Abstract: Objective: To analyze the relationship between visual function and macular microstructure in highly myopic patients undergoing surgery for rhegmatogenous retinal detachment (RRD). Methods: Fifty-eight highly myopic patients treated in the Baoding No. 1 Central Hospital between December 2021 and September 2023 were selected as the research participants for retrospective analysis. All patients were complicated with RRD and underwent retinal reattachment surgery at Baoding No. 1 Central Hospital after diagnosis. Best-corrected visual acuity (BCVA) examinations were performed before and 3 months after surgery, and visual field mean sensitivity (MS) and fixation stability (FS) were measured by microperimetry. Additionally, changes in postoperative macular microstructure and micro blood flow were determined by optical coherence tomography (OCT), and their correlations with visual function were analyzed. Results: Patients showed reduced BCVA, MS, and FS after surgery (all $P<0.05$), with 70.69% of them presenting with macular microstructural changes, mainly ellipsoid zone disruption and external limiting membrane disruption. Patients with macular microstructural changes exhibited significantly decreased BCVA, MS, and FS than those without (all $P<0.05$). In terms of micro blood flow, the BCVA, FS, and MS of patients with macular microstructural changes were negatively correlated with the foveal avascular zone (FAZ) area but were positively related to FAZ morphological index, PSCP, and VSCP (all $P<0.05$). Conclusions: Changes in patients' visual function after surgery for RRD can be effectively evaluated by observing the macular ellipsoid, the integrity of the external limiting membrane, and the alterations in micro-blood flow, enabling the formulation of early and targeted interventions.

Keywords: High myopia, rhegmatogenous retinal detachment, macular microstructure, foveal avascular zone, macular microbleed

Introduction

Myopia is a refractive error where parallel light rays are focused in front of the retina, resulting in blurred vision [1]. As society develops, myopia has become a global public health issue, affecting approximately 1.4 billion people and is increasing in prevalence [2]. According to a survey by the World Health Organization, the incidence of myopia reached 47.1% in 2022, an increase of about 7.9% compared with 2016 [3]. Among them, refractive errors with a degree of myopia ≥600° are defined as high myopia, accounting for about 10-20% of all myopic individuals. Such patients have more severe visual dysfunction, a great possibility of complications, a susceptibility to permanent visual impairment, and even blindness in severe cases [4]. Among them, retinal detachment (RD) is an extremely common complication in high myopia. Pathologically, RD is related to the elongation of the eye axis and the thinning of the posterior part of the eyeball, leading to bleeding and varying degrees of RD, which is also the major cause of visual loss [5]. Clinical statistics indicate that approximately 10% of patients with high myopia develop RD, with rhegmatogenous retinal detachment (RRD) being the most common type [6]. As medical technology advances, timely retinal reattachment surgery for RRD can preserve the visual function of patients, though the highest rate of anatomical retinal reattachment is only 91-98%, with 50-60% of patients achieving the best-corrected visual acuity (BCVA) less than 0.4 [7]. Therefore, accurately evaluating chang-

https://doi.org/10.62347/SPLN8778

es in visual function after retinal reattachment surgery and implementing early, targeted interventions is crucial for improving patient prognosis.

The macular region is in the retina center, where the retina is the thinnest and only consists of two layers of retinal pigment epithelial cells and cone cells, making it the most sensitive area of vision [8]. Normal morphology and structure of the macular retina are essential for achieving good vision [9]. Microstructural damage to the macular area, such as cystoid macular edema, epiretinal membrane, and persistent submacular fluid, which occur after retinal reattachment surgery, are the key reasons for the inability of patients to fully recover their visual function.

Therefore, monitoring changes in the macular microstructure is speculated to provide valuable insights for the prognosis and visual rehabilitation of patients. However, there is still a lack of reliable and objective research to support our viewpoint. This study intends to observe changes in the macular microstructure after retinal reattachment and analyze the correlation of macular microstructural changes with visual function through microperimetry. This study pioneers the investigation of the relationship between postoperative visual acuity and macular microstructure after RRD, and these results could serve as an important reference for evaluating postoperative visual acuity in highly myopic RRD patients seen in clinical practice.

