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Correlation between optical coherence tomography angiography-based data and postoperative visual acuity in patients that underwent surgery for macula-on RRD and macula-off RRD

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Background: *Despite advances in surgical techniques for rhegmatogenous retinal detachment (RRD) repair, patients are still at high risk for low functional outcomes. Given the above, it is important to find reasons for disappointment at the outcomes of vitreoretinal surgery for RRD. Impaired retinal microcirculation is a possible cause of insufficiently good functional outcomes in surgery for RRD.*

Purpose: *To compare postoperative optical coherence tomography angiography (OCTA)-based changes in retinal microcirculation in the eyes of patients that underwent surgery for macula-on RRD versus the eyes of patients that underwent surgery for macula-off RRD and (2) to establish a relationship between OCTA data and best-corrected visual acuity (BCVA).*

Material and Methods: *This prospective study included 116 patients. Of these, 65 underwent surgery for macular-on RRD (group 1) and 51, surgery for macular-off RRD (group 2). OCTA-based retinal vasculature parameters (foveal avascular zone (FAZ) area, parafoveal superficial capillary plexus (SCP) density and deep capillary plexus (DCP) density, vessel diameter, and vessel tortuosity index (VTI)) and their correlation with BCVA were assessed. Follow-up duration was 12 months.*

Results: *In group 1, there was a negative correlation between the FAZ area and the macular thickness (r = - 0.299, p = 0.025) at month 12. The final BCVA was associated with the parafoveal DCP density (r = - 0.340, p = 0.010) and FAZ area (r= 0.390, p = 0.003). At 12 months, in group 2, the BCVA negatively correlated with the FAZ area (r = - 0.408, p = 0.012) and parafoveal SCP density (r = - 0.451, p = 0.005). In addition, there was a negative correlation between the parafoveal DCP density and the postoperative BCVA (r = - 0.418). There was no correlation between the FAZ area and the macular thickness (r = - 0.282, p = 0.080).*

Conclusion: *The poorer vessel tortuosity index and parafoveal vessel density and diameter, the lower was postoperative visual acuity.*

Keywords:

rhegmatogenous retinal detachment, retinal microcirculation, optical coherence tomography angiography, macular-off retinal detachment

Introduction

Surgical repair of rhegmatogenous retinal detachment (RRD) is a significant technical and clinical challenge for the eye surgeon. Pars plana vitrectomy (PPV) is an option for the surgical repair of RRD, and constantly undergoes improvements [1]. Although improvements in re-attachment rates have been observed [2], a significant proportion of patients still have low visual outcomes [3], and the risk of low postoperative vision is high. It has been reported that only 42% of eyes with reattached retinas had a visual acuity (VA) ≥ 20/40. Patients with primary RRD require a secondary surgery approximately 10–40% of the time [4]. Given the above, it is important to find reasons for disappointment at the outcomes of vitreoretinal surgery for RRD. Because impaired retinal microcirculation resulting in hypoxia is a possible cause of insufficiently good functional outcomes in surgery for RRD [5], we believe it is reasonable to use non-invasive optical coherence tomography angiography (OCTA) for assessing retinal and choroidal microcirculation in patients with RRD. A number of studies [6, 7] have reported on measurements of OCTA-based retinal vascular density indices, but there is no unified opinion on the types and levels of changes in retinal blood supply.

The purpose of the study was (1) to compare postoperative OCTA-based changes in retinal microcirculation in the eyes of patients that underwent surgery for macula-on RRD versus the eyes of patients that underwent surgery for macula-off RRD and (2) to establish a relationship between OCTA data and best-corrected visual acuity (BCVA).

Material and Methods

This prospective study included 116 patients: 65 patients that underwent surgery for macular-on RRD (group 1) and 51 patients that underwent surgery for macular-off RRD (group 2).

Exclusion criteria included high myopia (axial length ≥ 26.0 mm), ocular comorbidities (diabetic retinopathy, glaucoma, and age-related macular degeneration), uveitis, retinal vascular disorders, or the presence of an epiretinal membrane in any eye, and retinal detachment for longer than three days with postoperative complications (re-detachment, proliferative vitreoretinopathy, or intravitreal hemorrhage).

