

The Distribution of Corneal Thickness in Rural Population

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Abstract- To determine the distribution of corneal thickness and its associated factors in the over 5-year-old population in the north and south rural areas in Iran. In this study, samples were selected using multi-stage cluster sampling. After vision and refraction tests and the slit lamp exam, the central corneal thickness (CCT), apical corneal thickness (ACT), and the thickness at four peripheral areas of the cornea were measured using Pentacam. Of the 3851 selected samples, after applying the exclusion criteria, the analysis was done on data from 2681 people. The mean age of the participants was 36.03±18.51 years, ranging from 6 to 90 years, and 58.1% of them were female. Mean CCT and ACT were 533.87 µm (95%CI: 532.05 -535.69) and 536.72 µm (95%CI: 534.9 -538.54), respectively. Mean peripheral corneal thickness was 637.46 µm (95%CI: 635.09 -639.83) in the superior quadrant, and 594.34 µm (95%CI: 592.2 -596.47), 620.81 µm (95%CI: 618.66 -622.97), and 584.55 µm (95%CI: 582.18 -586.93) in the inferior, nasal, and temporal quadrants, respectively. Linear regression analysis showed significant associations between CCT and gender ($P=0.001$), age ($P<0.001$), geographical location of residence ($P<0.001$), the radius of corneal curvature ($P<0.001$), anterior chamber depth ($P<0.001$), and corneal volume ($P<0.001$). This study is one of the few studies describing the distribution of the corneal thickness in a population of over 5-year-olds using Pentacam. Gender, anterior chamber depth, and corneal radius of curvature are some of the factors associated with CCT.

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Keywords: Corneal thickness; Cross-sectional study; Distribution

Introduction

Corneal thickness, especially the central corneal thickness (CCT), is an important parameter for evaluating corneal health, and in particular, corneal endothelial cells. In recent years, several studies have emphasized the importance of CCT assessment for accurate measurement of the intraocular pressure and better diagnosis of glaucoma (1-5), as well as for determining patient eligibility for refractive surgery (6-9). Studies in different populations have addressed corneal thickness determinants. Age, gender, refractive errors (10-12), smoking, body mass index, diabetes, and hyperglycemia (12,13) are major factors. Also, given the anatomical location of the cornea, dry weather and air pollution in industrial cities (14) were other factors

considered in these studies.

Ultrasound pachymetry is the gold standard method for corneal thickness measurement; however, in light of the limitations and weaknesses of this tool, such as underestimation or overestimation of corneal thickness, as well as lower patient cooperation due to the need for topical anesthesia for using this technique, (8,15) ophthalmologists sought alternative methods in their clinical practice. One of the devices that have recently received attention is the Pentacam which, not only lacks the limitations of ultrasound pachymeters, it also provides valid and reliable information about the corneal thickness (16,17).

The increasing popularity of contact lenses and refractive surgery, ethnic, and racial differences in corneal thickness, and the variety of measurement tools

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in different studies make it necessary to obtain comprehensive information on the status of the cornea in different populations. On the other hand, studies in the country and many parts of the world have been on a particular age group, a specific sample, or clinic-based, and thus, they fail to provide a complete picture of the corneal structure in the population. Therefore, the present study, as one of the largest population-based studies, aimed to investigate the distribution of corneal thickness in people over 5 years of age in the rural north and south Iran using Pentacam.

Materials and Methods

This cross-sectional study was conducted on underprivileged rural populations in Iran in 2015. The sampling frame of the present study was based on the roster of deprived rural areas provided by the Rural Development Office of the presidential administration in the Islamic Republic of Iran. Two districts were randomly chosen: Shahyoun in the southwest (a district of Dezful County, Khuzestan Province) and Kajour in the north (a district of Noshahr County, Mazandaran Province). Then, within each district, a number of villages were randomly selected.

Given the study sample size, the number of samples selected from each district was proportionate to their total population. Therefore, 15 villages were sampled in Shahyoun and 5 in Kajour, because the Shahyoun has smaller and less populated villages. All over-one-year old residents in each selected village were considered the target, and samples were chosen through a multistage cluster sampling approach. In each selected household, all members over 1 year of age were invited to participate in the study, and their exam date was set.

First, informed consent was obtained from all subjects. For cases under 18 years, the head of the household signed the consent form. An interview was conducted to collect demographics, and then, participants proceeded to the exam room. Examinations were conducted under normal room illumination by two optometrists. To assess inter-examiner agreement, 35 people were initially tested for visual acuity and objective refraction by both optometrists. Based on the intraclass correlation coefficients (ICC), an inter-examiner agreement was high (0.923 for uncorrected visual acuity (UCVA) and 0.897 for spherical equivalent refraction).

