Clinical and Epidemiologic Research

Determinants of Perimacular Inner Retinal Layer Thickness in Normal Eyes Measured by Fourier-Domain Optical Coherence Tomography

Na Rae Kim,[1,2] *Ji Hyun Kim,*[1] *Junwon Lee,*[1] *Eun Suk Lee,*[1] *Gong Je Seong,*[1] *and Chan Yun Kim*[1]

Purpose. To determine the effects of age, sex, spherical equivalent, axial length, anterior chamber depth, optic disc area, and central corneal thickness on perimacular inner retinal layer thickness in the normal human eye as measured by Fourier-domain optical coherence tomography (FD-OCT).

Methods. In this cross-sectional observational study, 182 Korean healthy subjects aged from 22 to 84 years were included. To obtain the inner retinal layer thickness, perimacular ganglion cell complex thickness, which extends from the internal limiting membrane to the inner nuclear layer, was measured by FD-OCT on one randomly selected eye of each subject. Linear regression analyses of the effects of demographic and clinical variables, including age, sex, spherical equivalent, axial length, anterior chamber depth, optic disc area, and central corneal thickness, on perimacular inner retinal layer thickness were performed.

Results. The mean inner retinal layer thickness for the entire population was 93.87 μm. Thinner inner retinal layer measurements were associated with older age ($P = 0.010$) and greater axial length ($P = 0.021$). Mean inner retinal layer thickness decreased by approximately 1.59 μm for every decade of age and by approximately 1.56 μm for every 1-mm greater axial length. There was no relationship between inner retinal layer thickness and sex, anterior chamber depth, optic disc area, or central corneal thickness.

Conclusions. Inner retinal layer thickness, as measured by FD-OCT, varies significantly with age and axial length. The effect is small but clinically relevant in the interpretation of inner retinal layer thickness measurements. (*Invest Ophthalmol Vis Sci.* 2011;52:3413–3418) DOI:10.1167/iovs.10-6648

Glaucoma is a multifactorial optic neuropathy characterized by the selective loss of retinal ganglion cells (RGCs) and their respective axons.[1–3] Because the macular region contains more than 50% of RGCs, assessing ganglion cell changes in this region, rather than measuring peripapillary retinal nerve fiber layer (RNFL) thickness, could be useful for diagnosing glaucoma.[4–6] Recently, the Fourier-domain optical coherence tomography (FD-OCT) technique was introduced. Compared with time-domain (TD)-OCT, this technique improves depth resolution, resulting in considerably improved image quality and a greatly reduced acquisition time.[7–9] RTVue-100 (Optovue, Inc., Fremont, CA) is a commercially available OCT device that uses FD technology. FD-OCT software enables measurements of the thickness of the macular ganglion cell complex (GCC) layer, which extends from the internal limiting membrane to the inner nuclear layer and includes the ganglion cell layer.[10]

Previous studies measuring retinal thickness have demonstrated a relationship between retinal thickness and several demographic and ocular biometric factors.[11–26] However, no studies have investigated the relationship between ganglion cell layer thickness and ocular biometric factors. Furthermore, even though ocular biometric factors are possibly related to retinal thickness, previous studies often take into consideration only axial length and refractive error.

In this study, we used GCC thickness measurements obtained by FD-OCT to evaluate the effects of demographic and ocular biometric factors on inner retinal thickness measurements in healthy subjects. In addition to axial length and refractive error, anterior chamber depth, optic disc area, and central corneal thickness measurements were taken into account.

Subjects and Methods

Subjects

Subjects were consecutively enrolled from the Glaucoma-Cataract Clinic of Severance Hospital, Yonsei University (Seoul, Korea) from January 2009 to June 2010. Healthy subjects were recruited both from department personnel referrals and through an advertisement posted at Severance Hospital. This study was approved by the Institutional Review Board of Severance Hospital, Yonsei University, and was performed in adherence with the Declaration of Helsinki. Informed consent was obtained from all subjects.

All subjects underwent a full ophthalmological examination including measurement of visual acuity, intraocular pressure (IOP) measurements using Goldmann applanation tonometry, slit lamp examination, gonioscopy, fundus examination with a 90D lens, and standard automated perimetry (Humphrey Field Analyzer II with Swedish Interactive Thresholding Algorithm standard 24-2; Carl Zeiss Meditec, Dublin, CA). A reliable visual field (VF) test was defined as one with <20% fixation loss and with false-positive and false-negative errors <15%. Axial ocular dimensions were measured using partial laser interferometry (IOL Master; Carl Zeiss Meditec). Noncycloplegic refraction was measured using an autorefractor (RK-3; Canon USA., Inc., Lake Success, NY) and was further refined subjectively by experienced ophthalmologists. Refraction data were converted to spherical equivalents, which were calculated using the spherical diopter (D) plus one-half the cylindrical

From the [1]Institute of Vision Research, Department of Ophthalmology, Yonsei University College of Medicine, Seoul, Korea; and the [2]Department of Ophthalmology, Inha University School of Medicine, Incheon, Korea.