Materials and methods

Study subjects

Fifty-eight highly myopic patients with RRD admitted to the Baoding No. 1 Central Hospital from December 2021 to September 2023 were selected for this retrospective study. Retinal reattachment surgery was completed in Baoding No. 1 Central Hospital after diagnosis. The male-to-female ratio of the included patients was 37:21, and the age range was 28-78 years (mean: 52.31 ± 9.92). This study was conducted in strict accordance with the *Declaration of Helsinki*, and all subjects signed informed consent. The study was approved by the Ethics Committee of the First Central Hospital of Baoding.

Inclusion and exclusion criteria

Inclusion criteria: Patients with myopia ≥600° and RRD confirmed by eye B-ultrasound, fundus photography and other examinations [10]; patients who underwent retinal reattachment surgery in our hospital. Exclusion criteria: RD secondary to trauma, macular hole, traction, or other fundus diseases; previous history of intraocular surgery; previous or co-existing eye conditions that may affect the results of the study; refractive media turbidity that would affect examination/imaging and visual function; presence of systemic diseases such as hypertension and diabetes that would affect retinal blood flow; intolerance to surgery due to poor general condition; poor compliance and inability to continuously maintain a prone position; inability to complete microperimetry due to poor cooperation.

Surgical methods

All patients were treated with vitrectomy, retinal reattachment, retinal laser photocoagulation, and silicone oil tamponade of the vitreous cavity, completed by the same surgical team. Following a complete ophthalmologic examinations, the patient was placed in the supine position, and local anesthesia was administered by injecting 4 mL of 20 g/L lidocaine and 7.5 g/L bupivacaine behind the eye. During the operation, the Alcon microcannula 25G surgical system was used. Three cannulas were inserted 30° obliquely in the corneal limbus and fixed to the sclera, and the instillation cannulas were connected temporally with the cutting speed of 5,000-8,000 times/min. The vitreous axis was incised, retinal clots were aspirated, and membrane stripping and laser photocoagulation were performed. Heavy water was injected to flatten the retina and filled with silicone oil according to the patient's eye condition during the procedure. Subsequently, the supranasal, supratemporal, and infratemporal trocar-level irrigation tubes were removed, and the puncture was closed using a cotton swab to close the wound.

Inspection methods

Best-corrected visual acuity (BCVA) was examined before and 3 months after surgery. Optical coherence tomography (OCT) was performed 3 months after surgery to scan the macular reti-

Table 1. Clinical data of the patients

Parameters		n (%)
Age	52.31 ± 9.92	
Time of onset (d)	6.50 ± 2.68	
Preoperative BCVA	1.26 ± 0.28	
Sex	Male	34 (58.62)
	Female	24 (41.38)
Smoking	Yes	36 (62.07)
	No	22 (37.93)
Drinking	Yes	20 (34.48)
	No	38 (65.52)

Note: BCVA, Best-corrected visual acuity.

na of both eyes and determine the macular microstructural changes. In addition, patients were observed for submacular fluid, epiretinal membrane, macular holes, cystoid macular edema, macular retinal folds, as well as the disappearance of the continuity of the ellipsoid zone and external limiting membrane. Furthermore, blood flow OCT examinations were performed, with the macular fovea as the center and the scanning depth ranging from the internal limiting membrane to the inner plexiform layer, to measure the foveal avascular zone (FAZ) area, morphological index [11], retinal vessel densities of the superficial capillary plexus (VSCP), and retinal perfusion densities of the superficial capillary plexus (PSCP). Moreover, microperimeter MP-3 was used for microperimetry, with the basic brightness set to 10 cd/m^2, the duration of stimulation to 200 ms, and the stimulation range to 0-34 dB. The visual field mean sensitivity (MS) and fixation stability (FS) within 2° and 4° were recorded for each patient [12]. Stable fixation: Fixation point within 2° >75% (3 points); Relatively unstable fixation: Fixation point within 2° <75% and within 4° >75% (2 points); Unstable fixation: Fixation point within 4° <75% (1 point).