Examinations for each participant began with testing the UCVA using the Snellen E chart at 6 meters. For

illiterate participants, instructions were provided beforehand, and for children ≤ 5 years, the Lea Symbols acuity chart was used. Acuity testing was followed by objective refraction using the Nidek Ref/Keratometer ARK-510A, and results were refined through retinoscopy (Heine Beta 200 retinoscope, HEINE Optotechnik, Germany). If autorefraction was not possible for any child, objective refraction was determined by retinoscopy only. For cases with UCVA worse than 20/20, subjective refraction was done to determine best distance optical correction, and best-corrected distance visual acuity (BCVA) was recorded. Finally, all subjects had the slit lamp exam by an ophthalmologist.

All participants over the age of 5 years underwent corneal imaging with Pentacam. All images were acquired by the same technician throughout the study in accordance with the manufacturer's instructions. The latest version of the device (6.03, $r=11$) and Pentacam software (1.17, $r=72$) were used. Eye examinations (both eyes) were done under mydriasis between 9:00 AM and 2:00 PM. To avoid the effect of diurnal variations, examinations were done at least 3 hours after waking up. In case of error, imaging was repeated 10 minutes after instilling artificial tears. For each participant, we extracted the CCT, and the paracentral corneal thickness at 4 points (superior, inferior, temporal, and nasal) on the 3mm ring (3mm away from the apex).

Exclusion criteria

People with a history of intraocular surgery, use of contact lenses at the time of the study, corneal opacities, pterygium, strabismus, keratoconus, scissoring reflex on retinoscopy, Fleischer rings on slit lamp examination, corneal dystrophy, and ptosis was excluded. Also, Pentacam images displaying an error status were excluded from the study.

Statistical analysis

In this study, corneal thickness was described as mean and 95% confidence intervals (CI). In order to calculate standard errors, the design effect of the cluster sampling method was estimated. Simple linear and multiple regression and analysis of variance were used to investigate the relationship between corneal thickness and other studied variables.

Ethical issues

The Ethics Committee of Shahid Beheshti University of Medical Sciences approved the study protocol, which was conducted in accord with the tenets of the Helsinki

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Declaration. All participants signed a written informed consent.

Results

Of the 3851 people selected for this study, 3314 people participated in the study, and after applying the exclusion criteria 2681 people were eligible for inclusion. 58.1 % (1558) of the subjects of this study were female and the average age of study participants was 36.03 ± 18.51 .

The 6 to 20-year age group (25.3%) and the +70-year age group (3.7%) formed the largest and smallest age groups, respectively.

Mean CCT and apical corneal thickness (ACT) were respectively $533.87 \mu\text{m}$ (95%CI: 532.05 -535.69) and $536.72 \mu\text{m}$ (95%CI: 534.9 -538.54). Mean CCT and ACT based on gender, age, refractive status, and residence location are shown in Table 1. Mean CCT ($P=0.034$) was significantly higher in males compared to females.

Table 1. Distribution of central and apical corneal thickness by demographic variables and refractive status

		Central corneal thickness		Apical corneal thickness	
		Mean(95%CI)	P	Mean(95%CI)	P
Gender	Total	533.87(532.05 -535.69)		536.72(534.9 -538.54)	
	Female	532.52(530.19 -534.84)	0.034	535.37(533.05 -537.68)	0.019
	Male	535.81(532.91 -538.71)		538.64(535.73 -541.56)	
6-20	544.45(540.66 -548.25)	546.97(543.19 -550.75)			
Age	21-30	527.81(523.39 -532.22)		529.89(525.48 -534.3)	
	31-40	534.41(530.32 -538.5)		537.24(533.1 -541.37)	
	41-50	533.64(529.27 -538.01)	<0.001	536.8(532.39 -541.21)	<0.001
	51-60	525.74(521.18 -530.3)		529.15(524.54 -533.76)	
	61-70	532.24(525.06 -539.42)		535.87(528.82 -542.93)	
	>70	526.84(516.08 -537.59)		530.72(520.39 -541.06)	
Emmetropia	536.13(533.72 -538.54)	538.76(536.34 -541.17)			
Myopia	531.4(527.51 -535.29)	534.52(530.59 -538.45)			
Refractive errors	Hyperopia	530.02(525.81 -534.23)	<0.001	533.19(529.02 -537.36)	<0.001
	South	531.26(528.62 -533.9)	<0.001	533.67(531.03 -536.3)	<0.001
Residence location	North	536.14(533.64 -538.63)		539.36(536.87 -541.86)	

The highest CCT and ACT were observed in the under 10 age group; thicknesses significantly decreased with age and the lowest CCT and ACT were observed in the 71 to 80-year age group. Findings showed that mean CCT ($P=0.001$) and ACT ($P=0.001$) significantly differed between the rural north and south of Iran.

