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Original Article

Effects of Cataract on Retinal Nerve Fiber Layer and Ganglion Cell-Inner Plexiform Layer Thickness on Swept Source Optical Coherence Tomography

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Purpose: To evaluate the changes in peripapillary retinal nerve fiber layer (pRNFL) thickness and macular ganglion cell-inner plexiform layer (mGC-IPL) thickness measured by swept source optical coherence tomography (SS-OCT) following cataract surgery in patients with glaucoma.

Methods: We included 42 glaucoma eyes and 42 case-matched normal eyes that underwent cataract surgery without complications. One matching set included one glaucoma eye and one case-matched normal eye. The age, sex, and cataract subtype scores were similar for each group. Before and within 3 months of surgery, we measured the pRNFL thickness and mGC-IPL thickness by SS-OCT.

Results: Following cataract surgery, the image quality (IQ) of SS-OCT improved in both groups. The thickness of the pRNFL and mGC-IPL increased in the mean values and all areas, except for pRNFL from 1 to 4 o'clock in the glaucoma group and at 1 o'clock in the normal group. Posterior subcapsular cataract was related to the change in IQ following surgery. The glaucoma and normal group showed greater pRNFL thickness change due to lesser preoperative pRNFL thickness. Furthermore, the mGC-IPL thickness change was greater in the glaucoma group because of lesser preoperative mGC-IPL thickness. By contrast, the normal group demonstrated greater mGC-IPL thickness change due to higher cortical cataract scores.

Conclusions: Cataracts caused the deterioration of the IQ in SS-OCT, thereby resulting in an undermeasurement of the pRNFL and mGC-IPL thickness. Preoperative pRNFL and mGC-IPL were negatively associated with postoperative pRNFL and mGC-IPL thickness change in the glaucoma and normal groups. Therefore, ophthalmologists should particularly consider the effect of cataract while diagnosing glaucoma using SS-OCT.

Key Words: Cataract, Glaucoma, Image, Optical coherence tomography

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Glaucoma is a disease that affects the visual field (VF) due to the loss of optic nerve axons and structural changes in the optic nerve head and peripapillary retinal nerve fiber layer (pRNFL), thus leading to blindness [1]. It is essential to identify structural changes in the optic nerve head and pRNFL to detect glaucoma progression [2,3]. In addition, the degeneration of retinal ganglion cells is an important

indicator of glaucoma progression [4]. Introduced in 1991, optical coherence tomography (OCT) is useful for glaucoma diagnosis because it can assess cross section images of the nerve fiber layer using interference principles [5]. In 2002, spectral domain OCT (SD-OCT) was first utilized in vivo, and then, the development of from time domain OCT (TD-OCT) to SD-OCT brought high resolution of OCT image and accuracy of glaucoma diagnosis [6–8]. Swept source OCT (SS-OCT) was introduced in 2012, and has been widely used because of faster and deeper analysis than SD-OCT [7,9]. SS-OCT helps diagnose glaucoma by measuring the pRNFL and macular ganglion cell layer-inner plexiform layer (mGC-IPL) thickness by visualizing the wide field of posterior poles, including the optic nerve head and macula with single-scan protocol [6,7]. SS-OCT and SD-OCT have similar abilities while measuring the pRNFL thickness and mGC-IPL thickness in patients with or suspected with glaucoma [10–12]. Although OCT is widely used in the diagnosis of glaucoma, media opacity can lead to poor image quality (IQ) of OCT; thus, researchers have investigated the impact of cataracts on the pRNFL thickness in TD-OCT or SD-OCT [13–18]. In TD-OCT and SD-OCT, the pRNFL thickness increases following cataract surgery. Moreover, cataracts lead to the poor measurement of pRNFL thickness, which is a hindrance to glaucoma diagnosis [13–18]. Yang et al. [12] first reported on the efficacy of SS-OCT in diagnosing glaucoma in 2015. Because SS-OCT uses a wavelength of 1,060 nm, which is longer than that of SD-OCT, there is less light scattering, which means that SS-OCT is less affected by media opacity than SD-OCT [19]. SS-OCT is more sensitive for diagnosing macular disease with cataract than SD-OCT [20]. However, there are no studies on the effect of cataracts on pRNFL and mGC-IPL thickness measurements using SS-OCT [12].

Therefore, we aimed to compare the pRNFL thickness and mGC-IPL thickness in SS-OCT before and after cataract surgery, and to identify factors that influenced the thickness.

