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Macular morphologic changes following successful retinal detachment repair by scleral buckling surgery

Morfološke promene makule nakon uspešne operacije ablacije retine metodom „nabiranja“ sklere

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Abstract

Background/Aim. Spectral domain optical coherence tomography (SDOCT) is very useful for the accurate examination of macular microstructure. The aim of this study was to evaluate macular morphologic changes after successful retinal detachment (RD) surgery by scleral buckling (SB) using SDOCT and assess their impact on vision repair. **Methods.** SDOCT examination was performed in 1, 6, and 12 months in 27 eyes following SB surgery with the successful anatomical repair of rhegmatogenous RD, which also affected the macular region. The examination was performed in a 6 mm diameter central macular region and included measurements of the central foveal thickness, average total retinal thickness (TRT), and thickness of the inner and outer retinal layer (ORT) separately. The numerical values of parameters for each operated eye were compared with those of the fellow (control) eye of each patient. The condition of the external limiting membrane (ELM) and inner segment (IS) and outer segment (OS) of the photoreceptors was also examined. **Results.** The mean TRT and ORT in the reattached regions in the operated eyes were significantly thinner than the corresponding regions of the fellow (control) eye, and throughout the follow-up period, the difference was statistically significant. There was a statistically significant difference in TRT (after 1 month, p = 0.021, after 6 months, p = 0.026, after 12 months, p = 0.027) and ORT (after 1 month, p = 0.018, after 6 months, p = 0.019, after 12 months, p = 0.021) between the eyes with a longer preoperative duration of macular detachment (MD) of 2 weeks and eyes with shorter detachment period. Disruptions of the IS and OS of photoreceptors and ELM on SDOCT examination after one month were observed in 37.04% of eyes, after 6 months in 29.6% of eyes, and at the end of the follow-up period in 14.8% of eyes. A statistically significant difference was found in the frequency of disruptions of the IS and OS, and ELM depending on the preoperative duration of RD (p = 0.007). **Conclusion.** The overall decrease in the mean retinal thickness after successful anatomical repair of RD is the result of a decrease in the thickness of the outer retinal layers. The alterations of the ELM, IS and OS of photoreceptors observed on the early SDOCT scans are mostly associated with limited vision recovery. The prolonged MD leads to damaging the neurosensory tissue of the retina and especially the photoreceptors, which may explain the limited visual acuity recovery after successful SB repair of RD.

Key words:
eye diseases; macula lutea; retinal detachment; scleral buckling; tomography, optical coherence; treatment outcome; visual acuity.

Apstrakt

Uvod/Cilj. Optička koherentna tomografija spektralnog domena (OKTSD) je veoma korisna za precizno ispitivanje mikrostrukture makule. Cilj rada bio je da se procene morfološke promene makule nakon uspešne operacije ablacije retine (AR) metodom „nabiranja“ sklere koristeći metod OKTSD kao i procena njihovog uticaja na oporavak vida. **Metode.** Pregled OKTSD-om obavljen je na 27 očiju 1, 6 i 12 meseci nakon operacije „nabiranja“ sklere sa uspešnom anatomskom reparacijom regmatogene AR koja je istovremeno zahvatala i makularnu regiju. Pregled je bio izvršen u centralnom regionu makularne regije, promera 6 mm i uključivao je merenje centralne fovealne debljine, prosečne ukupne debljine retine (UDR) i debljine unutrašnjeg i spoljašnjeg sloja retine (SSR) pojedinačno. Numeričke vrednosti parametara svakog operisanog oka upoređene su sa vrednostima drugog (kontrolnog) oka istog bolesnika. Takođe, izvršena je analiza integriteta unutrašnjeg segmenta (US) i spoljašnjeg

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segmenta (SS) fotoreceptora i integriteta spoljašnje granične membrane (SGM). **Rezultati.** Tokom celokupnog perioda praćenja prosečna UDR i debljina SSR u repariranim regijama operisanih očiju bile su statistički značajno manje od odgovarajućih regija kontrolnih očiju. Postojala je statistički značajna razlika u UDR (nakon 1 meseca $p = 0,021$, posle 6 meseci $p = 0,026$, posle 12 meseci $p = 0,027$) i debljini SSR (posle 1 meseca $p = 0,018$, posle 6 meseci $p = 0,019$, nakon 12 meseci $p = 0,021$) između očiju sa preoperativnim trajanjem ablacije makule (AM) dužim od 2 nedelje i očiju sa kraćim preoperativnim trajanjem AM. Poremećaji US i SS fotoreceptora i SGM primećeni su na OKTSD pregledu nakon prvog postoperativnog meseca kod 37,04% očiju, nakon 6 meseci kod 29,6% očiju, a na kraju perioda praćenja kod 14,8% očiju. Utvrđena je statistički značajna razlika u učestalosti ovih promena u zavisnosti od preoperativnog trajanja AR ($p = 0,007$). **Zaključak.** Sveukupno umanjenje srednje debljine retine nakon uspešne anatomske reparacije AR rezultat je smanjenja debljine njenih spoljašnjih slojeva. Promene SGM, US i SS fotoreceptora uočene na ranim OKTSD snimcima uglavnom su povezane sa ograničenim oporavkom vida. Duže trajanje AM dovodi do oštećenja neurosenzornog tkiva retine, posebno fotoreceptora, što može objasniti nepotpun oporavak oštrine vida nakon uspešne reparacije AR metodom „nabiranja“ sklere.

Ključne reči:
oko, bolesti; žuta mrlja; retina, ablacija; beonjača, kopča; tomografija, optička, koherentna; lečenje, ishod; oštrina vida.

