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Original Article

Evaluation of the Effect of Uncomplicated Cataract Surgery on Retina and Optic Disc: Optical Coherence Tomography Angiography Study

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Purpose: The aim of the present study is to evaluate the effects of uncomplicated cataract surgery on microvascular structure of fovea, parafovea, optic disc, and peripapillary area with optical coherence tomography angiography (OCTA).

Methods: The study included 53 eyes of 53 patients, who undergone uncomplicated cataract surgery. The day before cataract surgery and at the 1st week, 1st month, 3rd month after surgery, best-corrected visual acuity, foveal avascular zone, acircularity index, superficial and deep foveal density, superficial and deep parafoveal density, central macular thickness, peripapillary retinal nerve fiber layer thickness value, and peripapillary vascular density were measured with OCTA.

Results: The mean age of the patients was 62.1 ± 7.2 years (range, 42–69 years) and the sex of the patients was 25 male and 28 female. The foveal avascular zone value was decreased compared to the preoperative value ($p < 0.05$). There was no significant change in acircularity index postoperatively ($p > 0.05$). There was a significant increase in superficial and deep foveal density and superficial and deep parafoveal density ($p < 0.05$). According to preoperative period, peripapillary retinal nerve fiber layer and inside disc capillary density of optic disc increased significantly ($p < 0.05$). There was no significant change in peripapillary vascular density postoperatively ($p > 0.05$).

Conclusions: Changes in the vascular density of the retina were detected with OCTA in eyes without ocular or systemic disease, which underwent uncomplicated cataract surgery. In the postsurgical period, OCTA provides important information in the evaluation and follow-up of these changes.

Key Words: Cataract surgery, Foveal avascular zone, Optical coherence tomography angiography, Retinal vascularity

Cataracts are the most common cause of preventable blindness and representing approximately 20 million people [1]. This makes phacoemulsification the most frequent procedure performed in cataract surgery in ophthalmology [2]. Although cataract surgery is an anterior segment surgery, its effects on the posterior segment are also proven [3].

Optical coherence tomography angiography (OCTA) is currently in use as a noninvasive imaging method that demonstrates the vascular density changes of the retina and choroid by capturing the contrast of the movement in the intravascular blood flow, without using intravenous

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contrast agents such as fluorescein [4]. With OCTA, the microvascular network can be easily visualized, facilitating investigations into the development of retinal and choroidal diseases and the follow-up of the effectiveness of treatment [4].

The aim of this study was to evaluate whether uneventful cataract surgery in eyes without ocular pathologies affected the microvascular structure of the retina and optic disc head by using OCTA.

Materials and Methods

Ethics statement

This prospective cross-sectional study was performed at Adana City Training and Research Hospital, Adana, Turkey between March 2019 and January 2020. The study was performed in accordance with the tenets of the Declaration of Helsinki for research involving human subjects. The study was approved by the Clinical Research Ethics Committee of Adana City Training and Research Hospital (No. 396-2019) and informed consent was obtained from all participants.

Patient selection

Fifty-three eyes of 53 patients who had no systemic comorbid diseases such as diabetes mellitus, hypertension, and coronary artery disease, and who did not use any systemic and ocular drugs that could affect vascular flow and diameter, were enrolled in this study. Progression of nuclear sclerosis based on the Emery-Little classification. Patients with nuclear sclerosis with a signal quality of 6 / 10 and above were included in the study.

The common exclusion criteria were as follows: history of diabetes and hypertension, history of ocular surgery, amblyopia, >3 diopters refractive error, with axial length outside the range of 22 to 24.5 mm, presence of any retinal or optic nerve disease, glaucoma, regular medication, and smoking. The common inclusion criteria were as follows: age between 40 to 70 years, sufficiently clear ocular media, and adequate pupillary dilation and fixation to permit quality OCTA imaging.