Statistical methods

Statistical analyses were performed using SPSS 25.0. Normally distributed data were presented in the form of ($\overline{x}$±s) and compared using independent sample t-tests for intergroup comparison and paired t-tests for intragroup comparison. Data that did not conform to a normal distribution were represented by medians (inter-quartile ranges), and the non-parametric Mann-Whitney U test and Willcoxon rank sum test were used for comparisons. Correlations were analyzed using Pearson and Spearman correlation coefficients. The significance level was P<0.05.

Results

Patient general information

There were 58 patients with 58 affected eyes. The mean age was (52.31 ± 9.92) years, with an onset time of (6.50 ± 2.68) d, and a preoperative BCVA of (1.26 ± 0.28). All patients underwent successful retina reattachment surgery without experiencing serious postoperative complications such as secondary glaucoma, infectious endophthalmitis, corneal endothelial decompensation, or severe proliferative vitreoretinopathy (**Table 1**).

Fundus B-ultrasound findings

Figure 1 demonstrates typical fundus B-ultrasound findings in a myopic patient. **Figure 1A**: In the right eye, the axial diameter was 28.5 mm, and in the left eye, it was 29.4 mm. Weak echoes and strips and bands of echoes were detected in the left eye vitreous cavity, with bands of echoes connecting to the optic disc and temporal side of the spherical wall. Color Doppler flow imaging (CDFI) revealed visible blood flow signals, suggesting large retinal detachment in the left eye. **Figure 1B**: In the right eye, the axial diameter was 26.5 mm, and in the left eye, it was 27.3 mm. Strongly detected band echoes were observed in the left eye vitreous body, connected with the optic disc echo, and CDFI indicated blood flow signals. B-ultrasound findings suggested cloudy vitreous and possible high-grade limited retinal detachment in the left eye.

Comparison of changes before and after the operation

After surgery, there was a significant decrease in postoperative best-corrected visual acuity (BCVA) to 0.69 ± 0.19 compared to preoperative levels (P<0.05). After the operation, the FAZ area increased and the FAZ morphological index decreased compared with the contralateral eye (all P<0.05). However, there were no significant differences in PSCP and VSCP compared to those of the contralateral eye (P>0.05). In terms of microperimetry, the affected eye

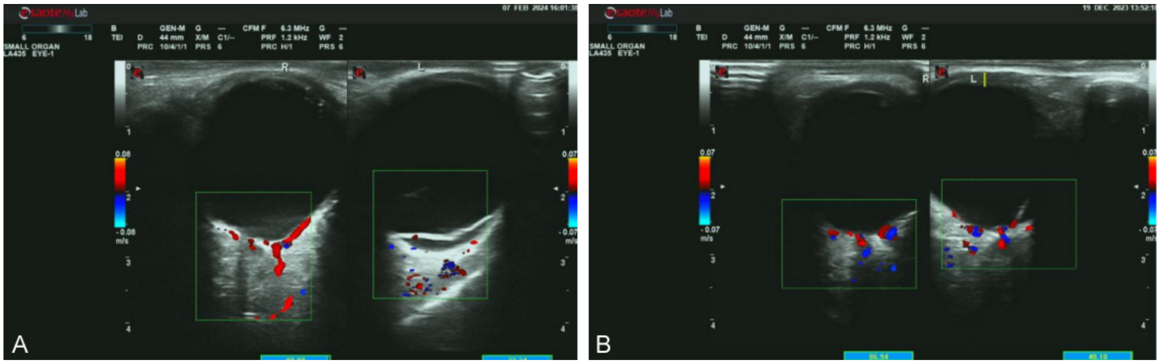

Figure 1. Typical fundus B-ultrasound image. A. Weak echoes and striated and banded echoes are captured in the vitreous cavity of the left eye, and the banded echoes are connected to the optic disc and temporal bulbar wall echoes; B. A strong intravitreal band echo is captured in the left eye, which is connected to the optic disc echo, and a blood flow signal is seen on color Doppler flow imaging.

showed lower postoperative MS and FS than the contralateral eye (all P<0.05) (**Figure 2**).

