



Changes of Optical Coherence Tomography Parameters after Cataract Surgery in Primary Open-Angle Glaucoma Eyes

SoHyeon Kim, Youn Hye Jo

Department of Ophthalmology, Konkuk University Medical Center, Konkuk University School of Medicine, Seoul, Korea

Purpose: To investigate the impact of uncomplicated cataract surgery on the measurement of Bruch's membrane opening-minimum rim width (BMO-MRW) and retinal nerve fiber layer thickness (RNFLT) using spectral domain optical coherence tomography (SD-OCT) in primary open-angle glaucoma (POAG) patients.

Methods: This retrospective study included 63 eyes of 63 patients, including 32 POAG eyes and 31 normal eyes who underwent uneventful cataract surgery and follow-up for at least 6 months. Using SD-OCT, BMO-MRW and RNFLT were measured preoperatively and postoperatively at 6 months. Paired *t*-test was used to compare intraocular pressure (IOP), BMO-MRW, RNFLT, and image quality before and after surgery. These parameters and their changes were compared between POAG and normal groups. Univariate and multivariate linear regression analyses were performed to determine the factors associated with the postoperative change (Δ) in RNFLT and BMO-MRW.

Results: BMO-MRW and RNFLT were significantly increased and IOP was decreased after phacoemulsification in both groups ($p < 0.001$, respectively). The Δ RNFLT was significantly greater in POAG eyes compared with the normal eyes ($p < 0.001$). The Δ RNFLT was associated with the postoperative IOP reduction and glaucoma diagnosis ($p < 0.001$ and $p = 0.001$, respectively). In the normal group, only the Δ IOP had a significant influence on the Δ RNFLT ($p = 0.003$), but in the POAG group, not only the Δ IOP ($p = 0.044$) but also preoperative visual field mean deviation ($p = 0.029$) showed a significant influence. The Δ BMO-MRW showed no difference between POAG and normal eyes.

Conclusions: The postoperative increase of RNFLT was significantly greater in the POAG group, and the postoperative increase of RNFLT was associated with the preoperative visual field mean deviation and Δ IOP in POAG eyes and with the Δ IOP in normal eyes. Our results imply that RNFLT is more affected than BMO-MRW in POAG eyes compared to normal eyes by cataract surgery.

Key Words: Bruch's membrane opening-minimum rim width, Cataract surgery, Open-angle glaucoma, Retinal nerve fiber layer thickness, Spectral domain optical coherence tomography

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Corresponding Author: Youn Hye Jo, MD. Department of Ophthalmology, Konkuk University Medical Center, Konkuk University School of Medicine, 120 Neungdong-ro, Gwangjin-gu, Seoul 05029, Korea. Tel: 82-2-2030-7653, Fax: 82-2-2030-5273, E-mail: eyedr_yh@kuh.ac.kr

Glaucoma is a group of eye diseases characterized by progressive optic nerve damage, which results in optic nerve damage and visual field (VF) defect. Since defects of the retinal nerve fiber layer (RNFL) and optic nerve head (ONH) appear earlier than the VF defect and progress irreversibly, it is important to detect preceding structural ab-

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normalities before the VF defect occurs [1]. With the advent of optical coherence tomography (OCT), it has become possible to objectively measure changes in the structure of the ONH in glaucoma eyes and quantitatively evaluate the progression of glaucoma. OCT has established itself as an essential test tool for glaucoma screening, diagnosis, and treatment progress [2,3].

The clinical usefulness of OCT in glaucoma assessment has been mainly focused on the parapapillary RNFL thickness (RNFLT) as it allows for a comprehensive evaluation of retinal ganglion cell axons approaching ONH. However, the variability of structures around the ONH and the presence of coexisting pathologies may affect reliable measurements; Bruch's membrane opening-minimum rim width (BMO-MRW), the minimum distance from the BMO to the internal limiting membrane, has emerged as a new parameter that can compensate for these shortcomings [4–6]. Therefore, a precise measurement of the RNFLT and BMO-MRW using spectral domain OCT (SD-OCT) is crucial for diagnosing and monitoring glaucoma.

Since cataracts frequently coexist in elderly glaucoma patients and cataract surgery is commonly performed in glaucoma patients during the glaucoma follow-up [7], understanding the effect of cataract surgery on OCT parameters is important for accurate glaucoma damage assessment. Several studies have reported the effect of cataract surgery on RNFLT and the macula in healthy eyes [8–11]. However, there have been few studies addressing changes of OCT parameters, including BMO-MRW, after cataract surgery in glaucoma patients. Therefore, this study aims to determine the effect of cataract surgery on RNFLT and BMO-MRW, and to compare the change between glaucoma and normal eyes.

