Myopic Optic Disc Tilt and the Characteristics of Peripapillary Retinal Nerve Fiber Layer Thickness Measured by Spectral-domain Optical Coherence Tomography

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Purpose: To investigate the correlation between myopic optic disc tilt and the characteristics of peripapillary retinal nerve fiber layer (RNFL) thickness measured by Cirrus HD spectral-domain optical coherence tomography (Cirrus HD OCT; Carl Zeiss Meditec, Dublin, CA).

Methods: A total of 255 eyes of 255 healthy young male participants with various degrees of refractive errors (mean spherical equivalent, -3.17 ± 2.40 D; range, -11.00 to 0.00 D) underwent ophthalmic examinations, including refractive error, axial length, and optic disc area measurement. The degree of horizontal/vertical optic disc tilt was evaluated by cross-sectional images obtained by the Cirrus HD OCT. The average, superior, nasal, inferior, and temporal quadrant thickness and superior/inferior peak locations of the peripapillary RNFL were also measured with the Cirrus HD OCT.

Results: On the univariate analysis, eyes with more temporally tilted optic discs (horizontal tilt) had higher myopia, greater axial length, a thinner average, superior, nasal, and inferior RNFL, thicker temporal RNFL, and more temporally positioned superior/inferior peak locations (all P values < 0.001). The degree of inferior optic disc tilt (vertical tilt) was associated with high myopia and a more temporally positioned inferior peak location (all P values < 0.05). On multivariate analysis, eyes with more temporally tilted optic discs had a thicker temporal RNFL and more temporally positioned superior/inferior peak locations.

Conclusions: The characteristics of the peripapillary RNFL thickness were associated with the degree of myopic optic disc tilt, especially in the temporal area. The degree of myopic optic disc tilt should be considered when interpreting the RNFL thickness measured by the Cirrus HD OCT.

Key Words: myopia, optic disc tilt, optical coherence tomography, retinal nerve fiber layer thickness

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Myopia is one of the most common ocular abnormalities worldwide. Ocular morbidities associated with myopia have become a major concern because of its high prevalence and increase in severity, especially in some Asian countries.[1,2] It has been reported that the risk of glaucoma increases with an increasing degree of myopia.[3,4] As glaucoma is associated with characteristic optic disc changes and retinal nerve fiber layer (RNFL) thinning, measurement of the RNFL thickness in myopic eyes has been proposed as a significant parameter for the evaluation of glaucoma. Optical coherence tomography (OCT) is an imaging device designed to measure the RNFL thickness. The most recent advancement in OCT imaging uses spectral-domain technology that provides higher resolution and faster scanning speed.[5]

Many studies have reported conflicting data on the relationship between myopia and RNFL thickness using OCT measurements.[6–10] Most of the earlier studies evaluated correlations of the refractive error, axial length (AL), and RNFL thickness. However, there is a paucity of studies analyzing the effect of the optic disc tilt on the peripapillary RNFL characteristics (thickness and peak location) measured by OCT. It has been reported that tilted optic discs are associated with myopia.[11–13] In myopic eyes, the optic disc usually inserts obliquely (Fig. 1A).[14–16] Once the optic disc tilts temporally, the nasal half of the optic disc elevates anteriorly, and the temporal half of the optic disc depresses posteriorly.[14–16] The changes in optic disc morphology and the association of the RNFL characteristics with the myopic optic disc tilt can complicate the accurate diagnosis of glaucoma.

This study was carried out to evaluate the correlation between the myopic optic disc tilt and the characteristics of the peripapillary RNFL thickness measured by the Cirrus HD spectral-domain OCT (Cirrus HD OCT; Carl Zeiss Meditec, Dublin, CA) in healthy young male participants with various degrees of refractive errors.