Submitted for publication September 29, 2010; revised February 10, 2011; accepted February 10, 2011.

Disclosure: **N.R. Kim**, None; **J.H. Kim**, None; **J. Lee**, None; **E.S. Lee**, None; **G.J. Seong**, None; **C.Y. Kim**, None

Corresponding author: Chan Yun Kim, Institute of Vision Research, Department of Ophthalmology, Yonsei University College of Medicine, 134 Shinchon-dong, Seodaemun-gu, Seoul, Korea, 120-752; kcyeye@yuhs.ac.

dioptric power. Central corneal thickness was measured with ultrasound pachymetry (DGH-1000; DGH Technology Inc., Frazer, PA). After pupillary dilation to a minimum diameter of 5 mm, each eye was imaged by RTVue-100 (Optovue, Inc.) spectral-domain OCT. All measurements on a healthy subject were performed in a single day.

No subject had any history of glaucoma in a first-degree relative, history or evidence of intraocular surgery, or retinal pathologic features. All subjects had a corrected visual acuity of 10/20 or better; refractive error from +3.00 to −8.00 D, and IOP of 21 mm Hg or less on three repeated measurements taken at different times on separate visits during clinical follow-up; open angle on gonioscopy; nonglaucomatous optic nerve head without evidence of cupping, rim loss, hemorrhages, or RNFL defects; reliable normal VF test results with normal glaucoma hemifield test results; and normal mean deviation and pattern standard deviation ($P > 0.05$).

Exclusion criteria were IOP ≥22 mm Hg based on three measurements on different days in either eye; evidence of a reproducible VF defect in either eye; a myopic refractive error exceeding −8.00 D; intraocular surgery in the study eye; history of ocular trauma in the study eye; diabetes mellitus or neurologic diseases; vitreoretinal disease in either eye; evidence of macular abnormality in either eye; and evidence of optic nerve or RNFL abnormality in either eye.

Optical Coherence Tomography Measurements

The average thickness of the GCC was measured using RTVue-100 (Optovue, Inc.; software version 4.0.5.39), which acquires 26,000 A-scans per second and has a 5-μm depth resolution in tissue. All scans were performed by one experienced operator.

GCC parameters were obtained by the macular map (MM7) protocols, centered 1 mm temporal to the fovea. This protocol uses one horizontal line with a 7-mm scan length (934 A-scans), followed by 15 vertical lines with a 7-mm scan length and 0.5-mm interval (800 A-scans). The GCC thickness was measured from the internal limiting membrane to the inner plexiform layer boundary. Also computed were the focal loss volume, which is the integral of deviation in areas of significant focal GCC loss, and the global loss volume, which is the sum of negative fractional deviation in the entire area.

Optic disc area measurements were obtained using the nerve head map (NHM4) mode, which creates a map from en face imaging using five circular scans ranging from 2.5 to 4.0 mm in diameter (587 or 775 A-scans each) and 12 linear data inputs (3.4-mm length, 452 A-scans each).

Images with a signal strength index of <35 with overt misalignment of the surface detection algorithm or with overt decentration of the measurement circle location were excluded.

Statistical Analysis

When both eyes of a patient were eligible for analysis, one eye was randomly selected for study. Independent variables were chosen based on both empiric and statistical (from univariate results) associations with GCC thickness. The demographic and clinical variables used in this study included age, sex, spherical equivalent, axial length, anterior chamber depth, optic disc area, and central corneal thickness.

Multiple linear regression analyses were performed to test whether demographic and clinical variables (independent variables) were related to average GCC thickness (dependent variable). Because the two variables—refractive error and axial length—highly correlated with one another ($r = -0.729$; $P < 0.001$), one or the other variable was used in two separate models. Axial length was considered more robust than refractive error because population variations in the refractive power of the cornea and lens could affect refractometry, but it likely does not affect axial length.[27] We also considered refractive error as a substitute for axial length in a second multiple linear regression model because the model including refractive error seems to be preferable in clinical settings.

Statistical analysis was performed using SPSS for Windows (version 12.0.0; SPSS Inc., Chicago, IL). $P < 0.05$ was considered statistically significant.

Results

Subjects

The major causes of subject exclusion were refractive errors less than −8.00 D, media opacities, history of ocular surgery such as cataract extraction or refractive surgery, epiretinal membrane, and abnormal findings on VF test. In total, 182 eyes of 182 healthy subjects were included in the study. All subjects were Asian. Their mean age was 55.50 ± 15.81 years (range, 22–84 years), and the male/female ratio was 73:109. The mean refractive error in spherical equivalent was −1.83 ± 3.04 D, and the mean axial length was 24.30 ± 1.42 mm. Table 1 summarizes the demographic characteristics.

