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Original Article

Vessel-Sparing Rectus Plication Surgery vs Recession/Resection: A Comparative Optical Coherence Tomography Angiography (OCT-A) Analysis of Iris Vessel Density Changes

Didem Dizdar Yigit,[1] Aslı Inal,[2] Ceren Gurez,[2] Zahid Huseyinhan,[2] Tolga Yilmaz,[2] Sadik Gorkem Cevik,[2] Ozgur Artunay,[2] Muhittin Taskapili,[2] Birsen Gokyigit,[2]

[1]Department of Ophthalmology, Marmara University School of Medicine, Istanbul, Türkiye
[2]Department of Ophthalmology, Beyoglu Research and Training Hospital, Istanbul, Türkiye

Abstract

Objectives: To compare the iris vessel density results before and after rectus plication, a vessel-sparing procedure, and resection/recession surgery using a non-invasive method, optical coherence tomography angiography (OCT-A).

Methods: This single-center, prospective observational study was held in Beyoglu Eye Research and Training Hospital. Ten patients were included in the study after excluding patients with systemic or ocular diseases, nystagmus or fixation loss. The anterior segment module of the OCT-A was utilized, and the eye-tracking feature was disabled to obtain the highest image quality. OCT-A imaging was performed one day before or on the day of the surgery and within three days after surgery.

Results: Ten patients (8 females) were included in the study. Five had esotropia, meanwhile 5 had exotropia. Two patients received muscle plication in one eye, and the other three received one rectus plication and antagonist recession on the same eye. Preoperative and postoperative images were analyzed both qualitatively and quantitatively with device software and ImageJ. The vessel density near the plicated rectus decreased less after surgery. The mean preoperative and postoperative vessel densities were 53.68% and 49.62% in the plication group ($p>0.05$). However, they were 60.19% preoperatively and 54.26% postoperatively in the resection/recession group ($p=0.043$).

Conclusion: In this study, OCT-A was utilized for the first time to evaluate the qualitative and objective quantitative changes in iris vessel density after rectus plication and recession/resection surgeries. The quantitative comparisons demonstrated that the iris vessel density decreased less after vessel-sparing surgery. Iris OCT-A shows promise for evaluating changes in iris vessel density.

Keywords: Iris vessels, Image J, Optical coherence tomography angiography, Plication, Strabismus surgery

Introduction

Anterior segment ischemia (ASI) is one of the most feared complications of strabismus surgery. Fortunately, it is a rare complication mostly seen after disinsertion of more than two muscles (1). However, there are reports of ASI after disinsertion of two rectus muscles (2).

Vessel sparing techniques have improved over the years and results showed that they are equally effective as tradi-

* This study was partially (only plication patients' results) presented before in the Subspeciality Day in WSPOS, ESCRS 2023 in Vienna.

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Address for correspondence: Didem Dizdar Yigit, MD. Department of Ophthalmology, Marmara University School of Medicine, Istanbul, Türkiye
Phone: +90 530 660 08 89 **E-mail:** drdidemdizdar@gmail.com

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tional strengthening procedures (3). Plication has the advantage of sparing ciliary vessels, thus not disturbing the anterior circulation if performed carefully (1). Especially in patients with a higher risk of ASI, such as patients with previous strabismus and retinal detachment surgery history, thyroid orbitopathy, atherosclerosis, hematological disorders increasing blood viscosity, limbal conjunctival incision, vessel sparing techniques should be considered. Studies revealed that the anterior segment is less disturbed after plication surgery(1).

Plication procedure is also supported to have other advantages. There is no risk of a lost muscle, less risk of trauma and bleeding. Pattern deviations might also be corrected with a technique described as plication with transposition (4).

The gold standard to assess iris circulation is fluorescein and indocyanine angiography. However, these procedures are invasive and have risks, such as allergic reactions, anaphylaxis, and even death. In recent years, there have been a few studies on anterior segment Optical Coherence Tomography-Angiography (OCT-A) due to its non-invasive nature. (5-7). Iris vessel imaging with OCT-A still has some limitations as image artifacts, pupil movements and dark iris color. Nevertheless, it has potential for anterior vasculature imaging as well as retinal imaging.

In a study assessing iris vessel density, OCT-A detected vascular filling defects in the quadrant adjacent to the operated muscle (6). In this study, iris vessel changes were assessed with OCT-A after strabismus surgery. In addition to that, to our knowledge, it is the first study to compare vessel sparing surgery with resection/recession surgery in terms of iris vessel density on OCT-A. Comparisons were made qualitatively and also quantitatively with ImageJ. (https://imagej.nih.gov/ij/) There is no funding used and there is no conflict of interest.