METHODS

The study protocol was approved by the Institutional Review Board of the Armed Forces Capital Hospital, Korea. All procedures conformed to the Declaration of Helsinki and all participants provided informed consent before enrollment. Participants with various degrees of refractive errors were recruited between May 2009 and December 2009 at the Armed Forces Capital Hospital. Each participant underwent a full ophthalmic examination, including the assessment of visual acuity, refractive error, intraocular pressure (IOP) by noncontact tonometer (Topcon CT-80; Topcon, Tokyo, Japan), AL measurement by A-scan (HiScan; Optikon, Rome, Italy), optic nerve head evaluation with a 90-D lens, dilated fundus examination with indirect ophthalmoscopy, fundus photography/red-free fundus photography (Zeiss FF450 fundus camera; Carl Zeiss Meditec, Dublin, CA),

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and peripapillary RNFL thickness/peak location measurement with the Cirrus HD OCT.

Inclusion criteria were as follows: age between 19 and 25 years (Korean soldiers from private to sergeant level), male sex, best corrected visual acuity of 20/20 or better, spherical equivalent (SE) equal to or <0 D, a normal IOP (<21 mm Hg), normal optic nerve head without glaucomatous changes (ie, increased cup-disc ratio, narrowing of neuroretinal rim), and no RNFL defect on the red-free fundus photography. Only the right eye of each participant was included in this study. Participants with a history of systemic diseases including hypertension and diabetes, ocular trauma or surgery earlier, or any large peripapillary atrophy extending >1.7 mm from the center of the optic disc were excluded.

A 200×200 cube Optic Disc Scan was obtained with the Cirrus HD OCT (software version 4.0.1.3) after pharmacologic pupil dilation with instillation of 2.5% phenylephrine hydrochloride eye drops (Mydfrin; Alcon, Fort Worth, TX) 3-time at 5-minute intervals. After the participants were seated and properly positioned, the scanning laser images were focused. Once the optic nerve head was centered on the live scanning laser image, a 6×6-mm square of data was captured. Any images without a prominent involuntary saccade during the scan and signal strength >8 were included. All images were acquired by a single, well-trained examiner (Y.H.H.).

Using the Glaucoma OU Analysis mode of the Cirrus HD OCT, the average, superior, nasal, inferior, and temporal RNFL thickness parameters were obtained. The peak locations of superior/inferior RNFL were evaluated by the RNFL TSNIT curve of the Cirrus HD OCT (Fig. 1B). The peak locations seemed as 1 of the 256 points that ranged from 0 to 255 provided by the Cirrus HD OCT algorithm. The obtained peak location from the TSNIT curve was translated to the units of degrees by multiplying 360/256. For example, the superior peak location of 42 in the TSNIT curve was translated to 59.06 degrees ($42\times360/256$). This means that the thickest superior RNFL was located at the point 59.06 degrees away from the temporal horizontal meridian. In the same manner, the inferior peak location was translated to the units of degrees. Thus, the calculated angle between the horizontal meridian and superior peak location, by clockwise rotation, was defined as the α angle and the angle between the horizontal meridian and inferior peak location, by counterclockwise rotation, was defined as the β angle (Fig. 1C).

Using the advanced visualization mode of the Cirrus HD OCT, cross-sectional images of the horizontal and vertical optic nerve head were saved and analyzed for the degree of optic disc tilt. The degree of optic disc tilt was measured in a 3-step process using the National Institutes of Health image-analysis software (ImageJ 1.42q; developed by Wayne Rasbands, National Institutes of Health,

