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Original Article

Swept-Source Optical Coherence Tomography and Optical Coherence Tomography Angiography Findings in Patients with Solar Retinopathy

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Abstract

Objectives: Solar retinopathy is a retinal disease caused by exposure to ultraviolet radiation from sunlight, primarily affecting the outer retinal layers, including photoreceptors and the retinal pigment epithelium. This cross-sectional study aimed to present the optical coherence tomography (OCT) and OCT angiography (OCTA) findings in patients with solar retinopathy.

Methods: Fourteen eyes from 11 patients with a history of solar exposure during a partial solar eclipse were included. OCT and OCTA were performed and parameters including central macular and choroidal thickness, outer retinal defect thickness, retinal pigment epithelium (RPE)-Bruch membrane thickness, outer retinal defect area on en face OCT, OCTA foveal avascular zone area, and vessel density in the central fovea were measured. Their correlation with the visual acuity (VA) was investigated.

Results: Hyporeflective outer retinal defects including the ellipsoid and interdigitation zones were observed in all eyes in B scan and en face structural OCT. OCTA indicated a normal vascular pattern with no choriocapillaris flow deficits corresponding to the outer retinal defects. A significant positive correlation was found between VA and RPE-Bruch membrane thickness under the outer retinal defect. There was no significant relationship between VA and other OCT and OCTA parameters.

Conclusion: The outer retina is affected in solar retinopathy. En face structural OCT enables the measurement of the area of outer retinal defect. The significant relationship between VA and RPE-Bruch membrane thickness suggests that this may be an indicator of severity.

Keywords: Optical coherence tomography angiography, optical coherence tomography, solar retinopathy

Introduction

The detrimental effects of staring at the sun have been acknowledged for a long time. The term used to characterize the retinal damage due to exposure to ultraviolet (UV) from solar radiation referred to as solar retinopathy (1). Evaluating solar retinopathy prevalence is not easy because many individuals who engage in unprotected sun viewing do not seek medical attention. Also diagnosing a patient with this pathology in the chronic phase proves challenging even evaluated by an ophthalmologist (1,2). The outer retinal layers including photoreceptors and the retinal pigment epithe-

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lium (RPE) are especially susceptible to the toxicity of UV radiation from sunlight (3). UV radiation primarily induces damage to the retina through the photochemical pathway (4). In the photochemical pathway, chemical damage occurs through various mechanisms, including the generation of reactive oxygen species and oxygen-dependent toxicity (1,2,4). Generation of free radicals results in lipid peroxidation and damage to tissues. The prognosis for solar retinopathy is generally positive, with most cases experiencing full recovery. Nonetheless, a notable proportion of patients may encounter persistent consequences, such as diminished visual acuity (VA) and lifelong central/paracentral scotomas. Despite the subjective improvement observed, there are irreversible changes in the external retina that can be demonstrated through retinal imaging in the majority of cases (2,5).

Optical coherence tomography (OCT) has emerged as a cornerstone in the diagnosis of various retinal disorders including solar retinopathy, offering high-resolution cross-sectional images that reveal alterations in the retinal layers and the RPE. This modality is very useful in detecting subtle retinal changes in solar retinopathy (6,7). OCT imaging studies mostly report defects in the outer retinal layers, mostly in photoreceptor and RPE cells (8,9). The abnormalities observed in the ellipsoid zone (EZ) and interdigitation zone (IZ) are occasionally referred to as outer retinal holes or defects (5,9). The studies reported a discrepancy between OCT findings and VA in patients with solar retinopathy, and the features detected through OCT demonstrated only a limited correlation with VA (5,9). OCT angiography (OCTA) is a valuable non-invasive imaging technique for identifying vascular abnormalities in retinal diseases, offering detailed insights into the retinal vasculature. There is a limited body of research on OCTA findings in patients with solar retinopathy (10). This study aims to present the OCT and OCTA findings in patients with solar retinopathy and explore the relationship between OCT and OCTA parameters and VA.

