Relationship Between Central Corneal Thickness, Refractive Error, Corneal Curvature, Anterior Chamber Depth and Axial Length

Mei-Ju Chen[1,2]*, Yin-Tzu Liu[1], Chia-Chen Tsai[2,3], Yen-Cheng Chen[2], Ching-Kuang Chou[1,2], Shu-Mei Lee[1,2]

[1]*Department of Ophthalmology, Taipei Veterans General Hospital,* [2]*National Yang-Ming University School of Medicine, and* [3]*Department of Ophthalmology, Cheng-Hsin General Hospital, Taipei, Taiwan, R.O.C.*

Background: To determine the relationship between central corneal thickness (CCT), refractive error, corneal curvature, anterior chamber depth and axial length in normal Taiwanese Chinese adults.

Methods: Five hundred normal Taiwanese Chinese patients aged 40–80 years were recruited for the study. Measurement procedures included CCT, refractive error, corneal curvature, anterior chamber depth and axial length. Exclusion criteria were previous ocular surgery, glaucoma, trauma history, external eye disease, and previous contact lens use. The relationships among parameters were tested using Pearson's correlation and linear regression analysis.

Results: The median CCT was 555 ± 27 μm for males and 553 ± 30 μm for females. Eyes with more myopic refractive error tended to have greater axial length ($r = -0.645$, $p < 0.001$). Eyes with axial elongation tended to have flatter cornea ($r = -0.502$, $p < 0.001$) and deeper anterior chamber ($r = 0.651$, $p < 0.001$). There were no significant correlations between the CCT and refractive error ($r = -0.034$, $p = 0.445$), corneal curvature ($r = 0.013$, $p = 0.770$), anterior chamber depth ($r = 0.023$, $p = 0.614$) and axial length ($r = -0.053$, $p = 0.223$).

Conclusion: CCT was not associated with refractive error, corneal curvature, anterior chamber depth and axial length. CCT is an independent factor unrelated to other ocular parameters. [*J Chin Med Assoc* 2009;72(3):133–137]

Key Words: anterior chamber depth, axial length, central corneal thickness, corneal curvature, refractive error

Introduction

There has been increased interest in central corneal thickness (CCT) because of its influence on the accuracy of intraocular pressure (IOP) measurement. Previous studies have demonstrated a positive correlation between CCT and IOP measured by applanation which causes overestimation of true IOP in thicker corneas and the converse in thinner ones.[1,2] It has been demonstrated that CCT is greater in patients with ocular hypertension compared to the general population[2,3] and that thin CCT is a risk factor for glaucoma in ocular hypertension.[4] Myopic eyes are associated with increased risk for glaucoma.[5] Greater axial length,[6] deeper anterior chamber and greater vitreous depth[7] with decreased sclera thickness[8] have been noted in myopes. Also, the corneas tended to be thinner in more myopic eyes.[9] The possible interrelationship of myopia and low CCT can help explain the increased risk for glaucoma.

To determine whether a thinner CCT is associated with eye length, the relationships between CCT, refractive error, corneal curvature, anterior chamber depth and axial length were assessed in a sample of normal Taiwanese Chinese adult eyes.

Methods

Five hundred patients (226 males, 274 females) aged 40–80 years were consecutively recruited from a general ophthalmology practice at Taipei Veterans General Hospital during 2006. Only participants who had no ocular disease other than refractive error within ±5 diopters and lens opacity less than NO4 NC4 C3 P2 as

*Correspondence to: Dr Mei-Ju Chen, Department of Ophthalmology, Taipei Veterans General Hospital, 201, Section 2, Shih-Pai Road, Taipei 112, Taiwan, R.O.C.
E-mail: mj_chen@vghtpe.gov.tw • Received: October 13, 2008 • Accepted: February 9, 2009

ELSEVIER

defined by the *Lens Opacities Classification System III*[10] were included. To eliminate possible confounding factors, the following exclusion criteria were used: IOP > 21 mmHg; previous contact lens use; connective tissue disorders; or history of ocular trauma or surgery. All study procedures adhered to the Declaration of Helsinki for research involving human subjects.