Macular microstructural changes

After surgery, 70.69% (41/58) of patients experienced macular microstructural changes. The most common changes were ellipsoid zone disruption (51.22%, 21/41) and external limiting membrane disruption (41.46%, 17/41). In addition, one patient (2.44%) developed submacular fluid, one (2.44%) experienced epiretinal membrane, and one (2.44%) suffered from cystoid macular edema. There were no cases of macular holes or retinal folds observed.

Relationship between macular microstructural changes and visual function

Patients with macular microstructural alterations exhibited a BCVA of (0.61 ± 0.15), MS of (22.70 ± 3.12) dB, and FS of (1.34 ± 0.48); in contrast, those without such alterations had a BCVA of (0.87 ± 0.16), MS of (27.23 ± 2.16) dB, and FS of (1.88 ± 0.33). The differences were statistically significant (all P<0.05), indicating that patients with macular microstructural changes had lower BCVA, MS, and FS compared to those without (**Figure 3**).

Differences in blood flow density between patients with and without macular microstructural changes

Comparative analysis of blood flow density between patients with and without macular microstructural changes revealed significant differences. Patients with macular microstructural changes showed a decrease in FAZ morphological index, VSCP, and PSCP (all P<0.05). Additionally, the FAZ area was found to increase in these patients (P<0.05) (**Figure 4**).

Relationship between macular blood flow density and visual function

According to Pearson and Spearman correlation coefficient analysis, BCVA was negatively correlated with FAZ area (r=-0.776, P<0.001) and positively correlated with FAZ morphological index (r=0.704, P<0.001), PSCP (r=0.634, P<0.001) and VSCP (r=0.589, P<0.001); MS was negatively correlated with FAZ area (r=-0.635, P<0.001) but positively correlated with FAZ morphological index (r=0.448, P=0.003), PSCP (r=0.530, P<0.001), and VSCP (r=0.413, P<0.007); FS was negatively correlated with FAZ area (r=-0.541, P<0.001) but positively correlated with FAZ morphological index (r= 0.636, P<0.001), PSCP (r=0.599, P<0.001), and VSCP (r=0.322, P<0.040) (**Figure 5**).

Discussion

Rhegmatogenous retinal detachment (RRD) is common in patients with high myopia due to tears caused by lattice-like and cystic degeneration of the peripheral retina, or vitreous traction on the degenerative retina; These tears allow liquefied vitreous to enter the subretinal space [13, 14]. Growing evidence indicates that patients with high myopia experience visual dysfunction such as blurred vision, distorted vision, darkened vision, and color vision changes of varying degrees after RRD surgery, seriously affecting patients' quality of life [15]. In