Methods

This cross-sectional study was conducted at the Ophthalmology Department of Niğde Ömer Halisdemir University Training and Research Hospital. The study was conducted in alignment with the principles set forth in the Declaration of Helsinki. The Non-Interventional Clinical Research Ethics Committee of Niğde Ömer Halisdemir University granted approval for the research (No: 2023/84). Comprehensive details regarding the procedures were communicated to all participants or their parents/legal representatives, and informed consent was obtained through written documentation as well as verbal communication.

The clinical identification of solar retinopathy was based on a patient's reported history of direct sunlight exposure during eclipse without eye protection, coupled with the subsequent onset of symptoms like a scotoma in the visual field or a discernible decline in VA. The diagnostic confirmation involved the utilization of OCT to visualize the presence of outer retinal damage in the affected eyes. Individuals with pre-existing retinal conditions or a history of retinal surgeries were excluded from the study. All participants underwent a comprehensive ophthalmologic assessment, encompassing the evaluation of best-corrected VA, biomicroscopic examination of the anterior segment, measurement of intraocular pressure, and examination of the fundus. For retinal imaging, color fundus photography was performed using TRC-50DX retinal camera (Topcon Corporation, Tokyo, Japan). OCT and OCTA imaging were performed using Triton™ DRI swept-source OCT (Topcon Corporation, Tokyo, Japan).

Analysis of OCT and OCTA Images

For OCT imaging, a radial macular scan was conducted using a 1,024 × 12 scan protocol, incorporating 12 radial scan lines centered on the fovea. Each of these lines comprised 1,024 A-scans, each with a length of 6 mm. IMAGEnet 6 software (Topcon Medical Systems, Inc.) was used for analysis. The software can produce thickness maps based on the conventional early treatment diabetic retinopathy study grid. This grid comprises inner and outer rings with diameters of 1–3 mm and 3–6 mm, respectively, producing nine sectors that include inner and outer sectors for each of the temporal, superior, inferior, and nasal regions, along with a central sector. Macular and choroidal thickness values were derived from the measurements obtained in the central sector of the thickness maps. The thickness of outer retinal defects (vertical depth) and the thickness of the RPE-Bruch membrane were also measured from OCT scans passing through the fovea. The OCT device's internal software measurement tool was used for these measurements.

Patients underwent OCTA imaging with a volume scan pattern of 3 mm × 3 mm, centered on the fovea. Automated segmentation of the device was employed to delineate specific retinal and choroidal layers, including the superficial capillary plexus (SCP) (from the internal limiting membrane to 15.6 μm below the junction between the inner plexiform and inner nuclear layers, IPL/INL), the deep plexus (from 15.6 μm below IPL/INL to 70.2 μm below IPL/INL), the outer retina (extending from 70.2 μm below IPL/INL to the Bruch membrane, BM), and the choriocapillaris (from BM to 20.8 μm below BM). The SCP and deep capillary plexus (DCP) slabs of each eye were analyzed using open-access software ImageJ/Fiji (11). The area of the foveal avascular zone (FAZ) was manually measured in square millimeters for the superficial (SCP) and DCP using the freehand tool in ImageJ. This involved connecting points along the edge of the capillary network in the foveal area. The vascular density (VD) of the

SCP was automatically measured using IMAGEnet 6 software (Topcon Medical Systems, Inc.). The software generates a VD map featuring a central region enclosed by a 1 mm diameter circle, surrounded by a ring with diameters of 1 to 2.5 mm. For our analysis, we focused on the vessel density within the central area. Vessel density values were determined as the ratio of the angiography signal to the total area in this specified region.

Structural en face OCT images of the outer retina were examined and the area of the hyporeflectivity seen in the outer retina was measured using OCT device's internal software measure tool.

Statistical Analysis

Statistical analyses were performed using the Statistical Package for the Social Sciences version 20.0 (IBM Corporation, Armonk, NY). Descriptive statistics for quantitative data were expressed as means±standard deviations, and qualitative data were presented as percentages. Spearman's correlation analysis was employed to evaluate the association between VA and the measured parameters obtained from OCT and OCTA. Statistical significance was defined as $p<0.05$.

