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), 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

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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-
results 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 (para-central 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-

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

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 (55.6 μm), Caucasian (55.4 μm), Filipino (55.6 μm), Hispanic (54.8 μm), Japanese (51.3 μm), and African-American (52.1 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 (yr)**         | Extreme myopia | 28.84 ± 5.64              | 22      | 46      |
|                      | High myopia   | 30.16 ± 5.86              | 22      | 44      |
|                      | Intermediate myopia | 30.03 ± 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 (diopter)**   | Extreme myopia | -16.61 ± 4.19             | -10.625 | -25.625 |
|                      | 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 length (mm)**| Extreme myopia | 29.57 ± 1.95              | 26.14   | 35.21   |
|                      | High myopia   | 26.29 ± 0.81              | 24.05   | 29.85   |
|                      | 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 corneal thickness (μm)** | Extreme myopia | 566.03 ± 3.25            | 476     | 634     |
|                      | High myopia   | 541.77 ± 3.18             | 481     | 628     |
|                      | Intermediate myopia | 539.46 ± 3.64  | 447     | 629     |
|                      | Low myopia    | 517.87 ± 3.41             | 448     | 643     |
|                      | Total         | 536.66 ± 3.71             | 447     | 643     |
| **Anterior chamber depth (mm)** | Extreme myopia | 5.23 ± 0.59              | 3.89    | 6.14    |
|                      | High myopia   | 3.68 ± 0.38               | 2.81    | 5.21    |
|                      | Intermediate myopia | 3.25 ± 0.26   | 1.95    | 3.94    |
|                      | Low myopia    | 3.13 ± 0.26               | 2.03    | 4.14    |
|                      | Total         | 3.49 ± 0.68               | 1.95    | 6.14    |
| **Lens thickness (mm)** | Extreme myopia | 2.93 ± 0.34              | 2.21    | 3.53    |
|                      | High myopia   | 3.55 ± 0.18               | 2.97    | 3.97    |
|                      | 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 chamber depth (mm)** | Extreme myopia | 20.84 ± 1.78             | 17.55   | 26.32   |
|                      | High myopia   | 18.53 ± 0.75              | 16.55   | 21.23   |
|                      | Intermediate myopia | 17.76 ± 0.83  | 14.62   | 20.72   |
|                      | Low myopia    | 16.12 ± 0.83              | 14.12   | 18.47   |
|                      | Total         | 17.73 ± 1.65              | 14.12   | 26.32   |

Dsph = spherical equivalent refractive error.
different 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.](image1)

![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.](image2)

**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∗ | -0.850∗  | 0.596∗   | -0.505∗ | 0.958∗   |
| AL             | 0.360∗| -0.885∗         | -0.505∗ | 0.958∗   | -0.633∗  |
| CCT            | 0.229∗| -0.263∗         | 0.348∗  |
| ACD            | -0.530∗| 0.684∗         |
| LT             |       |                 |         |

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.
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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