Methods

Participants

This is a prospective observational study including 10 (8 females, 2 males) strabismus patients. The subjects were selected from the outpatient clinic of the strabismus unit of Beyoglu Eye Research and Training Hospital. All included patients were operated on by the same surgeon. The Institutional Review Board (IRB) approved this study as it adhered to the ethics tenets of the Declaration of Helsinki. Data acquisition and analysis were performed in compliance with the protocols approved by the Ethical Committee of Marmara University. (Ethical approval number 09.2023.821) All the subjects gave informed consent after being informed in detail.

All subjects were assessed with a detailed ophthalmological examination, including deviation angle measurements with prisms. Deviation measurements were performed by the prism occlusion test or Krimsky, according to the patient's fixation status. Inclusion criteria were to be diagnosed with strabismus, to be a candidate for strabismus operation, to be older than 18 years, not to have a history of any ophthalmological operations, and not to have a systemic disease affecting blood circulation. Exclusion criteria were to have nystagmus and other fixation problems, to have previous strabismus or other ophthalmological surgeries, and not want to sign the informed consent.

Anterior Segment OCT-A Imaging

All detailed ophthalmological examinations were made before the operation and within three days after surgery. Anterior segment OCT-A images were obtained according to tips and protocols described by Iovino et al. (5) Triton DRI-OCT (Topcon Corporation, Tokyo, Japan) was used. It is an SS-OCTA that reaches up to 100,000 A-scans per second, and the algorithm it uses is called the OCTARA. To focus on the AS, the manufacturer provides an anterior segment-specific lens and a headrest attachment. It is also recommended to disable the eye tracking feature. The 6×6 macular cube is said to be the best scan size that allows to visualize iris with vascular details (Fig. 1). It is also possible to obtain 3×3 and 9×9 scan images. Mydriatic eye drops were avoided because pupil dilation worsens the image quality. An ambient room lighting was provided to create miosis and the same light setting was used at each visit in order to avoid variations due to pupil size. We could not obtain a scan of all quadrants separately because this process was frustrating for patients, especially in the postoperative period. We obtained images of the area adjacent to the operated muscle.

Image Processing

All the OCT-A images were analyzed with two protocols. Firstly, automated vascular density software analysis was used, which was commercially available in the OCT device, performing vascular density software analysis. It was used to calculate vessel density for selected quadrants preoperatively and postoperatively.

Secondly, all the OCT-A images were processed and analysed using ImageJ and Fiji applications. All the images were converted to 8-bit grayscale images by using a predefined formula [$V=0.299R+0.587G+0.114B$ (V=Y; R=red; G=green; B=blue)] (8). Brightness was adjusted in a standardized way. So, only the bright vessels were highlighted. All images were then processed using a combination of Gaussian filters, spectral bandpass filters and intensity thresholding to remove non-specific, non-contiguous artifacts (Fig. 2). Reflectivity of the vessels was measured with the ImageJ software, by which the gray scale images' reflectivity values were given as intensity per pixel.