Materials and Methods

This study was approved by the Institutional Review Board of the Veterans Health Service Medical Center (No. 2021-05-031-001). The requirement for informed consent was waived due to the retrospective nature of the study. This study adhered to the tenets of the Declaration of Helsinki.

From April 2020 to April 2021, a total of 84 eyes (68 patients), including 42 glaucoma eyes and 42 normal eyes underwent routine cataract surgery at the Department of Ophthalmology, Veterans Health Service Medical Center, and were retrospectively reviewed using medical records. All patients underwent cataract surgery by one surgeon (BRS), without complications. We excluded patients with media opacity factors, such as corneal edema, corneal opacity, and vitreous opacity, except those with cataract. Moreover, we excluded patients with a history of ocular surgery and ocular diseases, such as uveitis, other optic neuropathy, diabetic retinopathy, amblyopia, or retinal disease. In addition, we excluded patients without preoperative and postoperative OCT images. We defined postoperative OCT images as OCT performed within 3 months after surgery (glaucoma group, average 33.76 ± 13.42 days; normal group, average 32.7 ± 13.21 days). Based on the manufacturer's recommendation, we excluded OCT with IQ of <40. Patients with complications, such as postoperative intraocular pressure (IOP) rise, corneal edema, and clinically macular edema, were also excluded.

All patients underwent the following ophthalmologic examinations prior to surgery: best-corrected visual acuity measurement, IOP measurement, slit-lamp examination, dilated fundus examination, central corneal thickness measurement (SP-3000, Tomey Corp), axial length measurement (IOLMaster 700, Carl Zeiss Meditec), and SS-OCT imaging (DRI OCT Triton ver. 10.15, Topcon Corp).

Patients were diagnosed with primary open-angle glaucoma on observing glaucomatous optic disc damage, corresponding glaucomatous VF defects, and an open angle confirmed by gonioscopic examinations. The VF test results were suitable for the following Anderson's criteria: (1) a cluster of 3 points with $p < 0.05$ in the pattern deviation plot in a single hemifield, including at least 1 point with $p < 0.01$; (2) receiving glaucoma hemifield test results outside the normal limit; or (3) a pattern standard deviation of <0.05 [21].

Cataracts were graded as Lens Opacities Classification System II through the slit light test, following pupil dilation [22]. This system classifies the grade of nuclear opacity, cortical opacity, and posterior subcapsular opacity with a colored slit-lamp and retroillumination image. Each

opacities were scored respectively, and the overall cataract degree was defined as the sum of each score.

Before surgery, we used tropicamide (0.5%) and phenylephrine hydrochloride (0.5%) eye drops (Mydrin-P, Santen Pharmaceutical) for dilating the pupil. The skin, eyelid, and conjunctiva were disinfected with 5% povidone-iodine. One surgeon performed phacoemulsification and posterior chamber intraocular lens implantation. Following topical anesthesia with 0.5% proparacaine hydrochloride eye drops (Alcaine, Alcon), a side-port incision was per-

Table 1. Characteristics of the study participants (n=84)

Characteristic	Glaucoma group (n = 42)	Normal group (n = 42)	*p*-value
Age (yr)	76.3 ± 4.4	76.0 ± 4.0	0.763*
Sex			>0.999†
Male	37	37	
Female	5	5	
BCVA (logMAR)	0.2 ± 0.1	0.2 ± 0.2	0.960*
Intraocular pressure (mmHg)	14.3 ± 2.6	14.4 ± 2.3	0.859*
Central corneal thickness (μm)	531.4 ± 30.9	535.8 ± 32.2	0.145*
Axial length (mm)	23.7 ± 1.1	23.6 ± 0.8	0.761*
Nucleus opacity score	2.1 ± 0.5	2.1 ± 0.5	>0.999*
Cortical opacity score	1.4 ± 0.5	1.4 ± 0.5	>0.999*
Posterior subcapsular opacity score	0.3 ± 0.6	0.3 ± 0.6	>0.999*
The sum of cataract score	3.8 ± 0.7	3.8 ± 0.7	>0.999*
Visual field		-	-
Mean deviation (dB)	–7.19 ± 7.49		
Pattern standard deviation (dB)	4.87 ± 4.06		
Visual field index (%)	82.49 ± 23.36		

Values are presented as mean ± standard deviation or number of eyes.
BCVA = best-corrected visual acuity; logMAR = logarithm of the minimum angle of resolution.
*Independent *t*-test; †Fisher exact test.

