Analysis of retinal morphological and functional changes after successful treatment for rhegmatogenous retinal detachment

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Аналіз морфологічних та функціональних змін сітківки після успішного оперативного лікування регматогенного відшарування сітківки

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Abstract

Purpose. *To identify and analyze the main clinical, morphological and functional predictors of visual outcome after rhegmatogenous retinal detachment (RRD) surgery.*

Material and Methods. *This retrospective-prospective study included 85 patients (85 eyes) who received 25-G subtotal pars plana vitrectomy for primary rhegmatogenous retinal detachment. Follow-up duration was 12 months. Visual acuity assessment, perimetry, optical coherence tomography (OCT), OCT angiography (OCTA) and microperimetry were used to assess anatomical, morphological and functional outcomes.*

Results. *The rate of anatomical success was 91.8%. Better functional outcomes were observed in patients with macula-on RRD and detachment duration shorter than 7 days (p < 0.01). There was OCT evidence of restoration of foveal microstructure in 80.0% of eyes, which was significantly correlated with higher visual acuity (p < 0.001). OCT-A characteristics (the deep capillary plexus density and foveal avascular zone area) were strongly correlated with the functional outcome.*

Conclusion. *The prognosis of visual outcome after RRD surgery is determined not only by anatomical retinal reattachment, but also by the state of the macula, duration of RRD, and restoration of foveal microstructure and macular microcirculation. OCT and OCT-A provide valuable data for evaluating treatment outcomes and predicting visual rehabilitation outcomes.*

Keywords: *rhegmatogenous retinal detachment, optical coherence tomography, OCT angiography, vitrectomy, macula, retina, prognostic criteria*

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Резюме

Мета. *Визначити та проаналізувати основні клінічні, морфологічні та функціональні прогностичні критерії, що впливають на отримання високих зорових функцій після оперативного лікування регматогенного відшарування сітківки.*

Матеріал та методи. *Проведено ретроспективно-проспективне дослідження 85 пацієнтів (85 очей) з первинним регматогенним відшаруванням сітківки, яким виконано закриту субтотальну 25G-вітректомію. Тривалість спостереження становила 12 місяців. Оцінювали анатомічні, морфологічні та функціональні результати із застосуванням візометрії, периметрії, ОКТ, ОКТ-ангіографії та мікропериметрії.*

Результати. *Анатомічний успіх досягнуто у 91,8% випадків. Кращі функціональні результати відзначено у хворих з Macula-on та при тривалості відшарування менше семи днів (p<0,01). За даними ОКТ, повне відновлення фовеальної мікроструктури виявлено у 80,0%*

очей і достовірно корелювало з вищою гостротою зору (p<0,001). Показники ОКТ-ангіографії, зокрема щільність глибокого капілярного сплетення та площа FAZ, мали сильний зв'язок із функціональним результатом.

Висновки. *Функціональний прогноз після оперативного лікування регматогенного відшарування сітківки визначається не лише анатомічним приляганням сітківки, а й станом макули, тривалістю відшарування, відновленням фовеальної мікроструктури та макулярної мікроциркуляції. Використання ОКТ та ОКТ-ангіографії є інформативним інструментом для оцінки результатів лікування та прогнозування зорової реабілітації.*

Ключові слова: *регматогенне відшарування сітківки, оптична когерентна томографія, ОКТ-ангіографія, вітректомія, макула, сітківка, прогностичні критерії.*

Introduction

Rhegmatogenous retinal detachment (RRD) is a common vision-threatening condition, which, if untreated, can lead to permanent vision loss [1]. Globally, the annual incidence of RRD is approximately 10 to 18 per 100,000 individuals, with variations based on age, geography, and predisposing conditions such as eye injury and high myopia [2]. Pathogenetically, RRD is associated with a retinal break through which liquefied vitreous flows into the subretinal space, separating the neuroepithelium from the underlying retinal pigment epithelium [3].

The main goal of surgery for RRD is to achieve retinal reattachment and prevent re-detachment. Various techniques, including sclera buckling, pneumatic retinopexy, and vitrectomy combined with intraocular gas or silicone oil tamponade, are used for this purpose [4]. Despite recent technological advances in operative techniques, the recurrence rate remains substantial (5–15%), and the extent of visual function restoration does not match the anatomical success of surgery. This necessitates a comprehensive evaluation of treatment outcomes not only from a morphological but also from a functional point of view [5].