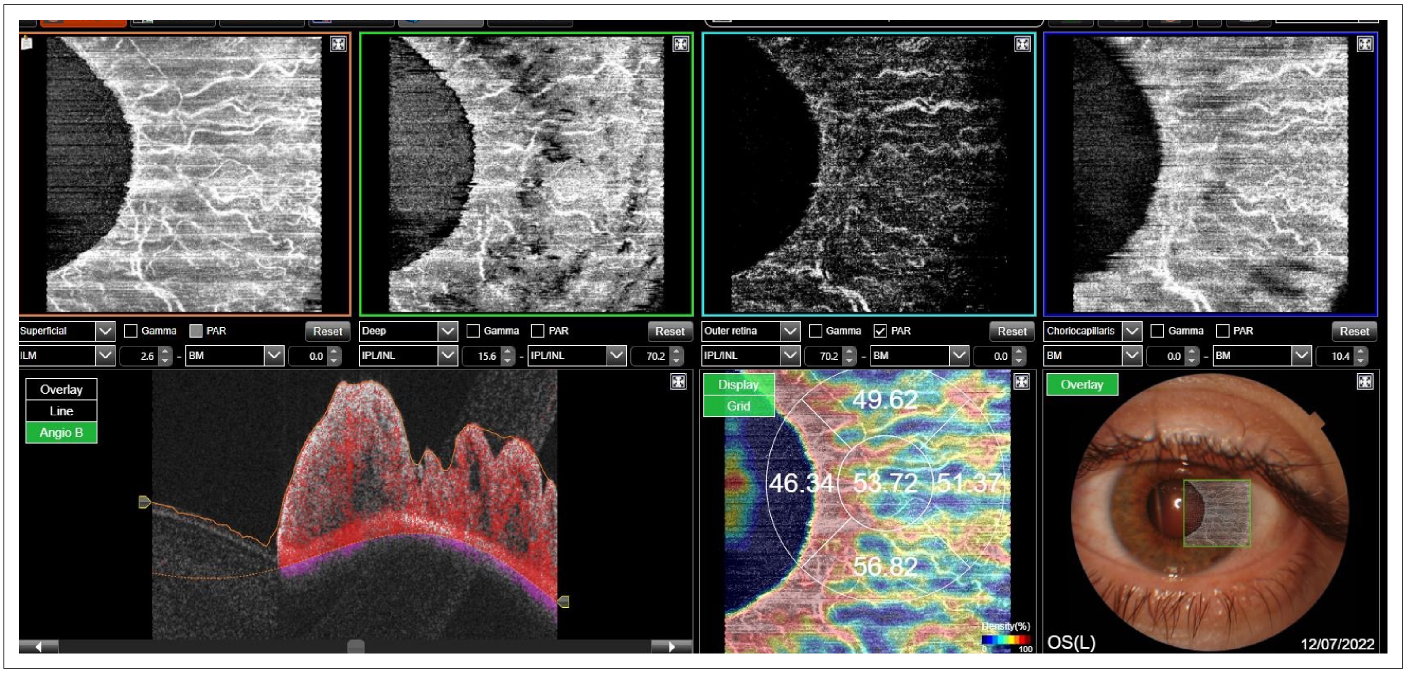

Figure 1. Preoperative 6x6 iris OCT-A images of a patient with Topcon Triton SS OCT-A device.

Statistical Evaluation

Descriptive statistics were given as mean, standard deviation, median, minimum, maximum, frequency, and ratio values where relevant. The distribution of data was analyzed with the Shapiro-Wilks test. The distribution of data did not meet the condition of normality. Non-parametric tests were used. The Wilcoxon test was used in the analysis of dependent quantitative data. The chi-square test was used to analyze qualitative independent data, and the Fischer test was used when the chi-square test conditions were not met. The analysis was made using the SPSS program version 28.0 (SPSS Inc, Chicago, IL). The significance level was set as p<0.05.

Results

The participants of this study were 80% female (n=8) and 20% (n=2) male, whose mean age was 38±15 (Median: 44, 17-60) years. The clinical characteristics of the patients and operations were given in Table 1. The mean visual aquity (Snellen) was 0.80±0.32 (Median: 1, Min-Max: 0.05- 1) in the right eyes, and 0.73±0.40 (Median: 1, Min-Max: 0.05-1) in the left eyes of the subjects. Mean pre-oparative angle of deviation (AD) was 36.5±14.73 (Median: 30, 20-60) prism diopters (PD) in near, and 36.6±16.89 (Median: 35, 16-70) PD in distance. Post-operative mean AD in near was 11.6±11.19 (Median: 11, 0-30) PD and 11.0±9.33 (Median: 12, 0-25) PD in distance.

Preoperative and postoperative vessel density measurements obtained by using the OCT-A internal software and image processing tool, Image J, are given in Table 2. It was noted that in resection/recession patients, the mean vessel density was reduced up to 6% postoperatively (Fig. 3). Even though it did not reach statistical significance, a reduction of up to 4% in the mean vessel density was also noted in the plication group. The measurements with Image J show