Mean CCT ($P=0.928$) and ACT ($P=0.738$) were lower in the hyperopic group compared to the myopic group, but the difference was not significant. Mean CCT and ACT in the emmetropic group were significantly different from myopic and hyperopic groups ($P<0.001$).

Mean peripheral corneal thickness was $637.46 \mu\text{m}$ (95%CI: 635.09 -639.83) in the superior quadrant, and $594.34 \mu\text{m}$ (95%CI: 592.2 -596.47), $620.81 \mu\text{m}$ (95%CI: 618.66 -622.97), and $584.55 \mu\text{m}$ (95%CI: 582.18 -586.93) in the inferior, nasal, and temporal quadrants, respectively. Table 2 summarizes the mean peripheral

corneal thickness by gender, age, refractive error, and residence location. Mean superior thickness was significantly higher in males ($P=0.042$). Residents of the northern and southern regions were significantly different in terms of peripheral thickness at all quadrants except the superior quadrant.

Linear regression analysis showed that each year of older age was associated with reduced corneal thickness by $0.51 \mu\text{m}$ ($P=<0.001$). CCT in males was on average $3.74 \mu\text{m}$ higher than in females ($P=0.016$). Also, CCT in the residents of northern Iran was higher compared to residents of southern Iran. For each millimeter increase in the radius of corneal curvature, CCT decreased by $3.09 \mu\text{m}$. For each millimeter increase in anterior chamber depth (ACD), CCT increased by $38.84 \mu\text{m}$. Also, for each 1 mm^2 increase in corneal volume, CCT is reduced by $0.47 \mu\text{m}$.

Table 2. Distribution of paracentral corneal thickness by demographic variables and refractive status

		Superior	Inferior	Nasal	Temporal
		Mean(95%CI)	Mean(95%CI)	Mean(95%CI)	Mean(95%CI)
Gender	Total	637.46(635.09 -639.83)	594.34(592.2 -596.47)	620.81(618.66 -622.97)	584.55(582.18 -586.93)
	Female	635.66(632.61 -638.71)	593.75(590.99 -596.52)	620.71(617.96 -623.47)	582.14(579.01 -585.28)
	Male	640.01(636.26 -643.77)	595.16(591.8 -598.52)	620.96(617.5 -624.41)	587.99(584.38 -591.59)
Age	6-20	650.92(646.14 -655.7)	604.07(599.59 -608.54)	635.79(631.39 -640.19)	590.25(585.81 -594.69)
	21-30	633.2(627.79 -638.61)	591.65(586.74 -596.55)	619.02(614 -624.04)	581.01(575.98 -586.03)
	31-40	643.07(637.96 -648.17)	596.85(591.89 -601.82)	623.28(618.32 -628.24)	587.47(580.37 -594.57)
	41-50	639.11(633.09 -645.14)	593.29(588.04 -598.55)	620.23(615.28 -625.18)	587.9(582.21 -593.59)
	51-60	623.11(617.27 -628.95)	586.35(581.01 -591.69)	608.13(602.8 -613.46)	578.24(572.28 -584.19)
	61-70	623.77(613.2 -634.35)	587.8(578.31 -597.3)	607.06(597.69 -616.42)	580.9(571.38 -590.42)
	>70	618.19(604.22 -632.15)	580.14(568.53 -591.75)	594.67(583.95 -605.4)	567.51(554.15 -580.87)
Refractive errors	Emmetropia	641.18(638.08 -644.27)	596.73(593.93 -599.54)	624.05(621.29 -626.82)	586.07(582.92 -589.22)
	Myopia	634.77(629.7 -639.83)	591.52(586.9 -596.14)	618.3(613.64 -622.96)	582.17(577.11 -587.23)
	Hyperopia	629.56(623.89 -635.22)	590.44(585.4 -595.47)	613.72(608.38 -619.06)	582.99(577.4 -588.59)
Residence location	South	636.24(632.73 -639.75)	591.93(588.87 -595)	616.95(613.8 -620.11)	585.08(581.42 -588.74)
	North	638.51(635.3 -641.72)	596.42(593.45 -599.39)	624.16(621.23 -627.1)	584.1(581 -587.19)

Table 3. The relationship between central corneal thickness with demographic and ocular variables linear regression analysis