Results

Individuals with a prior experience of observing the partial solar eclipse on October 25, 2022, and subsequently reporting issues such as scotoma in the visual field or reduced VA were subjected to evaluation upon presenting to the ophthalmology department. The study comprised 14 eyes from 11 patients (7 males and 4 females), who had examination and imaging results consistent with solar retinopathy. The average age of the study participants was 30.4±16.2 years, with a range from 13 to 55 years. The mean duration from solar exposure to presentation was 60.8±35.5 days, ranging from 21 to 135 days. Three cases exhibited bilateral solar retinopathy, while in 8 cases, unilateral solar retinopathy was present. The anterior segment examination revealed normal findings in all eyes. Fundus examination disclosed the absence of foveal reflex in four eyes, while the remaining eyes exhibited no abnormalities. The VA in the 11 affected eyes varied between 20/80 and 20/20, with five eyes having a Snellen VA of 20/20.

All eyes exhibited a focal outer retinal defect on B-scan SS-OCT, characterized by the absence of the EZ and interdigitation zone in the fovea (Fig. 1). The external limiting membrane anterior to the lesion displayed mild hyperreflectivity. There were no abnormalities detected in the inner retinal structures within the fovea. The mean vertical depth of the outer retinal defect was 54.2±8.5 µm, with a range extending from 33 to 65.0 µm, and the mean thickness of the RPE-Bruch membrane was 37.4±5.4 µm ranging from 26.0 to 49.0 µm (Fig. 2). In en face structural OCT, a focal defect in the outer retina was present in all affected eyes. The shape of this defect differed among the eyes affected. The mean area of the defect was 13.14±6.24 μm^2 ranging from 3.51 to 22.59 μm^2 (Fig. 3). The mean central macular thickness was 219.9±17.48 µm and the mean central choroidal thickness was 329.4±74.0 µm.

The OCTA results indicated a typical normal vascular pattern in the retinal layers. The superficial and deep capillary plexi showed no signs of non-perfusion or dilatation, and there were no observed flow deficits corresponding to the outer retinal defects in the choriocapillaris (Fig. 4). The mean superficial FAZ area was 0.341±0.137 mm^2 and the mean deep FAZ area was 0.437±0.136 mm^2. The mean vessel density in the central fovea for the superficial retinal layer was 18.3±6.1%.

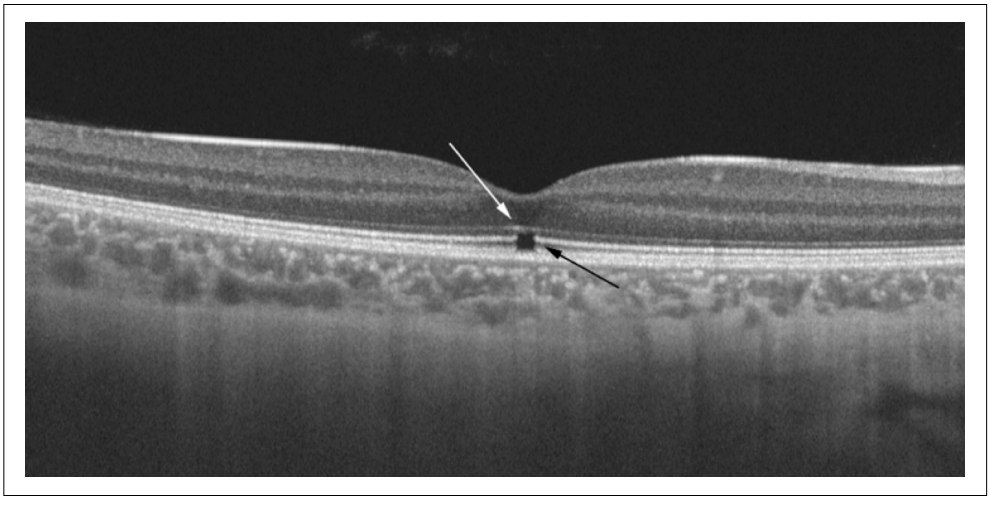

Figure 1. Optical coherence tomography image of a patient showing a focal outer retinal defect (black arrow) and mild hyperreflectivity of the external limiting membrane anterior to the defect (white arrow).

