KJO
pISSN: 1011-8942 eISSN: 2092-9382

Korean J Ophthalmol 2012;26(5):324-330
http://dx.doi.org/10.3341/kjo.2012.26.5.324

Original Article

Correlations between Magnitude of Refractive Error and Other Optical Components in Korean Myopes

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Purpose: We evaluated ocular optical components and their interrelationships in myopic Korean patients.

Methods: In this prospective observational study, 1,011 consecutive patients were recruited from a refractive surgery clinic. The best-corrected visual acuity was >20 / 20 in all patients. The refractive error, axial length (AL), anterior chamber depth (ACD), lens thickness (LT), and vitreous chamber depth (VCD) were measured by an autorefractor and partial coherence laser interferometry (IOL Master). Central corneal thickness (CCT) was measured by ORBscan II topography.

Results: The refractive errors had a positive correlation with LT but negative correlations with AL, ACD, VCD, and CCT. As the axial length increased, the ACD, VCD, and CCT increased but the LT decreased. The CCT had a positive correlation with gender, refractive errors, ACD, VCD, and AL but no correlation with age. The mean CCT was increased in proportion to the increase in AL.

Conclusions: In myopic Korean patients, as axial elongation progressed, the VCD and ACD deepened and the CCT thickened but the LT decreased. The CCT had a positive correlation with the degree of myopia and the AL.

Key Words: Axial length, Central corneal thickness, Koreans, Myopia, Refractive errors

The type and magnitude of the refractive error of an eye are determined by the relationships between the dimensions of its optical components. The relevant optical components include the corneal power and radius of curvature, the anterior chamber depth (ACD), the lens thickness (LT) and the power, the vitreous chamber depth (VCD), and the axial length (AL).

The AL is a major factor for both refractive error and intraocular lens power calculations [1,2]. Measurement of the corneal thickness is essential for refractive surgery, such as laser *in situ* keratomileusis (LASIK), laser-assisted sub-epithelial keratomileusis (LASEK), or Epi-LASIK in order to determine the amount of available corneal tissue for performing safe and effective corneal stromal ablation [3,4]. The central corneal thickness (CCT) is related to the measured intraocular pressure (IOP), i.e., the thicker the cornea, the greater is the difference between the measured IOP and the actual IOP [5-9].

Other ocular components, such as the ACD, have clinical significance in cataract intraocular surgery, such as phakic intraocular lens (IOL) implantation [10]. The correlation among the ocular components CCT, ACD, and AL has recently been studied; some studies have shown racial differences in the ocular components [10,11], while another study [12] has not.

There have been numerous studies about the relationship between the CCT and AL. Some of the studies have shown that, when the degree of myopia is increased (the axial length is increased), the CCT is decreased; other studies showed no such correlation. Only one study showed a positive correlation between the CCT and AL (Table 1) [5,13-25].

Consideration of various ocular optical components and the inter-relationships of their components are important when performing intra- or extra-ocular surgery. The re-

Received: January 27, 2011 *Accepted*: November 10, 2011

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sults of previous studies (Table 1) have shown that ocular optical components and the inter-relationships are different depending on the type of surgery.

There is a report that investigated the ocular parameters in Koreans [26] and showed a relationship between AL and ACD in myopic patients in whom the refraction was >-3 diopters. However, there are few studies that have reported ocular optical components and their inter-relationships in myopic Korean patients. Therefore, we evaluated the ocular biometries of myopic Korean patients, especially with respect to CCT.

Materials and Methods

A prospective, observational, clinic-based study was conducted involving 1,011 subjects (467 males and 544 females). All subjects were Koreans between 22 and 46 years of age (mean age, 30.05 years) who received care in the refractive surgery clinic between 1 May 2008 and 31 December 2009. Only the right eyes of the subjects were included in this study.