Patients were enrolled in the period from March 1, 2021, to March 1, 2022. All patients underwent successful surgery (PPV with C3F8 gas tamponade and phacoemulsification with intraocular lens implantation) within 72 hours after being diagnosed with primary RRD. Surgeries for RRD were conducted by a highest category board-certified surgeon at the Department of Ophthalmology, Poltava Regional Clinical Hospital.

Patients underwent a complete eye examination including visual acuity measured by Early Treatment Diabetic Retinopathy Study (ETDRS) charts, Goldmann intraocular pressure (IOP) measurement, slit-lamp biomicroscopy with a 90 D lens, optical coherence tomography (OCT) and OCTA. OCTA-based retinal vasculature parameters (foveal avascular zone (FAZ) area, parafoveal superficial capillary plexus (SCP) density and deep capillary plexus (DCP) density, vessel diameter, and vessel tortuosity index (VTI)) and their correlation with BCVA were assessed. Follow-up examinations were conducted 1, 3, 6, and 12 months after surgery.

Fellow unaffected eyes were used as controls. Fellow-eye examinations were conducted at each visit in all patients.

All procedures performed in the study were in accordance with the ethical standards of the Helsinki declaration. Prior to treatment, all patients signed informed consent to participate in the study and to undergo surgery. The study was approved by a local bioethics committee.

OCTA images of retinal microvascular bed (3 x 3 mm) were acquired using the Angio Vue OCTA system (RT-Vue XR OCT Avanti, Optovue, Inc.) which utilizes split-spectrum amplitude-decorrelation angiography (SSADA). OCTA images were obtained using the 3 x 3 mm scanning protocol in the Angio Retina mode to allow for improved image resolution and reduce the probability of eye motion artefacts and segmentation errors.

Statistical analyses were conducted using Statistica 10.0 (StatSoft, Tulsa, OK, USA) software. Paired t-test was used for comparison of mean plus or minus standard deviation (SD) values of parameters between eyes with RRD and fellow eyes. Unpaired t-test was used for comparison of measurements between group 1 and group 2. Pearson regression was used to assess the relation between parameters (FAZ, BCVA, SCP and DCP). $P \leq 0.05$ was considered statistical significant.

Results

Preoperatively, OCTA of the affected eye was performed only in patients of group 1. Mean values of parafoveal DCP and SCP density were 34.6 ± 1.2 % and 37.7 ± 0.6 %, respectively; retinal thickness in the macular region, 317.5 ± 25.6 μm; and FAZ area, 0.283 ± 0.048 mm^2.

There was a significant difference in OCTA-based parameters for patients of group 1 before and one month after surgery. At 1 month after surgery, in patients of group 1, parafoveal DCP density increased by 3.3 ± 2.4 % from baseline to 36.5 ± 2.8 % (range, 33.9-40.3%; $p < 0.05$); parafoveal SCP density increased by 1.3 ± 0.9 % to 38.3 ± 0.8 % (range, 37.8-39.7%; $p < 0.05$); retinal thickness in the macular region increased by 33.5 ± 3.4 μm from baseline to 321.8 ± 5.5 μm (range, 283-340 μm, $p < 0.05$); and FAZ area increased by 0.03 ± 0.013 mm2 from baseline to 0.313 ± 0.023) mm^2 (range, 0.295-0.336 mm^2; $p < 0.05$). In addition, at 1 month after surgery, mean diameter of retinal vessels in group 1 was 3.9 μm ($p < 0.05$).

At 3 months, in patients of group 1, parafoveal DCP density increased by 5.4 ± 2.6 % from baseline to 39.4 ± 1.8 % (range, 36.2-43.4%; $p < 0.05$); parafoveal SCP density increased by 6.5 ± 2.2 % from baseline to 43.1 ± 3.6 % (range, 39.9-45.4%); retinal thickness in the macular region decreased by 35.3 ± 5.4 μm from baseline to 280.8 ± 6.4 μm (range, 270-296 μm, $p < 0.05$); and FAZ area decreased by 0.001 ± 0.008 mm^2 from baseline to 0.288 ± 0.086 mm^2 (range, 0.275-0.312 mm^2; $p < 0.05$). In addition, mean retinal vessel diameter at 3 months was 4.0 μm ($p < 0.05$). Parafoveal SCP density stabilized in 48 eyes (73.84%), decreased in 11 eyes (16.92%), and did not change in 6 eyes (9.23%).

