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Selected Retinal and Choroidal Parameters Assessed by Optical Coherence Tomography and Optical Coherence Tomography Angiography in Patients With Obstructive Sleep Apnea

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Statistical Analysis C
Data Interpretation D
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Background: The aim of this study was to assess selected retinal parameters and choroidal thickness in patients with obstructive sleep apnea.

Material/Methods: Forty-nine patients (98 eyes) were included in this prospective cross-sectional study: 33 patients with moderate or severe OSA (66 eyes) and 16 controls with no or mild OSA (32 eyes). Control and study group participants were classified according to polysomnography results. Foveal avascular zone parameters, vessel density of the superficial (SVD) and deep (DVD) capillary plexuses in the macular region, and choroidal thickness were assessed using the AngioVue Imaging System (Optovue). Results were compared between the study and control groups. Correlations between age and these measurements were calculated.

Results: There were no significant differences in SVD or DVD between the groups (all *P*>0.05). Foveal avascular zone area and perimeter were significantly larger in the OSA group than in controls (*P*=0.0163 and *P*=0.0236, respectively). No significant differences were observed in foveal vessel density within 300 µm (FD-300) values (*P*=0.2852). Choroidal thickness measurements were significantly higher in the OSA group overall (*P*=0.0054), although these values showed a moderate negative correlation with age (r=-0.36, *P*=0.0002).

Conclusions: Subtle retinal microvascular alterations and increased choroidal thickness in OSA may indicate an impact of intermittent hypoxia on ocular structures. The relatively small study sample represents a limitation of the study.

Keywords: **Choroid • Ophthalmology • Optical Imaging • Retina • Sleep Apnea Syndromes**

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Introduction

Obstructive sleep apnea (OSA) is a disorder characterized by repeated collapse of the upper airway during sleep, which may partially limit or completely block airflow [1]. Early diagnosis of OSA is crucial to improve sleep quality and reduce associated health risks. One of the primary diagnostic tools is polysomnography (PSG), a comprehensive sleep study that records various functions of the respiratory system [2]. Whereas PSG remains the gold standard in the diagnostic process, respiratory polygraphy is a less complex alternative. However, it may underestimate apnea-hypopnea index (AHI) values, which can potentially affect clinical decisions, particularly in mild to moderate cases [3].

OSA severity is commonly assessed using the AHI, which represents the number of apneas and hypopneas per hour of sleep. According to the American Academy of Sleep Medicine guidelines, as summarized by Epstein et al, an AHI of fewer than 5 events per hour is considered within the normal range; 5 to 14.9 events per hour corresponds to mild OSA, 15 to 29.9 represents moderate OSA, and 30 or more events per hour indicates severe OSA [4].

The prevalence of moderate and severe OSA ranges from 1.2% to 23.4% in women and from 3.9% to 49.7% in men [5-7]. According to the HypnoLaus study, the overall prevalence of sleep-disordered breathing (defined as AHI >5) reached 60.8% in women and 83.8% in men [7]. Major risk factors for OSA include overweight, obesity, male sex, older age, hypertension, and a family history of the condition [8].

OSA treatment methods include continuous positive airway pressure therapy, the use of oral appliances, weight reduction, and various types of upper airway surgery [9]. If left untreated, the disease may lead to serious long-term health complications and substantially increase the risk of cardiovascular disease, stroke, and metabolic disorders [10,11]. Additionally, patients frequently experience excessive daytime sleepiness, memory and concentration difficulties, and mood disturbances [8,10]. Therefore, early diagnosis and timely implementation of treatment are crucial to reduce the adverse effects of OSA [8,10,11].

Repetitive episodes of breathing cessation during sleep can lead to oxidative stress, increased inflammatory responses, and autonomic dysfunction, which may result in ocular complications [12]. Previous studies have highlighted associations between OSA and several disorders, including glaucoma, floppy eyelid syndrome, nonarteritic anterior ischemic optic neuropathy, and dry eye disease [13,14]. One study showed that 66.67% of patients with OSA using continuous positive airway pressure therapy had been diagnosed with dry eye disease, and 54.17% of these patients also exhibited floppy eyelid syndrome [15]. Treatment options for OSA-related ocular conditions include artificial tear supplements, high-viscosity topical gels, bandage contact lenses, and, in severe cases, eyelid surgery. Early detection and appropriate treatment are important for improving quality of life [15].