Materials and Methods

Ethical statements

The Institutional Review Board of Konkuk University Medical Center approved this study (No. KUMC 2022-06-003). All procedures conformed to the principles of the Declaration of Helsinki. Written informed consent from the participants was waived due to the retrospective nature of this study.

Patient selection

We reviewed patients who had undergone cataract surgery in one eye between September 2017 and August 2021 and follow-up for at least 6 months. Among them, eyes having reliable OCT images (no projection or motion artifact and no segmentation error) preoperatively and postoperatively at 6 months were consecutively recruited. All participants underwent a review of past medical history and a comprehensive ophthalmic examination including best-corrected visual acuity with manifest refraction, intraocular pressure (IOP) by Goldmann applanation tonometry, central corneal thickness by ultrasound pachymetry (AL-2000, Tomey), slit-lamp biomicroscopy including gonioscopy, axial length with IOLMaster (Carl Zeiss Meditec), VF with Humphrey Field Analyzer Swedish Interactive Threshold Algorithm 24-2 (Carl Zeiss Meditec), dilated color fundus photography (OPTOS 200TX, OPTOS), red-free RNFL photography (Spectralis, Heidelberg Engineering), and SD-OCT (Spectralis, Heidelberg Engineering).

The eyes with only cataract and no other diseases were classified into the normal group. The eye in the normal group showed deep anterior chamber, open angle on gonioscopy, and normal ONH examination. The eyes diagnosed with open-angle glaucoma were classified into the primary open-angle glaucoma (POAG) group. Glaucoma diagnosis was determined by the appearance of glaucomatous optic disc change, glaucomatous peripapillary RNFL thinning, and corresponding VF defects. All glaucoma eyes have open angles on gonioscopy exam and well-controlled IOP under medications.

Exclusion criteria included with the following condition: (1) had ophthalmic diseases other than glaucoma, which could affect the VF or ONH evaluation, such as macular disease (diabetic retinopathy, epiretinal membrane, or age-related macular degeneration); (2) had a history of intraocular surgery other than uneventful cataract surgery; (3) had systemic or neurological diseases that could influence the VF tests; (4) had angle closure on gonioscopic examination; or (5) had high myopia (axial length, >25.50 mm) causing high frequency of OCT segmentation errors.

Surgical technique

Cataract surgery was performed under topical anesthesia

by two surgeons (YHJ and BJC). A side-port incision was made with a 1-mm diamond knife, and then the main clear corneal incision was made with a 2.8-mm diamond knife. The surgery involved a standard phacoemulsification with an in-the-bag monofocal hydrophobic foldable intraocular lens (Artis, Cristalens Industrie) or hydrophilic acrylic aspheric monofocal intraocular lens (Rayner, Rayner Intraocular Lenses Ltd) implantation using the Centurion Vision System (Alcon Laboratories Inc). Postoperative medications consisted of topical 1% prednisolone and 0.5% moxifloxacin four times per day for 4 weeks, as well as nonsteroidal anti-inflammatory drugs (0.45% ketorolac tromethamine or bromfenac) twice per day for 2 weeks.

Optical coherence tomography

All participants underwent the SD-OCT (software ver. 6.0) scanning preoperatively and postoperatively at 6 months by the ONH acquisition protocol available in the new Glaucoma Module Premium Edition with automatic

real time function for noise reduction. Additionally, OCT imaging used anatomical positioning system which recognizes individual anatomic landmarks and provides the exact placement of subsequent scans at the center of the fovea and the center of the BMO, creating a fovea-BMO center axis [12]. The image quality (Q) was obtained with a Q score which is a term for signal strength.

BMO-MRW was measured from 24 radial B-scans over a 15° area automatically centered at the ONH. Each B-scan consisted of 1,536 A-scans and was the average of 25 repetitions to improve image accuracy. BMO-MRW was defined as the minimum distance between BMO and internal limiting membrane, and two BMO-MRW values of each B-scan were calculated and averaged.