We excluded those subjects with previous eye surgery, glaucoma, ocular hypertension, retinal disease, diabetes mellitus, or other acute or chronic diseases that could possibly affect the components of the eye globe. Subjects were excluded when they had subclinical keratoconus (paracentral corneal thinning and central corneal steepening was identified with topography, but the CCT was >450 µm [27]) or when keratoconus was suspected. Those subjects with a corrected visual acuity <20 / 20 were also excluded. The institutional review board provided approval for the protocol of this study, and written informed consent was obtained from all patients.

In the case of contact lens wearers, after an at least two week lens-free period, ocular biometry were measured. All the ocular parameters were measured after cycloplegia, which was performed in a mixture of 2.0% phenylephrine and 2% tropicamide (Santen, Osaka, Japan) and 1% cyclopentolate (B&L, Tampa, FL, USA). At least four cycloplegic eyedrops were instilled into the conjunctival fornix at ten minute intervals, and the iris was checked with a slit lamp. Lack of pupil movement or pupil dilation of at least 6 mm in diameter was considered complete cycloplegia.

Each subject was objectively refracted using a RK-

Table 1. Previously published papers on the relationship between CCT and AL

Authors	Year	Country	Race	No. of subject (myopia)	Subject recruitment	Equipment	CCT-AL relationship
Kunert et al. [13]	2003	India	Indian	615	LASIK/ LASEK patients	USG/ORBscan	Thicker in high myopic
Von Bahr [14]	1956	Sweden		125 (12)		Optical	Thinner when >-4 diopters
Alsbirk et al. [15]	1978	Greenland		325		Optical	Thinner when myopic
Chang et al. [16]	2001	Taiwan	Chinese	216		USG	Thinner when high myopic
Srivannaboon [17]	2002	Thailand		280	Refractive surgery clinic	USG/ORBscan	Thinner when high myopic
Touzeau et al. [18]	2003	France		95	General ophthalmic clinic	ORBscan	Thinner when myopic
Martola et al. [19]	1968	USA	Multi ethnic	121		Optical	No correlation
Hansen [20]	1971	Denmark		113		Optical	No correlation
Ehlers et al. [5]	1975	Denmark		101		Optical	No correlation
Cho et al. [21]	1999	China		151		USG	No correlation
Price et al. [22]	1999	USA		450	Multicenter, refractive surgery clinic	USG	No correlation
Liu et al. [23]	2000	China		30		ORBscan	No correlation
Shimmyo et al. [12]	2004	USA	Multi ethnic	1,084	General ophthalmic clinic	USG/ IOL master	No correlation
Aghaian et al. [11]	2004	USA	Multi ethnic	801	Glaucoma clinic	USG	No correlation
Pedersen et al. [24]	2005	Denmark		105 (48)	Refractive surgery clinic	Optical	No correlation
Fam et al. [25]	2006	Singapore	Chinese	714	Refractive surgery clinic	ORBscan	No correlation to myopic degree

CCT = central corneal thickness; AL = axial length; LASIK = laser *in situ* keratomileusis; LASEK = laser-assisted sub-epithelial keratomileusis; USG = ultrasonography.

F1 autorefractor (Canon, Lake Success, NY, USA). The biometrics was measured by an IOL Master (Zeiss, Jena, Germany). CCT was measured using ORBscan II (Bausch & Lomb, New York, NY, USA) according to the manufacturer's instruction manuals.

The degree of myopia was divided as follows: low, <-3 diopters; intermediate, >-3 diopters and <-6 diopters; high, >-6 diopters and <-10 diopters [27,28]; and extreme, >-10 diopters (we do not recommend LASIK/LASEK, even when a safe corneal stromal bed thickness is secured, when the refraction is >-10 diopters).

The data was analyzed using SPSS ver. 12.0 (SPSS Inc., Chicago, IL, USA) to perform ANOVA, Pearson correlations, and a regression test. A critical p-value of 0.05 was chosen to denote statistical significance.

