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Latin American Journal of Ophthalmology

Retina *Case Series*

Long-term Post-operative perfusion outcomes in giant retinal tears treated with and without scleral buckling

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Received : 04 June 2022
Accepted : 13 July 2022
Published : 08 August 2022

DOI
10.25259/LAJO_2_2022

Quick Response Code:

ABSTRACT

Limited data are available on the long-term perfusional status of patients who have undergone successful surgery for giant retinal tear (GRT) macula-off rhegmatogenous retinal detachment (RRD). This study examines the long-term outcomes in eyes treated for varying degrees of GRT-associated RRD extensions and compared them with two control groups. Twenty-five emmetropic normal eyes (control emmetropic), 20 healthy myopic eyes (control myopic), and 33 eyes surgically treated for GRT (surgical) were included in this study for a comparison of long-term structural, perfusional, and functional outcomes. The surgical eyes were categorized based on degree of GRT-associated RRD extension: 19 eyes with GRT-associated RRD extension <180° and 14 eyes with extension >180°. The eyes were further separated by whether they required placement of a complementary 360° scleral buckle. The mean age of the patients was 55.18 years and the mean pre-operative evolution of GRT was 2.36 weeks. The average pre- and post-operative best-corrected visual acuities (BCVAs) were 1.90 logMAR and 0.59 logMAR, respectively, which were different with statistical significance. Proliferative vitreoretinopathy resulted in multiple surgeries in nine eyes (27.3%). Long-term post-operative optical coherence tomography (OCT) showed 11 eyes (33.3%) with abnormal foveal contour, 13 eyes (39.4%) with ellipsoid zone disruption, two eyes with dissociated optic nerve fiber layer defects, and 15 eyes (45.4%) with external limiting membrane line discontinuities. OCT angiography yielded abnormal perfusion indices in the surgically treated eyes ($P < 0.0001$). Correlation analysis found that post-surgical BCVA was negatively correlated with superficial foveal avascular zone area, superficial parafoveal vessel density, and central subfoveal thickness, while positively correlated with choriocapillaris flow area. Our data showed that eyes with GRT-associated RRD have multiple structural alterations in spectral-domain OCT biomarkers that are correlated with visual outcomes. Despite successful retina reattachment without proliferation, management of GRT-associated RRD remains challenging.

Keywords: Deep vascular plexus, Giant retinal tears, Rhegmatogenous retinal detachment, Post-operative perfusion indices, Choriocapillaris subfoveal plexus, Superficial vascular plexus, Vessel density

INTRODUCTION

Rhegmatogenous retinal detachment (RRD) associated with giant retinal tears (GRTs) is a rare condition associated with potentially significant visual impairment from retinal detachment (RD).[1] This condition is an acute-onset, tractional incident involving pathological contraction at the bed of a normal or predisposed retina and vitreous that lead to a full-thickness circumferential retinal tear of at least 90° associated with vitreous detachment.[2,3] In addition, proliferative vitreoretinopathy (PVR) occurs frequently and is a result of the release of retinal pigment epithelial (RPE) cells and fibrous metaplasia (RPE cell dispersion), elevated levels of pro-inflammatory factors and cytokines, and inflammatory deterioration of the retina-blood barrier.[1] The annual incidence of GRT is estimated to be between 0.05% and 0.09% of the general population and represents 1.5% of all RRD cases.[2-7] GRT predominantly affects males (72% of patients), with an average age of 42 years at diagnosis.[3,6]

The development of GRT is associated with combined occurrences of dynamic vitreous traction and contraction, as well as retinal abnormalities.[3] Tears in GRT occur acutely at different degrees, which are dependent on the condition of the eye.[8] The presence of multiple horseshoe tears at the posterior border of the vitreous base (as caused by acute vitreous contractions) may also be a contributor to the formation of GRTs.

Multiple risk factors are associated with these pathologic changes, including local and systemic risk factors and other unknown or secondary conditions.[2,3,8-10] A large epidemiological study conducted in 2010 in the United Kingdom found that more than 55% of GRT cases are idiopathic. Other studies found that GRT is associated with several ocular and systemic conditions: 25% of cases with myopia, 14% of cases with hereditary conditions, such as Type 2 collagen synthesis defects (e.g., Marfan's, Stickler-Wagner, and Ehlers-Danlos syndromes), and 12.3% of cases from closed-eye blunt trauma.[2,3,8-10] Additional risk factors include high myopia, blunt trauma, aphakia, and pseudophakia.[2,3,8-10] Other less common conditions that have been found to be associated with GRT include lens coloboma, microspherophakia, aniridia, retinitis pigmentosa, and endogenous endophthalmitis.[11]

Previously, the success rate after the initial surgery for GRT was quantified to be between 80% and 90%, whereas the final reattachment rate after multiple interventions was between 94% and 100%.[12,13] Despite these high success rates, GRT is very difficult to manage due to the potential development of both intra- and post-operative complications. Furthermore, additional histopathological abnormalities may occur during surgery, which could lead to disruption of the blood supply to the anterior eye segment.[14-17]

This study aims to quantitatively evaluate the long-term post-operative vasculature perfusion indices (retinal and choroidal) using optical coherence tomography (OCT) angiography in 33 eyes with GRT-associated RRD that underwent vitrectomy with or without scleral buckling surgery. We contrasted macular microcirculation indices in normal emmetropic [Figure 1a-i], normal healthy myopic [Figure 1j-r], and eyes with GRT macula-off RRD that resolved completely after vitrectomy surgery with and without complementary scleral buckling procedure. This report expands on a preprint of a previous preliminary case report that included three eyes with GRT-associated RRD.[18]

Findings from this study may lead to improved vitrectomy techniques and a reduction in probable deleterious effects of scleral buckling on retinal and choroidal perfusion.

MATERIALS AND METHODS

Study design

This study abides by the tenets of the Declaration of Helsinki and was approved by the ethics and teaching committees of the enrolled institution. Written informed consent was obtained from all patients in accordance with institutional guidelines.

Data from 25 normal emmetropic eyes and 20 normal myopic eyes were included as normal control eyes. Patients with GRT-associated RRD who underwent pars plana vitrectomy (PPV) techniques with or without 360° scleral buckling were selected to undergo post-operative perfusion evaluation. The collected perfusion indices were compared according to surgical technique and correlated with structural and functional outcomes.

Patients from a previous publication Quiroz-Reyes *et al.*[19] who met the following inclusion criteria were included in the surgical cohort: Age ≥18 years, the presence of GRT-associated RRD, evidence of PVR of Grade B or less, retinal attachment at the last follow-up examination visit, and a well-documented long-term structural and functional evaluation during follow-up, with an additional long-term perfusion assessment of the macula at the last follow-up visit. Only eyes with retinas that were successfully reattached without intraocular silicon for at least 6 months after the last vitreoretinal surgical procedure were included in the study.