OCT Measurements

A summary of GCC measurements is presented in Table 2. Mean GCC thickness in the study population was 93.87 ± 7.76 μm (95% confidence interval [CI], 93.73–95.00 μm).

Relationship between Demographic and Clinical Variables and GCC

The relationship between the demographic and clinical variables and the GCC thickness was evaluated using univariate linear regression analysis (Table 3). Age was found to have a significant negative relationship with mean GCC thickness and superior GCC thickness ($P = 0.023$ and $P = 0.009$, respectively). Figure 1A shows the relationship between mean GCC thickness and age plotted as a continuous variable. Sex, spherical equivalent, axial length, anterior chamber depth, optic disc area, and central corneal thickness were statistically nonsignificantly associated with GCC thickness by univariate correlation analysis. Figure 1B shows the relationship between axial length and mean GCC thickness.

Multiple linear regression analysis demonstrated the effect of demographic and clinical variables on GCC thickness as measured by FD-OCT (model with axial length; Table 4). The multiple R^2 for this model was 0.12, 0.10, and 0.15 for mean, superior, and inferior GCC, respectively. GCC thickness measurements were significantly associated with age ($P = 0.010$, $P = 0.010$, and $P = 0.012$; mean, superior, and inferior GCC, respectively). No major differences in regression coefficients were present among mean, superior, and inferior GCC thicknesses (regression coefficient: −0.159, −0.162, and −0.169, respectively). The mean GCC was thinner by approximately 1.59 μm for every decade of increased age (95% CI, −0.28 to −0.04 μm). Mean GCC thickness and inferior GCC thickness were also associated significantly with axial length ($P = 0.021$ and $P = 0.002$, respectively). The regression slope of the multiple regression models for axial length was more negative for the inferior GCC thickness than for the superior GCC thickness (regression coefficient, −2.298 and −0.956, respec-

Table 1. Subjects

Variables	Mean ± SD	95% CI
Age, y	55.50 ± 15.81	53.19 to 57.81
Female sex, *n* (%)	109 (59.9)	
Mean deviation, dB	−2.70 ± 2.19	−3.02 to −2.38
Pattern standard deviation, dB	2.16 ± 1.03	2.02 to 2.31
Spherical equivalent, diopters	−1.83 ± 3.04	−2.34 to −1.31
Axial length, mm	24.30 ± 1.42	24.08 to 24.51
Anterior chamber depth, mm	3.32 ± 0.52	3.24 to 3.40
Optic disc area, mm^2	2.52 ± 0.58	2.44 to 2.61
Intraocular pressure, mm Hg	13.64 ± 3.10	13.18 to 14.09
Central corneal thickness, μm	548.84 ± 32.87	542.80 to 554.89

$n = 182$.

Table 2. Mean of Ganglion Cell Complex Parameters

Ganglion Cell Complex Parameters	Mean ± SD	95% CI
Signal strength	60.14 ± 10.19	58.65 to 61.63
Average thickness, μm	93.87 ± 7.76	93.73 to 95.00
Superior thickness, μm	93.46 ± 8.48	92.22 to 94.70
Inferior thickness, μm	94.00 ± 8.52	92.76 to 95.25
Focal loss volume, %	1.89 ± 2.62	1.51 to 2.28
Global loss volume, %	8.80 ± 6.07	7.91 to 9.69

tively). A 1-mm increase in axial length resulted in a decrease in mean GCC thickness by approximately 1.56 μm (95% CI, −2.87 to −0.24 μm).

Regression coefficients of the multiple regression model using refractive error substituted for axial length are presented in Table 5. The regression coefficient for refractive error was also significant with mean and inferior GCC thickness. Mean and inferior GCC thicknesses were decreased by approximately 0.77 μm ($P = 0.048$) and 1.15 μm ($P = 0.008$) for every 1-D change in SE toward greater myopia.

Multivariate regression analysis demonstrated that average GCC parameters obtained using the RTVue-100 (Optovue, Inc.) were not significantly associated with sex, anterior chamber depth, optic disc area, or central corneal thickness (Tables 4, 5).

Discussion

A newer FD-OCT technique has recently become available that enables measuring of the thickness of the three inner retinal layers, known collectively as the macular GCC.[10] In the present study, we assessed the relationships between demographic and clinical variables and GCC thickness as determined by FD-OCT. Although some studies have investigated macular retinal thickness and peripapillary RNFL measurements, little is known about the relationships between clinical and demographic factors and perimacular inner retinal layer thickness. In this study, we performed multiple linear regression analysis with GCC thickness as the dependent variable and age, sex, axial length (or spherical equivalent), anterior chamber depth, optic disc area, and central corneal thickness as influencing variables. We found a reduction of 1.59 μm for the average GCC thickness per decade and a reduction of 1.56 μm per 1-mm longer axial length.