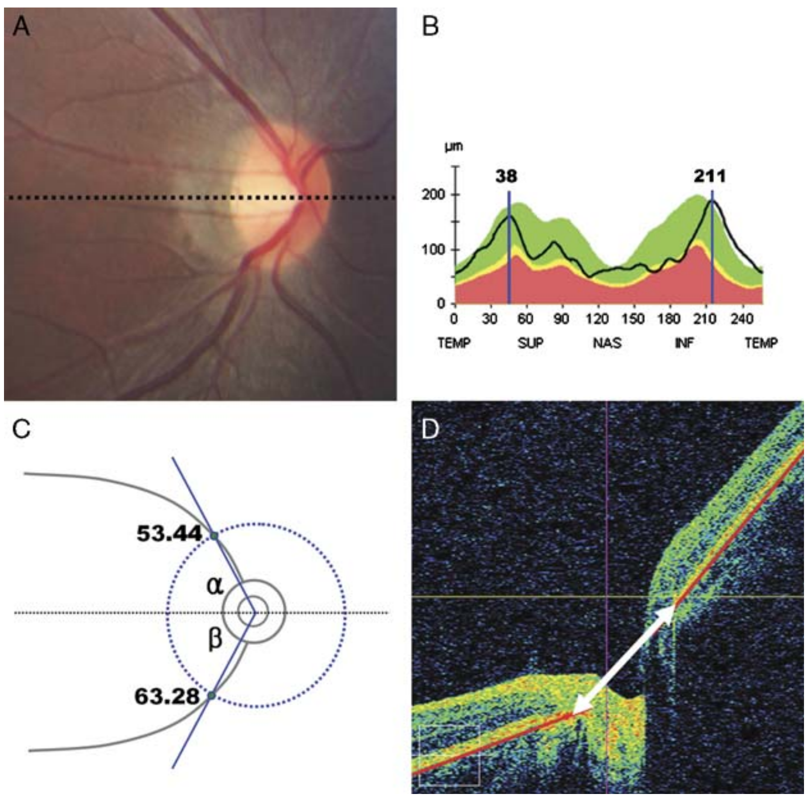

FIGURE 1. An example of a measurement of the retinal nerve fiber layer characteristics in an eye with a -5.13 D of spherical equivalent and a 25.52 mm of axial length: (A) Fundus photograph of the optic disc. Dotted line represents imaginary horizontal meridian; (B) the peak locations at the superior and inferior area were 38 and 211, respectively; (C) the peak locations were translated to units of degrees by multiplying 360/256 (ie, $38\times360/256=53.44$). Angles between the horizontal meridian and the superior/inferior peak locations were defined as the α (superior) and β (inferior) angles; (D) the horizontal cross-sectional image at the level of the dotted line in the fundus photograph. The degree of horizontal optic disc tilt was defined as the angle between the white line in the figure and an imaginary horizontal line.

Bethesda, MD). First, 2 lines were drawn along the inferior border of the retinal pigment epithelium at the opposite sides, bilaterally (nasal and temporal sides for horizontal tilt, superior and inferior sides for vertical tilt; red lines in Fig. 1D). Second, the points of crossing, where the line and retinal pigment epithelium meet, were identified and interconnected with a new line (the white line in Fig. 1D). Third, the angle between the line drawn during the second step and an imaginary horizontal line was measured. The angle, thus calculated was considered as the degree of optic disc tilt. The optic disc tilt in the temporal direction was used for the horizontal optic disc tilt measurement, and the optic disc tilt in the inferior direction was used for the vertical optic disc tilt measurement; both measurements are represented as positive values.

The optic disc area was measured by digital retinal planimetry as described earlier.[17] In brief, digitalized photograph image files were obtained. The optic disc margins, defined as the inner border of the peripapillary scleral ring, were lined and the inner areas were measured using ImageJ by a single, blinded, well-trained examiner (Y.H.H.). The Littmann formula was used to correct the effects of ocular magnification of the optic disc area.[18]

A univariate analysis of the correlations between SE, AL, optic disc area, the degree of optic disc tilt, and the characteristics of the RNFL (average and quadrant RNFL thickness, superior/inferior peak locations) for all the participants were determined by linear regression analysis. To determine the factors significantly influencing the RNFL characteristics, multivariate regression analysis was carried out. For the multivariate regression analysis, the independent variables with a significance level at $P<0.05$ on the univariate analysis were included. All statistical analyses of the data were carried out using commercial software (Statistical Package for Social Science, version 12.0; SPSS Inc., Chicago, IL) and the significance level was set at a $P<0.05$.