	Unstandardized Coefficients		Standardized Coefficients	P
	B	Std. Error	Beta	
Age	-0.51	0.053	25.644	<0.001
Gender	3.74	1.545	-0.255	0.016
Myopia	-0.45	1.765	0.050	0.801
Residence location	9.43	1.488	-0.005	<0.001
Radius of corneal curvature	-3.09	0.524	0.127	<0.001
Pupil diameter	0.60	1.155	-0.124	0.602
Anterior chamber depth	38.84	4.413	0.012	<0.001
Corneal volume	-0.47	0.046	0.409	<0.001

Discussion

The present study is one of the largest population-based studies in Iran, which for the first time, studies the distribution of corneal thickness and its associated factors by sampling residents of two different geographic regions in the north and south of Iran and covering a wide range of different age groups. Our findings showed that mean CCT in the studied population was 533.87 μm , which is close to the findings of some similar studies with the same mean age of our study (18-20), but as displayed in table 4, overall, there are large differences among results of different studies. In these studies, the lowest CCT was 503.3 μm in the study by Tayyab *et al.*, (31) in Pakistan, and the highest CCT was 593.3 μm in the study by Su *et al.*,

(13) in Singapore. Among the few population-based studies that have been conducted in rural areas, mean CCT was 514 μm in a sample of 4711 rural-dwellers over 30 years of age in India (25) and 505 μm in another study (33) which are lower than the averages observed in the rural population in Iran. However, differences among studied age groups in our study with the rural studies in India should be considered. Lekskul *et al.*, (34) reported a mean CCT of 535.2 μm in the over 12 year age group in rural Thailand which is close to our findings. Type of design study, type of applied tools and techniques, as well as genetic and socio-economic differences can be the most important reasons for varied results in the literature. The study by Pan *et al.*, in China clearly showed racial differences in mean CCT variation (35). Study of genetic differences by Aghaian *et al.*, who

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compared Asians, African-Americans, the Chinese, and the Japanese revealed significantly thinner corneas in the black African-American race compared to other races, and among Asians, the Japanese had thinner corneas than other countries such as China and the Philippines (22). In the study by Suzuki *et al.*, (36), mean CCT in more than 7,000 Japanese over 40-year-old was 517 μm , and in the study by Dohadwala *et al.*, (37), mean CCT was lower in blacks than whites, which confirms the role of genetic differences in normal corneal thickness. One of the strengths of the present study is examining two different ethnicities in two different geographical regions. Our findings showed that mean CCT in northern rural-dwellers was about 5 μm higher than in

southern ones. Given that no study has been done in Iranian rural populations, our ability to make any comparisons is limited. To explain the significant difference, two points should be noted. First: ethnic differences and their role in corneal thickness in different ethnicities. Second: differences in geographical location. Khuzestan is a province in the south of Iran where people are exposed to sunlight and UV radiation much more than in the north which usually has many cloudy and rainy days and less sunshine during the year. Therefore, the thinner CCT is an interesting finding in the rural south of the country which might suggest the influence of sunlight on corneal thinning.

Table 4. Comparison of mean central corneal thickness (CCT) values in different studies

Author	Country and Date	Age Group (years)	CCT Mean \pm SD (μm)	Measurement Tool
Nishitsuka <i>et al.</i> ¹²	Japan 2005- 2007	≥ 35	544.7 \pm 34.6	Automated specular-type pachymeter
Tomidokoro <i>et al.</i> ²¹	Japan 2007	≥ 40	0.521 \pm 0.032	Specular-type pachymeter
Hashemi <i>et al.</i> ¹	Iran 2009	≥ 14	555.6 \pm 39.9	Orbscan II
Hashemi <i>et al.</i> ¹⁰	Iran 2011	40-64	528.5 \pm 35.8	Pentacam
Su DH <i>et al.</i> ¹³	Singapore 2008	40-80	593.3 \pm 0.70	Ultrasound pachymeter
Aghaian <i>et al.</i> ²²	USA 2004	≥ 30	542.9	Ultrasound pachymeter
Gao <i>et al.</i> ²³	USA 2013	≥ 40	551.6 \pm 33.4	Ultrasound pachymeter
Zhang <i>et al.</i> ²⁴	China 2008	≥ 40	556.2 \pm 33.1	slit lamp-based optical
Nangia <i>et al.</i> ²⁵	India 2010	≥ 30	514 \pm 33	ultrasound pachymeter
Nemesure <i>et al.</i> ²⁶	USA 2003	50- 79	533.3 \pm 37.2	Ultrasound pachymeter
Rashid <i>et al.</i> ²⁷	Iraq 2016	25 – 60	551.02 \pm 36.28	Pentacam
Rufer <i>et al.</i> ¹⁹	--	18- 83	534 \pm 36	Pentacam
Landers <i>et al.</i> ²⁸	Australia 2007	14- 51	511 \pm 34	Pentacam
Altinok <i>et al.</i> ²⁹	Turkey 2007	6-88	552.2 \pm 35.9	not mentioned
Doughty <i>et al.</i> ³⁰	UK 2002	32-60	0.533 \pm -0.033 mm	Ultrasound pachymeter
Sng <i>et al.</i> ¹⁸	2016	≥ 40	533.9 \pm 34.0	Ultrasound pachymeter
Tayyab <i>et al.</i> ³¹	2016	47.31 \pm 11.78	503.96 \pm 12.47	TopCon non-contact specular microscope
Kivanc <i>et al.</i> ³²	2016	5- 8	526.8 \pm 37.9	Ultrasound pachymeter
Current Study	2015	6-90	533.87 (95%CI: 532.05-535.69)	Pentacam