Relationship between GCC and Age

The present study demonstrates that OCT measurements show the GCC to be thinner in elderly subjects than in younger subjects. These results are consistent with previous histologic human retina studies that have demonstrated a decrease in the density of photoreceptors, ganglion cells, and retinal pigment epithelial cells with age.[28,29] Optic nerve fibers are estimated to be lost at a rate of 4000 to 5000 fibers per year, resulting in a total reduction of 35% of the optic nerve fibers over a lifetime.[30,31] Although the effect of aging on GCC (at 1.59 μm per decade of increased age) is clinically small, age-related change should be taken into account to avoid confusing the normal aging effect in GCC thickness with glaucomatous GCC thinning.

Age was found to have no significant correlation with macular thickness parameters in several studies using the retinal thickness analyzer (RTA; Talia Technology Ltd., Neveh Ilan, Israel),[11,12] second-generation TD-OCT (OCT2000; Carl Zeiss Meditec),[13,14] and third-generation TD-OCT (Stratus OCT; Carl Zeiss Meditec).[15,16] However, other studies using second-generation TD-OCT,[17,18] third-generation TD-OCT,[19,20] and FD-OCT[21,22,26] have suggested that macular thickness decreases with age. Although the exact mechanisms accounting for the differences among studies using various instruments are unclear, studies using spectral-domain OCT with improved resolution and faster scanning speed are likely to accomplish more reliable results. To clarify this relationship, it seems necessary to examine the longitudinal relationship between age and inner retinal layer thickness in future studies.

Table 3. Univariate Analysis to Identify the Relationship between Ganglion Cell Complex Measurements and Demographic and Clinical Variables in Healthy Subjects

	Regression Coefficient	*P*	95% CI
Mean			
Age (per year)	−0.083	0.023	−0.15 to −0.01
Sex (female)	−1.731	0.141	−4.04 to 0.58
Spherical equivalent (per diopter)	0.108	0.615	−0.32 to 0.53
Axial length (per mm)	−0.035	0.933	−0.87 to 0.80
Anterior chamber depth (per mm)	0.700	0.550	−1.61 to 3.01
Optic disc area (per mm^2)	0.848	0.401	−1.14 to 2.84
Central corneal thickness (per μm)	0.006	0.803	−0.04 to 0.05
Superior			
Age (per year)	−0.104	0.009	−0.18 to −0.03
Sex (female)	−1.109	0.389	−3.64 to 1.43
Spherical equivalent (per diopter)	−0.150	0.514	−0.60 to 0.30
Axial length (per mm)	0.431	0.354	−0.48 to 1.35
Anterior chamber depth (per mm)	1.523	0.235	−1.00 to 4.04
Optic disc area (per mm^2)	0.100	0.928	−2.08 to 2.28
Central corneal thickness (per μm)	0.010	0.644	−0.03 to 0.06
Inferior			
Age (per year)	−0.071	0.076	−0.15 to −0.01
Sex (female)	−2.221	0.085	−4.75 to 0.31
Spherical equivalent (per diopter)	0.307	0.191	−0.16 to 0.77
Axial length (per mm)	−0.352	0.449	−1.27 to 0.56
Anterior chamber depth (per mm)	−0.033	0.980	−2.57 to 2.50
Optic disc area (per mm^2)	1.694	0.128	−0.50 to 3.88
Central corneal thickness (per μm)	−0.002	0.935	−0.05 to 0.05