Table 2. A comparison of the BCVA, IOP, and IQ of SS-OCT between the glaucoma and normal groups

Variable	Preoperative	Postoperative	*p*-value*
BCVA (logMAR)			
Glaucoma group	0.2 ± 0.1	0.1 ± 0.1	<0.001†
Normal group	0.2 ± 0.2	0 ± 0.1	<0.001†
IOP (mmHg)			
Glaucoma group	14.3 ± 2.6	13.2 ± 2.8	0.038†
Normal group	14.4 ± 2.3	13.3 ± 2.6	0.012†
IQ			
Glaucoma group	52.3 ± 6.4	59.4 ± 5.6	<0.001†
Normal group	53.1 ± 8.1	60.6 ± 5.4	<0.001†
p-value‡	0.632	0.337	

Values are presented as mean ± standard deviation.
BCVA = best-corrected visual acuity; IOP = intraocular pressure; IQ = image quality; SS-OCT = swept source optical coherence tomography; logMAR = logarithm of the minimum angle of resolution.
*Paired *t*-test; †Statistically significant; ‡Independent *t*-test.

Table 3. A comparison of the pRNFL thickness in SS-OCT between the glaucoma and normal groups

pRNFL thickness (μm)	Preoperative	Postoperative	*p*-value*
Average			
Glaucoma group	76.9 ± 17.7	83.1 ± 17.1	0.001†
Normal group	99.4 ± 12.6	105.6 ± 11.2	<0.001†
p-value‡	<0.001†	<0.001†	-
Superior			
Glaucoma group	92.7 ± 26.9	101.0 ± 24.3	0.013†
Normal group	121.8 ± 21.8	128.5 ± 18.5	<0.001†
Temporal			
Glaucoma group	62.7 ± 15.2	69.0 ± 15.3	<0.001†
Normal group	75.5 ± 10.1	79.4 ± 10.8	<0.001†
Inferior			
Glaucoma group	89.7 ± 36.5	96.6 ± 33.0	0.015†
Normal group	126.4 ± 23.3	134.9 ± 18.0	0.006†
Nasal			
Glaucoma group	62.3 ± 13.2	65.9 ± 15.0	<0.001†
Normal group	73.5 ± 11.9	79.4 ± 10.8	<0.001†
12 o'clock (superior)			
Glaucoma group	95.4 ± 32.3	104.7 ± 28.2	0.041†
Normal group	128.3 ± 32.4	135.8 ± 28.2	0.002†
11 o'clock			
Glaucoma group	94.3 ± 32.2	105.3 ± 28.7	0.003†
Normal group	123.0 ± 26.9	130.2 ± 24.3	0.005†
10 o'clock			
Glaucoma group	71.4 ± 19.4	79.2 ± 19.7	<0.001†
Normal group	84.1 ± 13.0	89.0 ± 13.4	<0.001†
9 o'clock (temporal)			
Glaucoma group	58.6 ± 14.6	65.8 ± 13.6	<0.001†
Normal group	66.3 ± 7.6	70.6 ± 8.8	<0.001†
8 o'clock			
Glaucoma group	58.4 ± 16.8	65.2 ± 17.0	<0.001†
Normal group	76.0 ± 15.6	78.7 ± 14.3	0.012†
7 o'clock			
Glaucoma group	94.5 ± 42.0	101.3 ± 39.0	0.014†
Normal group	131.4 ± 34.1	139.2 ± 30.2	0.011†
6 o'clock (inferior)			
Glaucoma group	98.5 ± 46.6	106.4 ± 42.7	0.040†
Normal group	145.4 ± 32.5	154.4 ± 26.0	0.024†
5 o'clock			
Glaucoma group	76.1 ± 30.7	82.4 ± 27.5	0.017†
Normal group	102.5 ± 21.9	110.9 ± 17.5	0.002†
4 o'clock			
Glaucoma group	59.2 ± 15.3	61.7 ± 18.1	0.246
Normal group	68.1 ± 11.6	75.0 ± 11.7	<0.001†
3 o'clock (nasal)			
Glaucoma group	57.5 ± 13.3	59.4 ± 13.5	0.289
Normal group	66.0 ± 13.7	71.6 ± 15.9	0.002†
2 o'clock			
Glaucoma group	70.6 ± 19.3	73.6 ± 18.4	0.111
Normal group	86.4 ± 18.0	91.6 ± 14.9	0.012†
1 o'clock			
Glaucoma group	88.3 ± 26.7	92.9 ± 24.8	0.085
Normal group	114.1 ± 28.9	120.4 ± 24.5	0.061