It seems that there is an interaction among residence location, environmental exposure, and race and ethnicity which can be responsible for CCT differences in different locations and different races. The comparison of mean CCT in urban and rural areas of Iran also shows a higher CCT in urban-dwellers compared to people living in rural areas. In the population-based study in Tehran, mean CCT was 26 μm thicker than our rural-dwellers of the south and 21 μm thicker than rural-dwellers of northern Iran (1). A similar difference was also observed in the 40 to 64-year-old population-based study in Shahroud, and mean CCT was higher in urban-dwellers in Shahroud compared to the corresponding age

group of the rural sample in our study (10). The difference in diet and lifestyle, and perhaps access to eye care can be some of the important reasons for these differences in mean CCT. Understanding the exact cause and effect in mean CCT difference in urban versus rural regions requires conducting analytical studies with different methodologies.

Our findings showed that mean CCT was approximately 3.5 μm higher in males than female. This result is consistent with the findings of other studies (24-226,36,38). However, Brandt *et al.*, (39) reported that mean CCT was higher in females, and Hashemi *et al.*, (1) found no significant inter-gender difference in this

regard. Since most studies agree that males have thicker corneas, researchers attribute it to physiological and hormonal differences such as estrogen levels in females (40). Goldich *et al.*, (41) reported corneas to be thinner at the beginning of the menstrual cycle and thicker at the end of the cycle; attention to this issue is of particular importance during screening programs and drawing conclusions about inter-gender thickness differences.

The most important strength of this study is including a large age range. One important question that has remained unanswered concerns the possible role of age in CCT changes and some researchers believe that age-related corneal thickness changes cannot be predicted. Lack of a clear relationship between age and CCT has been more common in studies of white populations rather than non-white ones. (42) Most studies (18,35, 43,44) agree that mean CCT is thinner in older people than younger people, and this study also showed that for every one-year increase in age, the corneal thickness reduces by about 0.50 μm . Our findings showed that mean CCT difference between the youngest and oldest age groups is more than 30.0 μm . Some studies also suggest that for each decade increase in age, the cornea thins by about 2 to 6.5 μm (45, 46). In a study of 485 people, Eballe *et al.*, (47) reported a 4.2 μm reduction in corneal thickness per decade of aging. In a population-based study of more than 1,600 Lithuanian adults aged 18 to 90 years, corneal thickness decreased by 2 to 8 μm per decade of aging (45). Due to methodological limitations of a cross-sectional study effect, prospective longitudinal studies are more powerful for identifying cohort effects or age effects. In the 40 to 64 year old Iranian population of the five-year cohort study by Hashemi *et al.*, mean CCT was 529.3 μm at baseline which significantly reduced by 1.5 μm to 527.8 μm after 5 years; the proper methodology of the study confirms the role of age on corneal thinning, or in other words, the age-effect (48).

In describing the effect of age on corneal thinning, Battle *et al.*, (49) state that when corneal endothelial cells are lined up next to each other, older age is associated with reduced endothelial cell density, and thus, reduced CCT. The reason behind the gradual loss of endothelial cells is still unclear, and the most likely hypothesis, as proposed by Green, is the dysfunction in hydrogen peroxide metabolizing enzymes and other free radicals in the process of aging (50). On the other hand, contrary to these findings, Ruffer *et al.*, reported a positive relationship between aging and increased corneal thickness in a study of 777 healthy eyes (51). There are also a few studies that reject any correlation

between age and CCT, and state that there is no significant increase or decrease in CCT in relation to age (29,52-54).

