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A review of corneal diameter, curvature and thickness values and influencing factors*

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Abstract

The cornea is an important ocular structure involved in the mediation of visual perception. It is the principal refractive surface of the eye and vision can be significantly affected by relatively small changes in its structure and parameters. Measurement of corneal parameters is important in the diagnosis and management of ocular diseases such as keratoconus and glaucoma, and also in the fitting of contact lenses or with refractive surgery such as Laser-Assisted in situ Keratomileusis (LASIK) and photorefractive keratectomy (PRK). The human corneal diameter, anterior curvature and centre thickness as well as factors influencing them are reviewed in this article. This review will be useful to eye care professionals who routinely measure these parameters when fitting contact lenses and assessing, diagnosing as well as managing corneal and other ocular conditions. (S Afr Optom 2013 **72**(4) 185-194)

Key words: Corneal parameters, corneal diameter, anterior corneal curvature, central corneal thickness

Introduction

Until recently, the cornea has been known to be composed of five layers; which from the anterior to posterior are the epithelium, Bowman's layer, stroma, Descemet's membrane and the endothelium[1]. A sixth layer called the Dua's layer, composed predominantly of type-1 collagen bundles, has recently been discovered and is located between the stroma and Descemet's membrane[2]. Including the tear film, the cornea is the first structure that light passes through, and these layers behave as converging lenses that direct incident light rays towards the pupil[1]. The cornea is the most significant refractive structure of the eye, contributing approximately two-thirds of the eye's refractive power[1]. Corneal refractive power is attributable[1] to its shape and the relatively large difference between its refractive index (1.376) and that of air (1).

Measurements of corneal parameters in their entirety are important for both diagnostic and therapeutic purposes. Many ocular pathological conditions such as keratoconus, glaucoma and ocular manifestations of diabetes mellitus cause changes in corneal architecture, leading to poor visual outcomes[3]. Abnormally small or large corneal diameters are used to diagnose microcornea and megalocornea respectively. Microcornea refers to a small corneal diameter, and may be unilateral or bilateral and is usually associated with other ocular abnormalities such as optic nerve hypoplasia, scleroderma, cataract formation, iris abnormalities and secondary angle-closure glaucoma[4]. In megalocornea, the cornea is abnormally large, and is usually associated with myopia, astigmatism, cataracts and, later on in life, lens dislocation and glaucoma[4]. Smaller diameters are found in Fuchs and macular corneal dystrophies, whereas diameters are larger in keratoconus and lattice

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and granular dystrophies[5]. A cornea that is too curved (radii are abnormally small) is found in keratoconus and a cornea that is too flat is found in conditions such as cornea plana, which is a rare bilateral condition associated with severe refractive errors, cataracts and coloboma[6]. Also, a thin cornea leads to underestimation of the intraocular pressure (IOP) whereas a thick cornea results in overestimation[3]. Due to the relationship between central corneal thickness (CCT) and IOP, low CCT values may lead to a delay in the diagnosis and treatment of glaucoma[3] which may in turn lead to visual impairment and blindness.

Considering the improvement in the technology for measuring ocular parameters and the surge in interest in corneal measurement in recent years, the author wishes to review the ocular parameters as presented here. Therefore the aim of this paper is to review three corneal parameters that are commonly measured by eye care practitioners, namely diameter, anterior curvature and centre thickness. Included also are the clinical importance of each parameter, methods of measurement, biometric values and factors influencing the values.

Corneal parameters

Corneal diameter

The corneal diameter (CD) is the limbus-to-limbus distance and clinically both the horizontal and vertical dimensions are regarded as important. The horizontal corneal diameter (horizontal visible iris diameter, HVID) is the distance between the nasal and temporal imaginary limbal tangents to the corneal circumference, HVID includes the centre of the pupil, as does the vertical visible iris diameter, VVID[7]. The corneal diameter is clinically important for many reasons. For example, it is important in ensuring that a soft lens total diameter is sufficient to maintain full corneal coverage[8]. Also, the accurate measurements of CD might be a useful approximation for sizing and producing anterior chamber intraocular lenses[9, 10]. Further, CD measurement is important in the accurate diagnosis of diseases such as microcornea, megalocornea, relative microphthalmos, and corneal dystrophies[11].