Efforts to identify economical and noninvasive screening methods are crucial for the detection and prediction of OSA complications. The increasing availability of ophthalmic imaging techniques has facilitated ocular condition monitoring. Optical coherence tomography (OCT) is a valuable tool for investigating alterations in the retina and choroid; it enables the detection of abnormalities in thickness and structure. Spectral domain OCT is a particularly noninvasive imaging technique that can identify even subtle alterations in the layers of ocular structures [16].

Optical coherence tomography angiography (OCTA) is a noninvasive technique used to image and quantify retinal vasculature, including superficial and deep vessel density (SVD and DVD), as well as nonperfusion areas such as the foveal avascular zone (FAZ). The use of standardized sectors for vessel density assessment in the macular and peripapillary regions enables consistent application of this method across various ophthalmologic conditions [17]. Given the capabilities of OCTA, visualization of specific vascular layers (eg, SVD and DVD) is possible without the need for intravenous dye injection [18,19]. Previous OCTA studies of OSA populations have shown reductions in SVD and DVD [17-19], particularly within the peripapillary and parafoveal regions; however, findings remain inconsistent, highlighting the need for further investigation.

The aim of the study was to assess the effect of OSA on the retina, including FAZ and vessel density parameters, as well as choroidal thickness (CT).

Material and Methods

Ethics Committee Approval

The study protocol was approved by the Bioethics Committee of the Military Institute of Aviation Medicine (approval no. 10/2020; date of approval: January 13, 2021); it was conducted in accordance with the Declaration of Helsinki. The results of the present study are part of the project entitled “Assessment of the visual system in patients with diagnosed obstructive sleep apnea syndrome.” This observational study did not require registration in a clinical trial registry.

Declaration of Patient Consent

The authors explained to participating patients that the clinical findings obtained from the study would be reported in a

Table 1. Inclusion and exclusion criteria for the control and study groups.

Inclusion criteria	Exclusion criteria
• Written informed consent to participate in the study • No OSA or mild OSA (control group) or moderate to severe OSA (study group), confirmed by PSG • No history of ophthalmologic disease or ocular injury • No previous ophthalmologic treatment or surgery • No previous OSA treatment (surgical procedures or CPAP) • No diagnosed chronic diseases, except well-controlled hypertension (≤grade 1) without ophthalmologic complications • Age ≥18 years	• Poor-quality OCT or OCTA scans (signal strength ≤6) or inability to assess choroid on OCT scans • Ophthalmologic disease diagnosed during examination • BCVA >0.9 (logMAR) • Myopia or hyperopia (>-3.0 diopter or >+3.0 diopter) • Axial length <22.0 mm or >24.0 mm • IOP >21 mmHg

OSA – obstructive sleep apnea; PSG – polysomnography; CPAP – continuous positive airway pressure; OCT – optical coherence tomography; OCTA – optical coherence tomography angiography; BCVA – best-corrected visual acuity; logMAR – logarithm of the minimum angle of resolution; IOP – intraocular pressure.

scientific journal to advance medical knowledge; patient identification and data would remain confidential. All patients provided informed consent to take part in the study.

Study Design

This prospective cross-sectional study was conducted between January 1, 2023, and January 1, 2025, at the Department of Ophthalmology, Military Institute of Aviation Medicine, Warsaw, Poland.

Consecutive patients from the Department of Otorhinolaryngology, Faculty of Medicine and Dentistry, Medical University of Warsaw, were prospectively enrolled. The control group included individuals with no or mild OSA, whereas the study group comprised patients with moderate to severe OSA. OSA presence and severity were defined based on the AHI. According to the American Academy of Sleep Medicine guidelines, a result of fewer than 5 events per hour indicated a nonpathological range; 5 to 14.9 events per hour indicated mild OSA; 15 to 29.9 indicated moderate OSA; and 30 or more events per hour indicated severe OSA. The following patient data were verified: age, sex, ophthalmologic diseases, general health status, previous treatments and surgeries, and prior ophthalmologic treatments and surgeries. Inclusion and exclusion criteria were applied as detailed in **Table 1**.