Our findings showed that mean CCT is significantly lower by 11 μm in hyperopics and 6.5 μm in myopic cases compared to emmetropic individuals. On the contrary, we found no significant CCT difference between hyperopic and myopic cases, but the literature suggests that the cornea is thinner in myopic people than hyperopics, and the thickness decreases linearly at higher levels of myopia (55). In the study by Pedersen *et al.*, (56), mean CCT was about 11 μm lower in myopics than emmetropic individuals, but the difference was not significant possibly due to low sample size. In the study by Ucakhan *et al.*, (57), there was a significant difference between emmetropes and high myopic cases but not low myopics. In contrast to these findings, mean CCT in myopics was about 13 μm thicker than normal eyes in the study by Wang *et al.*, (58). Given the importance of CCT in performing refractive surgery and the belief that a CCT less than 500 μm will result in serious complications, CCT measurement in various stages of myopia can have a significant impact on decision making about interventions.

In conclusion, the present study is the first to describe the corneal thickness in a sample of over 5-year-old-Iranians and the first to study the distribution of this parameter in the rural population in Iran. Results point to the effect of age, gender, geographic region, as well as the biometric parameters of the cornea and anterior chamber on CCT.

References

1. Hashemi H, Yazdani K, Mehravaran S, KhabazKhoob M, Mohammad K, Parsafar H, et al. Corneal thickness in a population-based, cross-sectional study: The tehran eye study. *Cornea* 2009;28:395-400.
2. Gordon MO, Beiser JA, Brandt JD, Heuer DK, Higginbotham EJ, Johnson CA, et al. The Ocular Hypertension Treatment Study: baseline factors that predict the onset of primary open-angle glaucoma. *Arch Ophthalmol* 2002;120:714-20.
3. Herndon LW, Weizer JS, Stinnett SS. Central corneal thickness as a risk factor for advanced glaucoma damage. *Arch Ophthalmol* 2004;122:17-21.
4. Leske MC, Heijl A, Hyman L, Bengtsson B, Dong L, Yang Z, et al. Predictors of long-term progression in the early manifest glaucoma trial. *Ophthalmology* 2007;114:1965-72.
5. Basic and Clinical Science course, By American