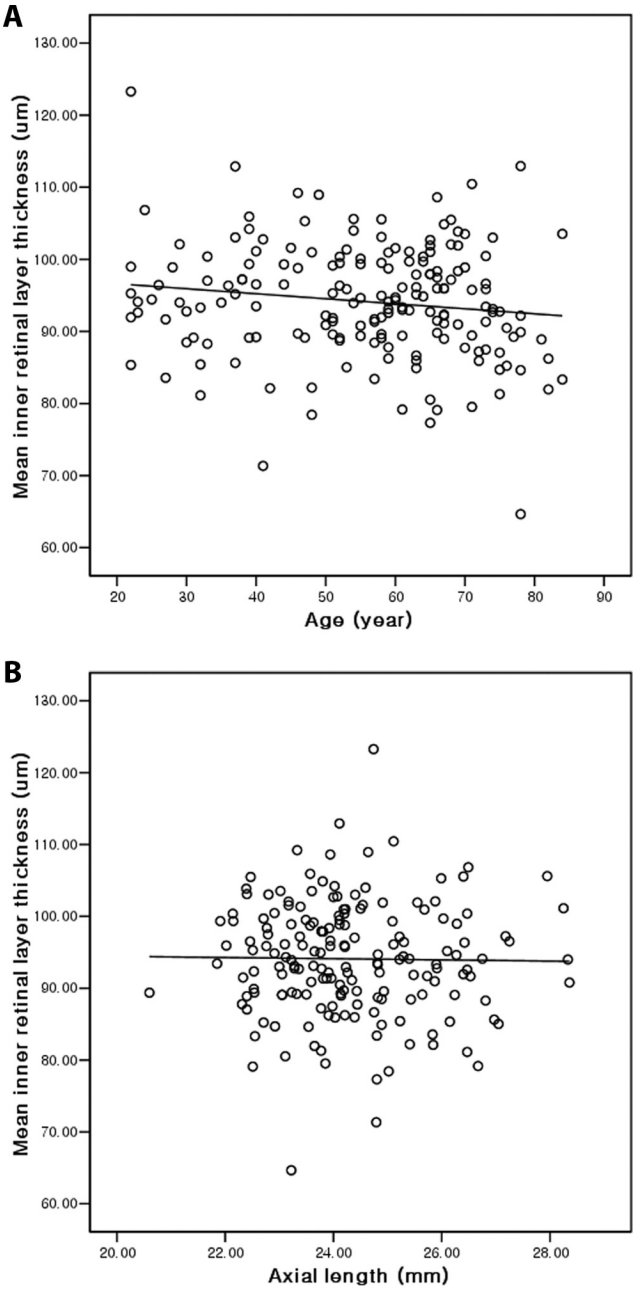

FIGURE 1. (**A**) Relationship between GCC thickness and age. Note that a decrease in GCC thickness is associated with older age ($r = -0.083$; $P = 0.023$). (**B**) Relationship between GCC thickness and axial length ($r = -0.035$; $P = 0.933$).

Relationship between GCC and Axial Length and Refractive Error

In this study, axial length was negatively correlated with inner retinal layer thickness in a statistical model that adjusted for other variables. This finding is consistent with recent studies conducted using the latest generation TD-OCT[16,24,25] and in a more recent study using FD-OCT (Cirrus OCT, Carl Zeiss Meditec),[21] which found a significant correlation between axial length and retinal thickness. However, another study using FD-OCT (3D OCT 1000; Topcon Corporation, Tokyo, Japan) found no significant relationship between axial length and retinal thickness.[22] In addition, the results of our study disagree with other earlier published studies conducted with first-generation TD-OCT (OCT1; Carl Zeiss Meditec),[23] second-generation TD-OCT,[13,14] and RTA.[11,12]

In myopic eyes, the globe is enlarged, the axial length is increased, and the retina may become thin as a result of stretching its beyond normal dimensions.[16,24] Previous histopathologic studies have demonstrated that increasing scleral and retinal thinning are associated with myopia.[32,33] On the other hand, the stretching of the internal limiting membrane and the traction of the posterior vitreous would elevate the fovea.[16,24] The results of our FD-OCT study corroborate data from recent studies showing that total retinal thickness and volume are decreased, axial length is increased, and the fovea is thicker in eyes with longer axial lengths.[16,23,25] It should be noted, however, that our study population included subjects with only a limited range of refractive errors (+3.00 to −8.00 D). Additionally, ocular magnification affects the actual projected scan length in myopic eyes and may result in slight underestimation of thickness.

Other Factors

In the present study, anterior chamber depth, optic disc area, and central corneal thickness were not significantly correlated with inner retinal layer thickness as analyzed by multiple regression analysis. However, the idea that the effect of these variables is not significant should be considered with caution. Anterior chamber depth was associated with age (r [correlation coefficient] $= -0.289$; $P < 0.001$) and axial length ($r = 0.443$; $P < 0.001$). Optic disc area was associated weakly with anterior chamber depth ($r = -0.184$; $P = 0.018$) and central corneal thickness ($r = -0.209$; $P = 0.026$) in this study. Central corneal thickness was also associated with axial length ($r = 0.230$; $P = 0.017$). Complicated associations between various factors could not be adjusted completely even using a multiple regression model.

Reproducibility of GCC Measurements

With FD technology, image acquisition time and image resolution are improved compared with TD-OCT. The reproducibility of GCC measurements with the RTVue-100 (Optovue, Inc.) was reported to be satisfactory for diagnostic purposes both in healthy subjects and in patients with glaucoma.[34] The relatively higher reproducibility of the FD devices suggests that they may provide more consistent readings than TD-OCT.