At 6 months, in patients of group 1, parafoveal DCP density increased by 8.3 ± 1.6 % from baseline to 42.4 ± 1.5 % (range, 40.9-45.7%; $p < 0.05$); retinal thickness in the macular region decreased by 56.8 ± 3.4 μm from baseline to 251.5 ± 4.5 μm (range, 243-260 μm); and FAZ area decreased by 0.023 ± 0.006 mm^2 from baseline to 0.253 ± 0.033 mm^2 (range, 0.235-0.287 mm^2; $p < 0.05$). In addition, mean retinal vessel diameter at 3 months was 4.2 μm ($p < 0.05$).

At 12 months, there were statistically significant changes in parameters: DCP density ranged from 41.2% to 46.7% ($p < 0.05$); in addition, within the whole follow-up period, there was a negative correlation between the parafoveal DCP density and the postoperative BCVA ($r = - 0.340$); FAZ area ranged from 0.219 mm2 to 0.286 mm2, $p < 0.05$; in addition, within the whole follow-up period, there was a negative correlation between the FAZ area and the postoperative BCVA ($r = - 0.390$); at 12 months, mean retinal vessel diameter and mean VTI were smaller in the affected eyes than in the fellow eyes ($p < 0.05$). Parafoveal SCP density deteriorated at 1 month and 3 month, but normalized at subsequent time points of the 12-month follow

up. By the end of month 12, retinal thickness stabilized in 51 eyes (78.46%), increased in 10 eyes (15.38%), and did not change in 4 eyes (6.15%).

Table 1 compares macula-on RRD eyes and fellow eyes in patients of group 1 in terms of retinal blood flow parameters in the macular region at 12 months after surgery.

Because BCVA is the primary functional outcome of surgery, it is this parameter that we used for comparison with the OCTA data. In the macula-on RRD group, mean BCVA of the affected eyes was 0.13 ± 0.17 logMAR at baseline and improved to 0.07 ± 0.06 logMAR at month 12 ($p = 0.002$, paired t-test), versus 0.02 ± 0.07 logMAR for the fellow-eyes. In group 1, there was a negative correlation between the FAZ area and the macular thickness ($r = - 0.299$, $p = 0.025$) at month 12. The BCVA was associated with the parafoveal DCP density ($r = - 0.340$, $p = 0.05$) and FAZ area ($r = - 0.390$, $p = 0.005$), (Fig. 1).

However, at 12 months, in group 1, 48 patients (74%) had a BCVA of 0.09 ± 0.03 logMAR in the affected eyes, which was lower than in the fellow eyes. In these patients, at month 12, parafoveal DCP density decreased to 42.2 ± 3.1 %, FAZ area increased to 0.247 ± 0.093 mm^2, mean retinal vessel diameter was 4.0 ± 0.2 µm, and mean VTI was 0.81, these values being smaller than for the fellow eyes ($p < 0.05$). In patients with macular-off RRD (group 2), not the affected eyes but the fellow eyes underwent OCTA imaging at baseline, and parafoveal DCP density was 52.2 ± 4.1 %; parafoveal SCP density, 46.8 ± 5.2 %; retinal thickness in the macular region, 265.0 ± 34.0 µm; and FAZ area, 0.255 ± 0.132 mm^2.

At 1 month after surgery, there were significant changes in the affected eyes of group 2 compared to the fellow eyes: parafoveal DCP density was 34.4 ± 2.8 % (range, 33.1-37.8%), which was by 14.8 ± 1.5% smaller than in the fellow eyes ($p < 0.05$); parafoveal SCP density was 36.3