Introduction

Rhegmatogenous retinal detachment (RRD) is a retinal disorder in which the neurosensory retina separates from retinal pigment epithelium (RPE). It is caused by one or more retinal breaks that allow vitreous fluid to pass through and collect in the potential space between the neurosensory retina and RPE. It causes various morphologic changes in the macular architecture and visual acuity (VA) reduction.

The scleral buckling (SB) procedure can be used successfully to treat the majority of RRD and represents a widely accepted surgical treatment for this retinal disorder. However, despite a successful anatomical repair, vision repair results do not reflect this high rate of anatomical success [1, 2]. When the retinal detachment (RD) involves the macula prior to surgery, the recovery of VA is often limited and usually does not return to baseline. In eyes with detached macula preoperatively, only 37% achieve 0.4 or better VA despite the anatomical success of the surgery of 90% [3].

The existence of microstructural macular changes that are not visible by fundus biomicroscopy can explain limited vision recovery after anatomically successful retinal reattachment [4]. That can be explained by various changes such as persistent residual subretinal fluid (RSRF), development of epimacular epiretinal membrane (EEM), cystoid macular edema (CME), or retinal folds and pigment migration [5–7].

Various histopathological changes occur during RD. It has been shown in experimental models that retinal tissue degeneration occurs very early following RD [8–10].

The nutrition and oxygen supply of the outer retinal layers (ORL) is one of the main problems after RD development. That causes prominent retinal structural changes, especially in photoreceptors and the outer nuclear layer (ONL). In terms of poor vision recovery in RRD, various factors were assessed, such as disruption of photoreceptors of the inner segment (IS) and outer segment (OS) and external limiting membrane (ELM) [11, 12].

After successful surgery, a few microscopic studies in the reattached human retina revealed the atrophy of the ORL, especially photoreceptor layers [13, 14]. Because these microscopic changes are very discrete, they are not often clinically visible. Recent development in spectral domain optical coherence tomography (SDOCT) allows more detailed retinal layers evaluation and provides better resolution of intraretinal structures [15].

In this study, we have tried to identify changes in retinal microstructure after SB surgery in successfully reattached retinas compared to fellow healthy eyes using SDOCT, as well as to estimate the influence of these changes on vision recovery. Moreover, based on SDOCT images, we quantified the thickness of all retinal layers and compared the thickness of reattached regions with the corresponding regions of the fellow healthy eye.

Methods

The study was performed at the Clinic of Ophthalmology, University Clinical Center Kragujevac, Serbia. The study was conducted in a period from 2017 to 2020. That was a prospective observational follow-up study of 27 patients following successful anatomical repair of RRD, which preoperatively also affected the macular region by SB surgery.

The study group of 27 eyes has been taken from a larger group of eyes that underwent SB and included only the eyes in which complete retinal repair was achieved after the first operation during the entire postoperative follow-up period. The eyes with retinal re-detachment during the follow-up period and requiring any additional intervention, either repeated SB or *pars plana* vitrectomy (PPV), were excluded from the study.

Only patients with successfully repaired RRD with macular involvement by a single SB procedure without any intra and postoperative complications were included in this study. Only eyes with transparent ocular media were include d in this study. Eyes with pre-existing ocular diseases or previous ocular surgery, except cataract surgery, were not included in the study.

The existence of various macular diseases in the operated and fellow eyes, such as diabetic retinopathy, retinal vascular occlusion, age-related macular degeneration, proliferative vitreo-retinopathy, conditions that affect the vitreomacular interface (e.g., epiretinal membrane and macular hole), the presence of glaucoma and uveitis or high myopia exceeding -6,0 diopters, were all exclusion criteria for this study.

Full ophthalmologic examination was performed preoperatively and postoperatively, including VA measurement (using standard Snellen eye charts), measurement of intraocular pressure with Goldmann applanation tonometer, fundus examination with indirect ophthalmoscopy and fundus biomicroscopy with Goldmann three-mirror contact lens and Volk 78 lenses, which make it possible to determine the extent and grading of RD.

With the approval of the institutional Ethics Committee (No 03/17-3807, from December 18, 2017) and according to the tenets of the Declaration of Helsinki, all enrolled patients gave their written consent at the beginning of the investigation.

In all patients, in the ophthalmologic operating room, under general anesthesia, standard SB surgery was done. In short, after a 360° limbal peritomy and placement of traction sutures beneath the rectus muscles, retinal breaks were identified by indirect ophthalmoscopy. Retinal breaks were treated with trans-scleral cryotherapy to freeze the outer surface of the eye. External drainage of the subretinal fluid (SRF) was avoided whenever possible and performed only when necessary.

Mattress sutures were placed with 5-0 polyester (Assut Astralen, Pully-Lausanne, Switzerland), and segmental radial or circumferential silicone scleral explant (Geuder AG, Heidelberg, Germany) was finally positioned to close the break(s). Finally, a 3.5 mm encircling circumferential band 360° buckle (Geuder AG, Heidelberg, Germany) was used and sutured with 5–0 polyester. At the end of the surgery, Dexamethasone and Gentamicin were injected subconjunctivally. Ofloxacin 0.3% and Dexamethasone 0.1% were applied topically five times a day for two postoperative weeks.