All patients underwent a comprehensive ophthalmologic examination, including mydriasis, within 1 month of PSG. OCT, en face OCT, and OCTA were also performed. No OSA treatment was initiated before the ophthalmologic examination.

Best-corrected visual acuity was measured monocularly using logarithm of the minimum angle of resolution (logMAR) charts (Lighthouse International, New York, NY, USA) at a distance of 5 m. Only participants with normal visual acuity (best-corrected visual acuity ≤0.9 logMAR) were included (**Table 1**). The ophthalmologic examination was performed using a Topcon SLD701 slit lamp and Volk SuperField lens.

OCT and OCTA examinations were performed using the AngioVue Imaging System (Optovue Inc., Fremont, CA, USA). Macular parameters were assessed in the foveal (0-1 mm) and parafoveal (1-3 mm) regions across the nasal (N), temporal (T), superior (S), and inferior (I) quadrants. The HD Angio Retina protocol was used, covering a 6×6 mm scanning area for OCT, en face OCT, and OCTA imaging. The FAZ area was automatically measured using the built-in AngioVue software. Measurement depth for FAZ assessment was automatically determined by the device software, and investigators did not influence the segmentation settings. Retinal blood flow was quantified within a circular region (1-mm radius; 3.14 mm^2) centered on the fovea at the level of the outer retina and choriocapillaris using an automated analysis algorithm. All OCT and OCTA scans were acquired by 2 qualified ophthalmologists with dedicated training in these imaging techniques. Image assessors were masked to group allocation during analysis. Quality control was performed before analysis by evaluating signal strength and the presence of artifacts. Scans with poor image quality, motion artifacts, segmentation errors, or signal strength of 6 or below were excluded to ensure the reliability of quantitative measurements.

Choroidal measurements were manually performed with tools provided in the AngioVue Imaging System software. Using deep choroidal imaging technology, the hyperreflective retinal pigment epithelium band and uveoscleral junction were identified on OCT scans. The distance from the outer border of the retinal pigment epithelium to the uveoscleral junction was then measured perpendicularly at the point of maximal CT. Measurements were performed 3 times by 2 independent observers, and the mean value was used for analysis. This

Table 2. Baseline characteristics of the study participants (n=49 individuals=98 eyes).

Analyzed trait	Study group	Control group	*P*-value
No. of participants, n [%]	33 (67.35)	16 (32.65)	
No. of eyes, n [%]	66 (67.35)	32 (32.65)	
Sex			
Female	6 (18.18)	6 (37.50)	0.1403
Male	27 (81.82)	10 (62.50)	
Age [years], M (SD), Me (Q_1-Q_3), SEM (95% CI)	56.54 (13.09), 60 (48-69), 1.61 (53.33-59.76)	42.13 (14.55), 46 (34-54), 2.57 (40.88-51.37)	**<0.0001**
Mean HR [beats/min], M (SD), Me (Q_1-Q_3), SEM (95% CI)	65.17 (7.79), 66 (60-68), 0.96 (63.26-67.09)	61.09 (6.39), 61 (56-63), 1.13 (58.76-63.37)	**<0.0001**
CT [µm], M (SD), Me (Q_1-Q_3), SEM (95% CI)	335.53 (88.59), 312.50 (267.00-419.00), 10.90 (313.75-357.31)	317.12 (81.93), 307.00 (280.50-344.00), 14.48 (287.59-346.66)	**0.0054**

n – number; % – percentage; M – mean; SD – standard deviation; Me – median; Q – quartiles; HR – heart rate; CT – choroidal thickness; SEM – standard error of the mean; CI – confidence interval.

approach was utilized to minimize measurement variability and ensure reliable CT assessment. To avoid diurnal variation in the measured parameters, all examinations were performed between 7: 00 AM and 10: 00 AM.

Statistical Analysis

Numerical variables were described using the mean (M), standard deviation (SD), median (Me), and lower and upper quartile (Q) values. Discrete variables were presented as counts and percentages. The normality of distribution was assessed using the Shapiro-Wilk test. Levene's test was used to evaluate homogeneity of variance. Multifactor analysis of variance without replication was performed for normally distributed numerical variables with homogeneous variance to estimate the significance of differences according to OSA status. In the analysis of variance without replication model, the following explanatory variables were included: age, sex, and body mass index. Generalized linear models were utilized when variables were not normally distributed or when the variance was heterogeneous. A logistic regression model was used for dichotomous dependent variables. Error correction procedures for intra-participant correlation due to binocular measurements were applied in the above-mentioned statistical analyses. *P*-values <0.05 were considered statistically significant. All statistical analyses were performed using Statistica 13.3 (TIBCO Software Inc., Palo Alto, CA, USA).