Values are presented as mean ± standard deviation.
pRNFL = peripapillary retinal nerve fiber layer; SS-OCT = swept source optical coherence tomography.
*Paired *t*-test; †Statistically significant; ‡Independent *t*-test.

formed with a sharp knife. The surgeon performed a 2.7-mm incision with a slit knife at the temporal cornea, and anterior capsulotomy was performed using a bent 25G needle after injecting 1.5% hyaluronic acid (Hyalu inj 1.5%, Hanmi Pharmaceutical). Following hydrodissection, phacoemulsification, irrigation and aspiration, and polishing, the foldable intraocular lens (SA60AT, Alcon Laboratories Inc) was inserted into the capsular bag. The anterior chamber was re-formed using a balanced salt solution. All patients were administered 0.3% gatifloxacin (Gatiflo, Handok Pharmaceuticals), 1% fluorometholone (Fumelon, Hanlim Pharmaceutical), and 1% diclofenac (Diclan, Hanlim Pharmaceutical) with postoperative medications. The glaucoma eyes were administered glaucoma medications.

To measure the pRNFL and mGC-IPL thickness, an experienced tester assessed all patients by SS-OCT following pupil dilation. This OCT uses 1,050 nm wavelength to scan the retina at a rate of 100,000 A-scan/sec and calculates the pRNFL and mGC-IPL thickness with a 12 × 9-mm three-dimensional (3D) wide scan [23].

The 3D wide scan program provides pRNFL thickness map and mGC-IPL thickness map. The pRNFL thickness map analyzed the average thickness, four quadrants (superior, inferior, nasal, temporal), and clock hours. In addition, the mGC-IPL thickness map has an average thickness and

Table 4. A comparison of the mGC-IPL thickness in SS-OCT between the glaucoma and normal groups

mGC-IPL thickness (μm)	Preoperative	Postoperative	*p*-value*
Average			
Glaucoma group	57.9 ± 10.5	61.8 ± 9.4	<0.001†
Normal group	65.7 ± 5.6	69.0 ± 5.5	<0.001†
p-value‡	<0.001†	<0.001†	-
Superior			
Glaucoma group	58.5 ± 11.3	62.0 ± 10.1	0.012†
Normal group	64.2 ± 8.4	68.2 ± 5.9	0.002†
Superotemporal			
Glaucoma group	56.4 ± 16.3	62.7 ± 11.4	0.011†
Normal group	65.7 ± 6.7	70.0 ± 6.3	<0.001†
Inferotemporal			
Glaucoma group	55.8 ± 16.1	61.4 ± 11.7	0.013†
Normal group	67.1 ± 8.3	70.7 ± 6.5	<0.001†
Inferior			
Glaucoma group	54.2 ± 11.2	57.2 ± 9.3	0.014†
Normal group	62.6 ± 6.2	64.3 ± 6.2	<0.001†
Inferonasal			
Glaucoma group	59.0 ± 11.2	61.3 ± 10.7	<0.001†
Normal group	66.1 ± 6.5	69.1 ± 5.8	<0.001†
Superonasal			
Glaucoma group	63.3 ± 11.2	66.1 ± 9.9	<0.001†
Normal group	68.4 ± 6.8	71.6 ± 5.6	<0.001†

Values are presented as mean ± standard deviation.
mGC-IPL = macular ganglion cell-inner plexiform layer; SS-OCT = swept source optical coherence tomography.
*Paired *t*-test; †Statistically significant; ‡Independent *t*-test.

thickness of six sectors (superionasal, superior, superiotemporal, inferiotemporal, inferior, inferionasal). IQ is shown at the top of the map and includes only 40 or more according to the manufacture's recommendation, excluding those that have been misaligned or decentered [24].

We performed one-to-one case matching. It is consisted of the glaucoma and normal eyes as the study and control eyes, respectively. The control eyes were set to match the age (±4 years), sex, nucleus opacity grade, cortical opacity grade, posterior subcapsular opacity grade, and the sum of cataract count score.

