Original Article

Corneal asphericity and its related factors

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ABSTRACT

Background: Proper correction of spherical aberration using intraocular lenses requires precise selection of the sphericity of intraocular lens surfaces based on individual biometric data and corneal asphericity coefficient (Q value). This study aimed to determine and analyze the corneal Q value and its related factors among Saudi participants.

Methods: In this cross-sectional study, normal right eyes of healthy Saudi participants aged 17 – 58 years who visited Al-Kahhal Medical Complex, Dammam, Saudi Arabia, were included. The Pentacam rotating Scheimpflug camera was used to determine the average Q value at 6-mm diameter. Q values were obtained from each quadrant (superior, nasal, inferior, and temporal) and two meridians (horizontal and vertical). Mean Q values of the anterior and posterior corneal surfaces were also obtained. Other factors including age, sex, refractive error, and central corneal radius were documented.

Results: Five hundred right eyes from 500 participants were included. The mean (standard deviation [SD]) (range) age was 27.2 (7.1) (18 – 58) years. The mean (SD) (range) Q value of 500 eyes was - 0.24 (0.10) (- 0.71 to + 0.09) anteriorly and - 0.16 (0.14) (- 0.70 to + 0.23) posteriorly, being significantly more prolate anteriorly ($P < 0.05$). The corneas were significantly more prolate in the nasal than in the temporal quadrant, in the superior than in the inferior quadrant, and in the horizontal than in the vertical meridian (all $P < 0.05$). There were statistically significant differences in anterior, nasal, temporal, inferior, horizontal, and vertical Q values among age groups (all $P < 0.05$) but not in the superior or posterior Q values (both $P > 0.05$). The corneas became less prolate with increasing age ($P < 0.05$). However, Q values were comparable between the sexes (all $P > 0.05$). There was no significant correlation between anterior ($r = +0.08$; $P = 0.095$) or posterior ($r = -0.08$; $P = 0.092$) Q value and spherical equivalent, but a significant trend was detected toward more prolate shape with increasing myopia in the temporal and inferior quadrants ($r = +0.19$; $P < 0.001$, $r = +0.10$; $P = 0.022$, respectively). There was a significant negligible correlation between the posterior Q value and central corneal radius ($r = -0.18$; $P < 0.001$) but no significant correlation between the anterior Q value and central corneal radius ($r = +0.02$; $P = 0.673$).

Conclusions: Most corneas in this Saudi population were prolate in contour. Anterior corneal asphericity was positively correlated with age and was not significantly related to sex, refractive error, or central corneal radius. Further studies are needed to verify our preliminary findings.

KEYWORDS

corneas, asphericity, Q value, Pentacam, reference value, refractive surgery

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INTRODUCTION

The cornea is the primary source of refraction in the human eye, contributing more than two-thirds of the total refractive power [1]. It is not perfectly spherical but rather conicoid in shape [2]. The physiological corneal asphericity coordinates with other optical components to help establish a natural aberration balance, minimize the spherical aberration, and maintain good quality of vision [3, 4].

Technological advances in corneal topography have provided more precise graphical and numerical depictions of the corneal shape [5]. The corneal asphericity coefficient (Q value) describes the rate of radial curvature variation of the corneal quadric surface from its center to the periphery. It is a quantitative topographic indicator of the degree of corneal asphericity, describing the corneal shape and its optical properties [4, 6]. In most cases, corneal asphericity is represented by a prolate ellipse, flattening from the corneal apex to the periphery [3]. A Q value < 0 is considered prolate and a value > 0 is oblate [5]. The relative corneal asphericity has implications for contact lens fitting, calculation of intraocular lens power, and refractive surgery [7].

Conventional refractive surgery can induce lower and higher ocular aberrations, such as spherical aberration and coma, by disturbing the physiological prolate surface of the cornea. This may influence the patient's visual function when measured as contrast sensitivity and low luminance visual acuity [3]. Minor variations in the corneal surface from conventional refractive surgery may decrease the image quality in the affected eye. Thus, customized corneal ablation surgery is often recommended [3]. Different target Q values are preoperatively set by refractive surgeons, at their own discretion, because a standardized target Q value is yet to be established [3]. Proper correction of spherical aberration using intraocular lenses requires the selection of lens surfaces with precise sphericity based on biometric data and individual corneal Q values [1].