The evaluation of the efficacy of surgical treatment for RRD includes the analysis of anatomical results [retinal reattachment, the presence of residual subretinal fluid (SRF), macular fixation stability, etc.] and functional results (recovery of visual acuity, macular sensitivity, retinal electrophysiological parameters and visual perception) [6].

A combination of conventional clinical diagnostic techniques (visual acuity assessment, perimetry, and ophthalmiscopy), advanced instrumental diagnostic techniques [optical coherence tomography (OCT), optical coherence tomography angiography (OCTA), microperimetry] and subjective quality of life scales enables a comprehensive evaluation of treatment results [7].

Investigation of the relationship between anatomical and functional results of surgical treatment is essential for optimizing the management strategy, selecting the surgical technique and developing prognostic criteria for success. It is for this reason that the question of how to evaluate the outcomes of surgical treatment for RRD remains relevant.

The purpose of this study was to determine and review the major clinical, morphological and functional factors for achieving high postoperative visual functions after RRD surgery.

Material and Methods

This retrospective-prospective study was conducted at the Ophthalmological Department of Sklifosovskyi Poltava Regional Clinical Hospital in 2021-2024. Follow-up duration was 12 months. The study followed ethical standards as outlined in the Declaration of Helsinki of the World Medical Association and the European Convention on Human Rights and Biomedicine, and relevant laws of Ukraine. Informed consent was obtained from all study subjects.

The study sample included 85 patients (85 eyes) who underwent primary surgery for RRD. Of these, 51 (60.0%) were men and 34 (40.0%) were women. Patient age ranged from 26 to 75 years [mean age ± standard deviation (SD), 52.8 ± 10.9 years]). The right eye was affected in 47 of the 85 cases (55.3%), and the left in 38 (44.7%). Of the 85 patients, 35 (41.2%) underwent surgery for macular-on RRD (group 1) and 50 (58.8%), surgery for macular-off RRD (group 2).

Inclusion criteria included primary RRD, the absence of ocular comorbidities (diabetic retinopathy, age-related macular degeneration, degenerative myopia with macular changes, glaucoma, etc.), and the opportunity for complete follow-up over 12 months. Exclusion criteria included retinal re-detachment, tractional detachment, grade C proliferative vitreoretinopathy, or substantial media opacity obstructing the view of the fundus.

Patients underwent a complete eye examination including visual acuity assessment, perimetry, OCT and OCTA, preoperatively and at 1, 3, 6 and 12 months after surgery.

Best-corrected visual acuity (BCVA) was measured by Early Treatment Diabetic Retinopathy Study (ETDRS) charts at 4-m distance. Visual acuity values were expressed as logarithm of the minimum angle of resolution (logMAR) units. Visual fields were measured by automated perimetry with Humphrey 740 Field Analyzer in 72 patients (84.7%). The fundus was examined by biomicroscopy and ophthalmoscopy and OCT (Zeiss Cirrus HD-OCT 5000; Carl Zeiss Meditec AG, Jena, Germany) was performed in all patients. The following OCTA parameters were examined:

1) Foveal avascular zone (FAZ) area, mm^2 (a FAZ size within a range of 0.25–0.35 mm^2 was considered normal; a FAZ area larger than 0.40 mm^2 was considered an unfavorable prognostic factor);

2) Superficial capillary plexus (SCP) vessel density, percentage (with the assessment performed in the central

and parafoveal zones; an SCP vessel density less than 45% was considered a criterion of microvascular deficiency);

3) Deep capillary plexus (DCP) vessel density, percentage (a major marker of functional prognosis; a DCP vessel density less than 45% was considered to be associated with lower recovery of BCVA);

4) Retinal perfusion index (RPI), an integral characteristic of macular microcirculation;

5) The presence of aneurysms, non-perfusion zones, and/or abnormalities in capillary network architecture.

All patients underwent 25G pars plana vitrectomy (PPV). Perfluoropropane (C_3F_8) tamponade was used in 59 patients (69.4%), and silicone oil tamponade, in 17 patients (20.0%). Postoperative head positioning depended on the break location, with the head position maintained for 5–7 days.