Results

A total of 1,011 Korean patients (467 males and 544 females) were recruited. The greater number of female patients was explained by the greater cosmetic desires of female patients. The mean age of the patients was 30.05 years, with a range between 22 and 46 years. The mean age of the extreme myopic group was relatively young because the inconvenience of high diopters of glasses or contact lenses caused the patients to seek evaluation at a refractive surgery clinic in their youth. The ages of the patients were not statistically different according to the degree of myopia, although the patients with extreme myopes were relatively younger than those in the other groups ($p > 0.05$).

In Table 2, the ocular biometries according to the degree of myopia are shown. The CCT of males (540.01 ± 4.07 μm) was thicker than females (532.66 ± 3.34 μm; unpaired t-test, $p < 0.01$). Other biometries did not differ as a function of age or gender ($p > 0.01$, data not shown). The standard deviations of Dsph, ACD, LT, VCD, and AL in the extreme myopic group were wider than those in the low and intermediate groups ($p < 0.01$). The standard deviation of the CCT was not different according to the degree of myopia ($p > 0.05$).

For the CCT, the difference between intermediate and high myopia was only 2.31 μm, which may not be clinical relevant. However, the difference between extreme and high myopia was 24.26 μm, a nearly ten-fold difference, suggesting that the cornea might be more ablated (1-1.5 diopters) by LASIK/LASEK (Table 2).

Refractive errors had a positive correlation with LT but negative correlations with AL, ACD, VCD, and CCT, i.e., as the degree of myopia was increased, the CCT, ACD, VCD, and AL all increased, while the LT decreased (Table 3).

As AL increased, ACD, VCD and CCT increased, but LT decreased. CCT had a positive correlation with the Dsph, ACD, VCD and AL but no correlation with age (Table 3). Fig. 1 shows that CCT had a positive correlation with the degree of myopia and AL. Also, sex had a positive correlation with the CCT ($p = 0.002$); we previously showed that the CCT of males was greater than that of females. Age had a correlation with Dsph ($p = 0.018$) and LT ($p = 0.001$) (Table 3).

The histogram of CCT showed a normal distribution (Fig. 2). Therefore, the Pearson correlation was applicable to the inter-relationships between CCT and other ocular biometries. The regression between CCT and AL based on the degree of myopia is shown in Table 4. The mean CCT was increased in proportion to the increase in AL. CCT and AL had a positive correlation in the intermediate, high, and extreme myopic groups but not in the low myopic group. The multivariate regression test is shown in Table 5. Patient age, sex, and Dsph had no effect on CCT, but ACD, LT, VCD, and AL had an effect on CCT.

Discussion

We used the IOL Master to measure biometries, and CCT was measured by ORBscan II. Partial coherence laser interferometry (IOL Master), a type of optic biometry, has several advantages over traditional immersion and applanation A-scan ultrasonography; specifically, a partial coherence laser interferometer has lower technician-dependence and does not make contact with the cornea. Therefore, the tests are easy and rapid [27,28]. ORBscan II also does not contact the cornea, so we used this instrument to measure CCT [27].

We showed that AL has positive correlations with ACD, VCD and CCT and negative correlations with the LT, similar to that reported in previous studies [10,29]. A positive correlation between CCT (measured by the ORBscan) and AL (measured by ultrasonography [USG]) has been previously reported in only one study [13]. The difference between our study and other studies is that included patients were undergoing refractive surgery, especially LASIK or LASEK. The included patients had good corrected visual acuity (>20 / 20), and the age range was between 22 and 46 years. Also, patients had sufficient central corneal thickness to perform LASIK, which may contribute to some selection bias.

Foster et al. [30] reported that the CCT of a Mongolian population (as measured by an optical pachymeter) was thinner than that of a Caucasian population. In one glaucoma clinic-based study using USG pachymetry [11], CCT differences were shown as a function of race, as follows: Chinese (555.6 μm), Caucasian (550.4 μm), Filipino (550.6 μm), Hispanic (548.1 μm), Japanese (513.7 μm), and African-American (521.0 μm). The resulting mean CCT values were different from the results of Fam et al. [25], which might have been caused by patient selection. The former study recruited patients from a glaucoma clinic, and the latter recruited from a refractive surgery clinic.