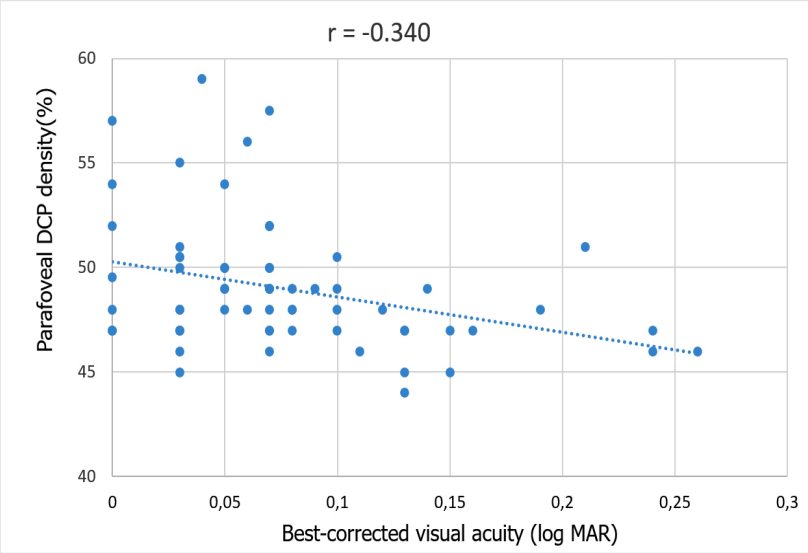

Fig. 1. Correlation between parafoveal deep capillary plexus (DCP) density and best-corrected visual acuity in patients of group 1 (after surgery for macula-on rhegmatogenous retinal detachment (RRD) repair)

Table 1. Mean values of the structural parameters of the retinal microvascular bed in the affected eyes and fellow eyes of patients of 1st group at 12 months after surgery for macula-on rhegmatogenous retinal detachment (RRD) repair

	Eyes with macular-on RRD (n =65)	Fellow eyes (n = 65)	P (paired t-test)
Macular thickness (µm)	245.8±5.5	263±13	0.123
Foveal avascular zone (FAZ) area (mm^2)	0.228±0.088	0.239±0.084	<0.05
Foveal SCP density (%)	22.8±8.2	23.0±8.4	0.256
Parafoveal SCP density (%)	45.4± 6.0	46.4±6.0	0.999
Foveal DCP density (%)	37.3±7.5	37.7±7.4	0.751
Parafoveal DCP density (%)	44.3±3.4	51.8±4.0	< 0.001
Mean vessel diameter (мкм)	4.6±0.4	6.2±0.5	< 0.001
Vessel tortuosity index	0.85	0.9	< 0.05

Note: n, number of patients; RRD, rhegmatogenous retinal detachment; SCP, superficial capillary plexus; DCP deep capillary plexus; P, significance of difference

± 1.8 % (range, 35.5-37.7%), which was by 10.5 ± 2.4% smaller than in the fellow eyes ($p < 0.05$); retinal thickness in the macular region was 281.8 ± 6.7 μm (range, 257-308 μm), which was by 21.0 ± 12.0 μm larger than in the fellow eyes ($p < 0.05$); FAZ area was 0.313 ± 0.083 mm^2 (range, 0.276-0.348 mm^2), which was by 0.074 ± 0.028 mm^2 larger than in the fellow eyes ($p < 0.05$); mean retinal vessel diameter (D) after surgery was 3.7 μm, which was by 2.5 ± 0.3 μm smaller than in the fellow eyes ($p < 0.05$).

At 3 months after surgery, there were significant improvements in parameters: parafoveal DCP density was 37.6 ± 2.8 % (range, 36.2-43.4%), which was by 14.6 ± 3.2% smaller than in the fellow eyes ($p < 0.05$); parafoveal SCP density was 39.5 ± 1.6 % (range, 37.5-39.9%), which was by 7.3 ± 4.5% smaller than in the fellow eyes ($p < 0.05$); retinal thickness in the macular region was 260.8 ± 6.4 μm (range, 250-276 μm), which was very close to that for the fellow eyes; FAZ area was 0.302 ± 0.004 mm2 (range, 0.284-0.317 mm^2), which was by 0.063 ± 0.022 mm^2 larger than in the fellow eyes ($p < 0.05$); mean retinal vessel diameter (D) was 3.9 μm, which was by 2.3 ± 0.2 μm smaller than in the fellow eyes ($p < 0.05$).

At 6 months after surgery, parafoveal DCP density was 41.6 ± 1.9 % (range, 39.5-43.7%), which was by 10.6 ± 3.8% smaller than in the fellow eyes ($p < 0.05$); parafoveal SCP density was 40.9 ± 2.5 % (range, 38.1-42.7%), which was by 5.9 ± 3.9% smaller than in the fellow eyes ($p < 0.05$); retinal thickness in the macular region was 221.5 ± 4.5 μm (range, 213-241 μm), which was by 44.0 ± 10.0 μm smaller than in the fellow eyes ($p < 0.05$); FAZ area was 0.322 ± 0.039 mm^2 (range, 0.301-0.334 mm2), which was by 0.083 ± 0.018 mm^2 larger than in the fellow eyes ($p < 0.05$); mean retinal vessel diameter (D) after surgery was 4.1 μm, which was by 1.9 ± 0.3 μm smaller than in the fellow eyes ($p < 0.05$).