Outcome measures

The first primary outcome measure was single-procedure anatomical success, defined as complete anatomical reattachment without recurrence at 6-12 months following the initial PPV. The second primary outcome measure was functional outcome (BCVA). The third primary outcome measure was morphological success, defined as foveal structure recovery as assessed by OCT and OCTA.

SPSS v.27 and Microsoft Excel 2021 software were used for statistical analysis. The Student t-test was used to test the differences between two groups. Pearson correlation was used to assess the relationship between the variables. $P \leq 0.05$ was considered statistical significant. Data are presented as mean ± SD.

Results

Mean BCVA was significantly higher in the macula-on group than in the macula-off group preoperatively ($p < 0.001$), and improved compared to baseline as early as month 1 ($p < 0.05$). Postoperatively, BCVA improved in both groups, but was better in the macula-on group at all time points (Table 1).

The duration of retinal detachment had a significant effect on the functional outcome (Table 2).

Table 2. Best-corrected visual acuity (LogMAR) for eyes with a detachment duration less than 7 days, 7-14 days, and more than 14 days

Detachment duration	LogMAR
<7 days	0.27 ± 0.18
7–14 days	0.41 ± 0.20
>14 days	0.66 ± 0.24

Note: LogMAR, logarithm of the minimum angle of resolution (smaller LogMAR values correspond to better visual acuity)

The best functional outcomes were seen in patients with RRD of duration less than 7 days, and the worst, in patients with RRD of duration more than 14 days.

Anatomical outcomes. Complete anatomical reattachment without recurrence at 6-12 months following the initial PPV was achieved in 78 patients (91.8%) of the study sample. Particularly, primary anatomical success was achieved in 34 patients (97.1%) in the macula-on group, and 44 patients (88.0%) in the macula-off group. Recurrent RRD occurred in 7 patients (8.2%) and was most commonly seen in patients with RRD of duration more than 14 days and/or the presence of several retinal tears.

Morphological outcomes. The most common postoperative morphological OCT changes in the retina were distortion of the photoreceptor inner/outer segments (IS/OS) junction (19 eyes; 22.3%), followed by SRF (14 eyes; 16.5%), and local atrophy in the outer nuclear layer (11 eyes; 12.9%). These changes significantly correlated with lower BCVA ($r = 0.78$; $p < 0.01$).

Pathological changes in the macula were significantly more common in the macula-off group (Table 3).

Outer retinal abnormalities and signs of structural damage in the fovea associated with lower functional outcomes were also more common in the macula-off group.

At 12 months, 68 patients (80.0%) exhibited complete recovery of the foveal profile and retinal microstructure, and the rate of complete morphological recovery was sig-

Table 1. Best-corrected visual acuity (LogMAR) in the macular-on and macula-off groups preoperatively and at 1, 3, 6 and 12 months

Time points	Macula-on (n=35)	Macula-off (n=50)	P-value
Preoperative	0.42 ± 0.18	1.34 ± 0.27	<0.001
1 month	0.31 ± 0.16	0.92 ± 0.24	<0.001
3 months	0.24 ± 0.15	0.71 ± 0.22	<0.01
6 months	0.19 ± 0.13	0.54 ± 0.20	<0.01
12 months	0.14 ± 0.11	0.38 ± 0.18	<0.01

Note: LogMAR, logarithm of the minimum angle of resolution (smaller LogMAR values correspond to better visual acuity); macula-on, no separation of the macula; macula-off, separation of the macula; P-value, significance of difference

Table 3. Incidences (percentages) of postoperative morphological changes on OCT in the macular-on and macula-off groups

Morphological changes	Macula-on (n = 35)	Macula-off (n = 50)	P-value
Subretinal fluid	3 (7.9 %)	11 (23.9 %)	< 0.05
Distortion of the inner/outer segments (IS/OS) junction	5 (13.2 %)	14 (30.4 %)	< 0.05
Atrophy in the outer nuclear layer	2 (5.3 %)	9 (19.6 %)	< 0.05

Note: macula-on, no separation of the macula; macula-off, separation of the macula; P-value, significance of difference

nificantly higher in the macula-on group than in the macula-off group.

At all time points, retinal microcirculation characteristics as assessed by OCTA were better in the former group than in the latter group.

Preoperatively, FAZ area was statistically significantly larger, indicating more marked macular ischemic lesions, in the macula-off group.