All patients underwent complete ophthalmologic examinations, including the measurement of best-corrected distance visual acuity, intraocular pressure (IOP) using a Goldmann applanation tonometer (Model AT 900 C/M; Haag-Streit, Bern, Switzerland), axial length using partial coherence interferometry (IOL-Master 500; Carl Zeiss Meditec, Jena, Germany), slit-lamp biomicroscopy, and a dilated fundus examination using a three-mirror contact lens and OCTA. Blood pressure was also measured, and the mean arterial pressure was calculated as the diastolic blood pressure plus one-third of the difference between the diastolic and the systolic blood pressure.

Optical coherence tomography angiography data acquisition and processing

OCTA scans were obtained using the RTVue-XR Avanti spectral-domain system (Optovue RTVue-XR Avanti; Optovue Inc., Fremont, CA, USA). The macular area was covered by 3 × 3-mm OCTA scans. The foveal avascular zone (FAZ), superficial foveal density (SFD), deep foveal density (DFD), superficial parafoveal density (SPD), and deep parafoveal density (DPD) were measured using the "retina" tool of the software, which delineates it automatically. The vessel density (VD) of these two areas was automatically provided by the OCT system. Parafoveal VD was calculated for the ring-shaped area between a 0.3- and 1.25-mm radius from the center of the macula. The acircularity index (AI) is one of the FAZ variables and is measured the software in the automatized mode. AI is defined as the ratio of the FAZ perimeter to the circumference of a circle with an equal area to the FAZ [5].

Peripapillary images were acquired using a 4.5×4.5-mm scanning area centered on the optic disc. The eye-tracking function was activated. Motion correction was applied to minimize motion artifacts arising from microsaccades and fixation changes. The peripapillary capillary VD (PPCVD) was measured at a 1.00-mm wide elliptical annulus extending outward from the optic disc boundary in the radial peripapillary capillary zone. The radial peripapillary capillary layer extends from the internal limiting membrane to the nerve fiber layer. The capillary VD percentages were automatically calculated as the proportion of the area with flowing blood vessels, defined by pixels with decorrelation values above the split-spectrum amplitudedecorrelation angiography threshold level. The software version we used provides separate information on PPCVD (only information arriving from the radial peripapillary capillary layer capillaries is analyzed). For analyses, VD is automatically calculated for the inside-disc area and the peripapillary area, respectively.

Peripapillary retinal nerve fiber layer (PPRNFL) thickness was also measured using the AngioVue device (Optovue Inc.). The PPRNFL thickness was assessed at a 3.45-mm diameter circle around the optic disc in the optic nerve head mode.

Based on a study in the literature, OCTA measurements were made between 09.00 and 12.00 in the morning with the aim of minimizing the diurnal variation in OCTA measurements [6]. The measurements were obtained preoperatively and at the 1st week, 1st month, and 3rd month postoperatively.

Surgical technique

The cataract surgeries were performed using the Infiniti Vision System (Alcon Laboratories Inc., Fort Worth, TX, USA). The effective phacoemulsification time (in seconds) and phacoemulsification energy (percentage) of the device were documented. After topical anesthesia (Proparacain hydroclorur 0.5%) was administered, a 2.2-mm clear corneal self-sealing incision, capsulorhexis, hydrodissection, phacoemulsification, and irrigation/aspiration of the residual lens cortex were sequentially performed. A foldable intraocular lens was then implanted in the capsular bag. Patients with perioperative complications were excluded. Postoperative treatment consisted of prednisolone acetate 1.0% and moxifloxacin 0.5% eyedrops administered four times per day for 2 weeks. Nonsteroidal anti-inflammatory drugs such as nepafenac and ketorolac were not initiated at any preoperative and postoperative visits to minimize vascular change.

Statistical analysis

Statistical analyses were performed using IBM SPSS ver. 25.0 (IBM Corp., Armonk, NY, USA) Categorical measurements are summarized as numbers and percentages, and measurements as mean and standard deviation (required median and minimum). The assessment of normality of data distribution was performed using the Kolmogorov-Smirnov test. The paired-samples *t*-test and Wilcoxon test were used for the parametric distribution prerequisite assumption in the comparison of post hoc Bonferroni test. Time profile analysis of each parameter was performed by means of one-way analysis of variance model for repeated measures. A *p*-value less than 0.05 was considered statistically significant.