We used IBM SPSS ver. 20.0 (IBM Corp) for all statistical analysis. A *p*-value of <0.05 was considered statistically significant. We performed an independent *t*-test to compare the characteristics between the groups. Moreover, we performed the paired *t*-test to compare the IQ, the thickness of pRNFL, and mGC-IPL before and after surgery. Univariated linear regression was conducted to analyze the factors associated with the differences in IQ, average pRNFL thickness, and average mGC-IPL thickness following surgery. Furthermore, we performed a multivariate regression analysis for *p*-values of <0.20.

Results

A total of 84 eyes (68 patients) were selected with one-to-one matching. The average age of the glaucoma group and normal group was 76.3 ± 4.4 years and 76.0 ± 4.0 years, respectively. In addition, there was no significant difference between the groups in the best-corrected visual acuity, IOP, central corneal thickness, axial length, nucleus opacity grade, cortical opacity grade, posterior subcapsular opacity grade, and the sum of cataract scores (Table 1).

Following cataract surgery, the IQ increased significantly in the glaucoma and normal groups ($p < 0.001$). There was no statistical difference between the groups regarding the preoperative IQ ($p = 0.632$) and postoperative IQ ($p = 0.337$) (Table 2).

Before cataract surgery, the mean pRNFL thickness was 76.9 ± 17.7 and 99.4 ± 12.6 μm in the glaucoma and normal groups, respectively. Moreover, the significantly the glaucoma group was thinner than the normal group ($p < 0.001$). Following cataract surgery, both the glaucoma and normal groups showed an increase in the mean pRNFL thickness to 83.1 ± 17.1 and 105.6 ± 11.2 μm, respectively ($p = 0.001$ and $p < 0.001$, respectively). In addition, the pRNFL thickness significantly increased in all quadrants following cataract surgery in both groups. However, in the clockwise analysis, there was no significant increase in the postoperative pRNFL thickness from 1 to 4 o'clock in the glaucoma group. Moreover, the postoperative pRNFL thickness did not significantly increase at 1 o'clock in the normal group (Table 3).

Before cataract surgery, the mean mGC-IPL thickness was 57.9 ± 10.5 and 65.7 ± 5.6 μm in the glaucoma and normal groups, respectively. The mean mGC-IPL thickness of the glaucoma group was significantly thinner than that of the normal group ($p < 0.001$). Following cataract surgery, the mean mGC-IPL thickness significantly increased to

Table 5. Univariate and multivariate regression analysis of factors associated with the postoperative increase rate in the IQ of SS-OCT in the glaucoma and normal groups

Variable	Univariate analysis		Multivariate analysis	
	Regression coefficient	*p*-value	Regression coefficient	*p*-value
Age (yr)	0.412	0.056	0.076	0.297
Sex	–0.678	0.808	-	-
Hypertension	–2.481	0.209	-	-
Diabetes mellitus	–4.458	0.013*	–0.131	0.070
Glaucoma	–0.405	0.823	-	-
Preoperative BCVA (logMAR)	16.842	0.001*	0.086	0.275
Preoperative IOP (mmHg)	–0.248	0.507	-	-
Central corneal thickness (μm)	–0.018	0.528	-	-
Axial length (mm)	1.534	0.096	–0.037	0.625
Nucleus opacity score	–1.129	0.577	-	-
Cortical opacity score	5.182	0.006*	0.127	0.096
Posterior subcapsular opacity score	3.254	0.027*	2.302	0.019*
Sum of cataract score	4.482	<0.001*	0.053	0.607
Preoperative IQ	–0.855	<0.001*	–0.836	<0.001*

IQ = image quality; SS-OCT = swept source optical coherence tomography; BCVA = best-corrected visual acuity; logMAR = logarithm of the minimum angle of resolution; IOP = intraocular pressure.
*Statistically significant.

Table 6. Univariate and multivariate regression analysis of factors associated with the postoperative increase rate of pRNFL thickness in SS-OCT in the glaucoma group

Variable	Univariate analysis		Multivariate analysis	
	Regression coefficient	*p*-value	Regression coefficient	*p*-value
Age (yr)	0.443	0.299	-	-
Sex	8.784	0.123	0.221	0.101
Hypertension	3.721	0.433	-	-
Diabetes mellitus	–0.539	0.888	-	-
Preoperative BCVA (logMAR)	–18.739	0.165	–0.112	0.435
Preoperative IOP (mmHg)	–0.853	0.245	-	-
IOP change (mmHg)	0.416	0.446	-	-
Central corneal thickness (μm)	–0.069	0.259	-	-
Axial length (mm)	–1.033	0.530	-	-
Nucleus opacity score	2.164	0.604	-	-
Cortical opacity score	–0.924	0.815	-	-
Posterior subcapsular opacity score	–0.501	0.871	-	-
Sum of cataract score	0.086	0.975	-	-
Preoperative image quality	–0.407	0.167	–0.150	0.271
Preoperative mean pRNFL thickness	–0.256	0.013*	–0.368	<0.001*
Preoperative mean mGC-IPL thickness	–0.166	0.295	-	-