Routinely, in optometric practice, CD is often measured with a hand-held millimeter ruler, a ruler combined with a magnifier or use of the slit-lamp graticule[11]. But CD can be more accurately measured with the instruments such as an autorefractometer (for example, the Canon Autoref R-1), corneal topographers such as the Orbscan II system and via optical coherence tomograph[12].

The horizontal diameter of the cornea on average is 10 mm in infants and 11 mm in adults while the vertical diameter is usually 11 mm in infants and 12 mm in adults[11, 13]. From the literature, normative values for corneal diameters are shown in Table 1.

Anterior corneal curvature

The anterior corneal curvature (ACC) relates to the shape of the front surface of the cornea and is one of the important measurements used to characterize optical properties of the cornea[4]. In clinical practice, both horizontal and vertical anterior corneal curvatures are usually measured. The average cornea has a smaller radius in the vertical meridian compared to the horizontal meridian, which contributes to higher incidence of with-the-rule astigmatism in young adults[1]. Anterior curvature expressed in radii (typically millimeters) is important for contact lens fitting and management[8], ocular aberration analysis, corneal refractive surgery as well as diagnoses and management of corneal pathological conditions such as keratoconus[22].

Measurement of ACC can be made with a variety of instruments, such as a keratometer, IOLMaster, or corneal topographer[5, 6]. Although the keratometer provides a reliable and accurate assessment of the ACC, the instrument measures the corneal curvature based on an approximate central area of 3.2 mm of its surface. Also, the calculation of corneal radius assumes the cornea to be a sphere with a refractive index of 1.3375, which is not true[1, 4]. According to Veys *et al*[8], the variations in curvature across the surface of the cornea can be quantified by calculating the shape factor at different points across its surface. The shape factor can be described in terms of eccentricity (e), where shape factor (p) = $1 - e^2$. The shape factor varies between 0 and 1, where 1 is a perfect sphere. Techniques such as keratoscopy provide a measurement of shape factor, so the change in contour across the whole cornea can be assessed more comprehensively[8]. Table 2 below shows the range of ACC in normal populations.

Table 1: The range of normal CD in the human population as found in the literature. HVID = horizontal visible iris diameter, VVID = vertical visible iris diameter, M = male, F = female, ID = indirect caliper, OCT = ocular coherence tomography, CT = corneal topography, SSCT = scanning-slit corneal topography and NR = not reported.

Author/s	**Race/ Ethnicity**	**Method**	**No of Eyes**	**Age (years)**	**Gender**	**HVID (mm) Range**	**Mean±SD**	**VVID (mm) Range**	**Mean±SD**
Ganguli *et al*[14] (1975)	Indians	PD ruler	100	5-53	M F	NR	11.45 11.20	NR	10.86 10.67
Baumeister *et al*[15] (2004)	Caucasians	Caliper IOLMaster Orbscan Holladay-Godwin gauge	100 100 100 100 100	NR	NR	NR	11.91±0.71 12.02±0.38 11.78±0.43 11.8±0.60	NR	NR
Rufer *et al*[11] (2005)	Caucasians	Orbscan	743	10-80	M&F	10.7-12.58	11.71±0.42	NR	NR
Ashaye *et al*[9] (2006)	Africans (Nigerians)	ID	684	0-0.65	M&F	9-12.5	10.26±0.59	NR	NR
Kohnen *et al*[16] (2006)	Caucasians	IOLMaster Orbscan	52	NR	M&F	NR	12.17±0.45 11.84±0.41	NR	NR
Pinero *et al*[12] (2008)	Caucasians	OCT CT	30 30	20-51	M&F	10.03-12.92 11.34-13.16	11.76±0.52 12.25±0.49	NR	NR
Salouti *et al*[17] (2009)	Iranians	Galilei EyeSys Orbscan	74 74 74	27.4±7.2	M&F	10.37-13.72 10.7-14.59 11.1-12.5	12.01±0.61 12.09±0.87 11.67±0.29	NR	NR
Venkataraman *et al*[18] (2010)	Indians	Orbscan Eyemetrics	73 73	NR	M&F	NR	11.74±0.32 11.92±0.33	NR	NR
Hashemi *et al*[13] (2010)	Iranians	Orbscan	800	14 & >	M&F	10.76-12.6	11.68	NR	NR
Dinc *et al*[19] (2010)	Turks	IOLMaster Orbscan	80 80	 NR	M&F	NR	11.87±0.35 11.65±0.32	NR	NR
Iyamu & Osuobeni[7] (2012)	Africans (Nigerians)	Ruler	130	20-79	M&F	10-12	11.39±0.69	10-11	10.5±0.5
Sanchis-Gimeno *et al*[20] (2012)	Caucasians	SSCT	198 181 379	18-53	M F M&F	11.6-12.2 11.5-12.3 11.5-12.3	11.9±0.2 11.8±0.2 11.9±0.2	NR	NR
Zha *et al*[21] (2013)	Chinese	Orbscan	129	NR	M&F	10.5-12.4	10.57±0.34	NR	NR