RESULTS

Two hundred and fifty five young healthy men were enrolled in this study. The mean age of the 255 participants was 21.03 ± 1.45 years (range, 19 to 25), the mean SE, AL, and optic disc area were −3.17 ± 2.40 D (range, −11.00 to 0.00), 24.96 ± 1.25 mm (range, 22.79 to 28.13), and 2.76 ± 0.61 mm^2 (range, 1.57 to 5.72) respectively. The characteristics of the RNFL and optic disc tilt are listed in Table 1.

TABLE 1. Characteristics of the Participants (n=255)

	Mean ± Standard Deviation	Range
Age (y)	21.03 ± 1.45	19-25
Spherical equivalent (D)	−3.17 ± 2.40	−11.00-0.00
Axial length (mm)	24.96 ± 1.25	22.79-28.13
Optic disc area (mm^2)	2.76 ± 0.61	1.57-5.72
RNFL thickness (μm)		
Average	97.14 ± 6.63	73-118
Superior	124.11 ± 12.94	81-159
Nasal	67.56 ± 8.64	43-91
Inferior	122.81 ± 13.37	76-157
Temporal	74.03 ± 11.13	53-105
RNFL peak location (degree)		
Angle α	68.94 ± 9.46	45.00-99.84
Angle β	67.58 ± 11.01	43.59-97.03
Optic disc tilt (degree)		
Horizontal	22.36 ± 9.72	0.40-51.40
Vertical	4.61 ± 3.41	0.00-18.50

RNFL indicates retinal nerve fiber layer.

Results of the univariate correlation analysis are listed in Tables 2 and 3. A higher degree of myopia was significantly correlated with a thinner average, superior, nasal, inferior RNFL, thicker temporal RNFL, and smaller α and β angles. A greater AL was also associated with a thinner average, superior, nasal, inferior RNFL, thicker temporal RNFL, and smaller α and β angles. A greater optic disc area was correlated with a thicker temporal RNFL and smaller α/β angles (Table 2).

The degree of temporal (in the horizontal meridian) optic disc tilt was associated with higher myopia, greater AL, thinner superior and inferior RNFL, thicker temporal RNFL, and smaller α and β angles; however, the average and nasal RNFL thickness were not significantly associated with the degree of horizontal optic disc tilt. The degree of inferior (in the vertical meridian) optic disc tilt was associated with higher myopia and a smaller β angle; however, it was not significantly associated with the AL, average and quadrant RNFL thickness, or the α angle (Table 3).

TABLE 2. Correlation Analysis Between the Spherical Equivalent, Axial Length, Optic Disc Area, and RNFL Thickness and Peak Location (n=255)

	Spherical Equivalent			Axial Length			Optic Disc Area		
	r	*r*^{2}	*P*	*r*	*r*^{2}	*P*	*r*	*r*^{2}	*P*
RNFL thickness (μm)									
Average	0.340	0.116	< 0.001	−0.288	0.083	< 0.001	0.021	< 0.001	0.750
Superior	0.437	0.191	< 0.001	−0.400	0.160	< 0.001	−0.087	0.008	0.180
Nasal	0.329	0.108	< 0.001	−0.231	0.053	< 0.001	0.066	0.004	0.310
Inferior	0.435	0.189	< 0.001	−0.438	0.192	< 0.001	−0.089	0.008	0.168
Temporal	−0.459	0.210	< 0.001	0.464	0.216	< 0.001	0.201	0.040	0.002
RNFL peak locations (degree)									
Angle α	0.523	0.274	< 0.001	−0.549	0.302	< 0.001	−0.149	0.022	0.022
Angle β	0.605	0.365	< 0.001	−0.570	0.324	< 0.001	−0.200	0.040	0.002

P value: linear regression.
RNFL indicates retinal nerve fiber layer.