In the last two decades, various related studies have been conducted worldwide [1, 3, 7-10]. Although one study reported corneal asphericity and other corneal topographic parameters in children from Saudi Arabia with autism spectrum disorder and typical development [11], and another reported corneal asphericity and other corneal parameters in randomly selected participants of Saudi Arabian ethnicity [12], we found no studies concerning Q value-related factors in this population. Therefore, we aimed to determine and analyze corneal asphericity and its related factors, including age, sex, spherical equivalent (SE), and central corneal radius in the Saudi population.

METHODS

This cross-sectional study recruited healthy Saudi individuals aged 18 – 58 years undergoing routine outpatient or preoperative examinations for refractive surgery from October 2019 to January 2021 at Al-Kahhal Medical Complex, Dammam, Saudi Arabia. The study adhered to the tenets of the Declaration of Helsinki and was approved at the departmental level; consent was obtained from all participants.

Excluded participants were those with a history of ocular surgery or systemic comorbidities; current contact lens users; those with concurrent corneal opacities, pterygium, strabismus, dry eye disease, keratoconus, corneal dystrophy, or ptosis; those with erroneous Pentacam data; and pregnant or lactating women.

Demographic data of participants were recorded, and all underwent the following clinical examinations: manifest refraction tested using an auto-refractometer (Autorefractor Keratometer KR-8900; Topcon Co., Tokyo, Japan) and subjectively refined to determine spherical and cylindrical components of refraction and SE, calculated as sphere + half cylinder; best-corrected distance visual acuity (BCDVA) measured using a Snellen chart (Auto Chart Projector, CP 670; Nidek Co., Ltd., Gamagori, Japan) in decimal values and converted to logarithm of the minimum angle of resolution (logMAR) units for further analyses; detailed anterior and posterior segment examinations using slit-lamp biomicroscopy (Photo-Slit Lamp BX 900; Haag-Streit, Koeniz, Switzerland); and intraocular pressure measurements using Goldmann applanation tonometry (AT900; Haag-Streit).

The Pentacam HR (Oculus, Wetzlar, Germany) [7] was used to measure the average Q value and central corneal radius. Mean Q values of the anterior and posterior corneal surfaces were also obtained. Q values along a 6-mm-diameter circle from the corneal center were obtained from each quadrant (superior, inferior, nasal, and temporal) and two meridians (horizontal and vertical) [7]. In addition, mean Q values of the anterior and posterior corneal surfaces were obtained.

For the purpose of analysis, the patients were allocated to age groups with 10-year intervals as ≤ 19 years, 20 – 29 years, 30 – 39 years, 40 – 49 years, and ≥ 50 years [3]. Likewise, refractive errors were categorized based on the magnitude of SE [7] as follows: high hyperopia (SE ≥ + 4 diopters [D]), moderate hyperopia (+ 4 D > SE ≥ + 2 D), low hyperopia (+ 2 D > SE > + 0.25 D), emmetropia (+ 0.25 D ≥ SE ≥ - 0.25 D), low myopia (- 0.25 D > SE > - 3 D), moderate myopia (- 3 D ≥ SE > - 6 D), and high myopia (SE ≤ - 6 D).

Statistical analysis was performed using the Statistical Package for the Social Sciences software (version 22; SPSS Inc., IBM Corp., Armonk, NY, USA). Normality of the data distribution was assessed using the Kolmogorov – Smirnov test. Because we observed no statistical difference in Q values between the left and right eyes, data from the right eyes were analyzed ($P > 0.05$ using the paired *t*-test). Descriptive statistics were used to calculate mean and standard deviation (SD) per age, sex, and refractive error group. The Kruskal – Wallis H-test, Mann – Whitney U-test, Wilcoxon signed-rank test, or Spearman's rank correlation was used for analysis when applicable. A *P*-value < 0.05 was considered to indicate statistical significance.

RESULTS

Five hundred right eyes from 500 participants (209 [41.8%] men and 291 [58.2%] women) were included. The mean (SD) (range) age was 27.2 (7.1) (18 – 58) years. The mean (SD) BCDVA was 0.0 (0.06) logMAR.