Postoperatively, there was a gradual reduction in the FAZ area in both groups; however, even at 12 months, FAZ area characteristics were still worse in the macula-off group (Table 4).

An increase in the FAZ area significantly correlated with a reduction in macular sensitivity as assessed by mictoperimetry ($r = –0.62$; $p < 0.01$).

Postoperatively, both groups showed a gradual increase in the SCP vessel density, but the recovery was less marked in the macula-off group (Table 5).

SCP vessel density less than 45% was associated with lower postoperative BCVA ($p < 0.01$).

Most marked changes were found in the DCP. In the macula-off group, a preoperative reduction in the DCP vessel density was significantly more marked, and a postoperative recovery of the DCP vessel density was slower (Table 6).

Critically low DCP vessel density (<40%) was found in 21 patients (44.7%). It is the DCP vessel density that showed the strongest correlation with visual recovery ($r = 0.71$; $p < 0.001$).

RPI gradually increased over the postoperative period, but remained lower in the macula-off group at all time points (Table 7).

An RPI value less than 0.85 was associated with an incomplete recovery of the foveal structure.

Postoperatively, both groups showed a gradual improvement in the microvascular characteristics, which was

Table 4. Foveal avascular zone area (mm^2) in the macular-on and macula-off groups preoperatively and at 1, 3, 6 and 12 months

Time points	Macula-on	Macula-off	P-value
Preoperatively	0.31 ± 0.06	0.46 ± 0.09	< 0.001
1 month	0.33 ± 0.07	0.48 ± 0.10	< 0.001
3 months	0.32 ± 0.07	0.44 ± 0.09	< 0.01
6 months	0.32 ± 0.07	0.41 ± 0.08	< 0.01
12 months	0.31 ± 0.06	0.39 ± 0.08	< 0.01

Note: macula-on, no separation of the macula; macula-off, separation of the macula; P-value, significance of difference

Table 5. Superficial capillary plexus (SPC) vessel density (%) in the macular-on and macula-off groups preoperatively and at 1, 3, 6 and 12 months

Time points	Macula-on	Macula-off	P-value
Preoperatively	53.8 ± 5.1	41.6 ± 6.4	<0.001
1 month	51.2 ± 5.3	40.4 ± 6.1	<0.001
3 months	51.8 ± 5.2	42.8 ± 6.0	<0.01
6 months	52.1 ± 5.4	45.3 ± 6.1	<0.01
12 months	53.4 ± 5.0	46.9 ± 5.8	<0.01

Note: macula-on, no separation of the macula; macula-off, separation of the macula; P-value, significance of difference

Table 6. Deep capillary plexus (DPC) vessel density (%) in the macular-on and macula-off groups preoperatively and at 1, 3, 6 and 12 months

Time points	Macula-on	Macula-off	P-value
Preoperatively	48.1 ± 4.8	34.2 ± 5.3	< 0.001
1 month	44.6 ± 5.1	33.5 ± 5.4	< 0.001
3 months	45.5 ± 5.0	35.8 ± 5.3	< 0.001
6 місяців	46.8 ± 4.9	38.7 ± 5.1	< 0.001

Note: macula-on, no separation of the macula; macula-off, separation of the macula; P-value, significance of difference

Table 7. Retinal perfusion index (RPI) in the macular-on and macula-off groups preoperatively and at 1, 3, 6 and 12 months

Time points	Macula-on	Macula-off	P-value
Preoperatively	0.97 ± 0.05	0.79 ± 0.08	< 0.001
1 month	0.91 ± 0.06	0.77 ± 0.07	< 0.001
3 months	0.93 ± 0.05	0.82 ± 0.07	< 0.01
6 months	0.95 ± 0.05	0.88 ± 0.06	< 0.01
12 months	0.96 ± 0.05	0.90 ± 0.06	< 0.01

Note: macula-on, no separation of the macula; macula-off, separation of the macula; P-value, significance of difference

more complete and faster in the macula-on group. Morphologically, the most persistent changes were found in the DCP, which was confirmed by the strongest correlation found between the DCP vessel density and the postoperative BCVA ($r = 0.71$; $p < 0.001$).

Therefore, microcirculation recovery, especially at the level of the DCP, is a key factor in the functional rehabilitation after surgery for RRD.