RNFLT was measured using three circular scans (a diameter of inner circle, 3.5 mm; middle circle, 4.1 mm; and outer circle, 4.7 mm) at the center of the ONH. Each scan consisted of 768 A-scans and was the average of 100 repetitions. Image acquisition using Spectralis OCT was taken based on the fovea-to-BMO center axis. The OCT param-

Table 1. Demographic and preoperative characteristics of study participants

Characteristic	Normal eye (n = 31)	POAG eye (n = 32)	p-value
Age (yr)	68.16 ± 9.83 (38 to 85)	70.34 ± 8.53 (52 to 88)	0.350*
Sex			0.101†
Male	19 (61.3)	13 (40.6)	
Female	12 (38.7)	19 (59.4)	
Laterality			0.098†
Right	11 (35.5)	18 (56.3)	
Left	20 (64.5)	14 (43.8)	
Axial length (mm)	23.15 ± 0.84 (21.40 to 25.04)	23.44 ± 0.68 (21.65 to 24.65)	0.126*
Central corneal thickness (µm)	540.77 ± 38.38 (462 to 621)	525.03 ± 36.44 (462 to 594)	0.100*
Hypertension	14 (45.2)	19 (59.4)	0.259†
Diabetes mellitus	7 (22.6)	8 (25.0)	0.822†
Preoperative BCVA (logMAR)	0.30 ± 0.35 (0 to 2)	0.32 ± 0.42 (0 to 2)	0.837*
Preoperative IOP (mmHg)	13.94 ± 2.78 (10 to 19)	13.41 ± 3.19 (8 to 21)	0.485*
Preoperative BMO-MRW (µm)	252.54 ± 36.69 (179 to 390)	176.50 ± 44.16 (77 to 264)	<0.001**
Preoperative RNFLT (µm)	104.15 ± 7.85 (91 to 126)	73.56 ± 16.14 (41 to 100)	<0.001**
Preoperative VF MD (dB)	-	-8.14 ± 7.07 (-10.19 to -0.63)	-
Preoperative image Q	27.13 ± 4.38 (13 to 36)	26.94 ± 3.97 (15 to 32)	0.856*

Values are presented as mean ± standard deviation (range) or number (%).

POAG = primary open-angle glaucoma; BCVA = best-corrected visual acuity; logMAR = logarithm of the minimum angle of resolution; IOP = intraocular pressure; BMO-MRW = Bruch's membrane opening-minimum rim width; RNFLT = retinal nerve fiber layer thickness; VF = visual field; MD = mean deviation; Q = quality.

*Independent *t*-test; †Chi-square test ‡Statistically significant difference ($p < 0.05$).

ters such as BMO-MRW and RNFLT values were automatically calculated on a global and sectoral basis using the device's standard operating software. All scans were confirmed by the researcher and modified if necessary, and the figures provided by a 3.5-mm diameter of the inner circle scan were only included in the analysis.

Statistical analyses

All statistical analyses were performed with SPSS ver. 18.0 (SPSS Inc). Normal distribution was confirmed by the Kolmogorov–Smirnov test. Continuous variables were compared by the independent *t*-test, whereas categorical variables were compared by the chi-square test between glaucoma and normal groups. The paired *t*-test was performed to compare the preoperative and postoperative values. Univariate linear regression was used to analyze factors associated with a postoperative increase in RNFLT and BMO-MRW. Then, the factors with significance of *p* < 0.05 in the univariate analyses were included in the multivariate linear regression analysis model. The results are expressed as the means ± standard deviations. A *p*-value less than 0.05 was considered to be statistically significant.

Results

Thirty-two POAG eyes and 31 normal eyes were enrolled. The mean age of glaucoma and normal groups were 70.34 ± 8.53 and 68.16 ± 9.83 years old, respectively. There was no significant difference between the two groups in terms of age, sex, laterality, comorbidities including hypertension and diabetes mellitus, central corneal thickness, axial length, preoperative best-corrected visual acuity, IOP, and image Q (*p* > 0.05, each). The preoperative BMO-MRW and RNFLT were significantly thinner in the glaucoma group compared with the normal group (176.50 ± 44.16 μm vs. 252.54 ± 36.69 μm and 73.56 ± 16.14 μm vs. 104.15 ± 7.85 μm, respectively; *p* < 0.001). Table 1 illustrates the study participants' demographic characteristics.