The exclusion criteria included any patients with prior surgical complications (e.g., intravitreal injections or vitreoretinal surgery), previous GRT-associated RRD (e.g., due to open eye injuries), or previous GRT-associated RRD with retinal detachment associated macular holes in myopic traction maculopathy. Patients with PVR (posterior or anterior) with recurrent RRD, active glaucoma, or the presence of intraocular silicone oil during the final evaluation were also excluded from the study. Furthermore, patients who could not maintain the follow-up procedures or those with severe complications (e.g., endophthalmitis, complicated and severe PVR, recurrent disease, or refractory corneal opacities) were excluded from the study.[19]

Patients diagnosed with GRT-associated RRD treated between January 2015 and May 2021 were included in the study. Only eyes with fully attached retinas and functional

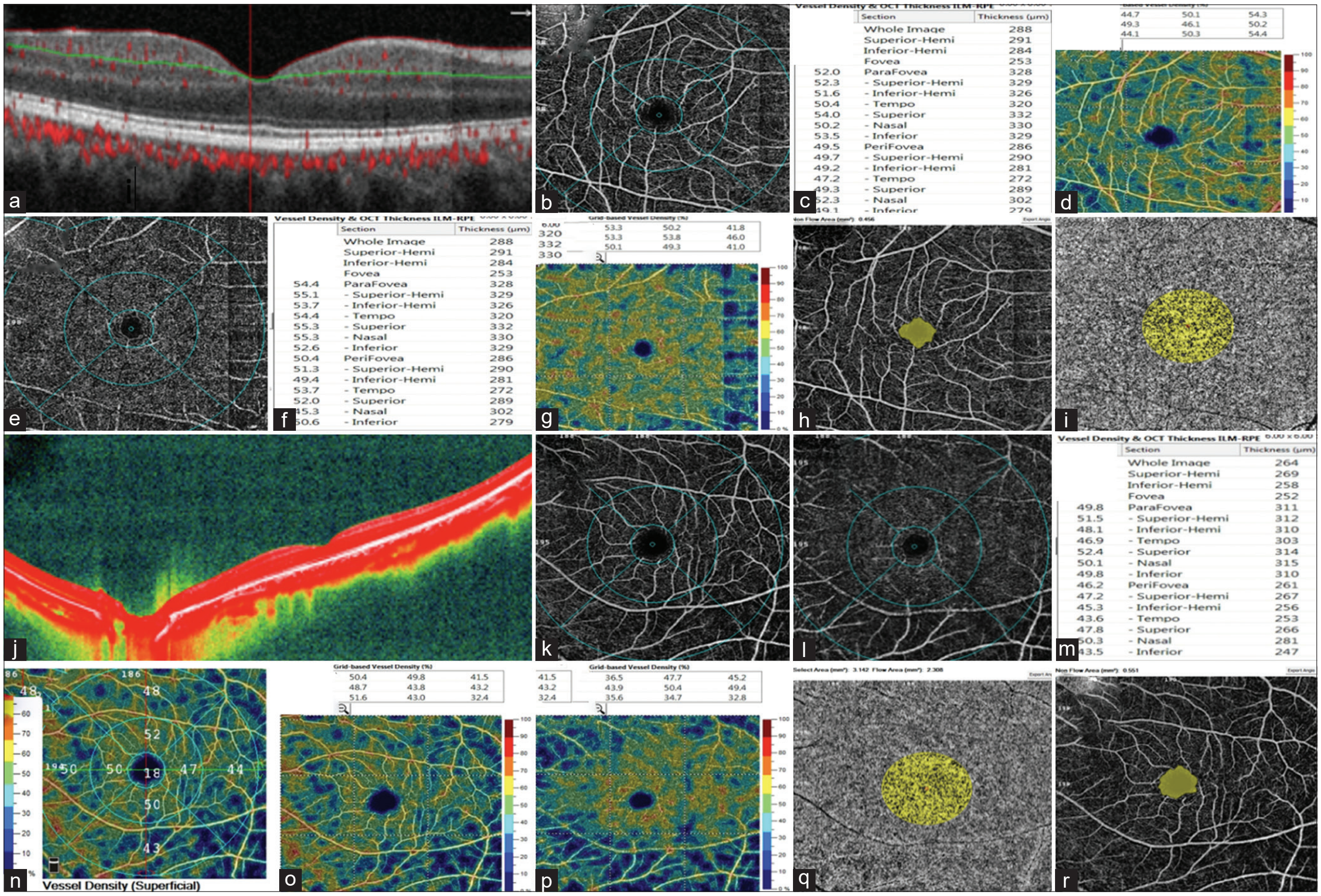

Figure 1: Control normal eyes. (a) Horizontal B-scan of a normal emmetropic eye with automated red and green segmentation lines. The red dots indicate the choriocapillaris flow. (b) Normal superficial vascular plexus (SVP) slab with the ETDRS-like sector grid overlay. (c) Superficial perfusion indices and retinal thickness at different macular subregions. (d) The color overlays on the optical coherence tomography angiography (OCTA) image indicate a normal vessel density (VD) value in the key to the right, and normal superficial perfusion indices are depicted above the image. (e) Normal values in a normal deep vascular plexus (DVP). (f) Deep perfusion indices and retinal thickness at different macular subregions. (g) The color overlays on the OCTA image indicate a normal VD value in the key to the right, and normal deep perfusion indices are depicted above the image. (h) A normal foveal avascular zone (FAZ) area of 0.456 mm^2. (i) A normal choriocapillaris flow area at the selected subfoveal choriocapillaris area of 3.142 mm^2. (j) A high-definition 12 mm horizontal B-scan of a normal myopic eye in a brighter color. (k) Corresponding normal SVP slab. (l) A normal DVP slab in a myopic eye. (m) Normal perfusion indices with corresponding retinal thickness values at the different macula subregions. (n) VD at the SVP slab in a normal myopic eye. The color overlays on the OCTA image indicate a normal VD value in the key to the left. (o and p) Images of the corresponding superficial and deep perfusion indices with different normal values as indicated above the images. (q) A normal choriocapillaris flow of 2.308 mm^2 at the selected subfoveal choriocapillaris area of 3.142 mm^2. (r) A normal, regular FAZ area of 0.561 mm^2.

vision on the last post-operative evaluation were included in the study, regardless of the number of prior surgical procedures that were needed. This led to the inclusion of 33 selected eyes from 27 patients who were categorized based on the circumferential size of the GRT.