Discussion

The results of the present study confirm recent literature reports indicating that anatomical success exceeded functional success after surgery for RRD. In large clinical series, anatomical success rates after primary vitrectomy for RRD climbed to 85-90% [1], whereas substantial functional improvement was seen only in 60–75% of patients [2]. This is in line with the present study, where anatomical success (91.8%) far exceeded functional success (74.1%).

Macular status at the time of surgery has been reported to remain a key determinant of postoperative vision. Studies have demonstrated that patients with macula-on RRD had significantly better postoperative RRD than those with macula-off RRD even when the anatomical outcome was similar [1, 15]. This is in agreement with the current study, where the mean BCVA at 12 months was substantially higher in the macular-on group than in the macular-off group, confirming the decisive role of a well-preserved foveal complex.

Numerous studies have reported that the duration of macular detachment before repair impacts recovery. Ong and colleagues [6] demonstrated that an RRD duration longer than 10–14 days was associated with worse functional prognosis. Similar findings were reported in reviews on the pathophysiology of RRD [10]. In the current study, the best functional outcomes were seen in patients with RRD duration shorter than 7 days, and visual recovery was significantly worse in those with detachment duration of more than 14 days.

There is an increasing evidence of a key role for the foveal morphological status as assessed by OCT. Hormel and colleagues [13] and Hayat and colleagues [17] reported that an intact outer retina (particularly, an intact IS/OS junction) was a major predictor of postoperative vision. Our findings confirmed the above, and a complete recovery of the foveal microstructure significantly correlated with better functional outcomes, whereas residual structural abnormalities were associated with worse postoperative vision.

OCTA holds a special place among the techniques for assessing the status of macular microcirculation after RRD. Persistent reductions in vessel density and increases in FAZ area have been reported after surgery for RRD (especially, macula-off RRD) [2, 3, 5]. In the present study, an increase in FAZ area to values exceeding 0.40 mm^2 was associated with reduced macular sensitivity, which is in agreement with the above findings.

Several studies have reported that it was the DCP vessel density that had the highest prognostic value for functional recovery. Nielsen and colleagues [7], Lu and colleagues [11], and Mete and colleagues [14] observed that the reduction in the DCP vessel density was more strongly correlated then the SCP vessel density with the BCVA. In the present study, the DCP vessel density had the strongest correlation with postoperative BCVA ($r = 0.71$; $p < 0.001$), confirming a key role of deep macular perfusion.

Our finding of the relationship between the RPI and macular recovery is consistent with the findings by Nam and colleagues and Diaz-Barreda and colleagues [12, 16, 19], who considered integral microvascular characteristics markers of long-term neurosensory recovery. This confirms that insufficient macular reperfusion may cause incomplete functional recovery even in the presence of anatomical success.

Therefore, the results of the present study confirm the reports in current literature that the functional prognosis after RRD is multifactorial and depends on the status of the macula, detachment duration, and recovery of foveal microstructure and microvascular perfusion. A comprehensive use of OCT and OCTA is advisable and promising for tailoring prognosis and postoperative management to the patient [13, 15, 17, 20].

Author Contributions

BIM – conceptualization; review and editing; IAYu – project preparation; design, writing and editing of the article; VLK – review and editing; RVV – methodology; review and editing; BAV – review and editing; AAT – software; formal analysis; review and editing.All authors read and approved the final version of the manuscript.

Disclaimers

The views expressed in this article are solely those of the authors and do not necessarily represent the official position of their affiliated institution or any funding source.

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Ethical Statement

This study was conducted in accordance with the principles of the Declaration of Helsinki. All ethical standards were observed during the study.

Conflict of Interest

The authors state that they have no conflict of interest that could influence their view on the subject matter or materials described and discussed in this manuscript.

Data Availability Declaration

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Abbreviations

RRD, rhegmatogenous retinal detachment; OCT, optical coherence tomography; OCT-A, optical coherence tomography–angiography; PVR, proliferative vitreoretinopathy; BCVA, best-corrected visual acuity; FAZ, foveal avascular zone; SCP, superficial capillary plexus; DCP, deep capillary plexus; RPI, retinal perfusion index; LogMAR (Logarithm of the minimum angle of resolution), logarithm of the minimum angle of resolution, a standard measure of visual acuity; macula-on, without macular detachment; macula-off, with macular detachment.

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