The mean (SD) (range) anterior Q value was - 0.24 (0.10) (- 0.71 to + 0.09), with only two eyes with positive Q values, and the mean posterior Q value was - 0.16 (0.14) (- 0.70 to + 0.23), with 55 eyes having positive Q values. The anterior surface was significantly more prolate ($P < 0.001$) than was the posterior surface.

The mean (SD) (range) Q value was - 0.33 (0.15) (- 0.90 to + 0.40) nasally and - 0.17 (0.08) (- 0.52 to + 0.42) temporally; the nasal quadrant was significantly more prolate ($P < 0.001$). The mean (SD) (range) Q value was - 0.24 (0.18) (- 1.10 to + 0.48) superiorly and - 0.22 (0.15) (- 0.94 to + 0.25) inferiorly; the superior quadrant was significantly more prolate ($P = 0.017$). The mean (SD) (range) Q value was - 0.25 (0.09) (- 0.63 to + 0.30) horizontally and - 0.23 (0.13) (- 0.90 to + 0.12) vertically; the horizontal meridian was significantly more prolate ($P < 0.001$).

Table 1. Corneal asphericity data per age group

Age group (y)	Q value, Mean ± SD							
	Anterior Surface	Posterior Surface	Nasal Quadrant	Temporal Quadrant	Superior Quadrant	Inferior Quadrant	Horizontal Meridian	Vertical Meridian
≤ 19 (n = 50)	- 0.27 ± 0.09	- 0.18 ± 0.14	- 0.36 ± 0.19	- 0.18 ± 0.07	- 0.25 ± 0.18	- 0.26 ± 0.11	- 0.28 ± 0.09	- 0.25 ± 0.12
20 – 29 (n = 301)	- 0.25 ± 0.09	- 0.16 ± 0.13	- 0.34 ± 0.13	- 0.17 ± 0.08	- 0.25 ± 0.18	- 0.23 ± 0.15	- 0.25 ± 0.09	- 0.24 ± 0.13
30 – 39 (n = 115)	- 0.23 ± 0.10	- 0.15 ± 0.14	- 0.33 ± 0.15	- 0.16 ± 0.08	- 0.21 ± 0.18	- 0.21 ± 0.16	- 0.24 ± 0.09	- 0.21 ± 0.14
40 – 49 (n = 31)	- 0.19 ± 0.12	- 0.18 ± 0.17	- 0.29 ± 0.18	- 0.15 ± 0.11	- 0.21 ± 0.23	- 0.13 ± 0.14	- 0.22 ± 0.12	- 0.17 ± 0.14
≥ 50 (n = 3)	- 0.16 ± 0.13	- 0.15 ± 0.27	- 0.21 ± 0.15	- 0.09 ± 0.08	- 0.17 ± 0.09	- 0.17 ± 0.32	- 0.15 ± 0.08	- 0.17 ± 0.20
***P*-value**	**0.003**	0.371	**0.041**	**0.031**	0.154	**0.001**	**0.002**	**0.011**

Abbreviations: Q value, corneal asphericity; SD, standard deviation; y, years; n, number of eyes in each age group. Note: *P*-values < 0.05 are shown in bold.

Table 2. Pairwise comparisons of corneal asphericity between age groups using post-hoc Tukey's test

Q value	*P*-value for pair-wise comparison									
	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	P_{10}
Anterior Surface	0.699	0.151	**0.014**	0.400	0.411	**0.042**	0.588	0.452	0.794	0.984
Posterior Surface	0.647	0.503	> 0.99	0.991	0.982	0.815	> 0.99	0.686	> 0.99	0.992
Nasal Quadrant	0.908	0.702	0.191	0.423	0.939	0.302	0.542	0.639	0.643	0.908
Temporal Quadrant	0.921	0.396	0.551	0.400	0.519	0.770	0.510	0.999	0.706	0.778
Inferior Quadrant	0.519	0.266	**0.001**	0.842	0.892	**0.005**	0.968	**0.047**	0.990	0.990
Superior Quadrant	> 0.99	0.666	0.859	0.945	0.393	0.843	0.954	> 0.99	0.996	0.996
Horizontal Meridian	0.337	0.116	**0.028**	0.141	0.799	0.241	0.328	0.684	0.460	0.771
Vertical Meridian	0.946	0.391	0.051	0.852	0.433	0.055	0.920	0.499	0.986	> 0.99