At 12 months after surgery, in the affected eyes, parafoveal DCP density was by 8.7 ± 2.8 % smaller than for the fellow eyes (range, 41.5-48.6%) ($p < 0.05$); in addition, there was a negative correlation between the parafoveal DCP density and the postoperative BCVA ($r = - 0.418$); parafoveal SCP density was by 3.6 ± 2.2 % smaller than for the fellow eyes (range, 37.9-49.7%) ($p < 0.05$); in addition, there was a negative correlation between the parafoveal SCP density and the postoperative BCVA ($r = - 0.451$); FAZ area was by 0.082 ± 0.093 mm^2 larger than in the fellow eyes, ranging from 0.316 mm^2 to 0.345 mm^2, and there was a negative correlation between the FAZ area and the postoperative BCVA; mean retinal vessel diameter (D) was by 1.7 ± 0.6 μm smaller than in the fellow eyes ($p < 0.05$). By the end of month 12, retinal thickness stabilized in 40 eyes (78.43%), increased in 7 eyes (13.72%), and did not change in 4 eyes (7.84%).

Table 2 compares macula-off RRD eyes and fellow eyes in patients of group 2 in terms of retinal blood flow parameters in the macular region at 12 months after surgery.

In the macula-off RRD group, mean BCVA of the fellow eyes was 0.03 ± 0.12 logMAR; mean preoperative BCVA was 1.33 ± 0.18 logMAR and improved to 0.42 ± 0.24 logMAR at month 12 ($p = 0.001$, paired t-test).

At 12 months, in group 2, the BCVA negatively correlated with the FAZ area ($r = - 0.408$, $p = 0.05$) and parafoveal SCP density ($r = - 0.451$, $p = 0.05$), Fig. 2.

In addition, the BCVA negatively correlated with the parafoveal DCP density ($r = - 0.418$, $p = 0.010$), Fig. 3.

There was no correlation between the FAZ area and the macular thickness ($r = - 0.282$, $p = 0.080$).

However, at 12 months after surgery, in group 2, 47 patients (92%) had a mean BCVA of 0.42 ± 0.24 logMAR, which was lower than in the fellow eyes. In these patients, parafoveal DCP density decreased to 38.8 ± 0.6%, and parafoveal SCP density, to 40.0 ± 3.0%; FAZ area increased to 0.358 ± 0.098 mm2; retinal thickness decreased to 207.5 ± 14.0 μm; and mean retinal vessel diameter was 3.7 ± 0.3 μm, and mean VTI was 0.75, these values being smaller than for the fellow eyes.

Table 2. Mean values of the structural parameters of the retinal microvascular bed in the affected eyes and fellow eyes of patients of 2nd group at 12 months after surgery for macula-on rhegmatogenous retinal detachment (RRD) repair

	Eyes with macular-on RRD (n =65)	Fellow eyes (n = 65)	P (paired t-test)
Macular thickness (μm)	232,8±22	265±34	<0,05
Foveal avascular zone (FAZ) area (mm^2)	0,337±0,093	0,255±0,132	<0,05
Foveal SCP density (%)	24,1±6,1	24,2±6,7	0,931
Parafoveal SCP density (%)	43,4±5,5	46,8±5,2	<0,05
Foveal DCP density (%)	33,7±8,7	38,5±7,3	0,011
Parafoveal DCP density (%)	43,5±3,1	52,2±4,1	< 0,001
Mean vessel diameter (мкм)	4,5± 0,5	6,4± 0,5	< 0,001
Vessel tortuosity index	0.82	0.92	< 0,05

Примітка: n – кількість хворих, РВС – регматогенне відшарування сітківки, ПКС – поверхневе капілярне сплетіння, ГКС – глибоке капілярне сплетіння, Р – рівень значущості різниці показників.