Examinations

A detailed pre-operative eye examination was carried out for all included participants, which included visual acuity evaluation, fundoscopy, slit-lamp examination, and indirect ophthalmoscopy. The examination protocols used were previously reported in Quiroz-Reyes *et al*.[19] Briefly, Spectralis OCT (Heidelberg Engineering, Heidelberg, Germany) or, in some cases, spectral-domain OCT (SD-OCT) (Optovue Inc., Fremont, CA, USA; RTVue-XR platform SD-OCT) was used to collect cross-sectional images of the macular region through the foveal center along the horizontal plane. Partial coherence laser interferometry (Zeiss IOL Master 700; Carl Zeiss Meditec AG, Oberkochen, Germany) was used to measure the axial length.

Indirect ophthalmoscopy and B-scan ultrasonography (A and B Ultrasound Unit, Quantel Medical, Du Bois Loli, Auvergne, France) were used to identify GRT-associated RRD. SD-OCT Spectralis OCT and RTVue-XR platform SD-OCT were used to perform the post-operative microstructural evaluation. The following structural and perfusional measurements were statistically analyzed among the study groups: Long-term post-operative structural SD-OCT findings, central subfoveal ellipsoid zone (EZ) structure, foveal contour profile, integrity of the central subfoveal external limiting membrane (ELM) line, the presence of dissociated optic nerve fiber layer (DONFL) defects measured by en-face imaging or cross-sectional SD-OCT B-scan, and the existence of epiretinal membrane (ERM) proliferation in the macular region. Post-operative macular perfusion indices that were evaluated included the vessel density (VD) at the superficial vascular plexus (SVP), foveal avascular zone (FAZ), deep vascular plexus (DVP), and choriocapillaris subfoveal plexus (CSP).

Post-operative perfusion, VD, and choroidal flow evaluations were obtained with an OCT angiography device (RTVue XR OCT Avanti with AngioVue Software; OptoVue Inc., Fremont, CA, USA). Details of the equipment can be found in Quiroz-Reyes *et al*.[20] Default settings were used for retinal imaging, while the built-in projection artifact removal tools were employed for image adjustment and segmentation. The AngioVue software was used to perform segmentation of the DVP, SVP, outer retinal layer, and CSP slices. Scan quality was quantified through the standard signal strength index (SSI) of the AngioVue, wherein only scans with an SSI >46 were included in the study.

Image analysis in this study was performed following a previously published protocol in Quiroz-Reyes *et al*.[20] Briefly, the FAZ area in the SVP slice and VD values was quantitatively determined using the AngioVue system.[21,22] All evaluations and images were independently analyzed by three retina specialists (coauthors) at the participating institutions.

Surgical technique

The surgical techniques that were performed in this study have been previously described in detail in Quiroz-Reyes *et al*.[19] Briefly, a standard 25-gauge 3-port PPV (Alcon Constellation Vision System, Alcon Labs, Fort Worth, TX, USA) was performed using a wide-angle viewing system or contact wide-angle viewing pre-corneal lens system (ROLS reinverted system; Volk Medilex, Miami, FL, USA) with a Resight non-contact lens (Carl Zeiss Meditec AG, Jena Germany). Beyond central vitrectomy, diluted triamcinolone acetonide adjuvant (Kenalog 40 mg/mL; Bristol-Myers Squibb, New York, NY, USA) was used to enhance visualization of the vitreous base and face, and its posterior border. Next, the cortical face was removed from the surface of the retina using a silicone-tipped cannula with active suction followed by perfluorocarbon liquid (PFCL) infusion and retinal reattachment.

Subretinal fluid (SRF) endodrainage was performed as described previously. Briefly, endodrainage was gradually completed by first implementing an air-to-fluid exchange over the edge of the GRT to circumvent posterior retinal slippage followed by an air-fluid exchange and SRF drainage. Continuous argon laser endophotocoagulation was performed after the retina was fully reattached. After the retina was fully reattached by vitrectomy techniques and laser retinopexy to avoid posterior retinal slippage or radial folds, some eyes received a complementary low lying scleral buckle (SB) surgical procedure based on the surgeon's judgment and the selected technique. A non-expandable bubble with 15% perfluoropropane (C_3F_8) gas mixture was used as a long-acting tamponade at the end of the procedure, as previously described in Quiroz-Reyes *et al*.[19]

Statistical analysis

All of the statistical analyses were performed using the software GraphPad Prism version 9.2.0 with statistical significance set at $P < 0.05$. The Wilcoxon matched signed-rank test was used to compare paired pre-operative and post-operative best-corrected visual acuity (BCVA) values (in logMAR) in the surgical group. The Mann–Whitney U-test was used to compare BCVA values in non-paired comparisons of BCVA values. The Kruskal–Wallis test with a Benjamini and Hochberg correction was used to test for significant differences in perfusion indices between groups. Non-parametric tests were used, as the normality of distribution tests showed that data were not normally distributed. Fisher's exact test was used to test for differences in proportion of abnormal SD-OCT findings between GRT groups. Spearman's rank-order correlation test was employed to correlate perfusion indices across groups with the final visual outcome.

RESULTS

Characteristics of eyes

Twenty-seven patients diagnosed with GRT-associated RRD and surgically managed between January 2015 and May 2021 were included in the study. All eyes in the surgical group had a fully attached retina without intraocular silicon and functional vision on the last post-operative evaluation (minimum of 6 months of follow-up), regardless of the number of surgical procedures needed. Thirty-three eyes from 27 patients were included and categorized according to the circumferential size of the GRT. Nineteen eyes had RRD associated with circumferential retinal tears of <180°, and 14 eyes had circumferential retinal tears >180°. Twenty-five normal emmetropic eyes and 20 normal myopic eyes were included as normal control eyes. Patient demographic data and pre-operative clinical observations are summarized in [Table 1].

Table 1: Patient demographic data and pre-operative clinical characteristics.

Study groups	N	Mean age	Mean pre-operative BCVA (logMAR)	Mean axial length (mm)	Mean post-operative follow-up (months)
Control emmetropic	25	49.32	-0.0024	20.53	-
Control myopic	20	59.65	0.047	29.45	-
Surgical	33	55.18	1.90	26.21	28.17
GRT<180°	19	48.74	1.88	27.45	26.5
GRT>180°	14	63.93	1.92	24.53	30.23

GRT: Giant retinal tear, BCVA: Best-corrected visual acuity

General surgical outcomes

In the surgical group, PVR was found with similar frequency in both eyes with GRT-associated RRD extensions <180° (*n* = 5, 26%) and >180° (*n* = 4, 29%). The mean post-operative follow-up period was 28.17 months. Post-operative BCVA (0.59 logMAR) was statistically better than the pre-operative BCVA (1.90 logMAR) in all of the surgical eyes ($P < 0.001$) [Table 2]. The post-operative BCVA values in the surgically treated groups were significantly worse than those in the emmetropic control group ($P < 0.0001$). Pre-operative and final post-operative BCVA values, as stratified by the degree of GRT-associated RRD extension, showed that the final visual acuity was significantly better in both categories. No significant differences in final BCVA were found between eyes with GRT-associated RRD extension <180° and > 180° ($P = 0.11$).