Using another data set in our institution, reproducibility was assessed by three measures: intraclass correlation (ICC), intratest variability, and coefficient of variation (CV) during the same session. ICC values for the average, superior, and inferior GCC were 99.5%, 99.4%, and 98.9%, respectively. For average, superior, and inferior GCC, the intratest variability values were 3.63 μm, 4.97 μm, and 4.05 μm, respectively. CV values for the average, superior, and inferior GCC measurements were 2.13%, 2.90%, and 2.36%, respectively. Our ICCs, intratest variabilities, and CVs were similar to the measures reported by Garas et al.,[34] who showed that reproducibility of the RNFL and GCC measurements with the RTVue-100 (Optovue, Inc.) was better than that reported for the TD-OCT. Clinicians have to consider test-retest reproducibility when interpreting the effect of age and axial length on GCC measurements.

Macular Full Retinal Thickness and Outer Retinal Thickness Measurements

The MM7 protocol also measures full retinal thickness and outer retinal thickness at the macula. In our study population, average full retinal thickness was significantly correlated with age, sex, and axial length ($r = -0.208$, $r = -7.733$, and $r = -2.696$; $P = 0.016$, $P = 0.001$, and $P = 0.004$) in a multivariate model with axial length. Sex and axial length also significantly

TABLE 4. Multiple Linear Regression Analysis to Identify the Relationship between Ganglion Cell Complex Measurements and Both Demographic and Clinical Variables in Healthy Subjects (Axial Length Model)

	Regression Coefficient	*P*	95% CI
Mean (R^2 = 0.12)			
Age (per year)	−0.159	0.010	−0.28 to −0.04
Sex (female)	−2.988	0.081	−6.35 to 0.38
Axial length (per mm)	−1.558	0.021	−2.87 to −0.24
Anterior chamber depth (per mm)	0.411	0.796	−2.73 to 3.55
Optic disc area (per mm^2)	1.240	0.370	−1.49 to 3.97
Central corneal thickness (per μm)	0.026	0.290	−0.02 to 0.08
Superior (R^2 = 0.10)			
Age (per year)	−0.162	0.010	−0.28 to −0.04
Sex (female)	−1.916	0.267	−5.32 to 1.49
Axial length (per mm)	−0.956	0.157	−2.29 to 0.38
Anterior chamber depth (per mm)	0.007	0.997	−3.17 to 3.19
Optic disc area (per mm^2)	0.825	0.555	−1.94 to 3.59
Central corneal thickness (per μm)	0.024	0.351	−0.03 to 0.07
Inferior (R^2 = 0.15)			
Age (per year)	−0.169	0.012	−0.30 to −0.04
Sex (female)	−4.425	0.019	−8.10 to −0.75
Axial length (per mm)	−2.298	0.002	−3.74 to −0.86
Anterior chamber depth (per mm)	0.826	0.634	−2.61 to 4.26
Optic disc area (per mm^2)	1.891	0.212	−1.10 to 4.88
Central corneal thickness (per μm)	0.029	0.295	−0.03 to 0.08

influenced the average outer retinal thickness (r = −3.646 and r = −1.424; P = 0.015 and P = 0.015) in the model. Age showed a marginal but insignificant correlation with outer retinal thickness (r = −0.102; P = 0.060). In a recent study using FD-OCT, Ooto et al.[22] suggested that an age-related decrease in macular retinal thickness seems to be partially due to an age-related decrease in RNFL thickness. In our study anterior chamber depth, optic disc area, and central corneal thickness did not influence either full retinal thickness or outer retinal thickness.

Limitations

This cross-sectional study has some limitations, including a relatively small sample size. It could not accurately present the decrease in inner retinal thickness with age, and it was conducted with only Asian subjects; there may be differences among ethnic groups. Further studies using a large and more ethnically diverse population are warranted. In our study, variables that were not significant in univariate analysis were included in a multiple regression model. Therefore, an element of randomness could have influenced the multivariate analysis. The clinical implications of the finding that GCC thickness measurements decrease with age and axial length cannot be overemphasized because the coefficient of determination of the entire multivariate model was small and the confidence interval on the slope of regression was wide. The effect of aging and long axial length on GCC thickness, at 1.59 μm per decade and 1.56 μm per 1-mm, though statistically significant, is still clinically small.