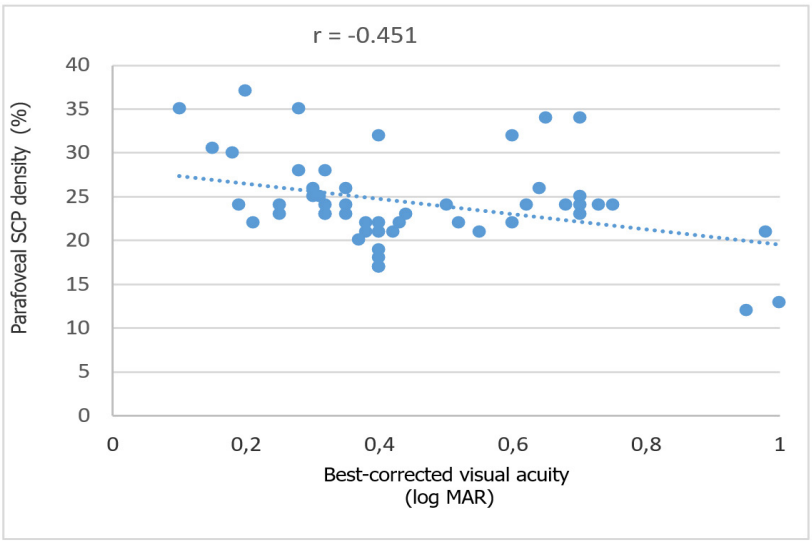

Fig. 2. Correlation between parafoveal superficial capillary plexus (SCP) density and best-corrected visual acuity in patients of group 2 (after surgery for macula-off rhegmatogenous retinal detachment (RRD) repair)

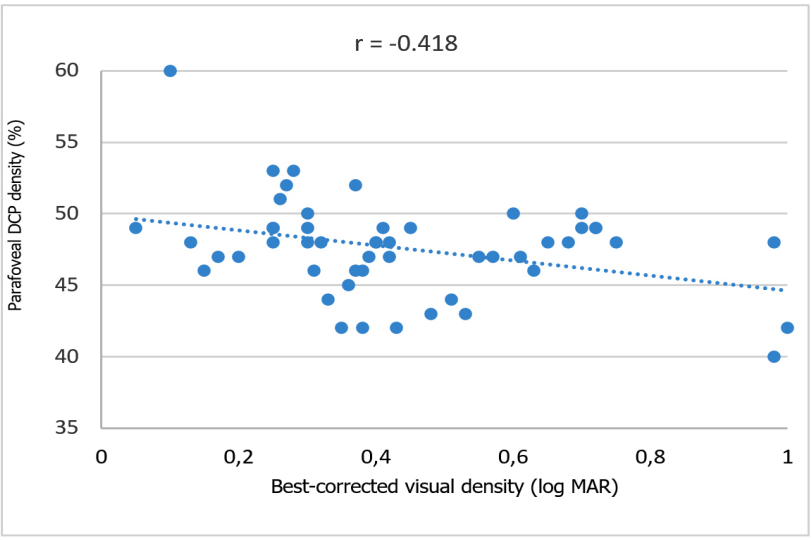

Fig. 3. Correlation between parafoveal deep capillary plexus (DCP) density and best-corrected visual acuity in patients of group 2 (after surgery for macula-off rhegmatogenous retinal detachment (RRD) repair)

At 12 months after surgery, patients that underwent surgery for macula-on RRD had better BCVA than patients that underwent surgery for macula-off RRD ($p < 0.05$), which could be a cause for greater OCTA-based changes in retinal vessels in group 2.

Discussion

Therefore, we found a correlation between the parafoveal DCP density and BCVA in eyes that underwent surgery for macula-on RRD. Retinal thickness in the macular region and FAZ area statistically increased by 33.5 ± 3.4 μm and by 0.03 ± 0.013 mm2, respectively, from baseline ($p < 0.05$), at month 1 after surgery, but at 12 months, retinal thickness stabilized with no statistically significant difference between the affected eyes and the fellow eyes. FAZ area continued to increase and negatively correlated with the deteriorated BCVA. There was a negative correlation between the FAZ area and the macular thickness, indicating the preservation of normal retinal anatomy in these eyes, which is in agreement with the findings of Bonfiglio et al [8]. In addition, the final BCVA was associated with the parafoveal DCP density and FAZ area whereas Woo et al [9] demonstrated that both superficial and deep FAZ areas were negatively correlated with postoperative BCVA.