pRNFL = peripapillary retinal nerve fiber layer; SS-OCT = swept source optical coherence tomography; BCVA = best-corrected visual acuity; logMAR = logarithm of the minimum angle of resolution; IOP = intraocular pressure; mGC-IPL = macular ganglion cell-inner plexiform layer.
*Statistically significant.

61.8 ± 9.4 and 69.0 ± 5.5 μm in the glaucoma and normal groups, respectively ($p < 0.001$). In addition, the postoperative mGC-IPL thickness significantly increased in the glaucoma and normal groups in all six sectors (Table 4).

In the multivariate analysis, the preoperative IQ was significantly negatively associated with IQ changes ($p < 0.001$), whereas the posterior subcapsular opacity grade was significantly positively associated with IQ changes ($p = 0.019$) (Table 5). The preoperative mean pRNFL thickness was negatively associated with mean pRNFL thickness changes in the glaucoma and normal group ($p < 0.001$ and $p = 0.002$) (Tables 6, 7).

According to the multivariate analysis, the preoperative mean mGC-IPL thickness was negatively associated with mean mGC-IPL thickness changes in the glaucoma group ($p = 0.001$) (Table 8). Moreover, the cortical opacity grade was positively associated with mean mGC-IPL thickness changes in the normal group ($p = 0.037$). The preoperative mean mGC-IPL thickness did not show significant association with mGC-IPL thickness changes in the normal group ($p = 0.055$). However, the preoperative mean mGC-IPL thickness demonstrated a negative relationship with mGC-IPL thickness changes in the normal group ($p = 0.043$) in the univariate analysis (Table 9).

Discussion

While treating patients with glaucoma in clinical practice, it is important to determine the impact of media opacity, such as cataracts, on the pRNFL thickness and mGC-IPL thickness with OCT. The primary reason is that OCT identifies the interference signals of reference mirrors and lasers irradiated in the eye, and cataracts supposedly cause the dispersion of the irradiated laser into the eye, thereby reducing the IQ of the OCT [5,13–18,25,26]. The pRNFL thickness increases following cataract surgery in TD-OCT and SD-OCT, and cataracts cause poor IQ and the low measurement of pRNFL thickness [13–18]. Kim et al. [18] reported that the IQ and pRNFL thickness measured by

Table 7. Univariate and multivariate regression analysis of factors associated with the postoperative increase rate of pRNFL thickness in SS-OCT in the normal group

Variable	Univariate analysis		Multivariate analysis	
	Regression coefficient	*p*-value	Regression coefficient	*p*-value
Age (yr)	–0.017	0.956	-	-
Sex	–0.870	0.815	-	-
Hypertension	–1.894	0.440	-	-
Diabetes mellitus	–2.515	0.297	-	-
Preoperative BCVA (logMAR)	3.749	0.531	-	-
Preoperative IOP (mmHg)	–0.136	0.794	-	-
IOP change (mmHg)	–0.061	0.893	-	-
Central corneal thickness (μm)	–0.005	0.901	-	-
Axial length (mm)	–0.828	0.591	-	-
Nucleus opacity score	–2.598	0.333	-	-
Cortical opacity score	0.727	0.776	-	-
Posterior subcapsular opacity score	4.277	0.026*	0.177	0.254
Sum of cataract score	2.567	0.137	0.108	0.462
Preoperative image quality	–0.162	0.281	-	-
Preoperative mean pRNFL thickness	–0.289	0.002*	–0.289	0.002*
Preoperative mean mGC-IPL thickness	0.037	0.867	-	-

pRNFL = peripapillary retinal nerve fiber layer; SS-OCT = swept source optical coherence tomography; BCVA = best-corrected visual acuity; logMAR = logarithm of the minimum angle of resolution; IOP = intraocular pressure; mGC-IPL = macular ganglion cell-inner plexiform layer.
*Statistically significant.