SDOCT examination was performed at least one month after surgery and then after 6 and 12 months (Optopol REVO NX 130 SDOCT, OPTOPOL Technology, Zawiercie, Poland). The examination and measurements of retinal layer thickness were performed in a 6 mm diameter central macular region, including nine macular sub-fields according to the Early Treatment Diabetic Retinopathy Study grid cells scheme (ETDRS). The central foveal thickness (CFT) was measured, and also the measurement of average overall retinal thicknesses in another eight analyzed macular fields was made. An automated segmentation protocol was used for thickness measurements of the ORL and inner retinal layers (IRL). The outer retina encompassed the following retinal layers: photoreceptor layer (PRL), ONL, and outer plexiform layer (OPL), i.e., marked as a distance from the proximal OPL boundary to the proximal RPE boundary. The inner retina encompassed the following retinal layers: inner nuclear layer (INL), inner plexiform layer (IPL), ganglion cell layer (GCL), and nerve fiber layer (NFL), i.e., marked as the distance from the internal limiting membrane (ILM) to the distal boundary of the INL. Furthermore, the thickness of NFL, GCL, and IPL was measured separately. The numerical values of operated and fellow (control) eyes were compared.

The condition of the photoreceptors of the IS and OS, and ELM was examined in particular detail, and so was the existence of other retinal changes such as residual subfoveal fluid (RSFF), cystic retinal spaces, and epimacular membranes (EMM).

SDOCT scans were then independently evaluated by two experienced retinal specialists.

In analyzing statistical data, SPSS version 22 (IBM Corp., Armonk, NY, USA) was used. The statistical differences in retinal thickness between the analyzed and control eyes were assessed by using a two-tailed *t*-test. Kruskal Wallis test was used for testing the changes in VA during the follow-up period. The chi-squared test (χ^2-test) was used to examine the incidence of the disruption of photoreceptors in the IS and OS, ELM, RSFF, CME, and EM. In the case of intergroup comparison, the Mann-Whitney U test was used. A value of p lower than 0.05 was considered statistically significant.

Results

The current study included 27 eyes of 27 patients. The mean age of patients was 51.7 ± 12.1 years (27–67 years). RD was noted in 16 females and 11 males, in the right eye in 17 patients, and in the left eye in 10 patients. Nineteen eyes (70.4%) were phakic, and the other 8 (29.6%) were pseudophakic. Thirteen eyes had a superior RD in one retinal quadrant, 8 had RD in 2 upper retinal quadrants, and the other 6 had RD in all four retinal quadrants. The average number of retinal breaks was 1.6 ± 1.1 (1-3) and, in all cases, they were located in superior retinal quadrants.

In all eyes, the macula was detached before the surgery. The mean [± standard deviation (SD)] duration of macular detachment (MD) was 1 to 42 days (mean, 13.0 ± 11.5 days). Eleven (40.7%) eyes had MD for less than 7 days, 8 (29.6%) eyes between 8-14 days, 5 (18.5%) eyes between 15–30 days, and another 3 (11.1%) for over 1 month.

Anatomic success (complete retinal reattachment) was noted in all cases after one surgical intervention, and the macula was successfully reattached in all cases. All surgeries went satisfactorily without any significant intra or postoperative complications. No vortex veins and muscles were damaged during the operation.

Figure 1 shows postoperative values of VA during the follow-up period, depending on the duration of RD before surgery. In all eyes, since there was macula detachment (MD), the preoperative VA was also very low and ranged from finger counting to hand motion.

In the eyes with a preoperative duration of RD for less than 7 days, the mean best corrected visual acuity (BCVA) was 0.38 ± 0.17 at the end of the first month, increasing to 0.48 ± 0.15 at the end of the sixth month, and to 0.55 ± 0.12 at the end of the twelfth month. In the eyes with a preoperative duration of RD between 8–14 days, the mean BCVA was 0.26 ± 0.11 at the end of the first month, increasing to 0.35 ± 0.09 at the end of the sixth month, and to 0.39 ± 0.09

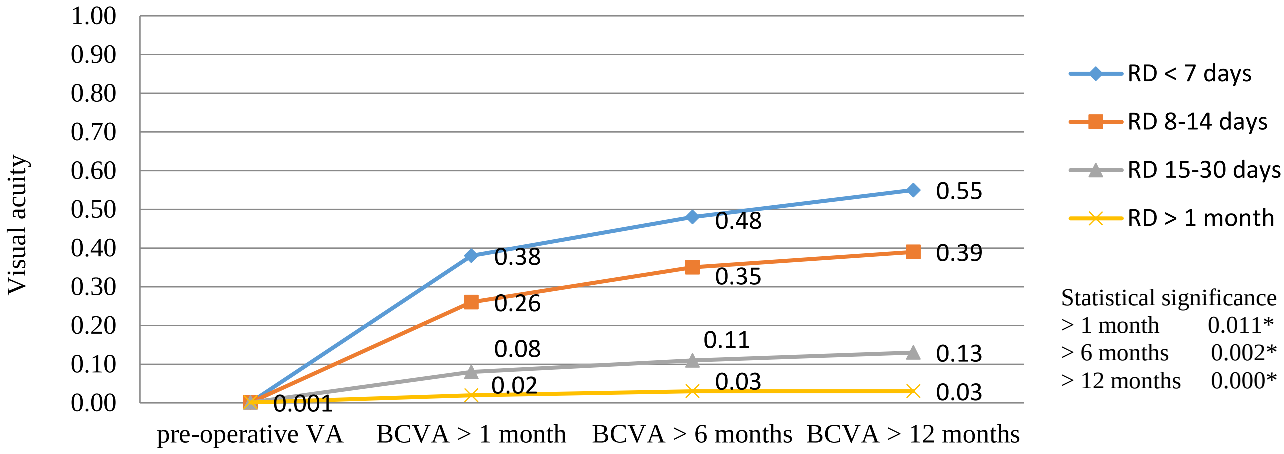

Fig. 1 – Postoperative values of best corrected visual acuity (BCVA) during the follow-up period, depending on the duration of retinal detachment (RD) before surgery. VA – visual acuity.