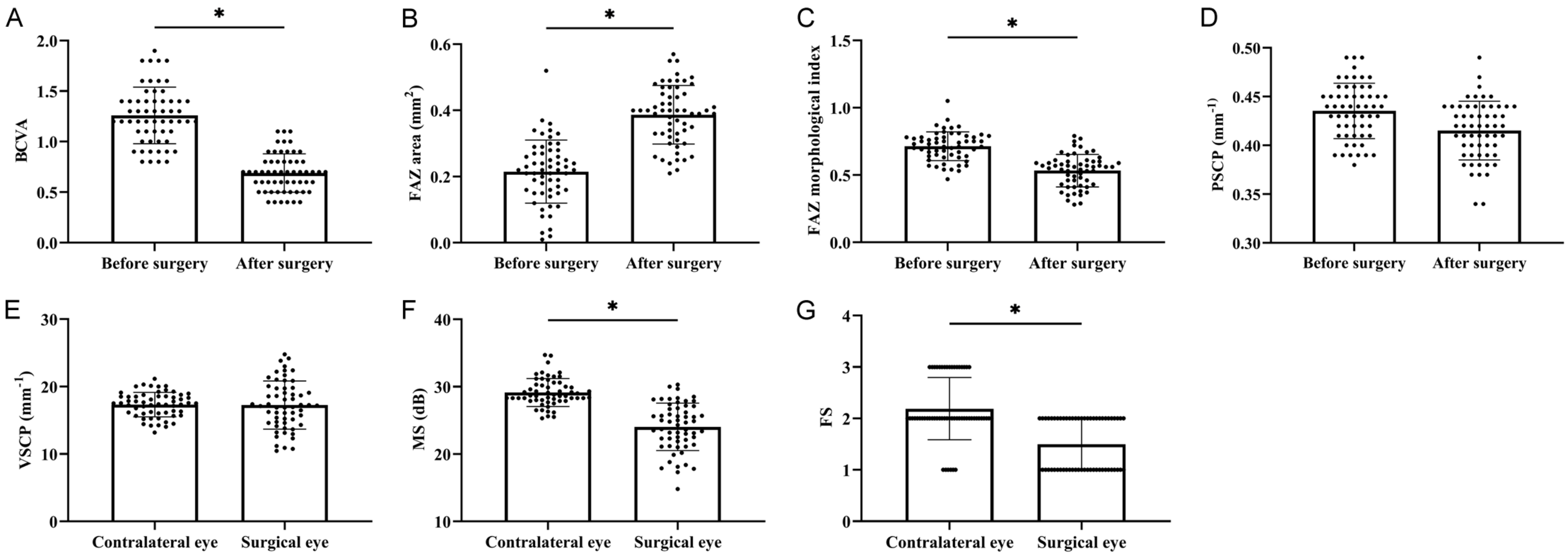

Figure 2. Comparison of changes before and after surgery. A. Comparison of BCVA before and after surgery; B. Comparison of FAZ area before and after surgery; C. Comparison of FAZ morphological index before and after surgery; D. Comparison of VSCP between the surgical eye and the contralateral eye after surgery; E. Comparison of VSCP between the surgical eye and the contralateral eye after surgery; F. Comparison of MS between the surgical eye and the contralateral eye after surgery; G. Comparison of FS between the surgical eye and the contralateral eye after surgery. Notes: BCVA, Best-corrected visual acuity; FS, fixation stability; MS, mean sensitivity; FAZ, foveal avascular zone; PSCP, perfusion densities of the superficial capillary plexus; VSCP, vessel densities of the superficial capillary plexus.

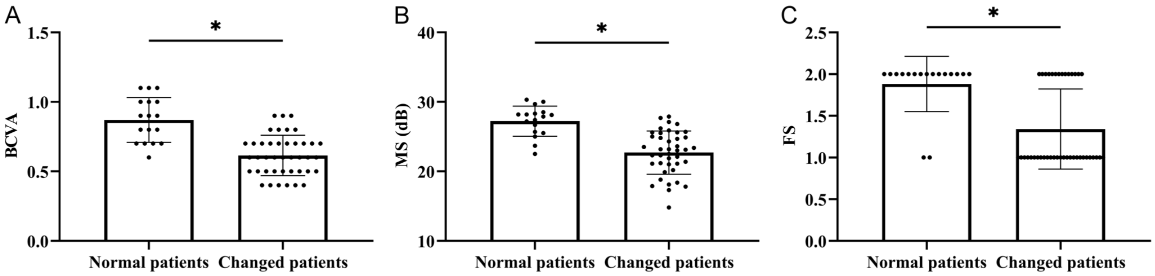

Figure 3. Comparison of BCVA (A), MS (B) and FS (C) between patients with and without macular microstructural changes. Notes: BCVA, Best corrected visual acuity; MS, Mean sensitivity; FS, Fixation stability.