TABLE 5. Multiple Linear Regression Analysis to Identify the Relationship between Ganglion Cell Complex Measurements and Both Demographic and Clinical Variables in Healthy Subjects (Spherical Equivalent Model)

	Regression Coefficient	*P*	95% CI
Mean (R^2 = 0.13)			
Age (per year)	−0.198	0.007	−0.34 to −0.06
Sex (female)	−2.276	0.207	−5.83 to 1.28
Spherical equivalent (per diopter)	0.774	0.048	0.01 to 1.54
Anterior chamber depth (per mm)	0.397	0.826	−3.18 to 3.98
Optic disc area (per mm^2)	0.807	0.609	−2.33 to 3.94
Central corneal thickness (per μm)	−0.003	0.923	−0.06 to 0.05
Superior (R^2 = 0.10)			
Age (per year)	−0.172	0.020	−0.32 to −0.03
Sex (female)	−1.784	0.328	−5.39 to 1.83
Spherical equivalent (per diopter)	0.352	0.371	−0.43 to 1.13
Anterior chamber depth (per mm)	−0.087	0.962	−3.72 to 3.55
Optic disc area (per mm^2)	0.446	0.781	−2.73 to 3.62
Central corneal thickness (per μm)	−0.011	0.687	−0.07 to 0.04
Inferior (R^2 = 0.17)			
Age (per year)	−0.227	0.005	−0.38 to −0.07
Sex (female)	−3.126	0.116	−7.05 to 0.79
Spherical equivalent (per diopter)	1.154	0.008	0.31 to 2.00
Anterior chamber depth (per mm)	0.805	0.686	−3.14 to 4.75
Optic disc area (per mm^2)	1.391	0.425	−2.06 to 4.84
Central corneal thickness (per μm)	0.003	0.916	−0.06 to 0.06

Conclusions

In conclusion, the results of this study, which used new-generation FD-OCT scanning with improved resolution and faster scan speed, demonstrate that thin perimacular GCC thickness is significantly correlated with old age and long axial length but not with sex, anterior chamber depth, optic disc area, or central corneal thickness in ophthalmologically healthy subjects. Although the effects of age and axial length on perimacular inner retinal layer thickness are clinically small, analysis of inner retinal thickness in glaucoma should be interpreted in the context of these findings. More finely divided layer segmentation with improved resolution of FD-OCT could be informative so that only layers affected by glaucomatous damage are measured.