Table 2 shows the preoperative and postoperative values of IOP, BMO-MRW, RNFLT, and image Q in both groups. The IOP significantly decreased from 13.41 ± 3.19 to 10.88 ± 2.51 mmHg in the glaucoma group and from 13.94 ± 2.78 to 12.03 ± 2.67 mmHg in the normal group (*p* < 0.001, respectively). The BMO-MRW significantly increased from a preoperative value of 176.50 ± 44.16 μm to a postoperative value of 185.22 ± 44.76 μm in glaucoma eyes and from 252.54 ± 36.69 to 260.96 ± 38.02 μm postoperatively in normal eyes. The RNFLT also significantly increased post-

Table 2. IOP, BMO-MRW, RNFLT, and image Q at baseline and the postoperative optical coherence tomography examination in glaucoma and normal eyes

Parameter	Preoperative	Postoperative	<i>p</i> -value*
IOP (mmHg)			
Normal	13.94 ± 2.78 (10 to 19)	12.03 ± 2.67 (6 to 18)	<0.001 [†]
Glaucoma	13.41 ± 3.19 (8 to 21)	10.88 ± 2.51 (5 to 18)	<0.001 [†]
BMO-MRW (μm)			
Normal	252.54 ± 36.69 (179 to 390)	260.96 ± 38.02 (186 to 409)	<0.001 [†]
Glaucoma	176.50 ± 44.16 (77 to 264)	185.22 ± 44.76 (80 to 265)	<0.001 [†]
RNFLT (μm)			
Normal	104.15 ± 7.85 (91 to 126)	106.75 ± 9.35 (93 to 133)	<0.001 [†]
Glaucoma	73.56 ± 16.14 (41 to 100)	80.75 ± 16.09 (48 to 112)	<0.001 [†]
Image Q			
Normal	27.13 ± 4.38 (13 to 36)	29.97 ± 4.14 (18 to 36)	0.003 [†]
Glaucoma	26.94 ± 3.97 (15 to 32)	29.13 ± 3.17 (19 to 34)	0.006 [†]

Values are presented as mean ± standard deviation (range).

IOP = intraocular pressure; BMO-MRW = Bruch's membrane opening-minimum rim width; RNFLT = retinal nerve fiber layer thickness; Q = quality.

*Paired *t*-test; [†]Statistically significant difference (*p* < 0.05).

Table 3. Comparison of changes in IOP, BMO-MRW, RNFLT, and image Q after cataract surgery between glaucoma and normal eyes

Variable	Normal eye (n = 31)	Glaucoma eye (n = 32)	p-value*
ΔIOP (mmHg)	-1.90 ± 1.94 (-9 to 0)	-2.72 ± 2.25 (-11 to 2)	0.129
ΔBMO-MRW (μm)	9.94 ± 6.77 (0 to 31)	8.72 ± 5.18 (0 to 21)	0.825
ΔRNFLT (μm)	3.42 ± 2.55 (0 to 11)	7.19 ± 4.69 (1 to 19)	<0.001†
ΔImage Q	2.84 ± 4.91 (18 to 36)	2.19 ± 4.19 (19 to 34)	0.573

Values are presented as mean ± standard deviation (range).

IOP = intraocular pressure; BMO-MRW = Bruch's membrane opening-minimum rim width; RNFLT = retinal nerve fiber layer thickness; Q = quality; Δ = change.

*Independent *t*-test; †Statistically significant difference (*p* < 0.05).

Table 4. Univariate and multivariate analysis of factors associated with a postoperative increase in RNFLT in glaucoma and normal eyes

Variable	Univariate			Multivariate		
	Coefficient	95% CI	p-value	Coefficient	95% CI	p-value
Age (yr)	0.028	-0.090 to 0.145	0.640	-		
Sex	1.884	-0.203 to 3.971	0.076	-		
Preoperative BCVA (logMAR)	-0.695	-3.492 to 2.102	0.621	-		
Preoperative IOP (mmHg)	0.404	0.074 to 0.734	0.017*	-		
Axial length (mm)	1.085	-0.285 to 2.454	0.118	-		
Central corneal thickness (μm)	0.006	-0.017 to 0.028	0.631	-		
Preoperative RNFLT (μm)	-0.086	-0.137 to -0.034	0.001*	-		
Preoperative image Q	-0.079	-0.339 to 0.180	0.543	-		
ΔIOP (mmHg)	-0.985	-1.426 to -0.543	<0.001*	-0.843	-1.256 to -0.432	<0.001*
ΔImage Q	-0.113	-0.350 to 0.123	0.341	-		
Glaucoma diagnosis	3.768	1.856 to 5.680	<0.001*	3.081	1.342 to 4.819	0.001*

RNFLT = retinal nerve fiber layer thickness; CI = confidence interval; BCVA = best-corrected visual acuity; logMAR = logarithm of the minimum angle of resolution; IOP = intraocular pressure; Δ = change; Q = quality.