Results

Fifty-three eyes of 53 patients with senile cataracts attended the assessment visits at baseline and after surgery. As a result, 53 eyes of 53 patients (25 male patients and 28 female patients) were included in the final analysis. The mean age of the patients was 62.1 ± 7.2 years (range, 42–69 years), and the mean axial length was 23.41 ± 1.1 mm (22.7–24.1 mm). The mean best-corrected distance visual acuity according to the Snellen chart was 0.25 ± 0.16 preoperatively, 0.94 ± 0.15 at 1 month postoperatively, and 0.95 ± 0.14 at 3 months postoperatively ($p < 0.001$). The mean effective phacoemulsification time was 21.2 ± 9.6 seconds, and the mean phacoemulsification energy was 28.87% ± 17.35%.

After the cataract surgery, IOP decreased, whereas the mean arterial pressure and ocular perfusion pressure remained unchanged during all visits. At 3 months postoperatively, the mean decrease in IOP was 3.20 ± 1.22 mm Hg ($p < 0.001$).

The central macular thickness value increased significantly in the 1st week, the 1st month, and the 3rd month after surgery compared with preoperatively ($p < 0.001$). A significant decrease was found in the FAZ in the postoperative period ($p < 0.001$). It was found that there was a significant increase in SFD, DFD, SPD, and DPD values at the 1st week, 1st month, and the 3rd month after surgery. When the SPD and DPD were divided into quadrants, a significant increase was found in the superior and inferior DPD quadrants; the change was not statistically significant in the temporal and nasal DPD. In SPD, the increase in all four quadrants was statistically significant ($p < 0.001$) (Table 1).

When PPRNFL was evaluated, a statistically significant increase was found after surgery ($p < 0.001$). When PPC-VD measurements were evaluated, no statistically significant difference was found between the measurements from baseline to 3 months after surgery ($p = 0.168$). There was a significant increase in postoperative inside-disc values. While there was no significant change between the 1st week and 1st month values; the 3rd month data were statistically significantly higher ($p < 0.001$) (Table 2). Quadrant vascular changes of the optic disc head and fovea region are presented in Tables 3 and 4.

Table 1. The optical coherence tomography angiography measurements of retinal vasculature

Variable	Preoperative	Postoperative 1st week	Postoperative 1st month	Postoperative 3rd month	*p*-value*
Foveal avascular zone (mm^2)	0.31 ± 0.10	0.30 ± 0.10	0.29 ± 0.10	0.29 ± 0.10	0.001†
p-value‡					
	Ref.	0.001	0.001	0.001	
	-	Ref.	0.054	0.219	
	-	-	Ref.	0.560	
Acircularity index	1.14 ± 0.03	1.15 ± 0.03	1.15 ± 0.03	1.15 ± 0.04	0.078
p-value‡					
	Ref.	0.322	0.368	0.052	
	-	Ref.	0.919	0.122	
	-	-	Ref.	0.109	
Central macular thickness (mm)	216.1 ± 18.9	217.2 ± 19.8	221.3 ± 20.1	225.0 ± 19.7	0.001†
p-value‡					
	Ref.	0.025	0.001	0.001	
	-	Ref.	0.001	0.001	
	-	-	Ref.	0.001	
Superficial foveal density (%)	13.2 ± 5.2	15.2 ± 5.0	15.1 ± 5.3	16.0 ± 5.3	0.001†
p-value‡					
	Ref.	0.001	0.001	0.001	
	-	Ref.	0.747	0.018	
	-	-	Ref.	0.001	
Superior parafoveal density (%)	46.3 ± 4.7	48.9 ± 3.4	48.5 ± 3.1	50.2 ± 2.7	0.001†
p-value‡					
	Ref.	0.001	0.001	0.001	
	-	Ref.	0.747	0.018	
	-	-	Ref.	0.001	
Deep foveal density (%)	30.3 ± 6.3	31.7 ± 6.2	31.0 ± 6.3	32.0 ± 6.3	0.001†
p-value‡					
	Ref.	0.001	0.035	0.001	
	-	Ref.	0.330	0.309	
	-	-	Ref.	0.013	
Deep parafoveal density (%)	52.2 ± 4.3	53.3 ± 3.9	53.1 ± 4.0	53.4 ± 3.3	0.049†
p-value‡					
	Ref.	0.039	0.114	0.029	
	-	Ref.	0.654	0.881	
	-	-	Ref.	0.525	