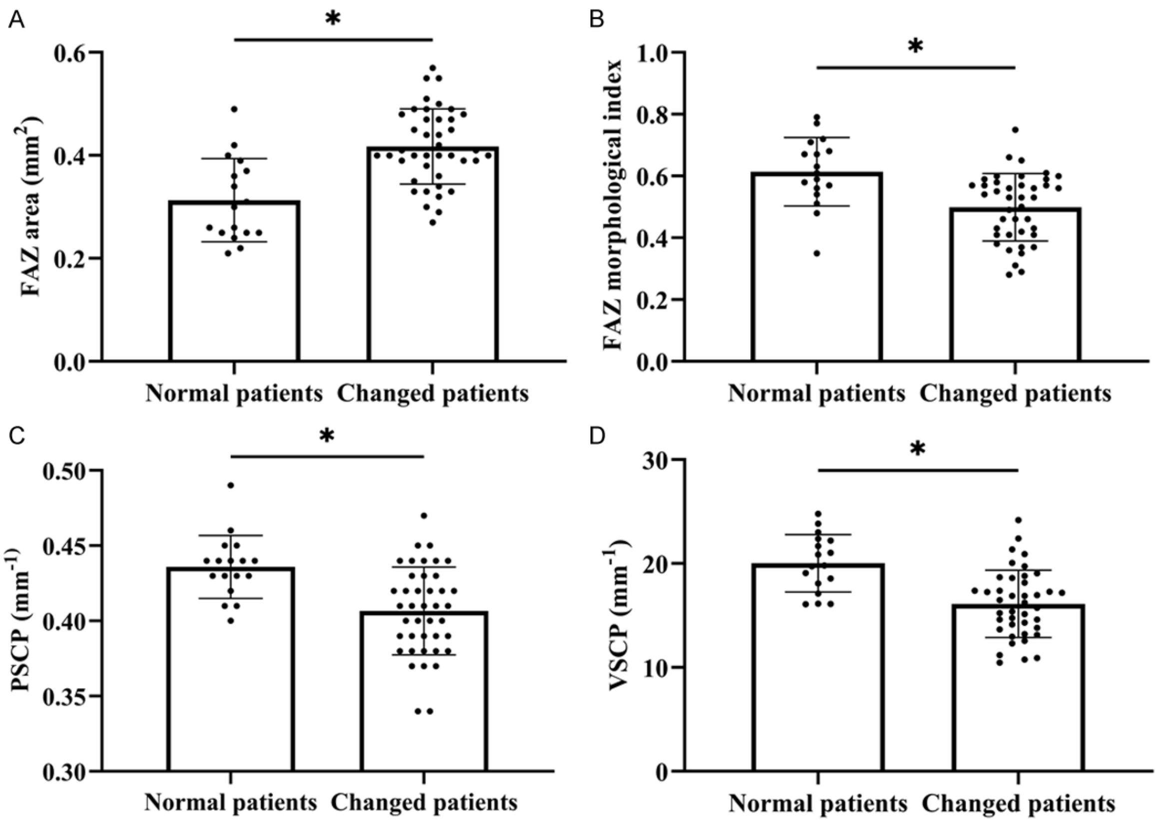

Figure 4. Comparison of blood flow density indices between patients with and without macular microstructural changes. A. FAZ area; B. FAZ morphological index; C. PSCP; D. VSCP. Notes: FAZ, Foveal avascular zone; VSCP, Vessel densities of superficial capillary plexus; PSCP, Perfusion densities of superficial capillary plexus.

this study, we explored the relationship between macular microstructural changes and visual function in highly myopic individuals, which can provide more reliable guidance for future RRD surgery.

After RRD surgery, patients experienced a decrease in BCVA, MS, FS, and FAZ morphological index, while the FAZ area increased. These findings are consistent with the results of Philippakis E et al. [16], which we believe is due to surgery-induced stress trauma. Photoreceptors are cells on the retina that consume a huge amount of oxygen and cannot be regenerated once damaged. Following RRD, photoreceptor cells undergo a series of pathological changes, such as degeneration, apoptosis, and autophagy, resulting in a decrease in retinal tissue oxygen consumption and even an inability to recover after retinal reattachment [17]. However, there was no significant change in PSCP and VSCP in the affected eye compared