Table 2: The studies of ACC of the normal human population are indicated. HK = horizontal corneal curvature, VK = vertical corneal curvature, AVK = average corneal curvature, M = male, F = female, KT = keratometer, PEK = photo electronic keratoscope, TMS-1 = topographic modeling system and NR = not reported.

Author/s	Race/ ethnicity	Method	No of Eyes	Age (years)	Gender	HK (mm) Range	Mean±SD	VK (mm) Range	Mean±SD	AVK
Ganguli *et al*[14] (1975)	Indians	KT	100	5-53	M F	NR	NR	NR	NR	7.75 7.65
Kiely *et al*[23] (1984)	Caucasians	PEK	196	21-40	M	7.10-8.75	7.79±0.26	7.06-8.66	7.69±0.28	NR
Fledelius & Stubgaard[24] (1986)	Caucasians	KT	454	5-80	M F	NR	NR	NR	NR	7.93 7.75
Guillon *et al*[25] (1986)	Caucasians	PEK	220	NR	M&F	7.14-8.54	7.87±0.25	7.03-8.46	7.7±0.27	NR
Dunne *et al*[26] (1991)	Caucasians	KT	60	19-25	M&F	NR	7.92±0.03	NR	7.81±0.03	NR
Lam & Loran[27] (1991)	Caucasians Chinese	PEK PEK	63 64	18-28 18-28	M M	7.10-8.36 7.21-8.31	7.98±0.21 7.47±0.24	7.29-8.43 7.46-8.48	8.03±0.20 7.9±0.23	NR
Lam & Douthwaite[28] (1996)	Chinese	KT	24	19-25	M&F	NR	7.87±0.26	NR	7.66±0.29	NR
Cheung *et al*[29] (2000)	Chinese	TMS-1	63	18-37	M&F	NR	7.82±0.26	NR	7.64±0.26	NR
Iyamu & Eze[30] (2011)	Africans (Nigerians)	KT	95	20-69	M&F	7.42-8.38	7.87±0.4	7.34-8.48	7.81±0.36	7.85±0.35

Central corneal thickness

Central corneal thickness (CCT) and its measurement are important in many eye care procedures, such as tonometry and refractive surgery[31]. Several studies[32-34] have shown that CCT significantly influences the measured IOP and consequently, the classification and management of glaucoma. Thinner than average corneas may result in underestimation of the true IOP, while thicker than average corneas may result in overestimation of IOP[3]. However, this factor alone is insufficient when explaining the increased susceptibility to glaucoma found in those with thinner corneas[3]. The detection and management of contact lens related complications and certain surgical procedures (such as astigmatic keratectomy, LASIK, PRK and Intacs placement) rely on the accurate measurement of CCT[35].

Corneal pachymetry is the process of measuring the thickness of the cornea and can be done using contact methods such as ultrasound and confocal microscopy or non-contact methods such as optical biometry with a single Scheimpflug camera (such as the Oculus Pentacam or Sirius), Dual Scheimpflug (for example, Galilei), coherence tomography (Visante, iVue or others), optical coherence pachymetry (with Orbscan)[35]. Average normal values for the human CCT as measured with different methods of pachymetry are shown in Table 3.