Table 3. Pearson product–moment correlation coefficients (r) and corresponding *P*-values for patient age and investigated clinical characteristics.

Trait	r	P-value
FAZ	0.02	0.8113
PERIM	0.07	0.5047
FD-300	-0.13	0.2041
Foveal SVD	-0.06	0.5759
Parafoveal SVD SQ	-0.12	0.2199
Parafoveal SVD IQ	-0.14	0.1599
Parafoveal SVD TQ	**-0.22**	**0.0263**
Parafoveal SVD NQ	-0.14	0.1540
Foveal DVD	-0.02	0.8673
Parafoveal DVD SQ	-0.12	0.2331
Parafoveal DVD IQ	-0.16	0.1094
Parafoveal DVD TQ	-0.19	0.0560
Parafoveal DVD NQ	-0.16	0.1096
CT	**-0.36**	**0.0002**

FAZ – foveal avascular zone; PERIM – perimeter; FD-300 – foveal vessel density within 300 µm; SVD – superficial vessel density; DVD – deep vessel density; SQ – superior quadrant; IQ – inferior quadrant; TQ – temporal quadrant; NQ – nasal quadrant; CT – choroidal thickness.

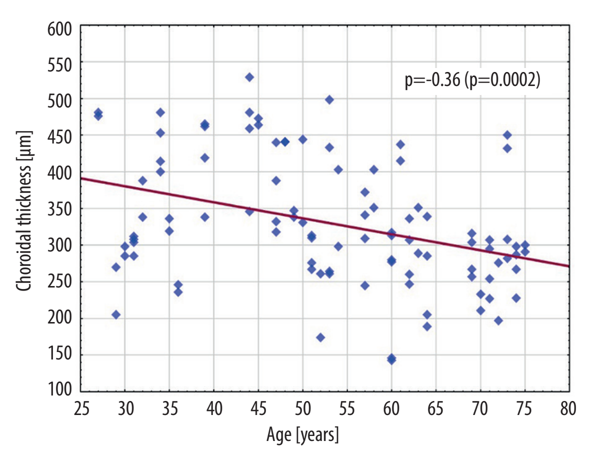

Figure 1. Scatter plot and linear regression showing a negative correlation between age and choroidal thickness.

Results

Forty-nine patients (98 eyes) were included in the study: 33 patients with moderate or severe OSA (66 eyes) and 16 controls (32 eyes). **Table 2** presents the baseline characteristics of the study cohort. Statistically significant differences between groups were observed in age, mean heart rate, and CT. The remaining parameters were examined with respect to sex and did not show statistically significant differences between the groups. Pearson correlation analysis revealed no significant relationships between age and most of the investigated ocular parameters (**Table 3**).

A statistically significant negative correlation was observed between age and parafoveal SVD in the temporal quadrant (TQ) (r=-0.22, *P*=0.0263). A stronger negative correlation was found between age and CT (r=-0.36, *P*=0.0002), indicating that CT decreases with age (**Figure 1**). Other correlations between age and clinical parameters, including FAZ, foveal vessel density within 300 µm (FD-300), SVD, and DVD in various regions, were not statistically significant (*P*>0.05).

PSG data for the control and study groups are presented in **Table 4**. Mean AHI in the study group was 46.41 events per hour, compared with 8.78 events per hour in the control group. Oxygen saturation metrics also significantly differed. The OSA group had lower mean SpO$_2$ (91.26% vs 93.35%), a greater mean SpO$_2$ drop (6.10% vs 3.63%), lower minimum SpO$_2$ (77.27% vs 86.81%), and a longer duration with SpO$_2$ below 90% (71.53 vs 9.38 minutes).

Table 4. Comparison of PSG results between participants in the study and control groups (n=49 individuals).