Price et al. [22] used corneal topography to show similar CCT values (550 µm) at multiple sites in the USA involving Caucasians with unknown ethnicities. For direct comparison of CCTs in different human races, the different measurement instruments and methods must be considered.

CCT corresponds to an age-related thinning of 6.3 µm per decade [9,30] and has also exhibited racial, sex, and age differences [9,29,30]. Brandt et al. [9] reported that the CCT of females was about 5 µm thicker than that of males, although the difference was not clinically significant. In our study, the reverse trend was revealed in myopic Korean patients.

The positive correlation between CCT and AL is striking. CCT of myopic Korean patients (536.66 µm) was dif-

Table 2. Demographic features, degree of myopia, and ocular components of study patients

	Myopic degree	Mean ± standard deviation	Minimum	Maximum
Age	Extreme myopia	28.84 ± 5.64	22	46
(yr)	High myopia	30.16 ± 5.86	22	44
	Intermediate myopia	30.05 ± 6.18	22	44
	Low myopia	30.36 ± 6.14	22	44
	Total	30.05 ± 6.06	22	46
Gender	Extreme myopia		M : F = 141 : 161 (302)	
	High myopia		M : F = 186 : 219 (405)	
	Intermediate myopia		M : F = 89 : 118 (207)	
	Low myopia		M : F = 51 : 46 (97)	
	Total		M : F = 467 : 544 (1,011)	
Dsph	Extreme myopia	-16.61 ± 4.19	-10.625	-25.625
(diopter)	High myopia	-7.33 ± 0.89	-6.125	-9.50
	Intermediate myopia	-5.05 ± 0.68	-3.125	-6.00
	Low myopia	-19.4 ± 0.62	-0.875	-3.00
	Total	-5.70 ± 4.30	-0.875	-25.625
Axial	Extreme myopia	29.57 ± 1.95	26.14	35.21
length	High myopia	26.29 ± 0.81	24.05	29.85
(mm)	Intermediate myopia	25.18 ± 0.70	22.31	27.17
	Low myopia	23.55 ± 0.80	22.15	26.57
	Total	25.35 ± 1.94	22.15	35.21
Central	Extreme myopia	566.03 ± 3.25	476	634
corneal	High myopia	541.77 ± 3.18	481	628
thickness	Intermediate myopia	539.46 ± 3.64	447	629
(µm)	Low myopia	517.87 ± 3.41	448	643
	Total	536.66 ± 3.71	447	643
Anterior	Extreme myopia	5.23 ± 0.59	3.89	6.14
chamber	High myopia	3.68 ± 0.38	2.81	5.21
depth	Intermediate myopia	3.25 ± 0.26	1.95	3.94
(mm)	Low myopia	3.13 ± 0.26	2.03	4.14
	Total	3.49 ± 0.68	1.95	6.14
Lens	Extreme myopia	2.93 ± 0.34	2.21	3.53
thickness	High myopia	3.55 ± 0.18	2.97	3.97
(mm)	Intermediate myopia	3.63 ± 0.26	2.59	5.14
	Low myopia	3.77 ± 0.43	2.69	4.98
	Total	3.59 ± 0.44	2.21	5.14
Vitreous	Extreme myopia	20.84 ± 1.78	17.55	26.32
chamber	High myopia	18.53 ± 0.75	16.55	21.23
depth	Intermediate myopia	17.76 ± 0.83	14.62	20.72
(mm)	Low myopia	16.12 ± 0.83	14.12	18.47
	Total	17.73 ± 1.65	14.12	26.32

Dsph = spherical equivalent refractive error.

ferent from other east Asian populations, such as Chinese (556 µm) or Japanese (513.7 µm) [11]. The inter-relationship between CCT and AL was different from that of Taiwanese Chinese [23] or Singaporean Chinese [25]. In our study, the mean CCT was increased in proportion to the increase in AL, and a positive correlation between the CCT and AL was shown in moderate, high, and extreme myopia.