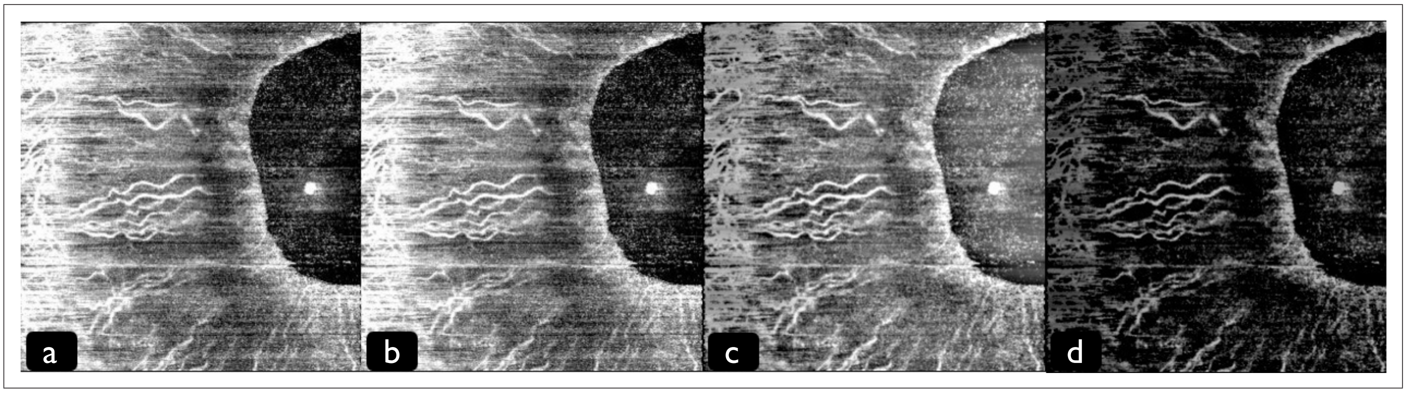

Figure 2. (a) 6x6 iris OCT-A image **(b)** Image transformed into 8-bit version **(c)** After bandpass filters applied **(d)** After brightness adjustment.

Table 1. Vessel density measurement with internal software in OCT-A device and Image J

	Preoperative Median (Min-Max) Mean±SD	Postoperative Median (Min-Max) Mean±SD	p*
Software			
Plication	61.64 (59.75- 69.63) 64.0±4.42	64.20 (59.75-69.62) 63.81±4.16	0.89
Resection-Recession	65.08 (62.15- 76.49) 66.92±5.86	60.16 (53.72-69.66) 60.37±5.23	0.08
Image J			
Plication	52.69 (42.99-66.96) 53.68±9.84	49.38 (39.31-60.01) 49.62±8.46	0.08
Resection-Recession	62.66 (24.52-90.22) 60.19±28.02	59.88 (15.66-89.66) 54.26±32.42	**0.043**

*Wilcoxon signed ranks test.

that there was a reduction in vessel densities in both groups, but the reduction in vessel density in the resection/recession group reached a statistically significant level (p=0.043).

Discussion

After strabismus surgery, what happens to iris circulation fed by anterior ciliary and long posterior ciliary vessels has been an interesting subject since years. First, researchers examined the iris vessels by fluorescein angiography and indocyanine angiography, which are still the gold standard to visualise iris vessels. It has been shown that a certain amount of iris filling defects might be seen postoperatively, especially at the quadrant adjacent to the operated muscle (6). It is also hypothesised that two long posterior ciliary arteries running in the horizontal recti, make horizontal midline more resistant to ischemia compared to vertical quadrants.

Even though it is a rare complication, anterior segment ischemia is a significant risk when several rectus muscles are included in the operation plan. This complication might have mild symptoms as mild iritis or severe changes, such as iris atrophy, keratopathy, posterior synechiae, cataracts, and phthisis bulbi (9).

In order to prevent postoperative ischemia, vessel sparing techniques as muscle-to-sclera plication have been studied in terms of effectiveness and safety (3). Not only was plication found as effective as resection, but it was also found to have other advantages as no risk of lost muscle, reversibility, relative simplicity and shorter operation time, less risk of trauma and hemorrhage (10).

The changes in the blood circulation of the anterior segment after muscle-to-sclera plication, recession and resection were investigated with iris angiography studies. It was shown that plication spared the ciliary muscles and blood circulation, especially in horizontal rectus operations (1). However, in a clinical setting, we know that it is difficult to perform iris angiography due to multiple obstacles, such as its invasive nature and the need for a skilled technician. It is also time-consuming. Because the iris is the slowest filling circulation compared to the choroid and retina and more time is needed to visualise the vessels (11). Another limitation is it can not be performed in patients with an allergy to dye, liver or kidney diseases and pregnant women (5).