Analyzed trait	Group	Statistical parameters					*P*-value*
		M	SD	95% CI	Me	Q1-Q3	
AH [n]	Study	273.76	140.35	239.25-308.26	255.00	154.00-392.00	<0.0001
	Control	54.75	27.40	44.87-64.63	60.50	35.00-76.50	
AHI [events/hour]	Study	46.41	23.70	40.59-52.24	43.90	26.30-64.40	<0.0001
	Control	8.78	4.33	7.22-10.34	10.40	5.90-11.60	
ODI [events/hour]	Study	45.83	23.27	40.11-51.55	45.10	26.90-62.80	<0.0001
	Control	7.98	4.07	6.51-9.45	7.85	5.25-11.20	
Mean SpO$_2$ [%]	Study	91.26	1.87	90.80-91.72	91.40	90.20-92.60	<0.0001
	Control	93.35	1.37	92.85-93.84	93.50	92.40-94.60	
Mean drop in SpO$_2$ [%]	Study	6.10	2.60	5.46-6.74	5.50	4.20-7.20	<0.0001
	Control	3.63	0.39	3.48-3.76	3.60	3.35-3.90	
Minimum SpOP$_2$ [%]	Study	77.27	7.02	75.55-79.00	76.00	72.00-84.00	<0.0001
	Control	86.81	3.16	85.67-87.95	87.00	84.50-89.50	
SpO$_2$ <90% [min]	Study	71.53	61.31	56.46-86.60	57.00	20.80-107.60	<0.0001
	Control	9.38	17.07	3.22-15.53	1.55	0.15-9.60	

* Controlled for participant age and sex. AH – apnea–hypopnea events; AHI – apnea–hypopnea index; ODI – oxygen desaturation index; SpO$_2$ – peripheral oxygen saturation; M – mean; SD – standard deviation; CI – confidence interval; Me – median; Q – quartiles.

Table 5. Descriptive statistics for FAZ parameters (n=98 eyes).

Analyzed trait	Group	Statistical parameters					*P*-value*
		M	SD	95% CI	Me	Q_1-Q_3	
FAZ [mm²]	**Study**	**0.2609**	**0.0852**	**0.2399-0.2819**	**0.2500**	**0.2000-0.3100**	**0.0163**
	Control	**0.2207**	**0.0800**	**0.1919-0.2496**	**0.2200**	**0.1805-0.25100**	
PERIM [mm]	**Study**	**1.98**	**0.34**	**1.90-2.06**	**1.93**	**1.74-2.23**	**0.0236**
	Control	**1.81**	**0.34**	**1.69-1.94**	**1.82**	**1.69-1.95**	
FD-300 [%]	**Study**	50.35	5.46	49.01-51.70	51.30	48.50-53.50	0.2852
	Control	49.73	3.80	48.36-51.10	50.30	48.25-52.00	

* Controlled for participant age and sex. FAZ – foveal avascular zone; PERIM – perimeter; FD-300 – foveal vessel density within 300 µm; M – mean; SD – standard deviation; CI – confidence interval; Me – median; Q – quartiles.

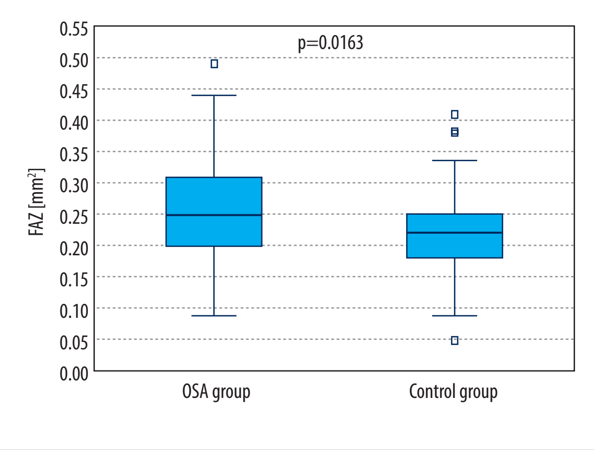

Figure 2. Boxplot showing the distribution of foveal avascular zone (FAZ) area values in the obstructive sleep apnea (OSA) and control groups.