**p* < 0.05.

Table 5. Univariate and multivariate analysis of factors associated with a postoperative increase in RNFLT in glaucoma eyes

Variable	Univariate			Multivariate		
	Coefficient	95% CI	p-value	Coefficient	95% CI	p-value
Age (yr)	0.046	-0.159 to 0.250	0.652	-		
Preoperative BCVA (logMAR)	-0.628	-4.808 to 3.551	0.761	-		
Preoperative IOP (mmHg)	0.483	0.009 to 0.956	0.046*	-		
Axial length (mm)	1.662	-0.824 to 4.148	0.182	-		
Central corneal thickness (μm)	0.023	-0.025 to 0.070	0.336	-		
Preoperative VF MD (dB)	-0.344	-0.549 to -0.140	0.002*	-0.243	-0.459 to -0.027	0.029*
Preoperative RNFLT (μm)	-0.045	-0.152 to 0.062	0.395	-		
ΔIOP (mmHg)	-0.963	-1.654 to -0.272	0.008*	-0.684	-1.349 to -0.019	0.044*
ΔImage Q	-0.090	-0.506 to 0.326	0.661	-		

RNFLT = retinal nerve fiber layer thickness; CI = confidence interval; BCVA = best-corrected visual acuity; logMAR = logarithm of the minimum angle of resolution; IOP = intraocular pressure; VF = visual field; MD = mean deviation; Δ = change; Q = quality.

**p* < 0.05.

surgery in both groups: from 73.56 ± 16.14 to 80.75 ± 16.09 μm in the glaucoma group and from 104.15 ± 7.85 to 106.75 ± 9.35 μm in the normal group. There was a significant increase in the image Q in both groups. Table 3 presents a comparison of the changes (Δ) in IOP, BMO-MRW, RNFLT, and image Q after surgery between the two groups. The ΔRNFLT was significantly different between the two groups (glaucoma eyes, 7.19 ± 4.69 ; normal eyes, 3.42 ± 2.55 ; $p < 0.001$), whereas ΔIOP , $\Delta\text{BMO-MRW}$, and $\Delta\text{image Q}$ were not ($p > 0.05$, each).

The results of univariate and multivariate linear regression analyses are summarized in Tables 4–9. Table 4 illus-

trates the factors associated with the ΔRNFLT in both groups. Multivariate linear regression analysis showed that the diagnosis of glaucoma and the ΔIOP had a significant association with the ΔRNFLT postoperatively at 6 months ($p < 0.001$, each) (Table 4). In the subgroup analyses, the preoperative VF mean deviation (MD) and the ΔIOP showed a significant association with the ΔRNFLT in glaucoma eyes (Table 5), whereas the ΔIOP was a factor associated with the ΔRNFLT postoperatively at 6 months after surgery in normal eyes (Table 6). On the other hand, there was no factors associated with $\Delta\text{BMO-MRW}$ (Tables 7–9).

Table 6. Univariate and multivariate analysis of factors associated a postoperative increase in RNFLT in normal eyes

Variable	Univariate			Multivariate		
	Coefficient	95% CI	<i>p</i> -value	Coefficient	95% CI	<i>p</i> -value
Age (yr)	-0.030	-0.128 to 0.068	0.531	-		
Preoperative BCVA (logMAR)	-1.110	-3.812 to 1.592	0.408	-		
Preoperative IOP (mmHg)	0.370	0.051 to 0.689	0.025*	-		
Axial length (mm)	-0.076	-1.232 to 1.079	0.893	-		
Central corneal thickness (μm)	0.005	-0.012 to 0.022	0.573	-		
Preoperative RNFLT (μm)	0.011	-0.088 to 0.110	0.821	-		
ΔIOP (mmHg)	-0.677	-1.106 to -0.247	0.003*	-0.677	-1.106 to -0.247	0.003*
$\Delta\text{Image Q}$	-0.079	-0.274 to 0.117	0.417	-		

RNFLT = retinal nerve fiber layer thickness; CI = confidence interval; BCVA = best-corrected visual acuity; logMAR = logarithm of the minimum angle of resolution; IOP = intraocular pressure; Δ = change; Q = quality.

* $p < 0.05$.