Despite its own limitations, it was noted that iris OCT-A can produce high-resolution cross-sectional images, allowing visualization of iris circulation. In the near future, it has the potential to be improved with an eye-tracking system and sophisticated segmentation software (5). It has already been

Table 2. Characteristics of patients included in the study

Patient	Sex	Age	VA (RE)	VA (LE)	Operation	Preop AD N (PD)	Preop AD D (PD)	Postop AD N (PD)	Postop AD D (PD)
No. 1	F	48	1	1	L/MR 4.5 mm rec+LR 5 mm res	30	30	0	0
No. 2	F	52	1	1	R/MR 5 mm rec+LR 6 mm plic	30	40	6	12
No. 3	F	60	0.7	0.7	R/LR 6 mm plic	25	20	12	12
No. 4	F	44	1	1	L/MR 5.5 mm rec+LR 5 mm plic	55	40	30	25
No. 5	F	44	0.7	0.05	L/MR 6.5 mm plic	60	70	30	25
No. 6	M	45	1	1	L/MR 5 mm plic+LR 7 mm rec	45	50	0	0
No. 7	F	27	1	0.05	L/LR 7.5 mm rec+MR 6 mm res	50	50	14	14
No. 8	F	25	1	1	L/LR 4.5 mm rec+LR 5 mm res	30	30	10	8
No. 9	M	17	0.5	0.5	R/LR 6 mm plic	20	20	14	14
No. 10	F	20	0.05	**1**	R/LR 6 mm rec	20	16	0	0

VA: Visual acuity, RE: Right eye, LE: Left eye, F: Female, M: Male, AD: Angle of deviation, N: Near, D: Distant, MR: Medial rectus, LR: Lateral rectus, Rec: Recession, Res: Resection, Plic: Plication.

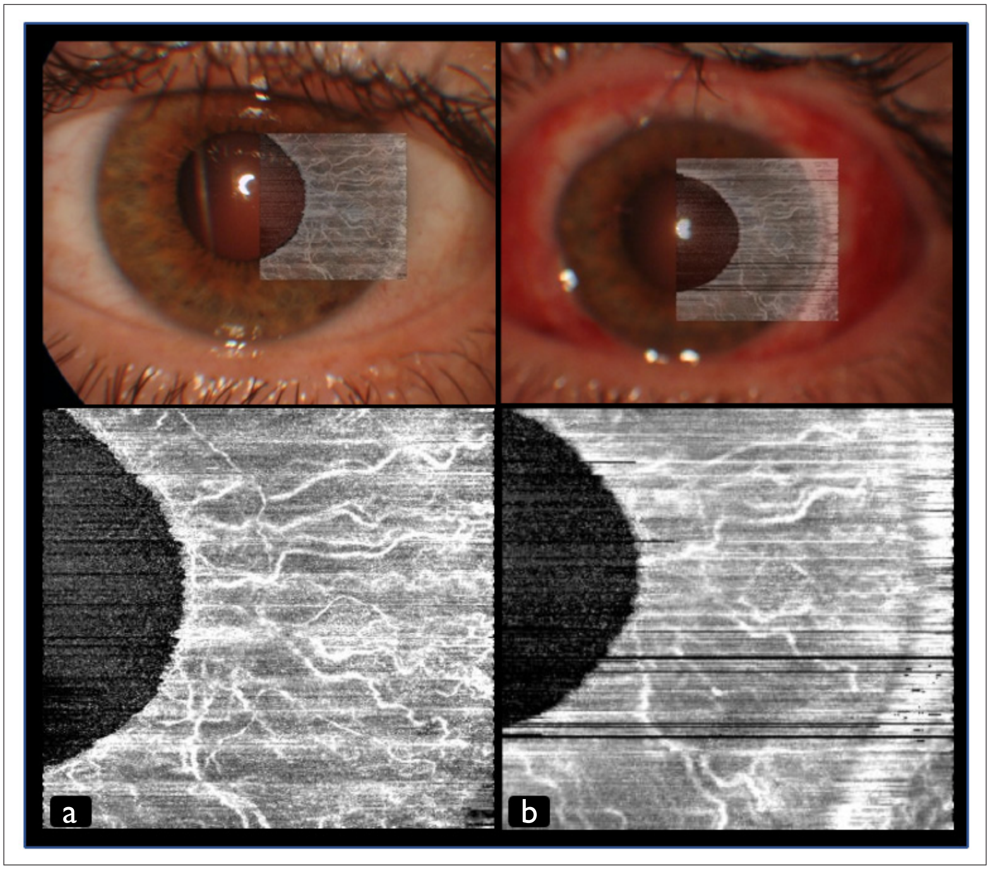

Figure 3. (a) Preoperative and **(b)** Postoperative 6x6 iris OCT-A images of a patient before and after lateral rectus recession.