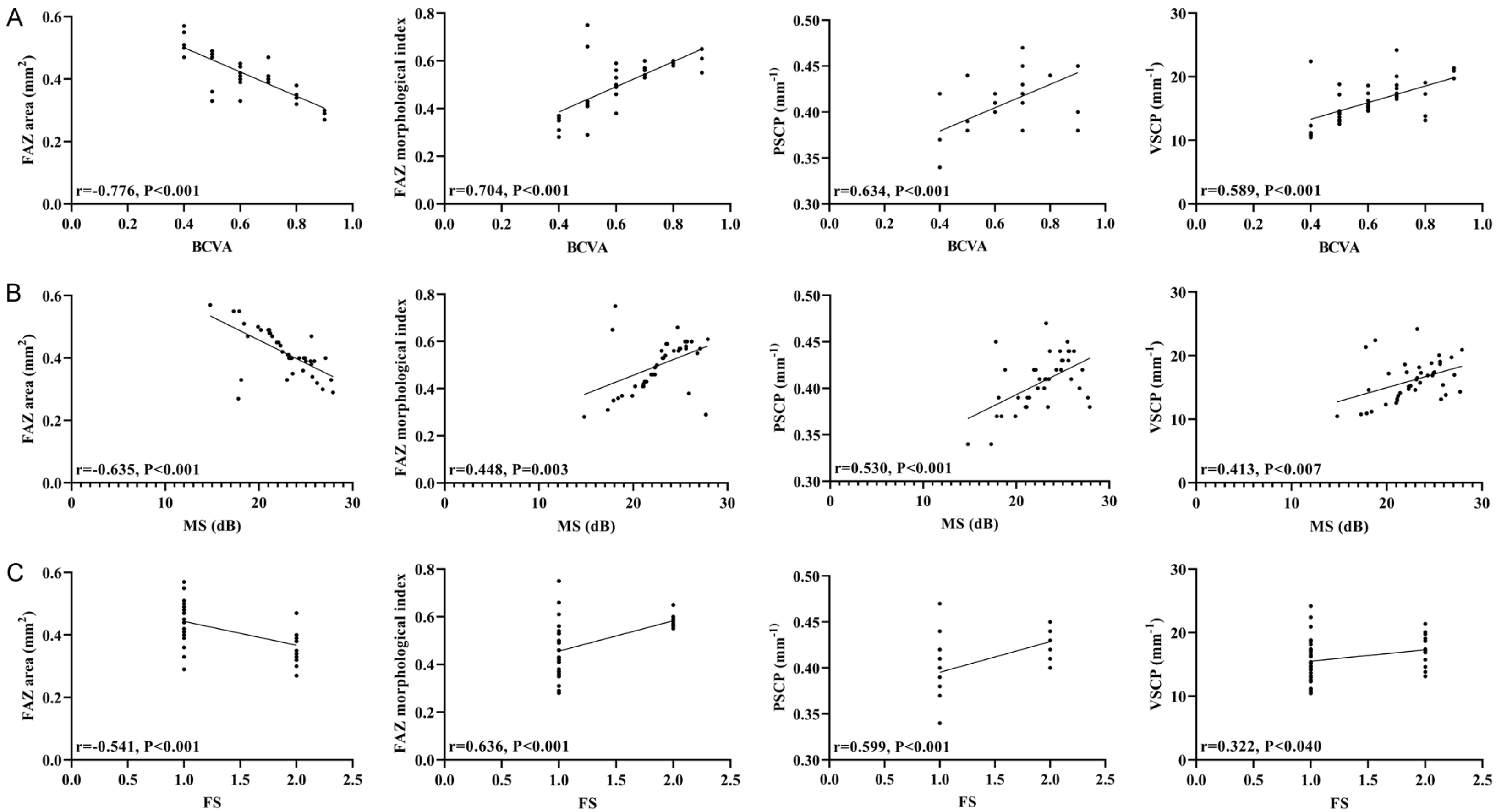

Figure 5. Relationship between macular blood flow density and visual function. A. Correlation of BCVA with FAZ area, FAZ morphological index, PSCP, and VSCP; B. Correlation of MS with FAZ area, FAZ morphological index, PSCP, and VSCP; C. Correlation of FS with FAZ area, FAZ morphological index, PSCP, and VSCP. Notes: FAZ, Foveal avascular zone; VSCP, Vessel densities of superficial capillary plexus; PSCP, Perfusion densities of superficial capillary plexus.

with the contralateral eye, which we hypothesize is due to the disappearance of negative effects after silicone oil removal. Studies have shown that silicone oil tamponade has a retinal oppressive effect and ganglion cytotoxicity, which will gradually resolve over time after removal [18], so there was no difference between the patient's PSCP, VSCP and the contralateral eye.