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- Academy of Ophthalmology, 2011-2012. (Accessed May 2018, 15, at <https://store.aao.org/clinical-education/product-line/basic-and-clinical-science-course-bcsc.html>).
- Gordon-Shaag A, Millodot M, Kaiserman I, Sela T, Barnett Itzhaki G, Zerbib Y, et al. Risk factors for keratoconus in Israel: a case-control study. *Ophthalmic Physiol Opt* 2015;35:673-81.
 - Bloom RI, Friedman IB, Chuck RS. Increasing rates of myopia: the long view. *Curr Opin Ophthalmol* 2010;21:247-8.
 - O'Donnell C, Maldonado-Codina C. Agreement and repeatability of central thickness measurement in normal corneas using ultrasound pachymetry and the OCULUS Pentacam. *Cornea* 2005;24:920-4.
 - Hashemi H, Taherzadeh M, Khabazkhoob M. Correction of High Myopia with Foldable Artiflex Phakic Intraocular Lenses: 1 Year Follow-up Results. *Acta Med Iran* 2013;51:620-5.
 - Hashemi H, Asgari S, Mehravaran S, Emamian MH, Shariati M, Fotouhi A. The distribution of corneal thickness in a 40- to 64-year-old population of Shahroud, Iran. *Cornea* 2011;30:1409-13.
 - Linke SJ, Steinberg J, Eddy MT, Richard G, Katz T. Relationship between minimum corneal thickness and refractive state, keratometry, age, sex, and left or right eye in refractive surgery candidates. *J Cataract Refract Surg* 2011;37:2175-80.
 - Nishitsuka K, Kawasaki R, Kanno M, Tanabe Y, Saito K, Honma K, et al. Determinants and risk factors for central corneal thickness in Japanese persons: the Funagata Study. *Ophthalmic Epidemiol* 2011;18:244-9.
 - Su DH, Wong TY, Wong WL, Saw SM, Tan DT, Shen SY, et al. Diabetes, hyperglycemia, and central corneal thickness: the Singapore Malay Eye Study. *Ophthalmology* 2008;115:964-8.
 - Totan Y, Hepsen IF, Cekic O, Gündüz A, Aydin E. Incidence of keratoconus in subjects with vernal keratoconjunctivitis: a videokeratographic study. *Ophthalmology* 2001;108:824-7.
 - Patwardhan AA, Khan M, Mollan SP, Haigh P. The importance of central corneal thickness measurements and decision making in general ophthalmology clinics: a masked observational study. *BMC Ophthalmol* 2008;8:1.
 - Ambrosio RJ, Belin MW. Imaging of the cornea: topography vs tomography. *J Refract Surg* 2010;26:847-49.
 - Chen D, Lam AK. Intrasession and intersession repeatability of the Pentacam system on posterior corneal assessment in the normal human eye. *J Cataract Refract Surg* 2007;33:448-54.
 - Sng C, Barton K, Kim H, Yuan S, Budenz DL. Central Corneal Thickness and its Associations with Ocular and Systemic Factors in an Urban West African Population. *Am J Ophthalmol* 2016;269:268-75.
 - Rufer F, Schroder A, Arvani MK, Erb C. Central and peripheral corneal pachymetry--standard evaluation with the Pentacam system. *Klin Monbl Augenheilkd* 2005;222:117-22.
 - Dohvoma VA, Nchifor A, Ebana Mvogo SR, Koki G, Attha E, Bella A, et al. Central Corneal Thickness in Newly Diagnosed Cameroonian Glaucoma Patients with 'Normal' Intraocular Pressures. *J Ophth Dis* 2015;1:103.
 - Tomidokoro A, Araie M, Iwase A. Corneal thickness and relating factors in a population-based study in Japan: the Tajimi study. *Am J Ophthalmol* 2007;144:152-4.
 - Aghaian E, Choe JE, Lin S, Stamper RL. Central corneal thickness of Caucasians, Chinese, Hispanics, Filipinos, African Americans, and Japanese in a glaucoma clinic. *Ophthalmology* 2004;111:2211-9.
 - Gao X, Gauderman WJ, Liu Y, Marjoram P, Torres M, Haritunians T, et al. A genome-wide association study of central corneal thickness in Latinos. *Invest Ophthalmol Vis Sci* 2013;54:2435-43.
 - 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.
 - Nangia V, Jonas JB, Sinha A, Matin A, Kulkarni M. Central corneal thickness and its association with ocular and general parameters in Indians: the Central India Eye and Medical Study. *Ophthalmology* 2010;117:705-10.
 - Nemesure B, Wu SY, Hennis A, Leske MC; Barbados Eye Study Group. Corneal thickness and intraocular pressure in the Barbados eye studies. *Arch Ophthalmol* 2003;121:240-24.
 - Rashid RF, Farhood QK. Measurement of central corneal thickness by ultrasonic pachymeter and oculus pentacam in patients with well-controlled glaucoma: hospital-based comparative study. *Clin Ophthalmol* 2016;10:359-64.
 - Landers JA, Billing KJ, Mills RA, Henderson TR, Craig JE. Central corneal thickness of indigenous Australians within Central Australia. *Am J Ophthalmol* 2007;143:360-2.
 - Altinok A, Sen E, Yazici A, Aksakal FN, Oncul H, Koklu G. Factors influencing central corneal thickness in a Turkish population. *Curr Eye Res* 2007;32:413-9.
 - Doughty MJ, Laiquzzaman M, Muller A, Oblak E, Button NF. Central corneal thickness in European (white) individuals, especially children and the elderly, and assessment of its possible importance in clinical measures of intra-ocular pressure. *Ophthalmic Physiol Opt*