Table 3: Summary of CCT studies conducted on different ethnic groups. UP = ultrasonic pachymetry, UPS = ultrasound pachymetry, TP = tono-pachymeter, M = male, F = female and NR = not reported.

Author/s	Race/ethnicity	Method	No of Eyes	Mean age (years)	Gender	CCT (µm)
La Rosa *et al*[36]	Caucasians	UP	51	65.2±10.3	NR	555.90±33.2
(2001)	African-Americans	UP	26	63.1±11.8	NR	533.80±33.9
Wong *et al*[37]	Hong Kong Chinese	UP	17	65.5±11.8	M	554±32.5
(2002)			22		F	560±34.6
Shimmyo *et al*[38]	African-Americans	UPS	118	37.2±9.78	M&F	535.46±33.4
(2003)	Asians		172	34.84±7.3	M&F	549.79±32.3
	Caucasians		1482	38.1±9.86	M&F	552.59±34.5
	Hispanics		204	34.21±9.4	M&F	551.1±35.54
Hahn *et al*[39]	Latinos	UP	1578	NR	M&F	546.5
(2003)			634		M	549.3
			944		F	544.7
Aghaian *et al*[40]	African-Americans	UP	26	NR	M&F	524.8±38.4
(2004)	Caucasians		36		M&F	562.8±31.1
	Chinese		41		M&F	569.5±31.8
	Filipinos		33		M&F	559±24.9
	Hispanics		27		M&F	563.6±29.1
	Japanese		38		M&F	538.5±29.6
Altinok *et al*[41]	Turks	UPS	276	44.1±16.6	M	552.2±35.9
(2007)			349	41±16.9	F	552.3±35.4
Durkin *et al*[34]	Australians	UPS	80	44.8±14.5	M	515.8±26
(2007)	Aboriginal		109		F	514.4±33.6
	Caucasians		51	47.2±14.8	M	542.6±31
			64		F	546.3±32.7
Landers *et al*[33]	Australians	UPS	26	51.14±14	M+F	508±33
(2007)	Aboriginal		65			
	Caucasians		38	56±15	M+F	541±31
			46			
Mercieca *et al*[32]	Africans	UPS	34	63.1±11.20	M&F	535±38
(2007)	(Nigerians)				M	541±47
					F	522±22
Iyamu & Memeh[42]	Africans	UPS	39	45.2±15.4	M	561.8±44.9
(2007)	(Nigerians)					541.5±31.1
Iyamu & Ituah[43]	Africans	UPS	24	46.0±11.0	M	556.4±48.8
(2008)	(Nigerians)		25		F	543.2±36.6
Casson *et al*[44]	Burmese	UP	1909	56.2±11.5	M&F	521.9±33.3
(2008)			756	NR	M	522±32.8
			1153	NR	F	521.9±33.2
Babalola *et al*[45]	Africans	UPS	88	64±13.8	NR	537.9±38.4
(2009)	(Nigerians)					
Mohammed *et al*[46]	Sudanese		94	NR	M&F	530.15±58.10
(2009)						
Eballe *et al*[47]	Africans	UPS	485	31.4±15.5	M&F	529.29±35.9
(2010)	(Cameroonians)		163	32.8±16.1	M	530.52±34.97
			322	30.6±15.1	F	528.67±36.40
Iyamu & Eze[30]	Africans	UPS	95	47.1±14.1	M	552±36.4
(2011)	(Nigerians)				F	544.5±28.8
					M&F	550.1±33.1
Iyamu & Osuobeni[7]	Africans	UPS	77	48.22±17.24	M	551±37.2
(2012)	(Nigerians)		53	47.15±16.37	F	546.06±29.62
			80	47.8±16.8	M&F	548.97±34.28
Sardiwalla *et al*[48]	South African	TP	100	20.1±1.6	M&F	512.4±38.9
(2012)	Blacks &		100		M&F	526.5±37.2
	Indians					

Factors influencing corneal parameters

Several factors influence the values of the corneal parameters as discussed above. These factors include age, gender, race and ethnicity, axial length and refractive status of the eye as well as certain anthropometric factors.