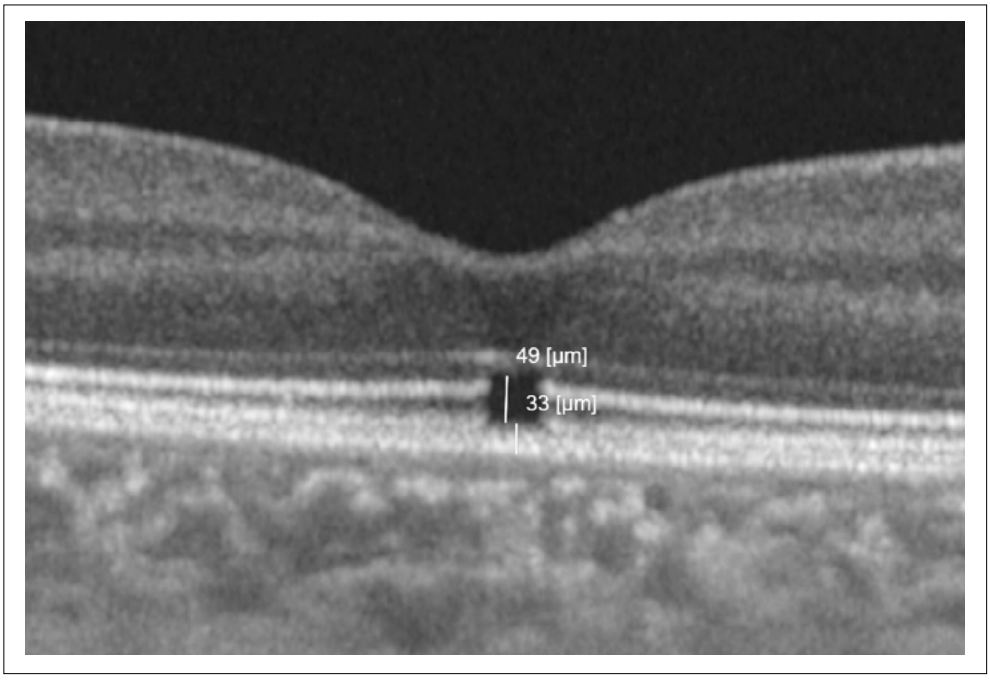

Figure 2. This optical coherence tomography image illustrates the measurement of the vertical depth of the outer retinal defect and the thickness of the retinal pigment epithelium-Bruch membrane under the defect.

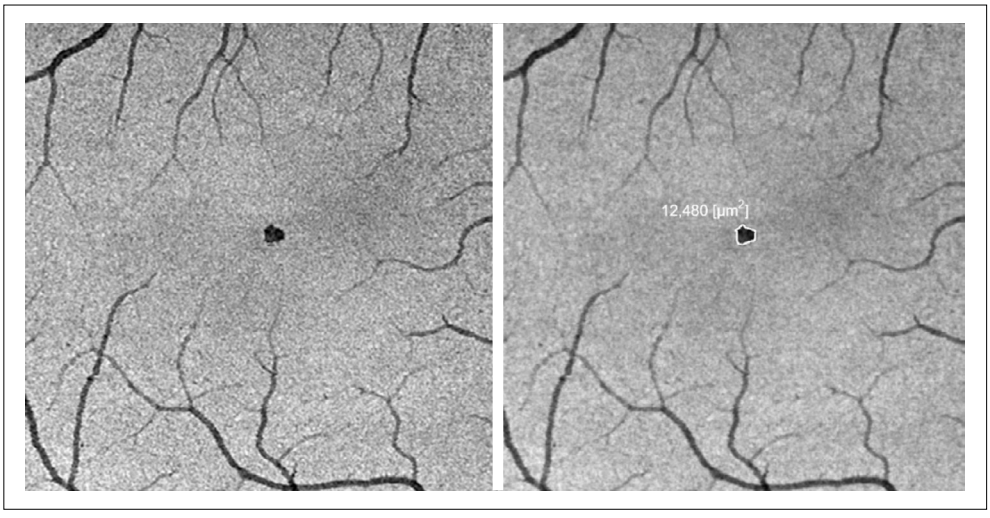

Figure 3. En face structural optical coherence tomography of a patient showing a focal defect in the outer retina accompanied by measurement of the defect area.