Table 2: Comparison between pre-operative and final post-operative BCVA.

Surgical eyes	Mean pre-surgical BCVA (logMAR)	Mean final BCVA (logMAR)	*P*
All surgical eyes	1.90	0.59	<0.001
GRT <180°	1.88	0.56	<0.0001
GRT >180°	1.92	0.63	<0.0001

GRT: Giant retinal tear

Structural analysis among eyes

The terminology proposed in the International Nomenclature for OCT Panel Report[23] was adapted to categorize abnormal post-operative SD-OCT structural findings [Table 3]. SD-OCT analysis was performed by two masked retina specialists, where a third specialist was involved in case of disagreement. Within the surgical group, 33.3% of eyes had foveal contour abnormalities, 39.4% of eyes had EZ disruption, 6.06% of eyes showed the presence of DONFL, and 45.4% of eyes had ELM line disruptions. With the exception of ELM line ($P = 0.033$), differences between GRT groups were not statistically significant ($P > 0.05$).

Table 3: Abnormal SD-OCT findings in the surgical group.

	Surgical, *n*=33	GRT<180°, *n*=19	GRT>180°, *n*=14	*P*-value
Foveal contour				0.707
Normal	22 (66.6%)	14	8	
Abnormal	11 (33.3%)	5	6	
Ellipsoid zone				0.273
Normal	20 (60.6%)	14	7	
Disrupted	13 (39.4%)	5	7	
DONFL defects				0.172
Absent	31 (93.9%)	19	12	
Present	2 (6.06%)	-	2	
ELM line				0.033
Normal	18 (54.6%)	7	11	
Disrupted	15 (45.4%)	12	3	

DONFL: Dissociated optic nerve fiber layer, ELM: External limiting membrane

Perfusion analysis

The long-term OCT angiography macular perfusion indices were assessed at the last patient visit. The eyes were separated into two groups by whether GRT extension was less than or more than 180° to facilitate comparative analysis. The eyes were then further separated by whether the buckling procedure was used. The statistical analysis showed that the mean superficial FAZ area in the control emmetropic eye was significantly smaller than that in the other eye groups ($P < 0.0001$) [Table 4]. In superficial and deep foveal VD indices, only eyes with buckled surgery and GRT <180° showed significantly less deep foveal VD than emmetropic eyes ($P = 0.04$). All of the groups except eyes with buckled surgery and GRT >180° had lower superficial parafoveal VD than emmetropic eyes ($P < 0.05$). For deep parafoveal VD, all of the surgical groups (except for eyes with non-buckled surgery and GRT >180°) had lower VD values ($P < 0.01$). In addition, all of the groups showed lower superficial and deep whole macula VD than the emmetropic group, except for eyes with non-buckled surgery and GRT >180° in the superficial whole macula VD index. Choriocapillaris flow area was smaller in all of the groups, except for eyes with non-buckled surgery and GRT <180°, wherein the small sample size may not be sufficient for detecting a difference. All of the surgical groups had significantly shorter CSFT compared to the emmetropic group.

The correlation analysis showed that among all of the surgical eyes, final BCVA was negatively correlated with superficial FAZ area and superficial parafoveal VD, and it was positively correlated with choriocapillaris flow area [Table 5]. When eyes were grouped by GRT extension status, BCVA in eyes with GRT >180° was negatively correlated with both superficial FAZ area and CSFT. When eyes were grouped by whether the buckled procedure was used, the BCVA of patients without the procedure was negatively correlated with CSFT, whereas the BCVA of patients with the procedure was positively correlated with choriocapillaris flow area.

Representative surgical cases

Surgical case 1

A 55-year-old phakic and symptomatic woman presented with the complaints of metamorphopsia and sudden visual loss in her right eye. The vision loss occurred over a period of 7 days. The pre-operative right eye visual acuity was 20/2000 (logMAR 02.00), with a refractive error of −2.00+1.25 × 10 and axial length of 22.54 mm, as well as an ocular tension by applanation tonometry of 10 mmHg. Evaluation of the fundus showed a total detachment of the retina due to a giant tear from meridian VIII to meridian I, with clear media, vitreous liquefaction, and a large amount of pigment granules. The tear bent in on itself, allowing us to observe a large amount of SRF beneath the macula [Figure 2a]. Multiple areas of thinning were detected in the retina with some liquid sockets and areas

Table 4: Functional, structural, and quantitative evaluations across study eyes.

Study groups	Superficial FAZ area (mm^2)	Superficial foveal VD (%)	Deep foveal VD (%)	Superficial parafoveal VD (%)	Deep parafoveal VD (%)	Superficial whole macula VD (%)	Deep whole macula VD (%)	Flow area (mm^2) at choriocapillaris subfoveal plexus	CSFT (μm)
Control emmetropic eyes	0.3386	27.17	31.39	58.76	56.08	56.93	58.50	2.514	246.4
Control myopia eyes	0.6470*	27.57	32.11	55.24*	54.98	46.35*	48.55*	2.252*	264.9
Surgically treated eyes									
Non-buckled GRT <180°	0.7008*	28.64	35.44	36.42*	46.52*	46.62*	43.86*	2.247	188.0*
Buckled GRT <180°	0.7749*	25.64	27.59*	43.91*	43.06*	42.23*	40.82*	1.548*	213.1*
Non-buckled GRT >180°	0.7076*	25.81	29.46	52.16*	53.17	51.83	51.82*	1.958*	178.3*
Buckled GRT >180°	1.143*	25.38	29.08	55.62	47.52*	47.82*	47.76*	1.123*	193.6*

*Indicates where data differed significantly (*P*<0.05) from the control emmetropic eyes. FAZ: Foveal avascular zone, VD: Vessel density, CSFT: Central subfoveal thickness.

Table 5: Correlation of the final visual outcome with the perfusion indices in surgical eyes.