Age

Iyamu and Osuobeni[7] found that the vertical corneal diameter of the younger age groups 20-40 years was significantly higher ($p = 0.01$) than for the oldest age group (70-79 years). The authors[7] suggested that this could be due to the smaller average height of the older group. Similarly, the horizontal corneal diameter was significantly different between age groups ($p = 0.03$). Rufer *et al*[11] found that corneal diameter measured with the Orbscan II decreased slightly with age. The decrease in corneal diameter with age together with age-related narrowing of the anterior chamber might have implications such as increasing glaucoma due to compacting of tissue in the angle or changes in the corneal architecture[11].

Zadnik *et al*[49] and Mohd-Ali *et al*[50] reported that the corneal curvature becomes steeper with increasing age and Hayashi *et al*[51] suggested that this could be due to some physiological changes that alter the elasticity of the cornea thus causing it to become steeper with age.

Several authors[32, 39, 40] have reported a significant reduction of CCT with age. Hahn *et al*[39] suggested that the decrease in density of keratocytes with age is responsible for the reduction of CCT values with age.

Gender

Iyamu and Osuobeni[7] found that males had significantly wider horizontal corneal diameters than their female counterparts in 130 healthy Nigerians with a mean age of 47.8 ± 16.8 years. The authors[7] concluded that this finding may be explained by the fact that men are generally taller and have correspondingly larger eyes than women. This is similar to the conclusion drawn by Quant *et al*[52], Goh and Lam[53] and Wong *et al*[54] who also found that males had significantly wider horizontal corneal diameters than females.

Mohd-Ali *et al*[50] and Matsuda *et al*[55] reported that females had significantly steeper average corneal curvature than males ($p < 0.001$). Also, several studies[56-60] have shown the tendency for females to have steeper corneas than males due to their shorter axial length. Goh and Lam[53] found that Hong Kong Chinese men aged 19-39 years had flatter corneal curvature than women of a similar age range in the same study. This trend was also observed by Lam *et al*[56] in subjects aged 40 years and older. These differences could be due to various factors such as physiological changes due to menstruation in females and refractive errors such as higher degree of myopia in females resulting in steeper corneas[27].

Several studies[32-34, 38-40, 61] have reported that gender influences CCT values. Shimmyo *et al*[38], Hahn *et al*[39] and Garcia-Medina *et al*[61] reported that males had thicker corneas than females. Hahn *et al*[39] found that the difference in CCT between the genders was only 4.6 µm, which is less than the mean interocular difference in CCT (7.7 µm) for their normal subjects. Therefore, they concluded that the difference between men and women CCT was statistically but not clinically significant. Other authors[34, 40] found that gender had no significant effect on CCT.

Race and ethnicity

Matsuda *et al*[55] measured the HVID among 125 Asian and 81 Caucasian eyes of different ages. The values varied significantly between Caucasians and Asians, with Asians having smaller values. The authors[55] suggested that these findings may be due to Asians being smaller in overall height in average than Caucasians and concluded that these may assist contact lens practitioners when choosing lens parameters and may guide contact lens manufacturers in setting parameters for lenses targeted to specific ethnic/population groups.

Lam and Loran[27] reported that the corneal curvature of Chinese subjects was significantly steeper compared to British subjects of the same age, gender and refractive error. The authors[27] suggested that this could be due to anatomical differences between the two races. In contrast, Shimmyo *et al*[38] compared corneal curvature measurements of Caucasians, Hispanics, Asians and African Americans and found no significant differences between the races studied. The difference between these results could have been influenced by the fact that in Shimmyo *et al*[38], the number of subjects in each category varied, with the largest number of subjects being Caucasians.

Studies[38, 39] have reported differences in CCT between different racial and ethnic groups. Shimmyo *et al*[38] showed that African Americans and other populations of African descent have thinner CCT than other races. Sardiwalla *et al*[48] compared CCT values of 100 Black and 100 Indian students from the University of KwaZulu-Natal, South Africa and found smaller values than those reported in other Black[38, 47] and Asian[62, 63] populations. The authors[48] suggested that this may result in a delayed diagnosis of glaucoma because of low IOP values expected in these ethnic groups in South Africa.