Spearman's correlation analysis was performed to assess the relationship between VA (logMAR) and the measured parameters from OCT and OCTA (Table 1). The results revealed a significant moderate positive correlation between VA and RPE-Bruch membrane thickness (r_s [12] = 0.57, p=0.032). However, no significant relationship was observed between VA and the other evaluated parameters.

Discussion

In this study, we presented the clinical and structural findings observed in a group of individuals with solar maculopathy. Outer retinal defects were observed in all affected eyes, as indicated by both B-scan and en face OCT. The defects included the EZ and interdigitation zone in the outer retina. Previous studies (5,12,13) also reported that the outer retinal layers were mostly affected by solar retinopathy. Mild

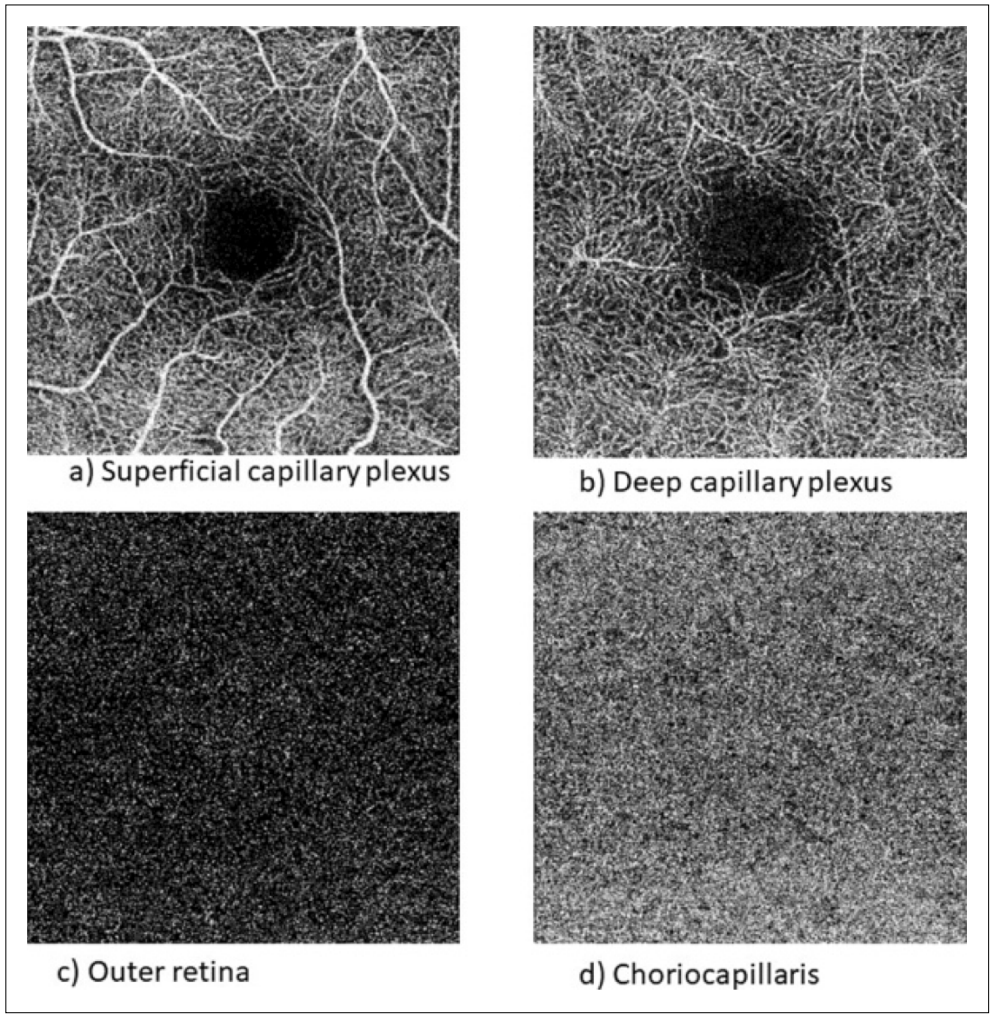

Figure 4. En face optical coherence tomography angiography images of a patient showing a typical normal vascular pattern in the retinal layers. Superficial capillary plexus **(a)**, deep capillary plexus **(b)**, outer retina **(c)**, choriocapillaris **(d)**.

Table 1. Spearman rank correlations for visual acuity and OCT-OCTA parameters

OCT and OCTA parameters	Correlation coefficient	p
Central macular thickness (μm)	-0.23	0.427
Central choroidal thickness (μm)	-0.25	0.382
Outer retinal defect thickness (μm)	-0.19	0.518
RPE-Bruch membrane thickness (μm)	0.57	0.032
Defect area on en face OCT (μm^2)	0.03	0.925
OCTA FAZ area (SCP) (mm^2)	0.31	0.283
OCTA FAZ area (DCP) (mm^2)	0.28	0.334
Vessel density in the central fovea	-0.33	0.257

RPE: Retinal pigment epithelium; FAZ: Foveal avascular zone; SCP: Superficial capillary plexus; DCP: Deep capillary plexus; OCT: Optical coherence tomography; OCTA: Optical coherence tomography angiography.

hyperreflectivity of the external limiting membrane was also present in the affected eyes in our study. This finding was also reported by Chen et al. (14) We did not observe changes in the inner retinal layers in the current study. While certain studies did not detect inner retinal injury, others reported damage to the inner retinal layer at a lower rate in cases of solar retinopathy (5,6). Damage to the inner retinal layers was also proposed as a risk factor for poorer VA in patients with solar retinopathy (12).