TABLE 3. Correlation Analysis Between the Spherical Equivalent, Axial Length, Optic Disc Area, the Degree of Horizontal/Vertical Optic Disc Tilt, and RNFL Thickness and Peak Location (n=255)

	Horizontal Optic Disc Tilt			Vertical Optic Disc Tilt		
	r	r^2	*P*	*r*	r^2	*P*
Spherical equivalent (D)	−0.604	0.364	< 0.001	−0.174	0.030	0.011
Axial length (mm)	0.556	0.309	< 0.001	0.112	0.012	0.104
Optic disc area (mm^2)	0.091	0.008	0.195	−0.011	< 0.001	0.874
RNFL thickness (μm)						
Average	−0.031	0.001	0.656	0.128	0.017	0.061
Superior	−0.341	0.117	< 0.001	0.004	< 0.001	0.948
Nasal	−0.114	0.013	0.094	0.042	0.002	0.543
Inferior	−0.179	0.032	0.008	0.098	0.010	0.152
Temporal	0.569	0.324	< 0.001	0.116	0.013	0.091
RNFL peak locations (degree)						
Angle α	−0.544	0.295	< 0.001	−0.102	0.010	0.139
Angle β	−0.512	0.263	< 0.001	−0.193	0.037	0.005

P value: linear regression.
RNFL indicates retinal nerve fiber layer.

Multivariate regression analysis was carried out with the RNFL thickness/peak location as the dependent variables and SE, AL, the degree of horizontal optic disc tilt (for superior, inferior, and temporal RNFL thickness, and α/β angles), optic disc area (for temporal RNFL thickness and α/β angles), and degree of vertical optic disc tilt for the β angle as the independent variables (chosen variables had significance levels at $P < 0.05$ on the univariate analysis). According to the results of the multivariate analysis, eyes with higher myopia had thinner average, superior, nasal, inferior RNFL, and smaller β angles; the inferior disc tilt had no significantly correlated variables; and eyes with more temporally tilted optic discs had a thicker temporal RNFL and smaller α/β angles (Table 4).

TABLE 4. Significant Factors by the Multivariate Regression Analysis With RNFL Thickness/Peak Location as the Dependent Variables and Spherical Equivalent, Axial Length, the Degree of Horizontal Optic Disc Tilt (for Superior, Inferior, and Temporal RNFL Thickness, Angle α/β), Optic Disc Area (for Temporal RNFL Thickness, Angle α/β), and Vertical Optic Disc Tilt Degree for Angle β as the Independent Variables (n=255)

	r^2	Standardized β	*P*
Average RNFL thickness	0.116		
Spherical equivalent		0.308	0.002
Superior RNFL thickness	0.200		
Spherical equivalent		0.286	0.015
Nasal RNFL thickness	0.111		
Spherical equivalent		0.405	< 0.001
Inferior RNFL thickness	0.218		
Spherical equivalent		0.301	0.009
Axial length		−0.267	0.016
Temporal RNFL thickness	0.366		
Horizontal optic disc tilt		0.462	< 0.001
Angle α	0.359		
Horizontal optic disc tilt		−0.376	< 0.001
Axial length		−0.303	< 0.001
Angle β	0.410		
Spherical equivalent		0.481	< 0.001
Horizontal optic disc tilt		−0.222	0.001

Nonsignificant independent variables are not listed.
P indicates linear regression; RNFL, retinal nerve fiber layer.

DISCUSSION

In this study, eyes with more temporally tilted optic discs had a thicker temporal RNFL and more temporally positioned superior/inferior peak locations of the RNFL. In addition, thinner average and nontemporal RNFL thickness, and less of an inferior peak location was associated with a higher degrees of myopia. This is the first study to identify the effects of myopic optic disc tilt on RNFL characteristics (thickness and peak location) measured using the Cirrus HD OCT.

The relationship between the optic disc tilt and the RNFL thickness has been studied earlier using various imaging technologies. In a study using the Stratus OCT, only the presence of a disc tilt was evaluated, Rauscher et al[7] reported that the correlation between the optic disc tilt and the RNFL thickness was not significant. Yu et al[19] observed a discrepancy in the RNFL thickness measured by scanning laser polarimetry with variable corneal compensation and OCT in the eyes with tilted discs and suggested that RNFL analysis with OCT is more suitable than scanning laser polarimetry for the eyes with a tilted disc. Tong et al[20] reported that the eyes with an optic disc tilt had a greater mean RNFL thickness measured by the Heidelberg retinal tomograph (HRT). A population based HRT study[21] showed that the high myopia group had a greater disc ovality and greater mean RNFL thickness, and that the mean RNFL thickness was significantly correlated with the disc ovality.