Values are presented as mean ± standard deviation.
Ref. = reference mean value.
*Correlation with time, analysis of variance with repeated measures (repeated factor "time") was used; †Statistically significant; ‡Significant *p*-values of the comparison between mean values with respect to reference time and post hoc Bonferroni test.

Discussion

In our study, we aimed to evaluate the vascular changes in the retina in the early postoperative period using OCTA in eyes without any retinopathy after cataract surgery with a phacoemulsification technique. Various techniques have been used to show blood flow in the large retinal vessels after cataract surgery. However, these techniques cannot show retinal microcirculation [3,7]. OCTA is capable of measuring both macrocirculation and microcirculation [8]. The purpose of cataract surgery is to provide a better visual acuity. However, even if an uncomplicated successful surgery has been performed, a detailed retinal examination is a critical part of successful surgery because vascular changes and existing pathologies of the retina affect the overall visual outcome [9].

In our study, images with signal quality below 6 / 10 were not included in the study. Clinically significant cataract may still impair the acquisition of volumetric data and lead to motion artifacts [10]. By using measurements with high signal quality, it was aimed that the results are least affected by the ambient opacity. The mean OCTA signal strength score reported by the OCTA device before surgery was 0.685 ± 0.415 (range, 0.6–0.8). Image artifacts were generally not severe in our study and did not significantly change after cataract surgery. It has been suggested that the FAZ area measurements are an excellent noninvasive monitoring tool for vascular changes in the retina due to its reproducibility and consistent results in healthy eyes [11]. In a study of 13 patients, significantly better distinguishability of the FAZ margin was observed 1 week after surgery, but the FAZ area and circumference measurements did not change significantly after cataract surgery [12] In another study involving 32 patients, it was found

Table 2. The optical coherence tomography angiography measurements of optic nerve head vasculature

Variable	Preoperative	Postoperative 1st week	Postoperative 1st month	Postoperative 3rd month	*p*-value*
PPRNFL mean (μm)	95.3 ± 10.9	96.0 ± 11.5	97.9 ± 12.3	97.4 ± 12.3	0.001†
p-value‡					
	Ref.	0.110	0.001	0.003	
	-	Ref.	0.001	0.034	
	-	-	Ref.	0.289	
PPCVD mean (%)	51.9 ± 3.4	51.3 ± 3.4	51.4 ± 3.6	51.3 ± 3.2	0.168
p-value‡					
	Ref.	0.089	0.115	0.074	
	-	Ref.	0.822	0.971	
	-	-	Ref.	0.794	
Whole image (%)	48.3 ± 3.2	48.7 ± 2.9	48.6 ± 3.2	49.2 ± 2.9	0.054
p-value‡					
	Ref.	0.224	0.073	0.065	
	-	Ref.	0.718	0.736	
	-	-	Ref.	0.912	
Inside disc (%)	45.9 ± 5.0	47.7 ± 4.7	47.5 ± 4.2	49.2 ± 4.5	0.001†
p-value‡					
	Ref.	0.009	0.009	0.001	
	-	Ref.	0.718	0.008	
	-	-	Ref.	0.001	

Values are presented as mean ± standard deviation.
PPRNFL = peripapillary retinal nerve fiber layer; PPCVD = peripapillary capillary vessel density; Ref. = reference mean value.
*Correlation with time, analysis of variance with repeated measures (repeated factor "time") was used; †Statistically significant; ‡Significant *p*-values of the comparison between mean values with respect to reference time and post hoc Bonferroni test.