at the end of the twelfth month. In the eyes with a preoperative duration of RD between 15–30 days, mean BCVA was 0.08 ± 0.03 at the end of the first month, increasing to 0.11 ± 0.05 at the end of the sixth month, and to 0.13 ± 0.07 at the end of the twelfth month. In the eyes with a preoperative duration of RD longer than 1 month, the mean BCVA was at the end of the first, sixth, and twelfth month 0.02 ± 0.01, 0.03 ± 0.01, and 0.03 ± 0.01, respectively. During the entire follow-up period, between eyes with preoperative RD duration for less than 14 days and eyes with a longer detachment duration, there was a statistically significant difference in postoperative VA (after 1 month, $p = 0.011$, after 6 months, $p = 0.002$, after 12 months, $p = 0.000$).

Table 1 shows the results of the SDOCT segmentation analysis and comparison of the thickness of the retinal layers between the reattached regions of the operated eye and corresponding regions in control (fellow) eyes.

In eyes that underwent SB, the mean CFT, total retinal thickness (TRT), outer retinal thickness (ORT), inner retinal thickness (IRT), and NFL + GCL + IPL thickness in the reattached regions were thinner than the corresponding region in the fellow eye. TRT and ORT in the reattached regions in the operated eyes were significantly thinner than the corresponding regions of the fellow eye, and throughout the follow-up period, the difference was statistically significant. Initial postoperative SDOCT after 1 month showed that the mean TRT and ORT in the reattached region were 296.6 ± 8.3 µm and 140.1 ± 4.3 µm, whereas the mean thicknesses of these layers in the corresponding regions of the fellow eyes were 314.1 ± 6.3 µm and 151.8 ± 4.3 µm, respectively. Statistical analysis of the variables showed that the difference was statistically significant compared to the value of control (fellow) eyes ($p = 0.028$, $p = 0.031$, respectively). On the follow-up, SDOCT 6 and 12 months later, the mean ORT in the reattached region was 141.5 ± 7.1 µm and 142.6 ± 4.3 µm, respectively. The difference was statistically significant after statistical analysis of the variables compared to the fellow eyes ($p = 0.018$, $p = 0.019$, respectively).

Table 2 shows the differences in the thickness of retinal layers of the reattached retinal area in the operated eyes depending on the preoperative detachment duration.

In operated eyes with a longer preoperative duration of RD, the mean CFT, TRT, ORT, IRT, and NFL + GCL + IPL thickness values were lower than in eyes with shorter detachment duration. By intergroup comparison, during the entire follow-up period, there was a statistically significant difference in TRT depending on the preoperative detachment duration (after 1 month, $p = 0.021$, after 6 months, $p = 0.026$, after 12 months, $p = 0.027$). In addition, a statistically significant difference was present in ORT (after 1 month, $p = 0.018$, after 6 months, $p = 0.019$, after 12 months, $p = 0.021$).

On SDOCT examination, disruptions and abnormalities of ELM and the photoreceptors in IS and OS were noticed in 10 eyes (37.04%) after one month, in 8 eyes (29.6%) after 6 months, and in 4 eyes (14.8%) at the end of the follow-up period after 12 months. In eyes with preoperative RD shorter than 7 days, these abnormalities were observed on SDOCT examination after 1 and 6 months in only 1 (9.1%) eye, but these changes were not detected in any eyes in this group at the end of the follow-up period. In the eyes with preoperative RD between 8–14 days, these abnormalities were observed on SDOCT examination after 1 month in 3 (37.5%) eyes, after 6 months in 2 (25.0%) eyes, and after 12 months, these abnormalities were not detected in any eyes in this group. In eyes with preoperative RD between 15–30 days, these abnormalities were detected in 3 (60.0%) eyes after the first month, after 6 months in 2 (40.0%) eyes, and after 12 months in only 1 (20.0%) eye. In eyes with preoperative RD longer than one month, disruptions of IS and OS, and ELM existed in all 3 (100%) eyes during all SDOCT recordings for the entire follow-up period.

There was a statistically significant difference in the frequency of disruptions of the photoreceptor IS and OS, and ELM depending on the preoperative duration of RD between eyes with a preoperative RD duration shorter than 2 weeks

Table 1

Comparison of the thickness of retinal layers of the reattached regions in the operated eyes between corresponding regions in the fellow eyes

OCT	CFT (µm) mean ± SD			TRT (µm) mean ± SD			ORT (µm) mean ± SD			IRT (µm) mean ± SD			NFL+ GCL+ IPL thickness (µm) mean ± SD		
	F n =27	O n = 27	*p*	F n = 27	O n = 27	*p*	F n = 27	O n = 27	*p*	F n = 27	O n = 27	*p*	F n = 27	O n = 27	*p*
> 1 month		205.9 ± 7.7	0.057		296.6 ± 8.3	0.021		140.1 ± 4.3	0.015		157.2 ± 7.5	0.074		118.1 ± 6.2	0.079
> 6 months	217.3 ± 6.3	207.8 ± 8.1	0.061	314.1 ± 6.3	299.0 ± 9.2	0.028	151.8 ± 4.3	141.5 ± 7.1	0.018	162.2 ± 6.7	157.4 ± 8.4	0.077	123.7 ± 4.8	118.7 ± 7.1	0.081
> 12 months		209.5 ± 8.9	0.065		300.1 ± 9.8	0.031		142.6 ± 4.3	0.019		157.7 ± 9.3	0.079		118.8 ± 7.6	0.082

OCT – optical coherence tomography; F – fellow (control) eyes; O – operated eyes; CFT – central foveal thickness; TRT – total retinal thickness; ORT - outer retinal thickness; IRT – inner retinal thickness; NFL – nerve fiber layer; GCL – ganglion cell layer; IPL – inner plexiform layer; SD – standard deviation.