Groups	Superficial FAZ area	Superficial foveal VD	Deep foveal VD	Superficial parafoveal VD	Deep parafoveal VD	Superficial whole macula VD	Deep whole macula VD	Flow area (mm^2) at choriocapillaris subfoveal plexus	CSFT
All eyes	0.3488*	0.01039	−0.03188	0.402*	0.05186	0.02727	0.0541	−0.3827*	0.2964
GRT <180°	0.08462	0.06173	−0.1025	0.2440	0.07171	−0.1712	−0.3074	−0.3950	0.3416
GRT >180°	0.6012*	−0.006814	0.2884	0.4929	−0.4379	−0.4106	−0.2654	−0.4424	0.7551*
Non-buckled	0.3756	0.01550	0.1188	0.2638	0.04754	0.1999	0.1331	0.1526	0.5563*
Buckled	0.2704	0.1269	0.1843	0.4345	0.3935	0.2158	0.2585	−0.6352*	0.03813

*Indicates a positive correlation with the final BCVA was observed (*P*<0.05). Spearman correlation coefficients are shown in the table. FAZ: Foveal avascular zone, VD: Vessel density, CSFT: Central subfoveal thickness

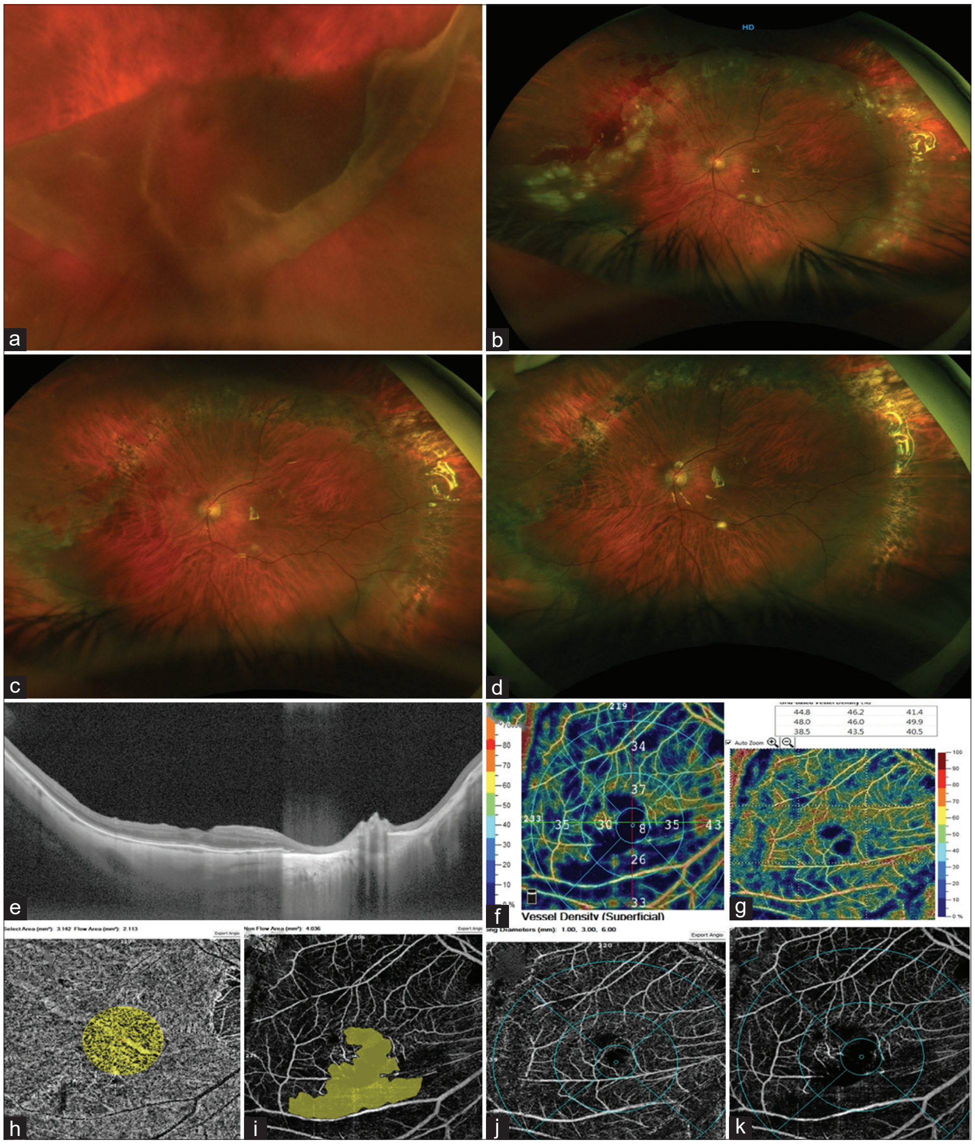

Figure 2: Surgical case 1. (a) Image showing the fundus of a 55-year-old phakic and symptomatic woman presenting with the complaints of metamorphopsia and sudden visual loss in her right eye. The visual loss occurred for 7 days. The image shows total retinal detachment due to a giant tear extending from meridians IX to I (the clinical image “a” corresponds to Figure 2j and is adopted from a previous publication[18]). (b) A 7-day post-operative image with laser treatment. (c) A 3-week post-operative image, in which a low lying 360° scleral buckle is observed. (d) Six-month post-operative image with the retina totally attached and the low lying scleral buckle in the equatorial position. (e) Post-operative high-definition 12 mm horizontal B-scan image. Spectral-domain optical coherence tomography biomarkers are noted, such as an irregular foveal contour and internal and external neuroretinal lines without total restoration of the central subfoveal ellipsoid zone or the external limiting membrane line. (f) The color overlays on the optical coherence tomography angiography (OCTA) image indicate abnormal superficial vessel density (VD) values with an early treatment diabetic retinopathy study-like sector grid overlay according to the values in the key to the left. (g) The color overlays on the OCTA image indicate a normal deep VD value according to the above numbers. (h) Choriocapillaris flow area of 2.113 mm^2 at the selected subfoveal choriocapillaris area of 3.142 mm^2. (i) Enlarged irregular non-flow tissue corresponding to a foveal avascular zone (FAZ) area of 4.036 mm^2. (k) Enlarged irregular non-flow tissue corresponding to an FAZ area of 4.036 mm^2. (j) Deep vascular plexus slab with better perfusion indices as compared with the superficial vascular plexus. (k) Superficial vascular plexus showing certain vascular deficiencies of the perfusion indices.

of vitreoretinal traction. The patient underwent uneventful gas vitrectomy with no scleral cerclage installation and 15% C_3F_8 gas injection. The evolution was satisfactory [Figure 2b]; the retina stayed attached, and visual acuity recovered in a satisfactory way [Figure 2c and d]. At 18 months of follow-up, the final BCVA was 20/60 (logMAR 0.48). Several SD-OCT biomarkers were noted, such as an irregular foveal contour and internal and external neuroretina lines without total restoration of the central subfoveal ellipsoid, such as at the EZ and the ELM lines [Figure 2e]. The long-term post-operative perfusion evaluation was abnormal, with lower-than-normal perfusion indices on the SVP [Figure 2f]. The perfusion indices were quantified and considered to be lower than normal [Figure 2g]. The choriocapillaris flow area was measured as approximately 2.113 mm^2 [Figure 2h] with an enlarged and irregular FAZ area of 4.036 mm^2 [Figure 2i]. The corresponding DVP and SVP are shown [Figure 2j and k].