We used en face structural OCT to identify and measure the area of the outer retinal defect. The study eyes exhibited hyporeflective outer retinal defects of varying sizes. Several other studies, (8,15) primarily comprising case reports, similarly described hyporeflective circular focal defects in the outer retina in en face OCT images. En face OCT imaging is suggested as a more effective imaging technique, given its comprehensive coverage of the macular region, thereby minimizing the risk of overlooking macular lesions. It has the

capability to confirm the existence of outer retina defects in solar retinopathy, even in cases where the B-scan OCT scan fails to traverse the foveal defect (15). It was proposed as a sensitive means to measure the extent of EZ loss, allowing for longitudinal tracking (8). In a case study, Wu et al. (16) described a circular zone of hyperreflectivity in the en face OCT image of the outer retina, along with central hyporeflectivity in a patient with acute solar retinopathy. In addition, a corresponding change was noted in the choriocapillaris region, appearing as a hyporeflective area. These observations were not evident in our case series. The disparity may stem from the acute nature of their case, contrasting with our series that comprised patients with a minimum of 3 weeks since solar exposure.

OCTA imaging indicated a typical normal vascular pattern in the retinal vascular layers, with no flow deficits corresponding to the outer retinal defects observed in the choriocapillaris layer in this study. There is limited research employing OCTA in individuals with solar retinopathy, and the available studies predominantly consist of case reports (1). In a case of acute solar retinopathy, Wu et al., (16) reported that OCTA images of the patient were normal. In a patient with chronic solar retinopathy, Goduni et al. (8) observed relatively symmetrical FAZs and slight vessel tortuosity using OCTA, with the superficial and DCP appearing normal. In a case of acute photic retinopathy induced by a laser pointer, Tabatabaei et al., (17) noted that OCTA revealed a typical vascular pattern in retinal layers but exhibited a distinct low-signal area in the choriocapillaris layer. The difference in OCTA findings between our findings and this laser-induced maculopathy case may be due to lasers' higher energy levels, potentially causing thermal or disruptive damage. Solar maculopathy, on the other hand primarily caused by photochemical damage, involves cellular harm from reactive oxygen species, with the local temperature increase insufficient to induce thermal damage (1,18,19). The reports also indicate that the damage induced by lasers is more severe and thermal effects may extend beyond the RPE to involve the choriocapillaris (20,21).