Table 2

Differences in thickness of retinal layers of the reattached regions in the operated eyes depending on the duration of retinal detachment throughout the follow-up period

Duration of RD (days)	CFT (µm) mean ± SD			TRT (µm) mean ± SD			ORT (µm) mean ± SD			IRT (µm) mean ± SD			NFL+ GCL+ IPL thickness (µm) mean ± SD		
	> 1m	> 6 m	> 12 m	> 1 m	> 6 m	>12m	>1m	>6m	> 12 m	> 1 m	> 6 m	>12 m	> 1 m	> 6 m	>12 m
< 7 (n = 11)	207.1 ± 5.8	210.1 ± 6.2	210.8 ± 6.9	301.8 ± 3.1	304.1 ± 3.9	304.8 ± 5.7	144.8 ± 3.8	146.3 ± 3.6	148.3 ± 4.2	158.8 ± 5.7	159.4 ± 5.9	159.9 ± 6.3	121.0 ± 4.3	121.9 ± 4.3	122.5 ± 4.2
8–14 (n = 8)	203.2 ± 4.2	204.1 ± 4.8	204.6 ± 5.4	298.5 ± 6.5	302.7 ± 5.6	304.7 ± 3.9	142.6 ± 3.8	144.0 ± 3.9	145.0 ± 4.0	158.0 ± 6.4	158.5 ± 6.8	159.8 ± 7.3	118.9 ± 4.3	119.0 ± 5.1	120.2 ± 5.3
15–30 (n = 5)	194.7 ± 3.9	195.7 ± 4.2	196.3 ± 4.4	293.1 ± 6.2	293.6 ± 6.4	293.9 ± 6.4	133.4 ± 3.9	134.6 ± 3.6	144.4 ± 3.6	158.1 ± 9.3	159.4 ± 10.2	159.0 ± 10.7	119.6 ± 2.6	120.8 ± 3.4	120.0 ± 4.4
> 30 (n = 3)	193.3 ± 6.3	193.1 ± 5.8	193.1 ± 5.8	281.3 ± 8.3	281.3 ± 9.2	281.0 ± 9.8	130.0 ± 1.2	129.0 ± 4.0	127.3 ± 6.5	156.3 ± 7.4	154.0 ± 7.9	153.3 ± 10.0	118.2 ± 5.7	118.4 ± 5.9	118.0 ± 5.6
p	0.051	0.053	0.056	0.021	0.026	0.027	0.018	0.019	0.021	0.079	0.085	0.088	0.092	0.112	0.115

RD – retinal detachment; CFT – central foveal thickness; TRT – total retinal thickness; ORT - outer retinal thickness; IRT – inner retinal thickness; NNFL – nerve fiber layer; GCL – ganglion cell layer; IPL – inner plexiform layer; m – month(s).

and eyes with a longer RD duration (p = 0.007). Figure 2 shows subtle IS and OS photoreceptors and ELM disruptions in the eye with a short duration of MD.

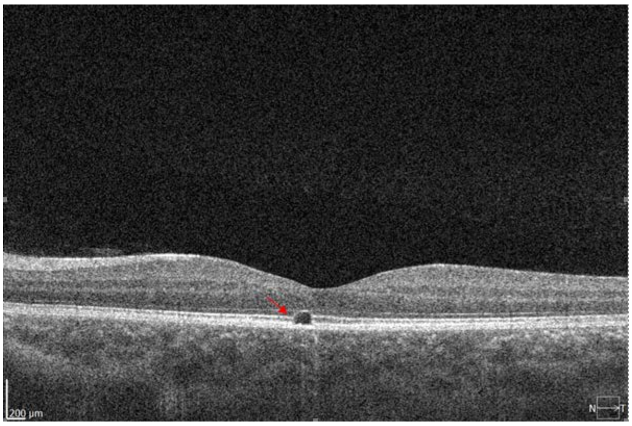

Fig. 2 – Subtle photoreceptors IS/OS and ELM disruptions in the eye with short duration of macular detachment. IS – inner segment; OS – outer segment; ELM – external limiting membrane.

Figure 3 shows multiple zones of IS and OS photoreceptors and ELM disruptions, and RSFF in the eye with a longer duration of MD.

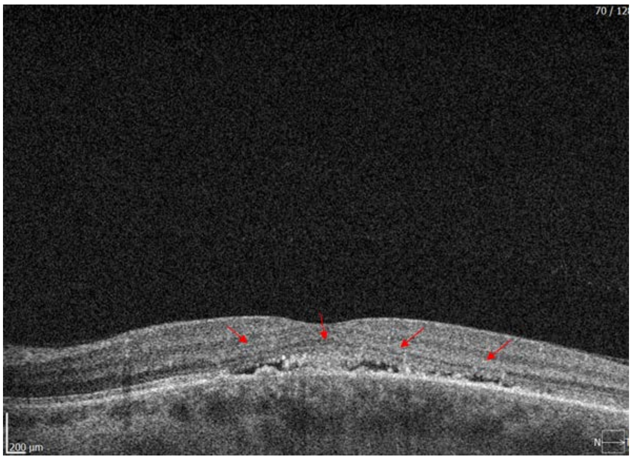

Fig. 3 – Multiple areas of photoreceptors IS/OS and ELM disruptions and residual subfoveal fluid in the eye with longer duration of macular detachment. IS – inner segment; OS – outer segment; ELM – external limiting membrane.