Surgical case 2

A 52-year-old phakic and symptomatic woman presented with the complaints of aggravating metamorphopsia and entopic phenomena; these symptoms were accompanied by a progressive and rapid drop in central vision and high myopia. The right eye with an axial length of 26.38 mm and a GRT macula-off associated RRD of 100° extension over the temporal and superior quadrants [Figure 3a] underwent uneventful gas vitrectomy surgery [Figure 3b]. The pre-operative BCVA was measured at 20/800 (logMAR 1.60). We performed a three-port 25-G PPV and perfluorocarbon liquid-assisted technique to flatten the retina and endodrain the SRF/[Figure 3c]. Fluid-air gas exchange was performed with 15% C_3F_8 tamponade. After a 26-month longitudinal follow-up, the operated eye showed a post-operative BCVA of 20/40 (logMAR 0.30) [Figure 3d]. The post-operative perfusion indices at the DVP [Figure 3e] were considered below the mean with no evidence of ERM proliferation. The post-operative quantified perfusion indices at the different subregions of the macula along with the retinal thickness were lower than normal [Figure 3f]. Color overlays on the OCTA angiography images indicated superficial [Figure 3g] and deep [Figure 3h] quantified VD values at the different subregions of the macula, according to the color keys to the right and above the panels, which were considered to be lower than the mean. The long-term high-definition 12 mm structural B-scan evaluation exhibited an irregular foveal profile with well-recognized outer retina biomarkers [Figure 3i and j]. The SVP showed some deficiencies on the flow at the different subregions of the macula, according to the ETDRS grid overlay [Figure 3k].

Surgical case 3

A 39-year-old man with 2 days of a sudden decrease in vision with metamorphopsia, high myopia, and severe PS presented to our institute and was diagnosed by the genetic unit with a familial condition consistent with Stickler's syndrome. A diagnosis of a GRT-associated RRD extension of more than 270° was made [Figure 4a and b]. The pre-operative BCVA was 20/2000 or counting fingers at 2 feet (logMAR 2.00), with PS and an axial length of 30.10 mm. The right phakic eye underwent 25-G three-port pars plana gas vitrectomy [Figure 4b-d]. Because of recurrent and complicated PVR RRD, this eye underwent a second surgical procedure consistent with vitrectomy revision and macular surgery consisting of a BBG dye assisted, ERM/ILM peeling *en bloc* removal technique, and silicon oil injection. Lighter-than-water silicon oil was uneventfully removed 4 months later. After a 15-month follow-up, the final post-operative BCVA was 20/80 (logMAR 0.60), and the eye showed an SD-OCT pattern consistent with an abnormal macular profile and the presence of abnormal biomarkers, such as inner and outer retina SD-OCT layers and abnormal subfoveal EZ and ELM line discontinuities with a well-preserved RPE layer in the 12 mm high-definition SD-OCT evaluation [Figure 4e and f]. The en-face aspect depicted multiple deep defects at the level of the RPE with a very abnormal perfusion evaluation on the SVP slab [Figure 4g] with better but deficient perfusion evaluation on the DVP slab [Figure 4h]. The superficial perfusion indices and corresponding retinal thickness values at different subregions of the retina were lower than normal [Figure 4i]. Color overlays on the OCTA angiography images indicated lower-than-normal superficial [Figure 4i] and deep [Figure 4j] quantified VD values at the different subregions of the macula, according to the color key to the right of the corresponding panels, and the VD percentage of the perfusion indices, which is seen above the panels, was considered to be lower than normal [Figure 4j]. The choriocapillaris flow was very deficient, with 1.366 mm^2 of flow from a selected area of 3.142 mm^2 [Figure 4k]. The last post-operative long-term structural cross-line SD-OCT B-scan evaluation showed an irregular foveal profile and irregular diffuse retinal thinning over the temporal and inferior sides of the macula in both horizontal and vertical B-scans, respectively, and evidence of DONFL defects and irregularities of the outer retina layer biomarkers [Figure 4l and m]. The FAZ area appeared irregular and enlarged, measuring 9.657 mm^2 [Figure 4n].

DISCUSSION

The question as to whether the addition of an encircling SB to vitrectomy in cases of GRT-associated RRD is beneficial is still controversial.[24,25] Some surgeons believe buckling to be an integral part of the surgical intervention since it relieves the tractional forces at the boundary of the tear and provides support to the vitreous base.[28] Recently, some consensus appeared to be forming that SB should be used for GRTs <180°, especially when there is no presence of retinal folding