Table 7. Univariate analysis of factors associated with a postoperative increase in BMO-MRW in glaucoma and normal eyes

Variable	Univariate		
	Coefficient	95% CI	<i>p</i> -value
Age (yr)	0.067	-0.099 to 0.233	0.423
Sex	3.567	0.660 to 6.473	0.017
Preoperative BCVA (logMAR)	-0.143	-4.130 to 3.843	0.943
Preoperative IOP (mmHg)	0.287	-0.199 to 0.773	0.242
Axial length (mm)	0.398	-1.596 to 2.393	0.691
Central corneal thickness (μm)	0.016	-0.017 to 0.048	0.335
Preoperative BMO-MRW (μm)	0.019	-0.006 to 0.045	0.140
Preoperative image Q	-0.237	-0.602 to 0.128	0.199
ΔIOP (mmHg)	-0.441	-1.134 to 0.252	0.208
$\Delta\text{Image Q}$	0.190	-0.145 to 0.525	0.260
Glaucoma diagnosis	-1.217	-4.247 to 1.814	0.425

BMO-MRW = Bruch’s membrane opening-minimum rim width; CI = confidence interval; BCVA = best-corrected visual acuity; logMAR = logarithm of the minimum angle of resolution; IOP = intraocular pressure; Q = quality; Δ = change.

Discussion

This study showed that the RNFLT, BMO-MRW, and image Q were significantly increased and IOP was significantly decreased at 6 months after cataract surgery in both glaucoma and normal eyes. Only the Δ RNFLT showed a difference between glaucoma and normal groups. The Δ RNFLT was associated with the Δ IOP and the diagnosis of glaucoma. In the glaucoma group, not only the Δ IOP but also the preoperative VF MD showed a correlation with the Δ RNFLT. On the other hand, BMO-MRW significantly increased in both groups after surgery, but there was no difference in the Δ BMO-MRW between the two groups, and the factors affecting the Δ BMO-MRW were not identified. These results suggest that RNFLT is more

affected by cataract surgery than BMO-MRW in glaucoma eyes compared to normal eyes. To the best of our knowledge, there has been no studies have investigated and compared the impact of cataract surgery on RNFLT and BMO-MRW measurements by SD-OCT between glaucoma and normal eyes.

Various previous studies reported the effect of cataract surgery on RNFLT measurements using OCT in healthy eyes [11–14]. They used different domains of OCT (time domain OCT and SD-OCT) and followed up on different postoperative days. Studies using the TD Stratus OCT (Carl Zeiss Meditec Inc) [13,14] reported that RNFLT is increased after cataract surgery as lens opacity contributes to decreasing RNFLT. Further studies with a larger number of patients also confirmed that cataract removal results

Table 8. Univariate analysis of factors associated with a postoperative increase in BMO-MRW in glaucoma eyes

Variable	Univariate		
	Coefficient	95% CI	<i>p</i> -value
Age (yr)	-0.094	-0.318 to 0.129	0.396
Preoperative BCVA (logMAR)	-1.645	-6.226 to 2.936	0.469
Preoperative IOP (mmHg)	0.069	-0.490 to 0.628	0.803
Axial length (mm)	1.775	-0.995 to 4.545	0.201
Central corneal thickness (μ m)	0.011	-0.042 to 0.064	0.684
Preoperative VF MD (dB)	-0.085	-0.367 to 0.196	0.539
Preoperative BMO-MRW (μ m)	0.007	-0.037 to 0.050	0.753
Δ IOP (mmHg)	-0.522	-0.310 to 0.266	0.186
Δ Image Q	0.034	-0.426 to 0.496	0.880

BMO-MRW = Bruch's membrane opening-minimum rim width; CI = confidence interval; BCVA = best-corrected visual acuity; logMAR = logarithm of the minimum angle of resolution; IOP = intraocular pressure; VF = visual field; MD = mean deviation; Δ = change; Q = quality.

Table 9. Univariate analysis of factors associated a postoperative increase in BMO-MRW thickness in normal eyes

Variable	Univariate		
	Coefficient	95% CI	<i>p</i> -value
Age (yr)	0.209	-0.040 to 0.458	0.097
Preoperative BCVA (logMAR)	2.117	-5.087 to 9.321	0.553
Preoperative IOP (mmHg)	0.603	-0.292 to 1.499	0.179
Axial length (mm)	-0.252	-3.314 to 2.809	0.867
Central corneal thickness (μ m)	0.016	-0.029 to 0.061	0.474
Preoperative BMO (μ m)	0.040	-0.018 to 0.098	0.171
Δ IOP (mmHg)	-0.469	-1.782 to 0.845	0.472
Δ Image Q	0.292	-0.219 to 0.803	0.252