Pedersen et al. [24] mentioned two hypotheses of "general overgrowth of the eye" or "mechanical hyper-inflation of the eye" in high myopia. The results of the present study cannot be completely explained by these hypotheses. In this study, the elongation of AL had a close relationship to the elongation of VCD, but the LT thinned as the AL increased. We reasoned that this is due to a compensatory mechanism to produce a clear retinal image in the presence of axial elongation.

Age had a correlation with Dsph ($p = 0.018$), which may have been caused by the progression of myopia as age increased. Age also had a positive correlation with LT ($p = 0.001$), which reflects a relationship with presbyopia, although the clinical implication is not clear.

In our study, as the axial elongation progressed, VCD and ACD deepened and CCT thickened. VCD accounts for the major myopic change of the eye, but the role of ACD increase was not clear. The change in ACD in myopia may be a passive change but an active protective mechanism for preventing excess corneal thinning. The simple fact that ACD was greater in the high (4.17 ± 0.86 mm) and extreme myopic groups (5.23 ± 0.59 mm) compared to the low or intermediate myopic groups was not sufficient to conclude that ACD has some role in protecting the cornea from excess thinning. Serial follow-up of CCT and axial length is necessary for understanding myopic changes of the eye, but such studies are difficult and time/cost-consuming.

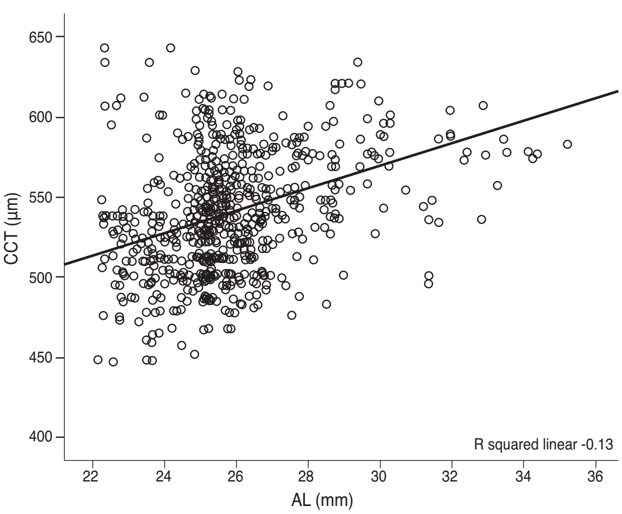

Fig. 1. The regression of central corneal thickness (CCT) to axial length (AL). CCT showed a positive correlation with AL.

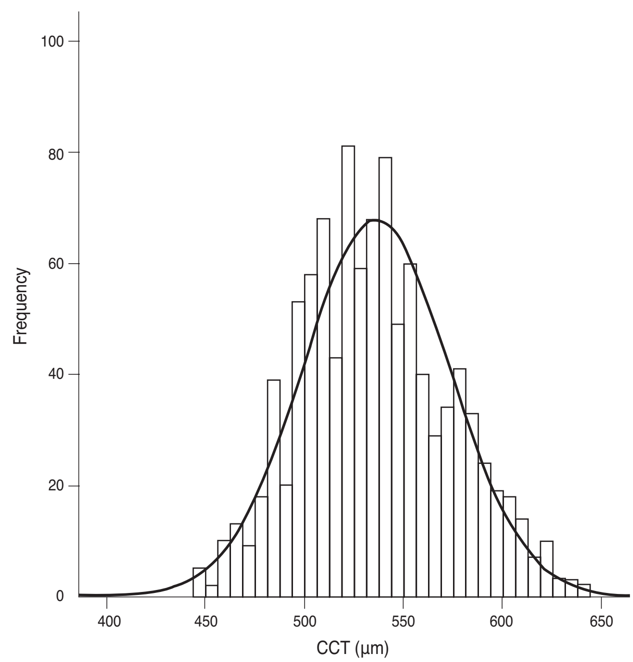

Fig. 2. The histogram of central corneal thickness (CCT). The histogram of CCT showed a nearly normal distribution. To demonstrate the linear correlation between CCT and axial length, the CCT must have a normal distribution.