- 2002;22:491-504.
31. Tayyab A, Masrur A, Afzal F, Iqbal F, Naseem K. Central Corneal Thickness and its Relationship to Intra-Ocular and Epidemiological Determinants. *J Coll Physicians Surg Pak* 2016; 26:494-7.
 32. Kivanc SA, Akova Budak B, Olcaysu OO. Association of Birth Parameters With Corneal Thickness in Prematurely Born and Full-Term School-Aged Children. *Cornea* 2016;35:634-7.
 33. Vijaya L, George R, Baskaran M, Arvind H, Raju P, Ramesh SV, et al. Prevalence of primary open-angle glaucoma in an urban south Indian population and comparison with a rural population. The Chennai Glaucoma Study. *Ophthalmology* 2008;115:648-54.
 34. Lekskul M, Aimpun P, Nawanopparatskul B, Bumrungsawat S, Trakulmungskijkarn T, Charoenvanichvisit J, et al. The correlations between Central Corneal Thickness and age, gender, intraocular pressure and refractive error of aged 12-60 years old in rural Thai community. *J Med Assoc Thai* 2005;88:S175-9.
 35. Pan CW, Li J, Zhong H, Shen W, Niu Z, Yuan Y, et al. Ethnic Variations in Central Corneal Thickness in a Rural Population in China: The Yunnan Minority Eye Studies. *PLoS One* 2015;10:e0135913.
 36. Suzuki S, Suzuki Y, Iwase A, Araie M. Corneal thickness in an ophthalmologically normal Japanese population. *Ophthalmology* 2005;112:1327-36.
 37. Dohadwala AA, Munger R, Damji KF. Positive correlation between Tono-Pen intraocular pressure and central corneal thickness. *Ophthalmology* 1998;105:1849-54.
 38. Nomura H, Ando F, Niino N, Shimokata H, Miyake Y. The relationship between age and intraocular pressure in a Japanese population: the influence of central corneal thickness. *Curr Eye Res* 2002;24:81-5.
 39. Brandt JD, Beiser JA, Kass MA, Gordon MO. Central corneal thickness in the Ocular Hypertension Treatment Study (OHTS). *Ophthalmology* 2001;108:1779-88.
 40. Giuffre G, Di Rosa L, Fiorino F, Bubella DM, Lodato G. Variations in central corneal thickness during the menstrual cycle in women. *Cornea* 2007;26:144-6.
 41. Goldich Y, Barkana Y, Pras E, Fish A, Mandel Y, Hirsh A, et al. Variations in corneal biomechanical parameters and central corneal thickness during the menstrual cycle. *J Cataract Refract Surg* 2011;37:1507-11.
 42. Doughty MJ, Zaman ML. Human corneal thickness and its impact on intraocular pressure measures: a review and meta-analysis approach. *Surv Ophthalmol* 2000;44:367-408.
 43. Hahn S, Azen S, Ying-Lai M, Varma R, Los Angeles Latino Eye Study Group. Central corneal thickness in Latinos. *Invest Ophthalmol Vis Sci* 2003;44:1508-12.
 44. Pfeiffer N, Torri V, Miglior S, Miglior S, Zeyen T, Adamsons I, et al. Central corneal thickness in the European Glaucoma Prevention Study. *Ophthalmology* 2007;114:454-9.
 45. Galguskas S, Juodkaite G, Tutkuviene J. Age-related changes in central corneal thickness in normal eyes among the adult Lithuanian population. *Clin Interv Aging* 2014;9:1145-51.
 46. Foster PJ, Baasanhu J, Alsbirk PH, Munkhbayar D, Uranchimeg D, Johnson GJ. Central corneal thickness and intraocular pressure in a Mongolian population. *Ophthalmology* 1998;105:969-73.
 47. Eballe AO, Koki G, Ellong A, Owono D, Epée E, Bella LA, et al. Central corneal thickness and intraocular pressure in the Cameroonian nonglaucomatous population. *Clin Ophthalmol* 2010;4:717-24.
 48. Hashemi H, Asgari S, Emamian MH, Mehravaran S, Fotouhi A. Five year changes in central and peripheral corneal thickness: The Shahroud Eye Cohort Study. *Cont Lens Anterior Eye* 2016;39:333-5.
 49. Blatt HL, Rao GN, Aquavella JV. Endothelial cell density in relation to morphology. *Invest Ophthalmol Vis Sci* 1979;18:856-9.
 50. Green K. Free radicals and aging of anterior segment tissues of the eye: a hypothesis. *Ophthalmic Res* 1995;27:143-9.
 51. Rufer F, Schroder A, Bader C, Erb C. Age-related changes in central and peripheral corneal thickness: determination of normal values with the Orbscan II topography system. *Cornea* 2007;26:1-5.
 52. Prasad A, Fry K, Hersh PS. Relationship of age and refraction to central corneal thickness. *Cornea* 2011;30:553-5.
 53. Yang Y, Hong J, Deng SX, Xu J. Age-related changes in human corneal epithelial thickness measured with anterior segment optical coherence tomography. *Invest Ophthalmol Vis Sci* 2014;55:5032-8.
 54. Eysteinnsson T, Jonasson F, Sasaki H, Arnarsson A, Sverrisson T, Sasaki K, 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.
 55. Wei W, Fan Z, Wang L, Li Z, Jiao W1, Li Y1. Correlation analysis between central corneal thickness and intraocular pressure in juveniles in Northern China: the Jinan city eye study. *PLoS One* 2014;9:e104842.
 56. Pedersen L, Hjortdal J, Ehlers N. Central corneal thickness in high myopia. *Acta Ophthalmol Scand* 2005;83:539-42.

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57. Ucakhan OO, Gesoglu P, Ozkan M, Kanpolat A. Corneal elevation and thickness in relation to the refractive status measured with the Pentacam Scheimpflug system. *J Cataract Refract Surg* 2008;34:1900-5.
58. Wang X, Dong J, Wu Q. Corneal thickness, epithelial thickness and axial length differences in normal and high myopia. *BMC Ophthalmol* 2015;15:49.