BMO-MRW = Bruch's membrane opening-minimum rim width; CI = confidence interval; BCVA = best-corrected visual acuity; logMAR = logarithm of the minimum angle of resolution; IOP = intraocular pressure; Δ = change; Q = quality.

in a significant increase of the RNFLT and image Q and they explained the underlying mechanisms are signal and quality reductions caused by lens opacities [15,16]. Renones de Abajo et al. [11] used SD-OCT and showed similar results with the present study. They found a significant increase in the RNFLT and BMO-MRW postoperatively at 1 and 6 months after femtosecond laser-assisted lens surgery (FLALS) in healthy eyes. They suggested that “optic disc cupping reversal” following the relative ocular hypotony after FLALS might have some tissue-expanding effect similar to that observed after glaucoma surgery, causing the postoperative increase in BMO-MRW. Although Mauschitz et al. [12] reported that RNFLT, BMO area, and BMO-MRW, taken by SD-OCT, remained unchanged after cataract surgery, they differ from our study in that they performed OCT examination on the 1st postoperative day and conducted only on normal subjects.

Compared with RNFLT, BMO-MRW, a relatively recently developed parameter, lacks research on changes after cataract surgery, especially for glaucoma patients. However, there are few studies on changes in BMO-MRW after glaucoma surgery [17–19]. Park and Cha [17] reported that BMO-MRW increased with decreasing IOP after filtering surgery, and the increase in the BMO-MRW was associated with the age of the patients and the amount of IOP reduction. Koenig and Hirneiss [18] confirmed that the Δ RNFL showed no significant correlations with the Δ IOP after trabeculectomy, but the Δ BMO-MRW correlated with the Δ IOP. This is contrary to our results. This difference is thought to be because glaucoma surgery much lowers IOP compared to cataract surgery, and the degree of glaucoma is more severe in the eyes undergoing glaucoma surgery than undergoing cataract surgery. In fact, in the study of Koenig and Hirneiss [18], the difference in IOP was approximately 11 mmHg, whereas in this study it was 2 mmHg, and the preoperative VF MD value was -12.7 ± 8.0 dB in that study, but in the present study it was -8.14 ± 7.07 dB.

Previous studies using time domain OCT reported that the Δ image Q and Δ RNFLT were significantly correlated with each other. Kim et al. [20] reported a significant change in the signal strength values and RNFLT measurements 8 weeks after cataract extraction. The Δ RNFLT and Δ signal strength can be explained by the fact that light attenuation and light scattering induced by cataract might cause the change in RNFLT after cataract surgery [12].

Mwanza et al. [15] showed that cataract may reduce RNFLT measurements on OCT images and therefore these measurements should be interpreted with caution, especially in eyes with advanced cataract where SS is much attenuated. Thinning of the RNFLT, which implies glaucoma progression, may be the result of an artifact caused by cataract progression rather than actual anatomical changes of RNFLT. However, there are few studies on the Δ image Q after cataract surgery using SD-OCT, which is technologically more advanced. In our study, the postoperative values of image Q on SD-OCT increased, but these changes did not affect the Δ RNFLT. The possible explanation for this result may lie in the smaller effect of light attenuation and scattering on SD-OCT, which works with confocal scanning laser ophthalmoscope techniques.

A significant decrease in IOP after cataract surgery is consistent with other previous studies [21,22]. This can be explained by the fact that anterior chamber depth, angle opening distance, and anterior chamber area all increase after lens removal. Melancia et al. [21] suggested that these anatomical changes in anterior chamber and modified biometrical factors correlate with postoperative IOP reduction in angle-closure glaucoma, open-angle glaucoma, and normal groups. They reported that the average IOP reduction postsurgery was 1.5 to 3.0 mmHg in mild glaucoma, whereas our study showed that the average postoperative IOP reduction was 2.72 ± 2.25 mmHg in POAG eyes. It was hypothesized that the lens extraction makes the posterior capsule to move posteriorly, dislodging the zonula over the ciliary body, and in consequence, the Schlemm’s canal is widened, and aqueous humor drainage is improved [21]. They also suggested that the ultrasound used in the phacoemulsification procedure can abruptly raise the anterior chamber pressure, producing inflammatory cytokines which consequently stimulate trabecular meshwork remodeling and improve aqueous humor drainage.