Table 3. The optical coherence tomography angiography measurements of optic nerve head quadrantal vasculature

Variable	Preoperative	Postoperative 1st week	Postoperative 1st month	Postoperative 3rd month	*p*-value*
Superior hemi (%)	52.2 ± 3.4	51.7 ± 3.6	51.5 ± 3.7	51.7 ± 3.4	0.086
p-value†					
	Ref.	0.056	0.116	0.400	
	-	Ref.	0.400	0.934	
	-	-	Ref.	0.359	
Inferior hemi (%)	51.5 ± 3.7	50.9 ± 3.6	51.3 ± 3.7	51.0 ± 3.4	0.236
p-value†					
	Ref.	0.130	0.562	0.110	
	-	Ref.	0.303	0.882	
	-	-	Ref.	0.170	
Superior quarter (%)	53.4 ± 4.4	51.8 ± 5.2	51.2 ± 4.8	51.7 ± 4.4	0.001‡
p-value†					
	Ref.	0.002	0.001	0.001	
	-	Ref.	0.243	0.778	
	-	-	Ref.	0.218	
Temporal quarter (%)	56.6 ± 4.6	55.5 ± 4.5	57.2 ± 4.4	55.9 ± 4.3	0.003‡
p-value†					
	Ref.	0.014	0.216	0.081	
	-	Ref.	0.005	0.428	
	-	-	Ref.	0.001	
Inferior quarter (%)	51.3 ± 6.0	52.6 ± 4.9	52.5 ± 5.2	52.0 ± 4.8	0.017‡
p-value†					
	Ref.	0.011	0.022	0.122	
	-	Ref.	0.704	0.133	
	-	-	Ref.	0.201	
Nasal quarter (%)	48.1 ± 5.0	46.5 ± 4.8	47.4 ± 4.8	48.1 ± 4.4	0.005‡
p-value†					
	Ref.	0.012	0.155	1.000	
	-	Ref.	0.041	0.001	
	-	-	Ref.	0.011	

Values are presented as mean ± standard deviation.
Ref. = reference mean value.
*Correlation with time, analysis of variance with repeated measures (repeated factor "time") was used; †Significant *p*-values of the comparison between mean values with respect to reference time and post hoc Bonferroni test; ‡Statistically significant.

that the FAZ area decreased significantly with cataract surgery [13]. Similar to the literature, a decrease was observed in the postoperative FAZ area, and the change was not significant in subsequent visits [12]. This situation can be explained by the increase in image and signal quality after surgery.

Krawitz et al. [5] reported that AI values correlated with the severity of retinopathy. In our study, there were no significant changes in AI values with surgery. Similarly, Feng et al. [14] found no significant AI change after cataract surgery in patients with and without diabetes. In light of this information, AI can be used as a parameter in monitoring the effects of surgery on the retina in eyes without retinopathy.

Table 4. The optical coherence tomography angiography measurements of foveal quadrantal vasculature

Variable (%)	Preoperative	Postoperative 1st week	Postoperative 1st month	Postoperative 3rd month	*p*-value*
Superficial temporal density (%)	45.1 ± 5.1	47.2 ± 3.5	46.6 ± 3.4	47.8 ± 3.5	0.001†
Superficial superior density (%)	47.4 ± 4.9	50.2 ± 4.1	49.8 ± 3.5	51.5 ± 3.3	0.001†
Superficial nasal density (%)	45.0 ± 5.1	47.8 ± 3.7	47.7 ± 3.3	49.5 ± 2.7	0.001†
Superficial inferior density (%)	47.8 ± 6.3	50.5 ± 4.1	49.7 ± 3.5	52.0 ± 3.0	0.001†
Deep temporal density (%)	52.5 ± 4.1	53.3 ± 3.9	53.3 ± 3.9	53.6 ± 3.5	0.087
Deep superior density (%)	51.8 ± 5.2	53.0 ± 4.9	52.4 ± 4.9	52.7 ± 4.2	0.001†
Deep nasal density (%)	53.1 ± 3.9	53.8 ± 3.9	54.0 ± 3.6	53.9 ± 3.3	0.158
Deep inferior density (%)	51.5 ± 5.2	53.2 ± 4.3	52.9 ± 4.4	53.3 ± 3.4	0.013†

Values are presented as mean ± standard deviation.
*Correlation with time, analysis of variance with repeated measures (repeated factor "time") was used; †Statistically significant.