Table 3. Pearson correlations of ocular components

	Sex	Dsph (diopters)	AL (mm)	CCT (mm)	ACD (mm)	LT (mm)	VCD (mm)
Age	-0.031	0.075*	-0.006	-0.003	-0.033	0.105**	-0.021
Gender		0.035	-0.007	-0.099**	-0.027	-0.027	0.012
Dsph			-0.915**	-0.365**	-0.885**	0.596**	-0.850**
AL				0.360**	-0.885**	-0.505**	0.958**
CCT					0.229**	-0.263**	0.348**
ACD						-0.530**	0.684**
LT							-0.633**

Dsph = spherical equivalent refractive error; AL = axial length; CCT = central corneal thickness; ACD = anterior chamber depth; LT = lens thickness; VCD = vitreous chamber depth.
*Correlation is significant at the $p < 0.05$ level; **Correlation is significant at the $p < 0.01$ level. For gender, male=1, female=2.

Table 4. The regression for CCT with AL according to myopic degree

	Constant coefficient	Coefficient	Standardized coefficient	R squared	Significance (*p*-value)
Low myopia (-3 to 0 D)	0.583	-0.003	-0.064	0.004	0.27
Intermediate myopia (-6 to -3 D)	0.256	0.011	0.215	0.044	0.00
High myopia (-10 to -6 D)	0.424	0.004	0.114	0.140	0.01
Extreme myopia (>-10 D)	0.496	0.002	0.143	0.020	0.03
Total	0.361	0.007	0.360	0.130	0.00

In low myopia, there was no linear regression between CCT and AL; however, intermediate, high, and extreme myopia showed a positive correlation between CCT and AL. In high and extreme myopia, the regression was significant at the $p < 0.05$ level. Overall, CCT had a positive correlation with AL at the $p < 0.01$ level.
CCT = central corneal thickness; AL = axial length; D = diopters.

Table 5. Multivariate regression test (enter method) for central corneal thickness

	Coefficient	Standardized coefficient	Significance (*p*-value)
Constant	4.45E-12	-	1.00
Age	1.61E-15	0	1.00
Sex	-5.44E-14	0	1.00
Dsph (diopters)	-2.48E-14	0	1.00
AL (mm)	1.00	52.09	0.00
ACD (mm)	-1.00	-18.43	0.00
LT (mm)	-1.00	-11.91	0.00
VCD (mm)	-1.00	-44.48	0.00

Dsph = spherical equivalent refractive error; AL = axial length; ACD = anterior chamber depth; LT = lens thickness; VCD = vitreous chamber depth.

From the results of the present study, we propose that, if the progression of myopia was small, CCT was not affected, i.e., VCD was primarily affected. However, when the change was >-3 diopters, the cornea may respond to the change. Some passive protective mechanism may be involved to prevent the cornea from excess thinning. The protective mechanism seems to vary according to ethnic, genetic, or environmental factors. In Koreans, for myopic change >-3 diopters, some kind of active protective mechanism may be involved, and CCT was relatively thickened. Alternatively, the patients who had factors which deteriorated to a greater extent than intermediate myopia inexplicably had thick corneas before the myopia progressed.

Also, we revealed that CCT of myopic Korean myopic patients is different from those of Chinese and Japanese patients. Korean myopes show a positive relationship between CCT and AL. A long-term, serial follow-up study is required to reveal the correlation among myopia, AL, and CCT.

Conflict of Interest

No potential conflict of interest relevant to this article was reported.

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