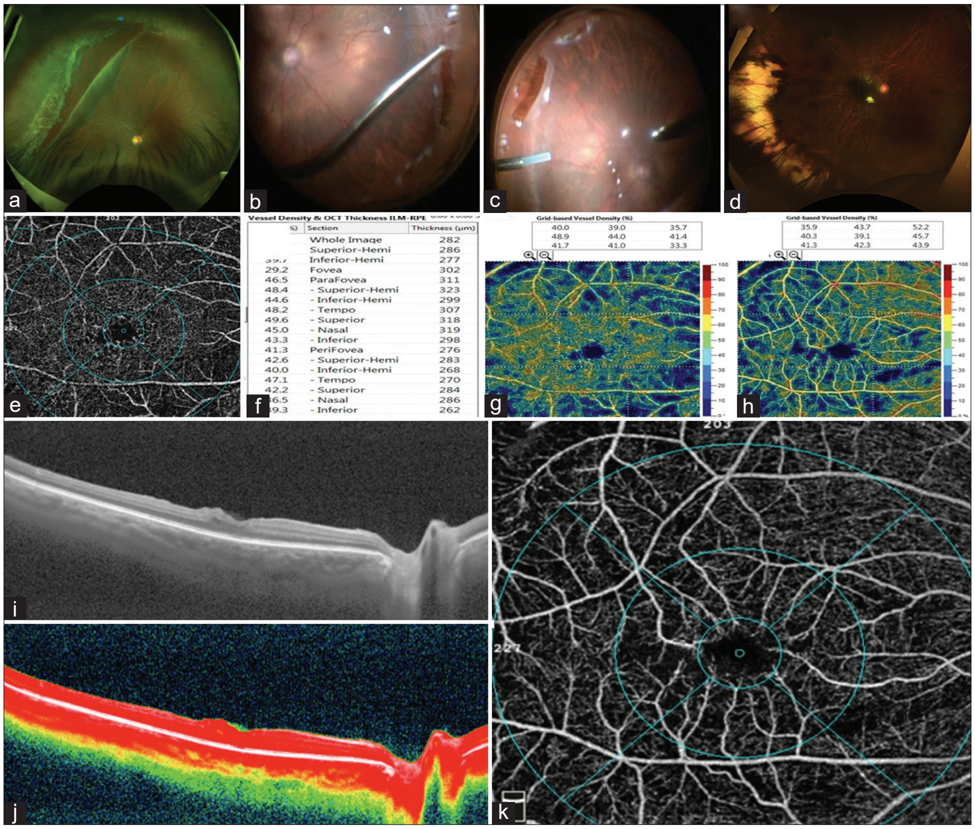

Figure 3: Surgical case 2. (a). Image showing the fundus of a 52-year-old phakic and symptomatic myopic woman who presented with complaints of aggravating metamorphopsia and entopic phenomena, which were accompanied by a progressive and rapid decrease in central vision. The right eye presented with an axial length of 26.38 mm and giant retinal tear-associated macula-off rhegmatogenous retinal detachment extension of 100° over the temporal and superior quadrants; she underwent uneventful gas vitrectomy surgery. (b and c) Surgical images of the corresponding eye. (d) Fundus at the 26 months of follow-up; the operated eye showed a postoperative best-corrected visual acuity (of 20/40 (logMAR 0.30). (e) Corresponding deep vascular plexus slab with vascular perfusion deficiencies. (f) Different values of the deep perfusion indices and retinal thickness at different subregions of the macula. (g and h) Color overlays on the optical coherence tomography angiography images indicate superficial and deep vessel density values according to the key to the right; the quantified perfusion indices in different subregions of the macula are depicted above. (i and j) Images depicting a high-definition horizontal spectral domain optical coherence tomography B-scan with an irregular foveal profile and diffuse retinal thinning; the outer retina biomarkers are identifiable. (k) Corresponding superficial vascular plexus slab with perfusion indices between the normal ranges.

or PVD. However, other surgeons have suggested that the abnormal vitreous base and reduced support of tractional forces could lead to breakage and GRT development.[26-28] Furthermore, buckling may not be appropriate as vitreous traction appears to be more common with GRT >180°, which may lead to unnecessary complications.

To evaluate the effects of buckling, this control–case series included GRT-associated RRD eyes that underwent PPV techniques with or without scleral buckling placement procedures. In these cases, we avoided certain surgical maneuvers that were previously associated with harmful histopathological consequences.[24,25] Our analysis included evaluations of long-term perfusion, as has been previously described.[29] Perfusion was measured since sustained VD can improve visual function and prevent further deterioration of vision.[30] Lower VD has also been documented in multiple retinal diseases, including macular telangiectasia, diabetic retinopathy, and radiation retinopathy.[24,31-33] In addition, quantitative perfusion indices obtained from OCT-A can reliably detect variation in post-operative structural outcomes. Our analysis of post-operative perfusion findings suggests that perfusion (both retinal and choroidal) was

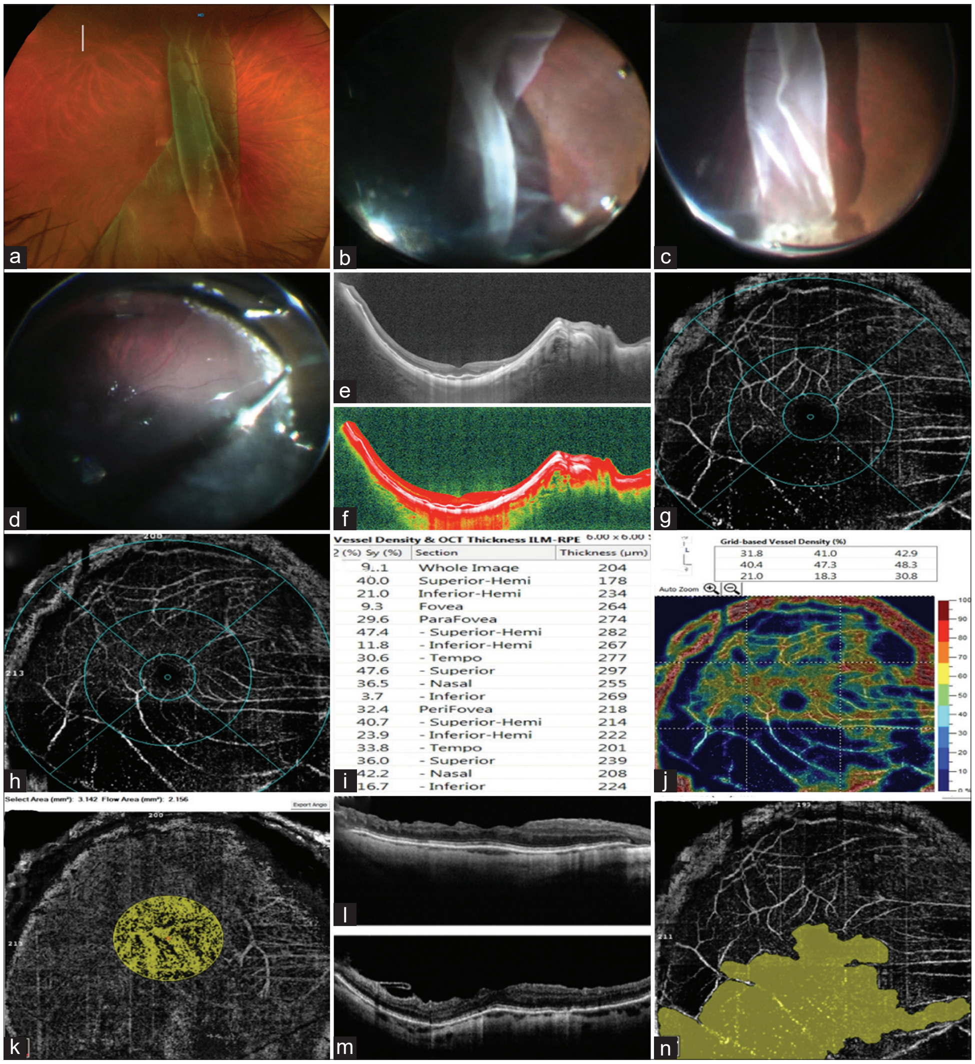

Figure 4: Surgical case 3. (a) A pre-operative photo of a 39-year-old man with a sudden decrease in vision with metamorphopsia and high myopia for 2 days. The patient was diagnosed with familial Stickler's syndrome by the genetic unit. The diagnosis of a giant retinal tear-associated rhegmatogenous retinal detachment extension of more than 270° was made. Counting fingers at 2 feet led to the designation of a visual acuity of 20/2000 during the pre-operative best-corrected visual acuity assessment (logMAR 2.00), with posterior staphyloma and an axial length of 30.10 mm (clinical images "a" to "d" correspond to Figure 2b and c, respectively, and are adopted from a clinical case of previous publication[18]). b, c and d corresponding surgical images. (e and f) Images after a 15-month follow-up showing a spectral domain optical coherence tomography (SD-OCT) pattern consistent with an abnormal macular profile and the presence of abnormal biomarkers, such as inner and irregular outer retina SD-OCT layers, an abnormal subfoveal ellipsoid zone, and external limiting membrane line discontinuities with a well-preserved retinal pigment epithelium layer. (g and h) The superficial and deep vascular plexuses with an ETDRS-like sector grid overlay. (i) Different perfusion index values and corresponding retinal thicknesses in different subregions of the macula. (j) Color overlays in the optical coherence tomography angiography images indicative of superficial and deep vessel density values, according to the key to the right; the quantified perfusion indices on the different subregions of the macula are depicted above. (k) A choriocapillaris flow area of 2.156 mm^2 at the selected subfoveal choriocapillaris area of 3.142 mm^2. (l and m) Long-term, post-operative cross-line images depicting dissociated optic nerve fiber layer defects, irregular foveal contour, irregularities in the EZ, and some extrafoveal remnants of the internal limiting membrane. (n) A highly abnormal, enlarged, and irregular foveal avascular non-perfused area of 9.657 mm^2.