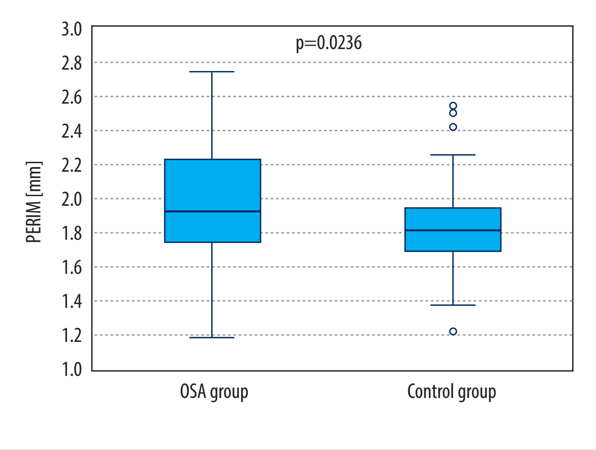

Figure 3. Boxplot showing the distribution of foveal avascular zone perimeter (PERIM) values in the obstructive sleep apnea (OSA) and control groups.

FAZ parameters were analyzed between the study and control groups (**Table 5**). The mean FAZ area was significantly larger in the study group than in controls (0.2609 mm^2 vs 0.2207 mm^2; *P*=0.0163) (**Figure 2**). Similarly, FAZ perimeter was greater in patients with moderate or severe OSA than in controls (1.98 mm vs 1.81 mm; *P*=0.0236) (**Figure 3**).

No difference was found in FD-300, with comparable values between the groups (50.35% vs 49.73%; *P*=0.2852). Furthermore, no differences were observed in SVD between the study and control groups across all evaluated retinal regions (**Table 6**). Similarly, no differences were observed in DVD between the groups across all evaluated retinal regions (**Table 7**).

Discussion

OSA can cause oxidative stress, systemic inflammation, and vascular changes [12]; therefore, the retina and choroid represent promising targets for identifying subclinical alterations associated with this condition.

The macular region is characterized by a central FAZ, devoid of capillaries, and surrounded by a parafoveal capillary network that plays a crucial role in maintaining retinal function [20,21]. In the present study, the FAZ area was significantly larger in the study group than in the controls (mean: 0.2609 mm^2 vs 0.2207 mm^2; *P*=0.0163), suggesting microvascular alterations in patients with OSA (**Table 5**). This finding contrasts with the work of Ye et al [22], who reported a smaller FAZ in individuals with OSA, which was attributed to hypoxia-induced redistribution

Table 6. Descriptive statistics for SVD parameters (n=98 eyes).

SVD [%]	Group	Statistical parameters					*P*-value*
		M	SD	95% CI	Me	Q_1-Q_3	
Foveal	**Study**	27.59	6.17	26.08-29.11	28.70	24.60-32.10	0.4877
	Control	28.52	4.24	26.99-30.05	28.55	26.45-30.95	
Parafoveal, SQ	**Study**	49.75	3.46	48.90-50.60	50.05	48.80-51.90	0.7210
	Control	50.44	2.20	49.65-51.24	50.15	49.25-52.10	
Parafoveal, IQ	**Study**	49.24	6.76	47.58-50.91	50.20	49.20-52.20	0.6727
	Control	50.60	2.25	49.79-51.41	50.85	49.00-52.35	
Parafoveal, TQ	**Study**	48.38	4.19	47.35-49.41	49.45	47.60-50.50	0.5035
	Control	49.47	2.31	48.64-50.31	49.40	48.05-50.95	
Parafoveal, NQ	**Study**	48.55	3.67	47.65-49.45	49.50	47.70-50.50	0.3849
	Control	49.17	1.92	48.48-49.86	49.20	48.15-50.65	

* Controlled for participant age and sex. SVD – superficial vessel density; SQ – superior quadrant; IQ – inferior quadrant; TQ – temporal quadrant; NQ – nasal quadrant; M – mean; SD – standard deviation; CI – confidence interval; Me – median; Q – quartiles.

Table 7. Descriptive statistics for DVD parameters (n=98 eyes).