Initial postoperative SDOCT after 1 month showed persistent foveal detachment in 8 (29.6%) eyes clinically invisible on binocular funduscopic examination. On follow-up SDOCT 6 months later, SRF was noted in 3 (11.1%) eyes. At the end of the follow-up period, all eyes had complete resorption of the SRF except for a small localized subfoveal fluid (SFF) accumulation noted in 1 (3.7%) eye. In eyes with RD duration shorter than 7 days, subtle SFF was present in 2 (18.2%) eyes on initial SDOCT imaging, and all of these eyes during the follow-up period had complete SFF resolution. In eyes with RD lasting 8–14 days, RSFF was noted in 3 (37.5%) eyes and 1 (12.5%) eye on SDOCT examination after 1 and 6 months, respectively. In the eyes with RD lasting 15-30 days, RSFF was noted in 2 (40.0%) eyes and 1 (20.0%) eye on SDOCT examination after 1 and 6 months, respectively. At the end of the follow-up period, complete resolution of SRF occurred in all of these eyes. In the eyes with RD for more than one month, RSFF was present in 1 (33.3%) eye throughout the whole follow-up period. There was a statistically significant difference in the incidence of RSRF between the eyes depending on the duration of MD (p = 0.041). Figure 4 shows persistent RSFF in operated eyes.

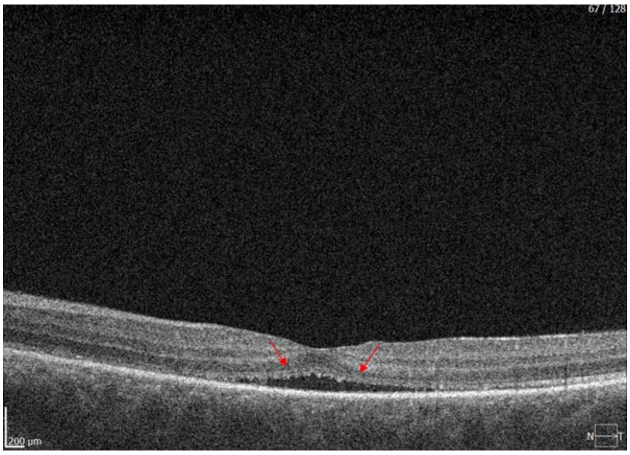

Fig. 4 – Residual persistent subfoveal fluid in operated eyes.

Cystic changes after retinal reattachment in the retinal layers were found in 4 (14.8%) eyes, 2 (7.4%) eyes, and 1 (3.7%) eye on OCT examination after 1, 6, and 12 months, respectively. Figure 5 shows cystic spaces in the reattached retina with areas of IS and OS photoreceptors and ELM disruptions.

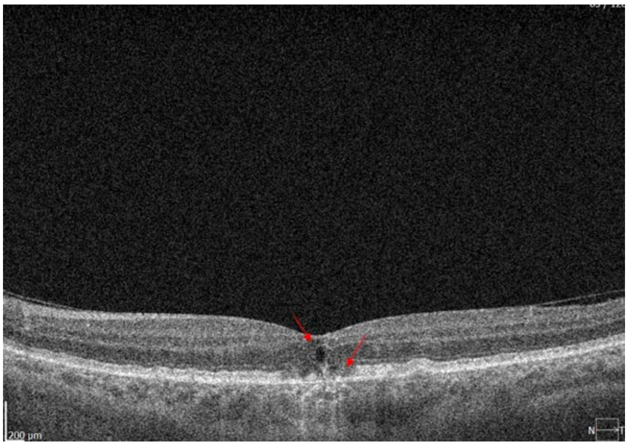

Fig 5. - Cystic spaces in reattached retina with areas of photoreceptors IS/OS and ELM disruptions. IS – inner segment; OS – outer segment; ELM – external limiting membrane.

ELM after retinal reattachment was detected in only 2 (7.4%) eyes on SDOCT examination after 6 and 12 months, and all of these eyes belonged to the group of eyes with a duration of RD longer than one month.

Discussion

A variety of histopathological changes occur during RD that may contribute to low functional success rates following retinal reattachment. Experimental RD models have shown degenerations of ORL [8, 9, 16]. RD primarily affects the photoreceptor layer, and the majority of the changes occur in this retinal layer. The central part of the macula, *fovea centralis*, mostly depends on the supply of oxygen and nutrients from the choroidal circulation [17]. The first pathologic changes in OS of the photoreceptors during RD occur due to loss of nutrition in ORL. During RD, OS and synaptic terminals of the photoreceptors and photoreceptor bodies in the ONL degenerate [18].