References

1. Garway-Heath DF, Caprioli J, Fitzke FW, Hitchings RA. Scaling the hill of vision: the physiological relationship between light sensitivity and ganglion cell numbers. *Invest Ophthalmol Vis Sci.* 2000; 41(7):1774–1782.
2. Harwerth RS, Carter-Dawson L, Shen F, Smith EL 3rd, Crawford ML. Ganglion cell losses underlying visual field defects from experimental glaucoma. *Invest Ophthalmol Vis Sci.* 1999;40(10): 2242–2250.
3. Zeimer R, Asrani S, Zou S, Quigley H, Jampel H. Quantitative detection of glaucomatous damage at the posterior pole by retinal thickness mapping: a pilot study. *Ophthalmology.* 1998;105(2): 224–231.
4. Ishikawa H, Stein DM, Wollstein G, Beaton S, Fujimoto JG, Schuman JS. Macular segmentation with optical coherence tomography. *Invest Ophthalmol Vis Sci.* 2005;46(6):2012–2017.
5. Tan O, Li G, Lu AT, Varma R, Huang D. Mapping of macular substructures with optical coherence tomography for glaucoma diagnosis. *Ophthalmology.* 2008;115(6):949–956.
6. Van Buren JM. *The Retinal Ganglion Cell Layer: A Physiological-Anatomical Correlation in Man and Primates of the Normal Topographical Anatomy of the Retinal Ganglion Cell Layer and Its Alterations with Lesions of the Visual Pathways*. Springfield, IL: Charles C. Thomas; 1963.
7. Chen TC, Cense B, Pierce MC, et al. Spectral domain optical coherence tomography: ultra-high speed, ultra-high resolution ophthalmic imaging. *Arch Ophthalmol.* 2005;123(12):1715–1720.
8. Leitgeb R, Hitzenberger C, Fercher A. Performance of Fourier domain vs. time domain optical coherence tomography. *Opt Express.* 2003;11(8):889–894.
9. Nassif N, Cense B, Park B, et al. In vivo high-resolution video-rate spectral-domain optical coherence tomography of the human retina and optic nerve. *Opt Express.* 2004;12(3):367–376.
10. Tan O, Chopra V, Lu AT, et al. Detection of macular ganglion cell loss in glaucoma by Fourier-domain optical coherence tomography. *Ophthalmology.* 2009;116(12):2305–2314 e2301–e2302.
11. Chan CM, Yu JH, Chen LJ, et al. Posterior pole retinal thickness measurements by the retinal thickness analyzer in healthy Chinese subjects. *Retina.* 2006;26(2):176–181.
12. Zou H, Zhang X, Xu X, Yu S. Quantitative in vivo retinal thickness measurement in chinese healthy subjects with retinal thickness analyzer. *Invest Ophthalmol Vis Sci.* 2006;47(1):341–347.
13. Gobel W, Hartmann F, Haigis W. [Determination of retinal thickness in relation to the age and axial length using optical coherence tomography]. *Ophthalmologe.* 2001;98(2):157–162.
14. Wakitani Y, Sasoh M, Sugimoto M, Ito Y, Ido M, Uji Y. Macular thickness measurements in healthy subjects with different axial lengths using optical coherence tomography. *Retina.* 2003;23(2): 177–182.
15. Chan A, Duker JS, Ko TH, Fujimoto JG, Schuman JS. Normal macular thickness measurements in healthy eyes using Stratus optical coherence tomography. *Arch Ophthalmol.* 2006;124(2): 193–198.
16. Lam DS, Leung KS, Mohamed S, et al. Regional variations in the relationship between macular thickness measurements and myopia. *Invest Ophthalmol Vis Sci.* 2007;48(1):376–382.
17. Alamouti B, Funk J. Retinal thickness decreases with age: an OCT study. *Br J Ophthalmol.* 2003;87(7):899–901.
18. Kanai K, Abe T, Murayama K, Yoneya S. [Retinal thickness and changes with age]. *Nippon Ganka Gakkai Zasshi.* 2002;106(3): 162–165.
19. Eriksson U, Alm A. Macular thickness decreases with age in normal eyes: a study on the macular thickness map protocol in the Stratus OCT. *Br J Ophthalmol.* 2009;93(11):1448–1452.
20. Manassakorn A, Chaidaroon W, Ausayakhun S, Aupapong S, Wattananikorn S. Normative database of retinal nerve fiber layer and macular retinal thickness in a Thai population. *Jpn J Ophthalmol.* 2008;52(6):450–456.
21. Song WK, Lee SC, Lee ES, Kim CY, Kim SS. Macular thickness variations with sex, age, and axial length in healthy subjects: a spectral domain-optical coherence tomography study. *Invest Ophthalmol Vis Sci.* 2010;51(8):3913–3918.
22. Ooto S, Hangai M, Sakamoto A, et al. Three-dimensional profile of macular retinal thickness in normal Japanese eyes. *Invest Ophthalmol Vis Sci.* 2010;51(1):465–473.
23. Lim MC, Hoh ST, Foster PJ, et al. Use of optical coherence tomography to assess variations in macular retinal thickness in myopia. *Invest Ophthalmol Vis Sci.* 2005;46(3):974–978.
24. Wu PC, Chen YJ, Chen CH, et al. Assessment of macular retinal thickness and volume in normal eyes and highly myopic eyes with third-generation optical coherence tomography. *Eye (Lond).* 2008; 22(4):551–555.
25. Luo HD, Gazzard G, Fong A, et al. Myopia, axial length, and OCT characteristics of the macula in Singaporean children. *Invest Ophthalmol Vis Sci.* 2006;47(7):2773–2781.
26. Rao HL, Kumar AU, Babu JG, Kumar A, Senthil S, Garudadri CS. Predictors of normal optic nerve head, retinal nerve fiber layer and macular parameters measured by spectral domain optical coherence tomograph. *Invest Ophthalmol Vis Sci.* 2011;52(2):1103–1110.
27. Rauscher FM, Sekhon N, Feuer WJ, Budenz DL. Myopia affects retinal nerve fiber layer measurements as determined by optical coherence tomography. *J Glaucoma.* 2009;18(7):501–505.
28. Gao H, Hollyfield JG. Aging of the human retina: differential loss of neurons and retinal pigment epithelial cells. *Invest Ophthalmol Vis Sci.* 1992;33(1):1–17.
29. Panda-Jonas S, Jonas JB, Jakobczyk-Zmija M. Retinal photoreceptor density decreases with age. *Ophthalmology.* 1995;102(12):1853–1859.
30. Balazsi AG, Rootman J, Drance SM, Schulzer M, Douglas GR. The effect of age on the nerve fiber population of the human optic nerve. *Am J Ophthalmol.* 1984;97(6):760–766.
31. Jonas JB, Schmidt AM, Muller-Bergh JA, Schlotzer-Schrehardt UM, Naumann GO. Human optic nerve fiber count and optic disc size. *Invest Ophthalmol Vis Sci.* 1992;33(6):2012–2018.
32. Apple DJ, Fabb MF. *Clinico-Pathologic Correlation of Ocular Disease: A Text and Stereoscopic Atlas*. St. Louis: CV Mosby; 1978:39–44.
33. Yanoff M, Fine BS. *Ocular Pathology: A Text and Atlas*. Philadelphia: Harper & Row; 1982:513–514.
34. Garas A, Vargha P, Hollo G. Reproducibility of retinal nerve fiber layer and macular thickness measurement with the RTVue-100 optical coherence tomograph. *Ophthalmology.* 2010;117(4):738–746.