Table 8. Univariate and multivariate regression analysis of factors associated with the postoperative increase rate of mGC-IPL thickness in SS-OCT in the glaucoma group

Variable	Univariate analysis		Multivariate analysis	
	Regression coefficient	*p*-value	Regression coefficient	*p*-value
Age (yr)	0.204	0.424	-	-
Sex	6.086	0.070	0.192	0.184
Hypertension	2.208	0.435	-	-
Diabetes mellitus	0.534	0.815	-	-
Preoperative BCVA (logMAR)	–0.198	0.981	-	-
Preoperative IOP (mmHg)	–0.758	0.078	–0.177	0.224
IOP change (mmHg)	0.190	0.557	-	-
Central corneal thickness (μm)	–0.064	0.079	–0.231	0.102
Axial length (mm)	0.099	0.920	-	-
Nucleus opacity score	1.415	0.572	-	-
Cortical opacity score	0.980	0.679	-	-
Posterior subcapsular opacity score	2.805	0.120	0.175	0.223
Sum of cataract score	3.212	0.041*	0.190	0.201
Preoperative image quality	–0.211	0.245	-	-
Preoperative mean pRNFL thickness	–0.020	0.763	-	-
Preoperative mean mGC-IPL thickness	–0.326	0.001*	–0.326	0.001*

mGC-IPL = macular ganglion cell-inner plexiform layer; SS-OCT = swept source optical coherence tomography; BCVA = best-corrected visual acuity; logMAR = logarithm of the minimum angle of resolution; IOP = intraocular pressure; pRNFL = peripapillary retinal nerve fiber layer.
*Statistically significant.

TD-OCT and SD-OCT increased in normal eyes following cataract surgery. Mwanza et al. [15] reported that cataracts degrade the signal strength and pRNFL thickness of TD-OCT in glaucoma. According to Nakatani et al. [17], cataracts cause the underestimation of pRNFL and mGC-IPL thickness in glaucoma upon using SD-OCT. Moreover, Roh et al. [26] reported on an increase in the mGC-IPL thickness of SD-OCT following cataract surgery in both normal and glaucoma eyes.

Similar to previous studies, the IQ, pRNFL thickness, and mGC-IPL thickness increased in both glaucoma and normal groups upon using SS-OCT following cataract surgery in this study. Nonetheless, while analyzing clockwise pRNFL thickness changes, there was no significant increase from 1 to 4 o'clock in the glaucoma group and at 1 o'clock in the normal group. We think there are two reasons which are complicative. First, in both groups, the preoperative pRNFL thickness of 1 o'clock is thicker than the preoperative mean pRNFL thickness. As one of our results showed that the preoperative pRNFL thickness was negatively associated with the postoperative increase rate of pRNFL thickness in the glaucoma and normal group, the increase rate of 1 o'clock might be less affected by cataract surgery. Second, cataract severity is not similar in all parts of the lens. Therefore, if the cataract was unevenly lower at 1 to 4 o'clock in the glaucoma group and 1 o'clock in the normal group than in the other parts, the pRNFL thickness increase rate of that part would be lower.

In previous studies, the mGC-IPL thickness measured by SD-OCT increased in normal and glaucoma eyes following cataract surgery [17,26–28]. Sari et al. [28] reported that mGC-IPL increased at 1 week and 1 month following surgery but returned to its original state after 3 months. Thus, the increase in mGC-IPL thickness following cataract surgery was presumably caused by postsurgical inflammation, and that the original thickness was restored after 3 months due to the disappearance of inflammation [28]. However, Nakatani et al. [17] reported that all parameters of ganglion cell complex thickness significantly increased 7 weeks following cataract surgery, which was at-

Table 9. Univariate and multivariate regression analysis of factors associated with the postoperative increase rate of mGC-IPL thickness in SS-OCT in the normal group

Variable	Univariate analysis		Multivariate analysis	
	Regression coefficient	*p*-value	Regression coefficient	*p*-value
Age (yr)	0.014	0.915	-	-
Sex	–1.057	0.517	-	-
Hypertension	1.076	0.315	-	-
Diabetes mellitus	–0.576	0.588	-	-
Preoperative BCVA (logMAR)	–1.306	0.619	-	-
Preoperative IOP (mmHg)	0.113	0.623	-	-
IOP change (mmHg)	–0.068	0.731	-	-
Central corneal thickness (μm)	–0.001	0.944	-	-
Axial length (mm)	–0.222	0.743	-	-
Nucleus opacity score	–1.446	0.217	-	-
Cortical opacity score	2.276	0.037*	2.276	0.037*
Posterior subcapsular opacity score	–1.366	0.111	–0.196	0.202
Sum of cataract score	–0.598	0.434	-	-
Preoperative image quality	–0.109	0.094	–0.168	0.300
Preoperative mean pRNFL thickness	0.001	0.985	-	-
Preoperative mean mGC-IPL thickness	–0.189	0.043*	–0.286	0.055