Axial length

Eyes with longer axial lengths have been reported to be associated with wider corneal diameters[64]. Lam *et al*[56] and Osuobeni[58] found a positive correlation between corneal radius of curvature and axial length. Chen *et al*[65] have shown that eyes with longer axial lengths tended to have flatter corneas ($r = -0.502$, $p < 0.001$) and Chang *et al*[66] reported that longer eyes are associated with thinner CCT.

Refractive status

Zha *et al*[21] assessed corneal diameters of 231 myopic eyes and 129 emmetropic eyes with the Orbscan II topography system. Eyes were divided into four groups as follows: Group 1: the emmetropic group with spherical equivalents (SE) between −0.50 and 0.50 D; Group 2 low myopia with SE between −0.50 and −3 D; Group 3: median myopic group, SE between −3 and −6 D and Group 4: high myopia group with SE −6 D and higher. The results showed that eyes with myopia of −3 D and higher had lower corneal diameter values.

Goh and Lam[53] and Lam *et al*[56] reported that the average radius of curvature did not vary significantly with the refractive status; however, myopes tended to have steeper corneas, followed by the emmetropes and lastly, the hyperopes. A subsequent study by Osuobeni[58] found similar results. Scott and Grosvenor[67] have explained this apparent contradiction by indicating that myopic eyes, which are long, have steeper or shorter radius of curvature because, together with an increase in axial length, corneal steepening also occurs during the development of myopia.

Mohammed *et al*[46] found that CCT correlates with refractive error, and myopes have the thinnest CCT (449.65 ± 39.27 μm), followed by emmetropes (542.66 ± 46.35 μm) and hyperopes (557.67 ± 41.83 μm). This is consistent with the findings of Nemesure *et al*[68] who found that CCT was directly related to refractive error. Price *et al*[69] suggested that thin CCT associated with myopic eyes may help explain their increased susceptibility to glaucoma.

Anthropometric factors

Iyamu and Osuobeni[7] have suggested that smaller corneal diameter may be associated with smaller average height. Eysteinsson *et al*[70] examined the relationship between adult stature, age and ocular dimensions in the largely homogenous white population of Reykjavik in Iceland. It was found that height was positively correlated with the radius of corneal curvature (95% CI 0.004-0.011 m, $p < 0.001$). Nangia *et al*[71] investigated associations between anthropometric parameters and ocular dimensions in a typical rural society untouched by the effects of urbanization in central India and found that after adjusting for age, gender, level of education and body mass index (BMI), taller subjects had larger eyes with flatter corneas. The authors[71] concluded that since the occurrence of some ocular diseases depends on eye size and refractive error, the results may be helpful for screening examinations and for elucidating pathogenic associations. Galgauskas *et al*[72] evaluated CCT of 518 eyes of a normal Lithuanian population to describe the relationship between CCT and anthropometric factors which included height and weight and the results showed that CCT correlated with height ($r = 0.108$, $p = 0.00$).

Inter-parameter relationships (CCT and corneal curvature)

Sawada *et al*[73] reported a positive correlation between CCT and corneal curvature in Japanese subjects ($N = 3021$) aged 40 years or older. However, Chen *et al*[65] found no significant correlations ($r = 0.013$, $p = 0.770$) between the two parameters in 500 normal Taiwanese Chinese adults, aged 40-80 years. Recently, Iyamu and Eze[30] investigated the relationship between CCT and corneal curvature in 95 Nigerian adults (56 males and 39 females) aged between 20 and 69 years (the mean and standard deviation were

47.1 ± 14.1 years). No significant association was found between CCT and corneal curvature ($r = 0.18$, $p = 0.07$). The authors did not provide an explanation for their findings.

Conclusion

Corneal parameters such as CD, ACC and CCT provide information about the healthy cornea and possible changes associated with ocular diseases or other factors such as ageing gender, ethnicity, *et cetera*. Normal values for CD in adults range from 10.50 to 12.75 mm, the ACC ranges from 7.06 to 8.66 mm and CCT ranges from 512 to 569.5 µm. These corneal parameters vary with age, gender, ethnicity, refractive state, stature and anthropometric factors. Such relationships may be important for early and accurate diagnosis of corneal diseases and glaucoma, and may also provide insight into disease mechanisms and processes.

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