Ophthalmic assessment included slit lamp examination, IOP measurement, refraction, corneal curvature, anterior chamber depth and axial length. IOP was measured using a non-contact air-puff tonometer (Topcon CT-80; Topcon Corp., Tokyo, Japan). Refraction and corneal curvature were measured using an autorefractor (Topcon KR-8800; Topcon Corp.). Refractive error was calculated in diopters as the spherical equivalent of spherical refractive error plus 0.5 × cylindrical refractive error. The 2 major corneal radii separated by 90° were averaged to give corneal curvature. Anterior chamber depth and axial length measurements were obtained using A-scan ultrasonography (Sonomed A-5500; Sonomed Inc., Lake Success, NY, USA). CCT was measured using a DGH-550 ultrasonic pachymeter (DGH Technology Inc., Exton, PA, USA). All measurements were performed by a single certified technician. The mean of 3 readings for each parameter was used for further analysis.

A power calculation was performed to justify the number of subjects tested. A sample size of 438 was calculated as sufficient to detect a correlation of CCT with axial length with a power of 80%. The sample sizes were based on a standard deviation for axial length of 1.2 mm and CCT of 29 μm and a 2-sample *t* test conducted at a 5% chance of type I error. Therefore, 500 patients were to be included in this study group.

One eye from each participant was selected for the statistical analysis, using the following algorithm: the right eye was chosen where both were normal, otherwise the eye meeting the inclusion criteria was used. Between-gender differences for each parameter were analyzed using Student's *t* test. The relationships between CCT, refractive error, corneal curvature, anterior chamber depth and axial length were tested using Pearson's correlation and linear regression analysis. Commercial software (SPSS version 12.0 for Windows; SPSS Inc., Chicago, IL, USA) was utilized for all analyses, with a probability of 0.05 considered statistically significant.

Results

A total of 500 subjects (mean age, 60.9 ± 11.2 years) were enrolled. There were 226 males (mean age, 61.3 ± 12.1 years) and 274 females (mean age, 60.5 ± 10.2 years). The CCT, refractive error, corneal curvature, anterior chamber depth and axial length are presented in Table 1. The average CCT was 558 ± 29 μm in males and 554 ± 32 in females. Males had greater axial length and flatter cornea. There was no significant difference in the mean CCT, refractive error and anterior chamber depth in gender comparison.

The correlations between CCT and other biometric parameters are presented in Table 2. In eyes with greater axial length, the corneal curvature was flatter ($r = -0.502$, $p < 0.001$) and the anterior chamber depth was greater ($r = 0.651$, $p < 0.001$). Eyeballs with more myopic refractive error were longer axially ($r = -0.645$, $p < 0.001$) and tended to have a deeper anterior

Table 1. Central corneal thickness, refractive error, corneal curvature, anterior chamber depth and axial length, stratified by gender*

	CCT (μm)	SE (D)	K (D)	ACD (mm)	AL (mm)
Male (*n* = 226)	555 ± 27	0.3 ± 2.0	43.5 ± 1.3	3.0 ± 0.5	23.5 ± 1.1
Female (*n* = 274)	553 ± 30	–0.4 ± 2.0	44.3 ± 1.6	2.9 ± 0.5	23.0 ± 1.2
Total (*n* = 500)	554 ± 29	0 ± 2.1	44.0 ± 1.5	2.9 ± 0.5	23.3 ± 1.2
p†	0.48	0.71	< 0.001	0.07	< 0.001

Data presented as mean ± standard deviation; †2-tailed statistical significance by Student's t test. CCT = central corneal thickness; SE = spherical equivalent of refraction error; D = diopters; K = corneal curvature; ACD = anterior chamber length; AL = axial length of the eyeball.

Table 2. Correlations between central corneal thickness and other biometric parameters

	CCT *vs.* SE	CCT *vs.* K	CCT *vs.* ACD	CCT *vs.* AL	SE *vs.* K	SE *vs.* ACD	SE *vs.* AL	K *vs.* ACD	K *vs.* AL	ACD *vs.* AL
r	–0.034	0.013	0.023	–0.053	–0.016	–0.435	–0.645	–0.188	–0.502	0.651
*p**	0.445	0.770	0.614	0.233	0.723	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001