DVD [%]	Group	Statistical parameters					*P*-value*
		M	SD	95% CI	Me	Q_1-Q_3	
Foveal	**Study**	28.98	4.92	27.77-30.20	29.15	26.00-31.90	0.0528
	Control	30.64	4.26	29.10-32.17	30.60	28.45-33.80	
Parafoveal, SQ	**Study**	53.61	3.00	52.87-54.34	53.80	52.40-55.20	0.5801
	Control	53.70	1.66	53.10-54.30	53.75	52.50-54.85	
Parafoveal, IQ	**Study**	53.16	4.68	52.01-54.31	54.00	52.20-55.30	0.3378
	Control	54.38	1.54	53.82-54.93	54.65	53.65-55.65	
Parafoveal, TQ	**Study**	53.98	2.53	53.35-54.60	54.45	52.50-55.70	0.6460
	Control	54.12	2.04	53.39-54.86	54.40	52.70-55.65	
Parafoveal, NQ	**Study**	53.88	3.78	52.95-54.80	54.55	52.80-55.60	0.6560
	Control	54.17	1.96	53.45-54.86	54.65	53.10-55.55	

* Controlled for participant age and sex. DVD – deep vessel density; SQ – superior quadrant; IQ – inferior quadrant; TQ – temporal quadrant; NQ – nasal quadrant; M – mean; SD – standard deviation; CI – confidence interval; Me – median; Q – quartiles.

of retinal perfusion. Conversely, another study showed no significant difference in FAZ size between patients with OSA and controls [23]. In our cohort, FAZ perimeter also was significantly larger in the study group (1.98 mm vs 1.81 mm; *P*=0.0236), supporting the possibility of capillary structure remodeling. However, no significant differences were observed in FD-300 values, indicating that although FAZ morphology was altered, the immediate perivascular capillary density remained relatively preserved (**Table 5**). These inconsistencies across studies may reflect differences in OSA severity, sample characteristics, and OCT/OCTA methodology [22,23], underscoring the need to interpret FAZ changes cautiously.

Vessel density reflects the percentage of a given area occupied by retinal blood vessels and is a sensitive biomarker of microvascular health. Prior research has suggested that OSA can lead to decreased SVD and DVD, particularly in relation to disease severity. Yu et al [24] reported reductions in vessel density in both the peripapillary and parafoveal regions among patients with OSA, which were attributed to recurrent hypoxemia and impaired cerebral autoregulation [25,26]. Our study did not confirm these findings. Analysis of SVD revealed no statistically significant differences between the study and control groups across all assessed regions (**Table 6**). Similarly, DVD showed no significant groupwise differences, with the exception of a borderline result in the foveal region (P=0.0528) (**Table 7**), which did not reach the conventional threshold for statistical significance. This discrepancy with previous studies may result from methodological differences, variations in OSA severity, or the timing of OCTA acquisition. Our findings suggest that, in cases of moderate to severe OSA, SVD and DVD may remain relatively preserved, possibly due to compensatory vascular mechanisms or regional resilience of the retinal vasculature. These results highlight the heterogeneity of OCTA findings in OSA cases and the need for standardized protocols to allow meaningful comparisons.

The choroid, located between the retina and sclera, supplies blood to the outer retina and plays a crucial role in metabolic processes, particularly those of photoreceptor cells. Changes in CT may affect structures deeper than the choroid and trigger a cascade of alterations across multiple vascular layers. The choroid receives approximately 90% to 95% of ocular blood flow; therefore, choroidal structure examination is essential for assessing ocular perfusion and understanding the potential consequences of abnormalities in ocular vasculature [27-29].

Repetitive episodes of hypoxia and hypercapnia can stimulate the release of vasoactive substances, leading to autonomic dysregulation and systemic vascular alterations in patients with OSA [4]. These changes may affect both systemic and choroidal circulation. The choroid plays a key role in the pathophysiology of several OSA-associated conditions, such as central serous chorioretinopathy, nonarteritic anterior ischemic optic neuropathy, and glaucoma [30-32]. Several studies have shown inconsistent CT findings in the OSA context. For example, Ozge et al [33] reported increased subfoveal CT in patients with OSA, consistent with our results (mean CT: 335.53 µm vs 317.12 µm in controls, P=0.0054), suggesting compensatory thickening. In contrast, other studies have identified reduced CT in severe OSA, possibly due to chronic vascular dysregulation and hypoxic tissue damage [34,35]. Such discrepancies likely reflect differences in study populations, disease severity, measurement techniques, and diurnal CT variation.