Even a short duration of RD can induce significant histological changes. The apoptosis of the photoreceptor can occur as early as 1–3 days after experimental RD [19]. In animal experiments, retinal degeneration tends to worsen as the detachment period increases [20]. Prolonged RD causes apoptosis and necrosis of the photoreceptors and ONL complex. These changes are irreversible [21]. Therefore, the patients may have limited visual function recovery despite successful RD repair and the absence of biomicroscopically visible alterations because of irreversible damage of photoreceptors via apoptosis which may have occurred before RD repair [9]. Loss and degeneration of photoreceptors lead to a reduction in retinal thickness. In the current study, the mean TRT of the normal eye was approximately 314 µm, while the mean TRT of affected eyes was nearly 15 µm less, demonstrating a mean reduction of 5%. In terms of average ORT, this thinning was also observed. In our study, the mean ORT of the normal eye was approximately 152 µm, while the mean ORT of affected eyes was nearly 10 µm less, demonstrating a mean reduction of 6.5%.

The overall decrease in the mean macular thickness is mainly the result of decreases in the thicknesses of ORL, including PRL, OPL, and ONL. In our study, we did not notice differences in the thicknesses of ORL among eyes with an MD duration of up to 2 weeks. However, notable additional decreases in the thickness of ORL were observed in the eyes with a longer detachment period. In our study, we revealed significant thinning of PRL and ONL in reattached retina even in the eyes with a mean duration of RD longer than 2 weeks. The thickness of outer retinal structures significantly decreased after detachment over time and correlated with the duration of RD. The significant thinning of ORL observed in the reattached region in our work agrees with the findings of previous studies [22, 23].

The structural integrity of the PRL and ONL are closely associated with visual function. Based on the previous studies, repair of a detached macula may be delayed up to 1 week without significant adverse effects on vision outcome [24, 25]. Early intervention is needed because long-term structural changes may remain despite only a few days of prolonged detachment duration. Thus, the structural changes found in our study may highlight the importance of initial injury to the retinal tissue, such as apoptosis [21].

Previous studies with 5- to 6-month follow-up periods after retinal reattachment showed gradual lengthening of the photoreceptor OS in animals with a detachment period of less than 7 days [16, 26]. Following retinal reattachment, the PRL regenerates and reestablish connections with RPE. Experimental models of RD have shown that the thickness of the outer retina increases progressively and almost normalizes after approximately 150 days after reattachment [18, 19]. In our study, in the eyes with a detachment period shorter than 2 weeks, the length of the photoreceptor OS was almost normalized at the end of the follow-up period.

With improved SDOCT technology (axial resolution of 3 µm to 5 µm), IS and OS photoreceptor disruptions were reported by several groups after the successful repair of RRD [27, 28]. On SDOCT scans, the abrupt boundary between the IS and OS junction is recognized as the back reflection. Recently, it has been suggested that the band, often attributed to the boundary between the IS and OS of the photoreceptors, may align with the ellipsoid portion of the inner segments. In this sense, the disrupted ellipsoid zone could be a marker of poor prognosis for vision recovery [12, 29]. Furthermore, ELM disruptions on SDOCT may indicate damage to the photoreceptor's nuclear bodies with their irreversible loss [4, 7, 11, 30]. In our study, in the eyes with the RD duration longer than 2 weeks before the surgery, the initial SDOCT scans acquired one month after repair of RD revealed multiple areas of IS and OS photoreceptor and ELM disruption located in the *fovea centralis*. This finding may explain the very modest vision recovery in these eyes despite successful anatomical repair.

Experimental models have shown that RD primarily affects the ORL while, at the same time, the IRL are minimally altered [31]. Only a few examiners have investigated the condition of the IRL after successful postoperative retinal reattachment, and they have reported mostly opposite results. In some studies, the thickness of IRL was normal, while other studies have shown a reduction in the IRT after successful surgery [32–34]. We evaluated NFL, GCL, and IPL thickness and found that these values were minimally lower in the eyes that underwent surgery than in the fellow eyes, and the difference was not statistically significant. It seems that neither the RD nor the surgical SB procedure significantly affects the thinning of the inner layers of the retina. In contrast, numerous studies have demonstrated a significant GCL and NFL thinning following PPV with air or silicone oil tamponade. It may be associated with additional traumatizing factors related to PPV itself, such as the surgical removal of the vitreous with loss of its protective and antioxidant function [31, 35].

Numerous previous studies have shown that after successful SB surgery, an RSRF in the *fovea centralis* can exist very often, probably due to poor adherence between the neurosensory retina and RPE. The persistent RSFF causes prolonged foveal detachments, and that may be responsible for the poor recovery of VA [5, 36]. The etiology of localized foveal detachment in patients after successful RD surgery is not clear, but it is presumed to be related to a disturbance in choroidal circulation [37, 38]. Several studies have indicated that the incidence of persistent fluid is higher if the encircling band is used during surgery. The placement of the cerclage performs circular compression in the entire equatorial zone of 360 degrees, which can disrupt choroidal circulation to a much greater extent than when only segmental scleral explant is used. The venous congestion and reduced drainage of the choroidal circulation can be caused by the overly tight encircling band. In addition, the use of cryotherapy may be responsible for the development of choroidal inflammation, which may lead to subfoveal choroidal thickening [39]. In our work, delayed SRF absorption on binocular funduscopic examination was not noted. However, initial postoperative SDOCT after 1 month revealed persistent foveal detachment in 8 eyes (29.6%), which was not clinically visible on binocular funduscopic examination. In our study, a high frequency of SRF in the early postoperative period can be explained by the fact that the encircling band was used in all patients. Initially, persistent SRF was believed to lead to a permanent reduction in BCVA after RD repair. However, studies that examined eyes with SRF over a longer period of follow-up showed that in most cases after SB surgery, there was complete resorption of SRF after 6 to 24 months without significant impact on the final visual function. Foveal detachment usually improves with time, and spontaneous resolution of SRF may take up to 12 months with corresponding postoperative improvement in VA. That could be explained by remodeling and adaptation of the choroidal vascular drainage [40]. All our patients had complete resolution of the SRF at the end of the follow-up period except for the small localized SFF accumulation noted in 1 eye (3.7%).