**2-tailed statistical significance by Pearson's correlation test. CCT = central corneal thickness; SE = spherical equivalent of refraction error; K = corneal curvature; ACD = anterior chamber length; AL = axial length of the eyeball; r = Pearson's correlation coefficient.*

chamber ($r=-0.435$, $p<0.001$). However, CCT was not correlated with refractive error ($r=-0.034$, $p=0.445$), corneal curvature ($r=0.013$, $p=0.770$), anterior chamber depth ($r=0.023$, $p=0.614$) and axial length ($r=-0.053$, $p=0.233$) in our patients. CCT and axial length were not related in this sample population (Figure 1). Regression between CCT (X) and axial length (Y) yielded: $Y=-0.002X+24.333$; $r^2=0.0028$; correlation coefficient, −0.053; $p=0.233$. The regression between refractive error and CCT is plotted in Figure 2. There was no correlation between CCT (X) and refractive error (Y) in the study population: $Y=-0.0022X+1.1925$; correlation coefficient, −0.034; $r^2=0.0012$; $p=0.445$. CCT (X) and corneal curvature (Y) did not appear to be related; regression formula: $Y=43.619+0.013X$; $r^2=0.0002$; $p=0.770$. There was no statistically significant association between CCT (X) and anterior chamber depth (Y): $Y=2.731+0.023X$; $r^2=0.0005$; $p=0.614$.

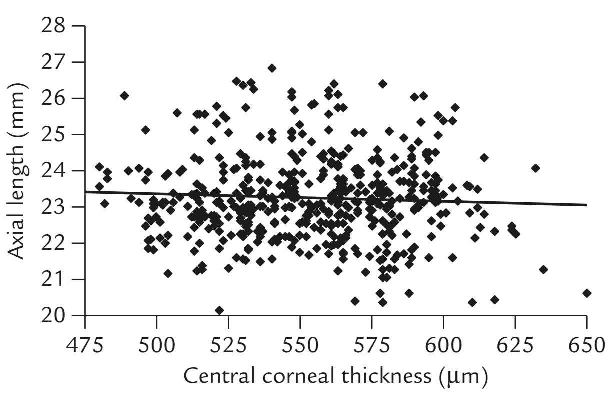

Figure 1. Regression and correlation between central corneal thickness and axial length. Correlation not significant: correlation coefficient, −0.053; $p=0.233$; $Y=-0.002X+24.333$; $r^2=0.0028$.

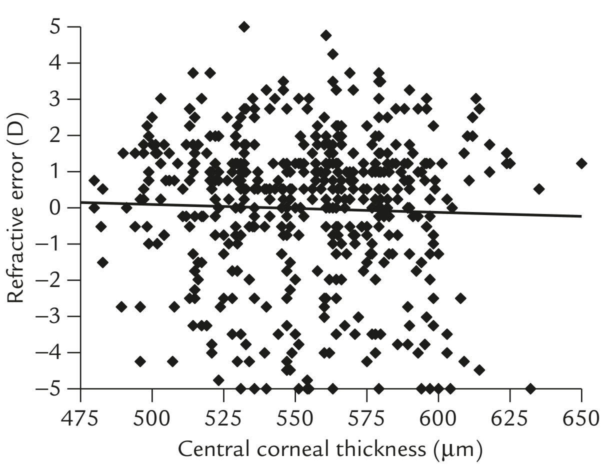

Figure 2. Regression and correlation between central corneal thickness and refractive error. Correlation not significant: correlation coefficient, −0.034; $p=0.445$; $Y=-0.0023X+1.244$; $r^2=0.0012$.

Discussion

CCT is an important indicator of cornea status and affects IOP measurements. However, there is no general consensus with respect to how CCT varies with refractive error, corneal curvature, anterior chamber depth and axial length. Further, whether the CCT is inversely associated with axial length and potentially higher risk of glaucoma also needs investigation.

The eyeball elongates[6] with scleral thinning[8] in the development of myopia. Eyes with higher myopia have deeper anterior chambers.[7] Further, a flatter anterior corneal surface has been demonstrated in eyes with greater vitreous depths.[11] Our study demonstrated that the eyeballs with greater axial lengths had more myopic refractive error, flatter corneal curvatures and greater anterior depths, confirming the results of a number of reports.[7,9,11]

The relationship between CCT and refractive error is controversial across earlier studies. For myopic populations, Chang et al reported that the corneas were thinner in more myopic eyes in 216 young adults with an averaged refractive error of −4.17 diopters,[9] whereas Fam et al found that CCT was not correlated with the degree of myopia in a study of 714 Singaporean Chinese with a mean refractive error of −5.3 diopters.[12] For normal populations, a significant correlation between CCT and refraction was demonstrated in 3,021 Japanese.[13] In contrast, the Beijing Eye Study,[14] Cho and Lam,[15] and Tong et al[16] failed to demonstrate a significant correlation between CCT and refraction in 4,439 Chinese, 151 Hong Kong Chinese and 652 Singaporean schoolchildren, respectively. In our study of normal populations, CCT was not correlated with refraction, which agreed with most of the studies mentioned above. In addition to race and age, differences in the measurement methods and techniques may compound the statistical inaccuracies, accounting for the lack of agreement demonstrated in the various studies.