Because the findings vary in the literature, we explored associations of quantitative retinal vessel characteristics (the diameter and VTI) with the BCVA, and found that the mean vessel diameter and VTI in the parafoveal region were by 1.7 ± 0.5 μm and 0.05, respectively, smaller than in the fellow eyes throughout the follow up for both study groups.

At 12 months, in group 1, 48 patients (74%) had poorer functional outcomes than patients of the main group. Their BCVA of 0.07 ± 0.06 logMAR was by 0.05±0.01 logMAR lower than that in the macula-on RRD group. In these patients, at month 12, parafoveal DCP density decreased by 2.1 ± 0.3 % ($p < 0.05$) and FAZ area increased by 0.019 ± 0.015 mm2 ($p < 0.05$), compared to patients of the main group, and vascular structure was impaired.

In addition, at month 12, mean retinal vessel diameter decreased by 0.6 ± 0.2 μm ($p < 0.05$), and mean VTI was by 0.04 smaller ($p < 0.05$) than for the eyes of the main group ($p < 0.05$). In patients that underwent surgery for macula-off RRD, not only the parafoveal DCP density, but also the parafoveal SCP density were negatively correlated with the BCVA, showing an impact on the functional outcome of surgery.

Others [12, 13, 14, 15] examined the relationships of the OCTA-based postoperative parameters with the BCVA after successful macula-off RRD repair surgery, but findings of these studies are inconsistent. Xu and colleagues [16] found no correlation between FAZ area and postoperative BCVA. Yui et al [17] reported no correlation of postoperative BCVA with DCP density and SCP density.

Retinal thickness statistically significantly increased by 41.0 ± 12.0 μm in the early postoperative period and gradually stabilized by month 12, which is contradictory to the findings by Woo et al [9]. Others [10, 11] have reported a decrease in retinal thickness at 1 and 3 months after surgery for macula-off RRD. The data obtained indicated that retinal thickening is associated with surgical manipulations in the macula. Correlation analysis found no correlation between the FAZ area and macular thickness.

In 47 patients (92%), the BCVA was 0.35 ± 0.10 logMAR worse than in the macula-off RRD group. In these patients, parafoveal DCP density decreased by 5.7 ± 2.1 % ($p < 0.05$), parafoveal SCP density decreased by 3.4 ± 2.5 % ($p < 0.05$), FAZ area increased by 0.021 ± 0.014 mm2 ($p < 0.05$), and retinal thickness decreased by 24.8 ± 8.0 μm ($p < 0.05$), compared to patients in the macula-off RRD group. In addition, at month 12, mean retinal vessel diameter decreased by 0.7 ± 0.2 μm ($p < 0.05$), and mean VTI was by 0.07 smaller ($p < 0.05$) than for the eyes of the main group ($p < 0.05$).

Therefore, it was demonstrated that RRD-induced vascular biomechanical instability can result in functional and anatomical changes in the vessels, with these changes affecting functional outcomes. The current study demonstrated that RRD affects both the number of retinal vessels and retinal vasculature morphology, with mean values of vessel diameter and VTI being smaller in the affected eyes than in the fellow eyes for both study groups.

OCTA-based quantitative parameters of the retinal vascular bed are potential factors for predicting functional outcomes in the eyes that underwent surgery for RRD. Therefore, given the findings of the current study, one may hypothesize that an improvement in the structural parameters of the retinal microcirculatory bed will improve functional outcomes in patients undergoing surgery for RRD.

Conclusion

First, in eyes that underwent surgery for macula-on RRD, final BCVA is associated with parafoveal DCP density ($r = -0.340$, $p = 0.010$).

Second, in eyes that underwent surgery for macula-off RRD, final BCVA is associated with parafoveal SCP density ($r = -0.451$, $p = 0.005$) and parafoveal DCP density ($r = -0.418$, $p = 0.010$).

Third, a 1.65 ± 0.7 μm decrease ($p < 0.05$) in the retinal vessel diameter affected a postoperative functional outcome of surgery for RRD.

Finally, vessel tortuosity index was significantly smaller in eyes that underwent surgery for macula-off RRD than in eyes that underwent surgery for macula-on RRD (0.81 versus 0.75; $p < 0.05$), which significantly affected postoperative BCVA.

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