CME is the formation of cystic spaces within the retinal tissue, and in longstanding cases, it may disrupt the photoreceptors and other layers of the retina and cause delayed or limited vision recovery. After SB surgery, the incidence of macular edema (whether cystoid or diffuse) has been reported by other studies with a wide range of incidence of 1.58–67% [41, 42]. In our study, cystic changes in the retinal layers were found only in 4 eyes after 1 month, 2 eyes after 6 months, and 1 eye at the end of the follow-up period.

We found EMM in only 2 eyes (7.4%) on SDOCT examination after 6 and 12 months, and all of these eyes belonged to the group of eyes with a duration of RD longer than 1 month. That is significantly lower than the values recorded in the eyes that underwent PPV vitrectomy. Wakabayashi et al. [12] observed ELM in 23% of their patients who underwent PPV [43]. This is likely due to differences in surgical techniques used in their studies. Apart from using cryopexy, they also used endolaser, silicone, or intravitreal gas tamponade, which could have led to an increase in the frequency of ELM in their patients.

According to available literature data, the SB procedure is a relatively safe surgical technique that does not itself change the microstructure of the macula, except for the changes in the choroidal circulation described above that may be the cause of prolonged RSFF.

Duration of RD is a well-confirmed predictive factor for vision gain after surgery [44]. The complete reattachment of the retina and macula does not necessarily imply a full return of visual function. Reattachment of the retina does not in itself guarantee a complete recovery of macular function. Many patients may have limited vision recovery despite successful RD repair and biomicroscopically invisible retinal abnormalities, indicating irreversible damage of photoreceptors via apoptosis which may have occurred before RD repair.

The postsurgical VA gain is mostly influenced by the duration and extent of the MD and postoperative macular changes [1, 2, 9, 18]. In the eyes with detached macula preoperatively, only 37% achieve 0.4 or better VA despite an anatomic success rate of 90% [3]. The results of our study are in complete agreement with these findings. In our work, even in the eyes with a duration of MD of less than 7 days, VA gain was limited and at the end of the follow-up period mean BCVA in these eyes was 0.55 ± 0.12. The postoperative VA correlated negatively with the duration of MD. In our work, there was a statistically significant difference in postoperative VA between the eyes with a duration of preoperative MD shorter than 2 weeks and the eyes with a longer MD throughout the follow-up period. The time within 2 weeks appeared to be critical for macular recovery. Our work has shown that if the macula was detached for several weeks, vision recovery would generally be worse, and postsurgical VA, despite reattachment, would range only between 0.1 and 0.2. All this indicates that photoreceptor damage via apoptosis occurs early during RD and tends to worsen as the detachment period increases [19, 20].

The disruption of photoreceptors IS and OS, and ELM abnormalities are strongly associated with VA in the early postoperative period and the longer follow-up. Our work confirmed that the integrity of the photoreceptor IS and OS junction is an important factor for vision restoration in the eyes after the repair of macula-involving RD.

In our study, 15 eyes with postoperative BCVA of 20/60 or more had intact IS and OS junctions on initial imaging. Moreover, our results showed a statistically significant difference in the frequency of disruption of the photoreceptor IS and OS, and ELM depending on the preoperative detachment duration ($p = 0.007$). In the eyes with MD duration of up to 2 weeks, these photoreceptor changes resolved completely during the follow-up period. One year after surgery, the final SDOCT showed complete restoration of IS and OS junction that correlated with improvement in BCVA. The eyes with persistent IS and OS disruptions (mostly the eyes with a preoperative duration of RD longer than a month) had persistently poor or worsening BCVA (0.02–0.03) at 1-year follow-up. In these eyes, the postoperative SDOCT scans made one year after surgery showed permanent IS and OS junction disruptions in the subfoveal region which in some eyes were even more pronounced compared to earlier SDOCT recordings.

Our results suggest a conclusion that does not differ from the conclusions of the previously published studies. Namely, a case with a macula-off RD must receive surgical treatment within a week in order to prevent irreversible changes in macular structure and achieve the highest improvement of VA.

The limitations of our study include the relatively small number of eyes analyzed and the fact we had to rely on the anamnesis of the examined patients about the length of the preoperative macula-off period, which may not be accurate to estimate its exact duration. More comprehensive studies are needed to investigate further the effect of macula-off duration on macular morphological changes and VA.

Conclusion

The photoreceptor degeneration via apoptosis occurs early after RD and leads to a reduction in retinal thickness. The overall decrease in the average retinal thickness after successful anatomical repair of RD is the result of the decrease in the thickness of ORL, including ONL, OPL, and PRL.

In the eyes, after the anatomically successful repair of RD, the alterations of the ELM and IS and OS of photoreceptors observed on the early SDOCT scans are mostly associated with limited vision recovery. The presence of SRF on the early postoperative SDOCT images may lead to a transient decrease in visual function, but it usually appears to resolve spontaneously with long-term follow-up. The postsurgical VA gain is mostly influenced by the duration and extent of the MD. The prolonged MD leads to damage of the neurosensory tissue of the retina and especially the photoreceptors, which may explain the limited vision recovery after successful SB surgery RD repair. In order to determine possible mechanisms for vision recovery, additional clinical and histological studies are required to evaluate the long-term macular morphologic and functional changes after successful RD and MD repair.

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