The relationship between CCT and corneal curvature was investigated in several earlier studies. Shimmyo et al[17] and the Tajimi study[18] reported that CCT was positively correlated with corneal curvature in 1,976 Americans and 2,868 Japanese. A weak correlation between CCT and corneal curvature was also demonstrated in Suzuki et al's[13] and Tong et al's series[16] mentioned earlier. In contrast, Eyesteinsson et al reported no correlation between CCT and corneal curvature in 925 Caucasians.[19] Similar findings were also found in Chang et al's,[9] Fam et al's[13] as well as Cho and Lam's[15] series mentioned earlier. Different methodologies could explain the discrepancies in previous investigations. Optical pachymetry measures the oblique section of the cornea using a split prism and is theoretically influenced by the corneal curvature. In the present study, CCT was not correlated with corneal curvature, which confirmed previous studies using ultrasound pachymetry.

There appears to be no consensus concerning the relationship between CCT and axial length. Chang et al[9] demonstrated significantly thinner CCTs in eyeballs with greater axial length. They proposed that as the surface area of the cornea increased, the corneal stroma became thinner and reduced corneal thickness could be expected as the eyeball elongated axially. Their subpopulation may be too small to give a true relationship between CCT and axial length in the general population. Oliveira et al[20] and Shimmyo and Orloff[21] found no association between CCT and axial length in American patients. The present study confirms the poor association between CCT and axial length. During the development of myopia, the eyeball elongates and the sclera thins, with greater involvement of the posterior segment.[22] Although collagen is the main component of the sclera and cornea, glycosaminoglycan and elastin content, hydration, as well as predominant collagen type vary between them.[23,24] CCT may be unaffected by the scleral thinning that occurs during eyeball elongation.

To the best of our knowledge, the relationship between CCT and anterior chamber depth has not been studied previously. However, it has been demonstrated that anterior chamber depth is negatively and positively correlated with lens thickness[3] and axial length,[7,9,11] respectively. In our study, no correlation was noticed between CCT and anterior chamber depth, which partly explains the lack of association of CCT and axial length mentioned above.

In the general population, CCT is associated with various demographic and ocular factors. Although the series of Shimmyo et al,[17] Suzuki et al,[13] the Tajimi study[18] and Hahn et al[25] showed that female corneas were significantly thinner, we were not able to demonstrate a gender difference in CCT in Taiwanese Chinese, confirming the analogous findings of Herndon et al[2] and Eyesteinsson et al.[19] The average CCT of 556 μm in our adult sample is similar to that previously reported for whites,[17] Chinese[14] and Hong Kong Chinese,[15] but greater than reports for African Americans,[17] Latinos,[22] Mongolians,[26] Singaporean Chinese[12] and Japanese.[13]

This study is limited by the clinical setting, which may have produced selection biases. However, our investigation was designed to recruit participants from the same ethnic background and therapeutic setting, providing relative homogeneity with respect to the method used to evaluate refraction and biometry.

In conclusion, significant relationships between CCT and refractive error, corneal curvature, anterior chamber depth and axial length were not demonstrated for our samples of normal Taiwanese Chinese adult eyes. Our results add to the evidence that CCT is an independent factor unrelated to other ocular parameters.