In the subsequent investigation of macular microstructural changes, we found primary disruption in ellipsoid zone and external limiting membrane, consistent with the previous research results [19]. Meanwhile, patients with macular microstructural changes exhibited significant reductions in BCVA, MS, and FS, further confirming the close relationship between macular microstructural changes and visual function. The rapid apoptosis of photoreceptors after RRD is a clinically recognized pathological change, and the continuity of the ellipsoid zone and external limiting membrane can ensure the integrity of photoreceptors [20]. Therefore, better continuity between the ellipsoidal zone and the external limiting membrane usually predicts better postoperative visual function. This can also be confirmed by the significant reduction in BCVA, MS, and FS in patients with ellipsoid zone disruption and external limiting membrane disruption in the analysis of the relationship between macular microstructural changes and visual function in this study. Retinal pigment epithelial cells, on the other hand, can diffuse through retinal tears to the inner surface of the retina and then proliferate. Following RD, the blood-retinal barrier is often damaged, leading to local retinal tissue inflammation, and release of massive inflammatory substances, which will stimulate the proliferation of capillary endothelial cells, fibroblasts, and smooth muscle cells, thus forming submacular fluid, epiretinal membrane, and cystoid macular edema [21]. These conditions may also affect the recovery of postoperative visual function to some extent. However, statistical analysis is challenging because this study included only one case each of submacular fluid, epiretinal membrane, and cystoid macular edema. This limitation makes it difficult to comprehensively assess the relationship between macular microstructural changes and visual function. We plan to expand the sample size in future studies to confirm these findings.

Finally, changes in blood flow density were further compared. The FAZ morphological index, PSCP, and VSCP were found to be decreased in patients with macular microstructural changes. Moreover, BCVA, FS, and MS were positively correlated with the FAZ morphological index, PSCP, and VSCP, but inversely correlated with the FAZ area. These results further confirm that macular microcirculation plays an important role in postoperative visual function changes. Among them, the FAZ area is a key region for fine vision formation, and its morphology and surrounding blood flow density can reflect the blood supply to the macular region, which is closely related to various retinal diseases and visual function changes [22]. RRD-induced ischemia and hypoxia may cause changes in the size and morphology of FAZ, while the FAZ size can indicate the severity of macular ischemia (a larger the FAZ area indicating more severe macular ischemia). Therefore, as the blood flow density in the macular area stabilizes after RRD surgery, the gradual recovery of photoreceptor function over time may promote further improvement in visual function. Similarly, Baba T et al. proposed a close correlation between the FAZ area and postoperative visual function in cataract patients [23], which supports our findings.

However, as mentioned earlier, the number of cases included in this study is limited, and individualized differences among patients may result in inaccurate results. In addition, it takes a long time for retinal structure and function to recover after RRD surgery. Yet, this study only conducted a 3-month follow-up, limiting the assessment the long-term prognostic visual function of patients. Furthermore, this study only measured the blood flow density of the superficial retinal capillaries and did not examine the blood flow density of the deep retinal capillaries and choroid, which may also impact prognostic visual function. In the future, more in-depth and comprehensive research and analysis will be carried out to address the above limitations.

Conclusion

Best corrected visual acuity (BCVA), visual field mean sensitivity (MS) and fixation stability (FS) are significantly decreased in patients with high myopia undergoing surgery for RRD, and these decreases are closely related to macular microstructural changes. Alterations in patients' postoperative visual function can be effectively assessed by observing changes in the macular ellipsoid, external limiting membrane integrity, and micro blood flow after RRD surgery. This allows for timely and early interventions to ensure optimal prognostic visual function.

Disclosure of conflict of interest

None.

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