When we compared the changes between the two groups, the Δ RNFLT only showed a significant difference. That is, the postoperative increase in RNFLT was greater in glaucoma eyes than in normal eyes. This may reflect that glaucoma eyes are more susceptible to Δ IOP as the compressed RNFLT can regain its original shape due to the IOP reduction after cataract surgery [18,23]. Unlike the Δ RNFLT, in this study, Δ BMO-MRW did not show a significant difference between the two groups. However, there were significant increases in BMO-MRW measurements in

both groups. Since BMO-MRW is a parameter that is relatively more affected by IOP and morphological change in ONH [24], it is thought to show significant changes even in normal eyes after cataract surgery.

We performed linear regression analysis to identify factors affecting the Δ RNFLT. Among them, the Δ IOP and the diagnosis of glaucoma were confirmed to be significant factors. In the subgroup analysis of glaucoma eyes, preoperative VF MD and Δ IOP were identified as factors affecting the postoperative Δ RNFLT. In other words, the greater the postoperative IOP reduction and the more advanced stage of glaucoma, the greater the postoperative increase in RNFLT in glaucoma eyes. These findings are similar with the results of previous studies on the effect of the IOP reduction on RNFLT [11,25]. In 2012, Raghu et al. [25] observed that the RNFLT increased and the cup area decreased for a short period after trabeculectomy but reverted to preoperative values after 3 months. More recently, Park and Cha [17] showed that the postoperative Δ BMO-MRW was significantly increased in younger patients and with greater IOP reduction. They presumed that these changes were due to the plasticity of distribution of the glial cells in neuroretinal rim and the age-dependent changes in glial cells with the decrease in IOP postoperatively. Several studies have reported that a decrease in cupping after IOP reduction following a glaucoma surgery is probably due to a simple shift in anatomic structures rather than a recovery or a reversal of damage [17,25]. When the IOP is decreased, the lamina cribrosa of the disc is less stretched, resulting in the return of the laminar surface to its previous position before the increased IOP causes it to bow back. This return may appear as a decreased cup area after the surgery [21]. This observation suggests that decreased IOP after a cataract surgery might also have a significant effect on ONH OCT parameters in a similar way. Our subgroup analysis of normal eyes showed the greater the decrease in IOP, the greater the increase in RNFLT, and these changes were significantly greater in the glaucoma group than in the normal group.

Unlike previous studies, our study compared the differences in changes of the BMO-based SD-OCT parameters after cataract surgery between glaucoma and normal eyes. The strengths of this study are that it consisted of well-characterized patient samples and that it used anatomical positioning system-guided SD-OCT to ensure precise scan alignment. However, our study is subject to sev-

eral limitations. First, we did not observe longer term Δ OCT parameters following cataract surgery because our study was limited to a follow-up of 6-month after surgery. Referring to a previous study showing that short-term fluctuation in the RNFLT after trabeculectomy soon returned to preoperative values [25], it would be crucial to analyze the long-term postoperative changes. Second, this study had a relatively small sample size and was conducted in a retrospective manner. Further studies with a larger sample size investigating more long-term effects of a cataract surgery on SD-OCT parameters are warranted. Third, this study did not include analyses by glaucoma severity. Because BMO-MRW is a more useful parameter in early-stage glaucoma, and Δ RNFLT are insignificant due to the floor effect and active remodeling of connective tissue in advanced stage, further study is need to analyze according to the severity of glaucoma with a larger sample. Fourth, we could not include the degree of cataract as a parameter, which may influence the Δ RNFLT and Δ BMO-MRW after cataract surgery. As the previous study [26] reported the degree of cataract did not affect the Δ IOP after cataract surgery, the missing of cataract severity would not have had a significant impact on the results of this study. In the follow-up study, we plan to perform an analysis including the cataract degree to determine how the degree of cataract influences OCT measurements.

In conclusion, our data indicate that RNFLT is more affected than BMO-MRW by phacoemulsification in glaucoma eyes compared to normal eyes. In this study, we found that the average RNFLT was increased up to 6 months following cataract surgery, and the postoperative Δ RNFLT was associated with preoperative VF MD and Δ IOP in the glaucoma group and with Δ IOP in the normal group. On the other hand, BMO-MRW significantly increased in both groups and there was no difference between two groups. Because glaucoma eyes are more susceptible to changes in the lamina cribrosa and ONH structures than normal eyes, interpretation of postoperative changes in peripapillary OCT parameters in glaucoma eyes should be cautious.

Conflicts of Interest: None.

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