We calculated Spearman rank correlations to examine the correlations between VA and OCT-OCTA parameters. In the correlation analysis, the only parameter with a statistically significant correlation with VA was the RPE-Bruch membrane thickness under the outer retinal defect. No significant relationships were observed between VA and the other evaluated parameters. Some of the previous studies have reported a correlation between VA and foveal thickness (6,22). Other research has indicated that visual symptoms may not consistently align with findings observed through OCT (9). In a study involving patients with photic retinopathy caused by sun gazing and welding, Kumar et al. (5) found a weak correlation between the thickness and horizontal dimensions of the outer retinal defect and VA. Their conclusion was that ultrastructural features assessed through OCT have limited correlation with either initial or eventual VA. We also assessed central macular thickness, central choroidal thickness, outer retinal defect thickness, and defect area, finding no correlation with VA. OCTA superficial and deep FAZ area and vascularity were also not correlated with VA. Regarding RPE, it was suggested that in cases of severe photochemical damage extending to the RPE, the probability of recovery decreases, and a tendency for progressive RPE remodeling may emerge (8). The observed correlation between the thinning of the RPE-Bruch membrane and reduced VA in our study suggests that it may indicate more severe damage resulting from solar retinopathy, leading to lower VA.

There are some limitations and strengths of the study. First, the study involved a relatively small sample size, comprising 14 eyes from 11 patients. A larger cohort might enhance the generalizability of the findings and provide a more comprehensive understanding of solar retinopathy but it is crucial to note that solar retinopathy is relatively rare, making it challenging to gather a larger cohort. Second, the study design is cross-sectional, limiting the ability to establish causation or explore changes over time. Longitudinal studies would be valuable in tracking the progression or resolution of structural changes. Another limitation of our study is that FAZ measurements for both the superficial and deep capillary plexuses were performed manually using the freehand tool in ImageJ. Although automated methods are available, we chose manual measurement to ensure greater control over FAZ boundary delineation and to overcome potential segmentation artifacts. Nevertheless, manual tracing may introduce observer-dependent variability. In addition, the vertical measurement of outer retinal defect thickness encompassed multiple microstructural components – such as the EZ, interdigitation zone, myoid zone, and photoreceptor outer segments – which may limit the ability to interpret the specific contribution of each individual layer. The strengths of the study include the comprehensive approach used in the study, combining clinical examination with OCT and OCTA to provide a thorough evaluation of solar maculopathy. In addition, our study focused exclusively on solar retinopathy cases, excluding other causes of photic retinopathy, which adds specificity to our research.

Conclusion

In conclusion, our study assesses clinical and structural findings in solar maculopathy, revealing consistent outer retinal defects, especially in the ellipsoid and interdigitation zones. En face structural OCT proves valuable for precise evaluation, offering advantages over traditional B-scan OCT ca-

pabilities. OCTA showed a normal vascular pattern with no choriocapillaris flow deficit corresponding to the outer retina defects. The correlation analysis indicates a significant link between VA and RPE-Bruch membrane thickness under the outer retinal defect, suggesting its potential as an indicator of severity. At present, no proven treatment exists, making prevention of solar retinopathy the most effective strategy. Further research is needed to understand long-term effects and refine diagnostic and management strategies for solar retinopathy.

Disclosures

Ethics Committee Approval: This study was approved by the Niğde Ömer Halisdemir University Ethics Committee (Date: 10.11.2023, Number: 2023/84) and conducted in accordance with the tenets of the Declaration of Helsinki.

Informed Consent: Written informed consent was obtained from all patients.

Conflict of Interest: None declared.

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