reduced at the end of the control-perfusion vitrectomy technique, which was more significant in the buckled eyes. In particular, the choriocapillaris flow area was significantly reduced in buckled eyes compared to non-buckled eyes.

This report, which was based on a case series analysis, also supports the view that microcirculation plays an important role in the post-operative visual recovery. We found that perfusion was generally reduced in the surgery group, thus indicating that a causal relationship may exist between perfusion mechanisms and the limited visual recovery in GRT-associated RRD.[19] Notably, Christou *et al*. also observed the same pattern,[34] which suggests that post-operative perfusion deficiencies may explain the suboptimal visual recovery. Furthermore, the final post-operative BCVA was found to be correlated with the superficial FAZ area, superficial parafoveal VD, and choriocapillaris flow area, thus reinforcing the view that perfusion likely plays a role in visual function. Thus, care should be taken to preserve choroidal perfusion during surgery, such as by reducing compression of the choroid during buckling procedures.[34]

It is worth pointing out that the control-perfusion vitrectomy technique is important for both improving the state of the eye and for the intraoperative assessment of the microcirculation. In our cases, early intervention reduces future damage to the eye. In addition, eyes with GRT <180° had fewer surgical complications, compared to eyes with GRT >180°. As a result, surgery should be performed quickly to prevent irreversible visual loss.

In our surgical protocol, a 360° endolaser was not used, even for GRTs with extension <180°, as the literature suggested that this technique is not needed in the absence of lattice degeneration.[27] Instead, extensive assisted vitreous base shaving was performed. In addition, fluid-air exchange is arguably the most critical component of surgical management of GRT-associated RRD, where retinal slippage or fold formation may occur due to improper techniques. During this process, the aqueous should be meticulously removed through an extrusion cannula at the air-PFCL interface and at the boundary of the tear. In our cases, no macular retinal folds due to posterior slippage were observed. We also did not use sulfur hexafluoride because it has been found to increase chances of redetachment,[35] whereas C_3F_8 was used in all of the cases. For tamponade, lighter-than-water silicon oil was used only in eyes with PVR and was eventually removed. Silicon oil was selected for several reasons, including the earlier report by Kunikata *et al*.[36] that used this type of tamponade in a majority of their GRT-associated RRD cases.

There are several risk factors associated with RRD recurrence, including development of anterior and posterior PVR and persistent or new epiretinal traction at the edge of the tear.[1,2] Several RRD recurrences due to posterior PVR were observed in our cases with the presence of post-operative ERM proliferation over the detached macula. These developments likely contributed to the formation or activation of new tears from diffuse posterior epiretinal tractions. During follow-up, recurrent RRD cases underwent epiretinal and macular membrane stripping, vitrectomy revision, and ERM/ILM *en bloc* removal procedures.

It has been reported that the reattachment rate is approximately 80–90% after one procedure, whereas the final rate is approximately 94–100%.[12,37] However, the visual prognosis is typically poor in cases with PVR, despite the reattachment and anatomic success, which was seen in this study and in a previous study.[2] In addition, macular ERM proliferation and cystoid macular edema were previously reported to be the most common postoperative complications, occurring in 39% of the eyes.[36] Li *et al*.[37] believe that good anatomical and functional results can only be obtained with vitrectomy in noncomplex cases. In our study, the reattachment rate after one surgical procedure was 66.7%, which is consistent with a previously reported rate of 65% at 2 years (95% confidence interval: 47–78%) by Li *et al*.[37]

Unfortunately, a prospective study found that even for eyes that received timely surgery, recovery of vision to 20/40 or better is unlikely, thus highlighting the difficulty in the management of GRT-associated RRD.[38] Several factors may contribute to poor visual outcomes, including low IOP (<10 mmHg), old age (>70 years), retinal detachment with five or more rhegmatogenous lesions, and retinal detachment of more than 3 quadrants.[39] There was no relationship between the number of breaks, lens extraction, and the type of surgery (primary vitrectomy vs. combined SB and vitrectomy techniques). This observation is also supported by the studies of Ting *et al*.[39] However, the post-operative perfusion status was clearly affected, mainly in the buckled eyes. The post-operative BCVA was significantly associated with the CSFT, normal foveal contour, and abnormal perfusion indices, according to our statistical analysis. Herein, we found significant evidence suggesting that perfusion abnormalities are correlated with visual outcomes. Therefore, we theorize that the combination of extensive retinal rupture and vitrectomy in conjunction with scleral buckling techniques can likely damage the microcirculation of the retina and choroid, thus leading to reduced perfusion and unsatisfactory post-operative visual outcomes.

CONCLUSION

GRT-associated RRD remains a potentially vision-threatening disorder, despite advances in the management of this condition. This study reports on a long-term follow-up perfusion evaluation. However, there are currently very little functional and perfusion correlated data on GRT-associated RRD. These new data provide novel insights into the management of the disease and may help lead to the development of better interventions for the patients. Progress in surgical interventions has improved our understanding of treatment methods; however, the assessment of perfusion status with visual outcomes has not been reported. Our study found that perfusion indices are correlated with visual outcomes, thus influencing patient management. In addition, GRT-associated RRD is a rare condition, so the data presented here have substantial clinical implications. In particular, we found that a carefully performed control-perfusion vitrectomy (preferably without the use of a complementary scleral buckling placement) may help to preserve the post-operative perfusion indices within the normal range, thus benefiting visual outcomes.

Acknowledgments

We express our deep appreciation to the technical staff of the participant institution.

Declaration of patient consent

The authors certify that they have obtained all appropriate patient consent.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

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How to cite this article: Quiroz-Reyes MA, Quiroz-Gonzalez EA, Quiroz-Gonzalez MA, Alsaber A, Lima-Gomez V. Long-term Post-operative perfusion outcomes in giant retinal tears treated with and without scleral buckling. Lat Am J Ophthalmol 2022:5:2.