References

1. Damji KF, Muni RH, Munger RM. Influence of corneal variables on accuracy of intraocular pressure measurement. *J Glaucoma* 2003;12:69–80.
2. Herndon LW, Choudhri SA, Cox T, Damji KF, Shields B, Allingham RR. Central corneal thickness in normal, glaucomatous, and ocular hypertensive eyes. *Arch Ophthalmol* 1997; 115:1137–41.
3. Singh RP, Goldberg I, Graham SL, Sharma A, Mohsin M. Central corneal thickness, tonometry, and ocular dimensions in glaucoma and ocular hypertension. *J Glaucoma* 2001;10: 206–10.
4. Gordon MO, Beiser JA, Brandt JD, Heuer DK, Higginbotham EJ, Johnson CA, Keltner JL, et al. The Ocular Hypertension Treatment Study: baseline factors that predict the onset of primary open-angle glaucoma. *Arch Ophthalmol* 2002;120: 714–20.
5. Mitchell P, Hourihan F, Sandbach J, Wang JJ. The relationship between glaucoma and myopia: the Blue Mountains Eye Study. *Ophthalmology* 1999;106:2010–5.
6. Lin LL, Shih YF, Tsai CB, Chen CJ, Lee LA, Hung PT, Hou PK. Epidemiologic study of ocular refraction among schoolchildren in Taiwan in 1995. *Optom Vis Sci* 1999;76:275–81.
7. Curtin BJ. Ocular findings and complications. In: *The Myopias: Basic Science and Clinical Management*. Philadelphia: Harper and Row, 1985:277–385.
8. Funata M, Tokoro T. Scleral change in experimentally myopic monkeys. *Graefes Arch Clin Exp Ophthalmol* 1990;228:174–9.
9. Chang SW, Tsai IL, Hu FR, Lin LL, Shih YF. The cornea in young myopic adults. *Br J Ophthalmol* 2001;85:961–70.
10. Chylack LT Jr, Wolfe JK, Singer DM, Singer DM, Leske MC, Bullimore MA, Bailey IL, et al. The Lens Opacities Classification System III. The Longitudinal Study of Cataract Study Group. *Arch Ophthalmol* 1993;111:831–6.
11. Goss DA, Van Veen HG, Rainey BB, Feng B. Ocular components measured by keratometry, phakometry, and ultrasonography in emmetropic and myopic optometry students. *Optom Vis Sci* 1997;74:489–95.
12. Fam HB, How AC, Baskaran M, Lim KY, Chan YH, Aung T. Central corneal thickness and its relationship to myopia in Chinese adults. *Br J Ophthalmol* 2006;90:1451–3.
13. Suzuki S, Suzuki Y, Iwase A, Araie M. Corneal thickness in an ophthalmologically normal Japanese population. *Ophthalmology* 2005;112:1327–36.
14. Zhang H, Xu L, Chen C, Jonas JB. Central corneal thickness in adult Chinese: association with ocular and general parameters. The Beijing Eye Study. *Graefes Arch Clin Exp Ophthalmol* 2008; 246:587–92.
15. Cho P, Lam C. Factors affecting the central corneal thickness of Hong Kong Chinese. *Curr Eye Res* 1999;18:368–74.
16. Tong L, Saw SM, Siak JK, Gazzard G, Tan D. Corneal thickness determination and correlates in Singaporean schoolchildren. *Invest Ophthalmol Vis Sci* 2004;45:4004–9.

17. Shimmyo M, Ross AJ, Moy AJ, Mostafavi B. Intraocular pressure, Goldmann applanation tension, cornea thickness, and corneal curvature in Caucasians, Asians, Hispanics, and African Americans. *Am J Ophthalmol* 2003;136:603–11.
18. Sawada A, Tomidokoro A, Araie M, Iwase A, Yamato T. Refractive errors in an elderly Japanese population: the Tajimi study. *Ophthalmology* 2008;115:363–70.
19. Eyesteinsson T, Jonasson F, Sasaki H, Arnarsson A, Sverrisson T, Sasaki K, Stefánsson E, et al. Central corneal thickness, radius of the corneal curvature and intraocular pressure in normal subjects using non-contact techniques: Reykjavik Eye Study. *Acta Ophthalmol Scand* 2002;80:11–5.
20. Oliveira C, Tello C, Liebmann J, Ritch R. Central corneal thickness is not related to anterior scleral thickness or axial length. *J Glaucoma* 2006;15:190–4.
21. Shimmyo M, Orloff PN. Cornea thickness and axial length. *Am J Ophthalmol* 2005;139:553–4.
22. Celorio JM, Pruett RC. Prevalence of lattice degeneration and its relation to axial length in axial myopia. *Am J Ophthalmol* 1991;1:20–3.
23. McBrien NA, Gentle A. Role of the sclera in the development and pathological complications of myopia. *Prog Retin Eye Res* 2003;22:307–38.
24. Hogan M. The sclera. In: Hogan M, ed. *Histology of the Human Eye*. Philadelphia: Saunders, 1971:183–201.
25. Hahn S, Azen S, Mei YL, Varma R. Central corneal thickness in Latinos. *Invest Ophthalmol Vis Sci* 2003;44:1508–12.
26. Foster PJ, Baasanhu J, Alsbirk PH, Munkhbayar D, Uranchimeg D, Johnson GJ. Central corneal thickness and intraocular pressure in a Mongolian population. *Ophthalmology* 1998;15:969–73.