The subfoveal region generally exhibits the maximum CT, whereas the choroid tends to be thinnest in the nasal portion of the macula. In the present study, due to the large number of parameters analyzed, we did not measure choroidal thickness in each region, leaving this aspect for future investigation. Instead, our analysis focused on the foveal and parafoveal regions within 0 to 3 mm, targeting the location where the choroid typically demonstrates maximal thickness. This approach aligns with current trends in studies of pachychoroid spectrum diseases (PDSs) [36]. The prevailing view is that the fundamental abnormality in PDSs is associated with dilated choroidal vessels [37-39]. According to Phasukkijwatana et al, individuals with peripapillary pachychoroid syndrome exhibit thickening of the choroid in the nasal macular region, with a sharp decline in thickness toward the temporal side [40]. This observation suggests that individuals with OSA, given their increased CT and associated vascular alterations, have an increased risk of developing PDS conditions such as peripapillary pachychoroid syndrome. Similarly, Lee et al suggested that increased CT exerts pressure on the optic nerve region, potentially leading to a lamina cribrosa defect and subsequent intraretinal fluid [41]. However, their study did not explore whether macular choroidal thickening was more prevalent in the nasal region among patients with PDS and glaucomatous optic neuropathy, as observed in the peripapillary pachychoroid syndrome pattern.

Male sex is recognized as a risk factor for OSA, with reported male-to-female prevalence ratios ranging from 1.5: 1 in some studies [42] to 3: 1 or 5: 1 in the general population, and increasing to 8: 1 or 10: 1 in certain clinical groups [43]. This disparity may be attributed to anatomical differences, including greater airway collapsibility and increased fat accumulation in the abdominal and neck regions in men. Additionally, the protective effects of female hormones such as progesterone and estrogen might contribute to the lower OSA prevalence in women [42]. In the present study, OSA was also more prevalent among male patients than among female patients: men were approximately 3 times more likely to have OSA than women (**Table 2**), confirming the sex-related predisposition.

The literature indicates that the prevalence of OSA increases with age, peaking in middle-aged individuals (45-64 years), and may slightly decline in older adults [44,45]. Our findings followed this trend. The mean age of patients in the study group was 56.54 years (SD=13.09), with a median of 60 years (Q1-Q3: 48-69), indicating that OSA predominantly affects middle-aged and older individuals (**Table 2**). In contrast, the control group was significantly younger, with a mean age of 42.13 years (SD=14.55) and a median of 46 years (Q1-Q3: 34-54), confirming a statistically significant difference (P<0.0001). These results support the hypothesis that OSA risk increases with age and highlight age as an independent risk factor for this condition.

Limitations

This study is limited by its cross-sectional design, which precludes causal inferences, a relatively small and unequal sample size, and the absence of longitudinal follow-up to assess long-term outcomes. All participants were from a Western population, and the lack of ethnic diversity may limit the generalizability of the findings to other populations. Although formal reliability metrics were not calculated, all measurements were performed by 2 trained ophthalmologists using a standardized protocol to minimize variability.

Strengths

The groups were selected with consideration of parameters that could affect the interpretation of results, such as patient age, refractive error, axial length, and visual acuity. Automated measurements were used to reduce potential errors associated with manual methods. For CT assessment, 3 repeated measurements were performed and averaged. Evaluation of the retina and choroid was conducted via multimodal imaging, including OCT and OCTA, allowing comprehensive assessment of both structural and vascular changes within the eye.

Conclusions

Our study demonstrates that patients with OSA exhibit subtle microvascular alterations in the retina, including FAZ enlargement, as well as a trend toward increased CT. Retinal vessel density remained relatively preserved, suggesting that some vascular parameters are resilient in moderate to severe OSA. These findings contribute to the understanding of the ocular effects of chronic intermittent hypoxia and highlight the potential of OCT and OCTA as noninvasive tools for detecting early retinal and choroidal changes. Further longitudinal studies are warranted to explore mechanisms underlying these alterations and evaluate their potential roles in early screening, risk stratification, and progression monitoring of OSA.

Declaration of Figures' Authenticity

All figures submitted have been created by the authors who confirm that the images are original with no duplication and have not been previously published in whole or in part.

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