studied in patients with anterior segment ischemia risk and after recession/resection surgeries. (6,12). However, to our knowledge, it is the first study comparing plication and resection/recession surgeries with OCT-A both qualitatively and quantitatively with Image J. Iris OCT-A has advantages like non-invasive, fast image capture. On the other hand, it has limitations, such as no eye tracking and no sequential image registration, which leads to artifacts and difficulty in locating the same area of interest. Secondly, the ocular tissue refraction affecting anterior OCT-A image parameters. Thirdly, non-parallel segmentation and pigment epithelium induced a mirror artifact. Moreover, the iris vessel caliber, density and tortuosity is affected by pupillary dilation, and despite trying to have the same ambient illumination conditions, pupil size is not constant during imaging. All of these factors have an influence on reproducibility and comparisons (5,12).

In this study, we used a swept-source OCT-A (SS OCT-A) system with a longer wavelength (1050 nm), enabling better penetration to deeper layers of the eye (13). It is a serious problem to obtain good-quality OCT-A images in pigmented irides. Ang et al. compared spectral domain OCT-A to SS OCT-A in showing iris neovascularization and normal vasculature in pigmented irides. They concluded that both systems were comparable in showing superficial neovascularizations, but SS OCT-A was better in visualizing normal iris vessels in stroma of pigmented irides (14). Thus, unlike previous studies on anterior segment circulation after strabismus surgeries, we did not use spectral domain OCT-A. Triton SS OCT-A was used in this study to better visualization in pigmented irides.

The vascular density calculated by OCT-A software is sensitive to variation in location and programmed to detect vessel segmentations in the posterior segment of the eye. Without eye tracking and modifications for anterior segment vessel segmentation, these calculations are not very reliable and reproducible. On the other hand, we found similar vascular densities to those found by Velez et al. and Vanlangenaeker et al (6,12). In the subgroup analysis of 3x3 images, Vanlangenaeker et al. found a mean decrease of 4.622%, which were mostly observed adjacent to recessed rectus areas. These findings were comparable to our results.

It was noted that both with internal software and Image J measurements, postoperatively, there is a decrease in vessel density in vessel sparing and non-sparing techniques, 6% and 4%, respectively. The clinical implication of this immediate decrease on the anterior segment is not known (12). Al-though the difference does not always reach a level of statistical significance, the vessel sparing technique seems to affect anterior segment circulation less. Previous iris angiography studies have shown this result. After image processing, our results supported angiography findings as the vessel density decrease in the vessel sparing technique was less (p=0.043).

Conclusion

In our study, image processing software, ImageJ, was used in order to compare internal software measurements and to compare preoperative to postoperative vessel densities. Standardized image processing techniques, described in the literature, were used to clean various artifacts (7). The results obtained with image processing techniques also supported measurements of internal software.

The advantages of this study are that first time in the literature vessel sparing and recession/resection techniques were compared in terms of anterior circulation changes. A non-invasive OCT-A technology and image processing were used. On the other hand, the limitations of this study were its small sample size, not including the long-term effects of surgery and not comparing OCT-A results with conventional iris angiograms.

To conclude, with this study, the iris vessel density changes in OCT-A after different surgical techniques were compared for the first time with an objective qualitative method. In the future, anterior segment OCT-A might be used more frequently after some modifications, such as eye tracking and anterior segment-adjusted software systems.

Disclosures

Ethics Committee Approval: This study was approved by the Marmara University Ethics Committee (Date: 25.09.2023, Number: 09.2023.821) and conducted in accordance with the tenets of the Declaration of Helsinki.

Informed Consent: Informed consents were obtained from all patients.

Conflict of Interest: None declared.

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Author Contributions: Concept – D.D.Y., A.I., C.G., Z.H., T.Y., S.G.C., O.A., M.T., B.G.; Design – D.D.Y., A.I., C.G., Z.H., T.Y., S.G.C., O.A., M.T., B.G.; Supervision – D.D.Y., A.I., C.G., Z.H., T.Y., S.G.C., O.A., M.T., B.G.; Resource – D.D.Y., A.I., C.G., Z.H., T.Y., S.G.C., O.A., M.T., B.G.; Data Collection and/or Processing – D.D.Y, A.I., S.G.C.; Analysis and/or Interpretation – D.D.Y, A.I., S.G.C.; Literature Search – D.D.Y.; Writing – D.D.Y.; Critical Reviews – D.D.Y, A.I., S.G.C.

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