In a study by Zhao et al. [13], it was shown that cataract surgery caused an increase in parafoveal and perifoveal density. In another study, similar to our study, an increase in superficial and deep capillary plexus VD was found in the postoperative period. One reason for the increased vascular changes of the retina may be this surgically induced cytokine burden. Xu et al. [15] found that cataract surgery caused the expression of interleukin 1-beta and chemokine ligand-2 from the neurosensory retina in the acute postoperative period. This inflammatory process and the increased amount of cytokines cause an increase in vascular dilatation and a deterioration in the blood-retinal barrier [15,16]. Another reason for the change in retinal vascularity may be increased metabolic needs after surgery and the increased retinovascular flow required to provide this. Increased light exposure with surgery can also lead to increased metabolic demands on the retina. Another reason for the increase in vascular density may be increased light exposure. Crystalline lenses can prevent 18% to 40% of light exposure [17]. In another study, in their examination with OCTA, Pilotto et al. [18] detected an increase in hyperreflective spots starting from the inner retinal layers and progressing to the outer retinal layers from the 1st postoperative day, and they attributed this to the aggregation and the migration of microglial cells.

In our study, we found that there was a greater effect in the DFD than in the SFD. Multiple properties, including the distance from the larger arterioles, the proximity to the high metabolic demand of the outer retina, and the complex vascular anatomic architecture may make the DFD more susceptible to damage [19]. It is possible to say that the outer retina is more susceptible to poor perfusion caused by generalized vasospasm due to its high metabolic activity and complex vascular structure.

Despite the increased retinal vascularity, the change in the entire image and PPCVD measurements at the optic nerve head was not statistically significant. Sakaguchi et al. [20] found significantly lower PPCVD values in the primary open-angle glaucoma group compared with a healthy control group with suspected glaucoma. These data can be used as a follow-up method of PPCVD measurements in terms of surgery-induced glaucoma progression after cataract surgery. In our study, a significant increase in internal disc values was found in the postoperative 3rd month. Similarly, in a study in which 24 eyes were evaluated in the 1st week and 1st month postoperatively, the change in inside-disc values was not statistically significant in the 1st week, but a significant increase was found in the 1st month [21]. The effect of a change in IOP on ocular hemodynamics has been shown in many studies [13,22]. The increase in optic disc head VD may be due to the postoperative decrease in IOP.

In our study, we found a significant increase in PPRNFL in the postoperative period. In similar studies, the increase found in PPRNFL with cataract surgery was found to be significant [23,24]. A limited decrease in IOP is seen after cataract surgery, and its mechanism is not fully known. Some mechanisms have been suggested such as anatomic relief in the angle, increase in the ease of outflow, decrease in aqueous production due to traction with pseudophakia in the ciliary body, and relief of the pressure on the trabecular meshwork and Schlemm canal with the backward movement of the zonules, increase in outflow ease with the release of postoperative interleukins, and increase in uveoscleral flow due to prostaglandin F2 [25,26]. This increase in thickness of the PPRNFL may be associated with the limited postsurgery decrease in IOP.

There are some limitations to this study. First, our study cannot compare with a control group accompanied by systemic diseases that may affect vascular components. Second, the follow-up period is limited to the 3rd postoperative month.

In conclusion, based on the literature and the findings of our study, uneventful cataract surgery causes microvascular changes on the retina and optic disc, and it is thought that cataract extraction may lead to microvascular system disruption in patients with underlying concurrent retinopathies or choroidal neovascularization [27]. OCTA guides the evaluation of these patients and provides important information. Further studies with larger series and longer follow-up periods are needed in this regard.

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