mGC-IPL = macular ganglion cell-inner plexiform layer; SS-OCT = swept source optical coherence tomography; BCVA = best-corrected visual acuity; logMAR = logarithm of the minimum angle of resolution; IOP = intraocular pressure; pRNFL = peripapillary retinal nerve fiber layer.
*Statistically significant.

tributed to segment error caused by cataracts. In our study, postoperative SS-OCT performed at a random date within 3 months of surgery was compared with preoperative SS-OCT imaging. The mGC-IPL thickness of all sectors increased in both groups. Our findings supported the theory that increased mGC-IPL thickness may be attributed to increased IQ.

Regarding the type of cataracts, previous studies have analyzed cataract type-specific effects on the IQ of TD-OCT and SD-OCT [15,17,25]. Mwanza et al. [15] reported on an increase in the IQ of TD-OCT in nucleus cataract and posterior subcapsular cataract types. van Velthoven et al. [25] reported that cortical cataract and posterior subcapsular cataract cause low IQ of TD-OCT than nucleus cataract. Nakatani et al. [17] reported that posterior subcapsular cataract is the only factor causing segment error to ganglion cell complex measurements in SD-OCT. In this study, posterior subcapsular cataract predominantly affected the IQ of SS-OCT. OCT technology measures the retardation of the reflected light signal from reference mirror and the light passing through the eyeball [15,29]. Thus, the plaque of posterior subcapsular opacity may be an important factor than other types of lens opacity in OCT IQ.

One of our major findings was that preoperative pRNFL and mGC-IPL thickness showed negative associations with postoperative pRNFL and mGC-IPL thickness changes, respectively. The preoperative pRNFL and mGC-IPL were associated with changes in the pRNFL and mGC-IPL following surgery regardless of the glaucoma group or normal group (Tables 6–9). However, the preoperative mGC-IPL thickness was a statistically insignificant factor in only univariate analysis. In multivariate analysis, the *p*-value was 0.055. This necessitates further studies with a larger sample. There are limited articles that reported similar findings. Nakatani et al. [17] reported that the preoperative pRNFL thickness is not associated with pRNFL thickness change in glaucoma and normal eyes, whereas the preoperative mGC-IPL thickness is not associated with mGC-IPL thickness change in the Fourier domain OCT. Nonetheless, Roh et al. [26] reported that the preoperative mGC-

IPL thickness is negatively associated with mGC-IPL thickness change in SD-OCT in glaucoma and normal eyes. Considering pRNFL and mGC-IPL thicknesses are lower in glaucoma than that in normal eyes, ophthalmologists should consider the effect of cataracts, particularly while interpreting the test results for patients with glaucoma.

There are several studies on the relevance of IOP changes to pRNFL and mGC-IPL thickness changes. Aydin et al. [30] reported that IOP reduction causes an increase in pRNFL thickness. However, Nakatani et al. [17] reported that it was not associated with IOP reduction and pRNFL thickness increase, and suggested that further research was needed. In our study, we observed significant IOP reduction in all groups following cataract surgery. However, IOP reduction was not associated with changes in the IQ, pRNFL thickness, and mGC-IPL thickness.

This study had two limitations. First, we included a relatively small number of patients due to the one-to-one matching design. Further prospective large-scale studies are needed. Second, the cause of difference between the glaucoma and normal group was unknown while analyzing clockwise pRNFL thickness changes. Although we have tried to objectively evaluate the degree of cataract by international standards, the judgment of the degree of cataract may differ from person to person. Considering this point, we consisted of only patients evaluated by one person (BRS).

In conclusion, cataracts, particularly posterior subcapsular cataract, cause a decrease in IQ even in SS-OCT. In addition, preoperative thinner pRNFL and mGC-IPL thickness were related to the effects of cataract on pRNFL and mGC-IPL thickness measurements. Thus, ophthalmologists should consider the effects of cataracts upon suspecting a patient of glaucoma who have been already administered glaucoma medications due to thin pRNFL and mGC-IPL thickness.

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