In this study, temporal myopic optic disc tilt was associated with thicker temporal RNFL and temporal positioning of the superior/inferior peak locations. To date, the mechanism explaining these findings is not clear. However, possible explanations include the following.

First, topographic changes in the RNFL, by the temporal optic disc tilt, can be associated with the changes in the RNFL thickness and peak location. Two earlier studies,[8,9] carried out at the same center as this study as different study arms, reported that the RNFL measured by the Cirrus HD OCT was thinner in the nontemporal areas, thicker in the temporal areas, and the superior/inferior peak locations were more temporally located in eyes with higher myopia and greater AL. These findings are consistent with the findings of this study. Kim et al[10] speculated that as the AL becomes longer, the retina could be dragged toward the temporal horizon and the RNFL layers would be compressed against the bundles originating from the opposite hemisphere at the horizontal raphe. In this study, the degree of myopic optic disc tilt was associated with the temporal RNFL thickness and the peak location when the SE and AL were adjusted. Therefore, the myopic optic disc tilt may play a more important role in the characteristics of the RNFL in the temporal area than the SE and AL. As an optic disc becomes temporally tilted, retinal dragging toward the temporal horizon could occur. This would result in thickening of the RNFL in the temporal quadrant and temporal dragging of the superior/inferior peak locations.

Second, the obliquity of the scanning of the RNFL can cause errors in the measurements of RNFL thickness in eyes with tilted optic discs. The OCT evaluates images presumed to be taken perpendicular to the longitudinal axis of the eyeball. When the optic disc and surrounding RNFL are tilted, errors in the RNFL measurements can occur by oblique scanning. Tsutsumi et al[21] postulated that HRT could place the reference plane at a falsely posterior position in eyes with oblique insertion of the optic disc, resulting in an artificial increase in the mean RNFL thickness. A similar phenomenon can also occur with the OCT, although the OCT and HRT use different algorithms. Recently, Hong et al[22] investigated the effect of the scan angle of the optic nerve head on RNFL thickness measured with the Cirrus HD OCT. In that study, the adjusted RNFL thickness generated by the 3-dimensional scan angle of the optic nerve head was significantly different from the original values. In the quadrant analysis, the adjusted temporal RNFL was 0.9 μm thicker than the original value. Although the differences between original values and adjusted values were not large, further study with 3-dimensional adjustments is needed, because we measured 2-dimensional horizontal/vertical cross-sectional angles of optic disc tilt.

Third, in eyes with myopia, as the optic disc becomes tilted, the temporal peripapillary ocular tissues become stretched and atrophied.[14–16] Such changes can lead to differences in reflectivity or backscatter detected by the OCT and subsequent differences in the RNFL thickness measurements.

It has been reported that the RNFL thickness measured by the OCT varies not only with SE and AL, but also with age, sex, and ethnicity.[23,24] The strength of this study includes a narrow age range, and the same sex and ethnicity of the participants, which enabled us to rule out their potential affects on the measurements of RNFL characteristics. In this study, only eyes with temporally tilted optic discs in the horizontal meridian and inferiorly tilted optic discs in the vertical meridian were included. However, theoretically, optic disc tilt in the nasal/superior direction could also affect the characteristics of the RNFL thickness. Further study of the eyes with various directions of optic disc tilt is needed.

In conclusion, eyes with more temporally tilted optic discs had thicker temporal RNFLs and more temporally positioned superior/inferior peak locations of the RNFL. These findings suggest that the degree of myopic optic disc tilt is correlated with the peripapillary RNFL characteristics measured by the Cirrus HD OCT in healthy young male myopic eyes. The degree of optic disc tilt should be taken into account when interpreting the RNFL thickness measured by the Cirrus HD OCT.

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