Note: *P*-values < 0.05 are shown in bold; P_1, *P*-value for the comparison between ≤ 19- and 20 – 29-year age group; P_2, *P*-value for the comparison between ≤ 19- and 30 – 39-year age group; P_3, *P*-value for the comparison between ≤ 19- and 40 – 49-year age group; P_4, *P*-value for the comparison between ≤ 19- and > 50-year age group; P_5, *P*-value for the comparison between 20 – 29- and 30 – 39-year age group; P_6, *P*-value for the comparison between 20 – 29- and 40 – 49-year age group; P_7, *P*-value for the comparison between 20 – 29- and > 50-year age group; P_8, *P*-value for the comparison between 30 – 39- and 40 – 49-year age group; P_9, *P*-value for the comparison between 30 – 39- and > 50-year age group; and P_{10}, *P*-value for the comparison between 40 – 49- and > 50-year age group.

Table 3. Corneal asphericity data per sex category

Sex group	Q value, Mean ± SD							
	Anterior Surface	Posterior Surface	Nasal Quadrant	Temporal Quadrant	Superior Quadrant	Inferior Quadrant	Horizontal Meridian	Vertical Meridian
Men (n = 209)	- 0.24 ± 0.11	- 0.15 ± 0.15	- 0.34 ± 0.15	- 0.17 ± 0.09	- 0.24 ± 0.15	- 0.23 ± 0.19	- 0.25 ± 0.10	- 0.23 ± 0.14
Women (n = 291)	- 0.24 ± 0.09	- 0.16 ± 0.13	- 0.33 ± 0.14	- 0.17 ± 0.08	- 0.21 ± 0.15	- 0.24 ± 0.17	- 0.25 ± 0.09	- 0.22 ± 0.13
P-value	0.744	0.150	0.915	0.848	0.479	0.058	0.944	0.562

Abbreviations: Q value, corneal asphericity; SD, standard deviation; n, number of eyes.

Table 4. Corneal asphericity per refractive error category

Refractive Error	Q value, Mean ± SD							
	Anterior Surface	Posterior Surface	Nasal Quadrant	Temporal Quadrant	Superior Quadrant	Inferior Quadrant	Horizontal Meridian	Vertical Meridian
High hyperopia (n = 1)	- 0.11	- 0.12	- 0.29	- 0.15	- 0.01	+ 0.03	- 0.22	+ 0.01
Moderate hyperopia (n = 11)	- 0.18 ± 0.10	- 0.26 ± 0.09	- 0.28 ± 0.18	- 0.13 ± 0.06	- 0.20 ± 0.18	- 0.11 ± 0.18	- 0.21 ± 0.09	- 0.16 ± 0.16
Low hyperopia (n = 7)	- 0.22 ± 0.11	- 0.17 ± 0.14	- 0.35 ± 0.14	- 0.14 ± 0.05	- 0.18 ± 0.17	- 0.20 ± 0.13	- 0.24 ± 0.08	- 0.19 ± 0.13
Emmetropia (n = 3)	- 0.17 ± 0.13	- 0.11 ± 0.07	- 0.25 ± 0.14	- 0.08 ± 0.05	+ 0.09 ± 0.28	- 0.26 ± 0.11	- 0.17 ± 0.08	- 0.17 ± 0.18
Low myopia (n = 237)	- 0.23 ± 0.10	- 0.16 ± 0.14	- 0.34 ± 0.15	- 0.15 ± 0.08	- 0.23 ± 0.18	- 0.21 ± 0.15	- 0.25 ± 0.09	- 0.22 ± 0.13
Moderate myopia (n = 224)	- 0.25 ± 0.10	- 0.15 ± 0.14	- 0.33 ± 0.14	- 0.18 ± 0.08	- 0.25 ± 0.18	- 0.23 ± 0.15	- 0.25 ± 0.10	- 0.24 ± 0.13
High myopia (n = 17)	- 0.29 ± 0.13	- 0.19 ± 0.16	- 0.35 ± 0.15	-0.23 ± 0.13	- 0.29 ± 0.26	- 0.30 ± 0.15	- 0.29 ± 0.09	- 0.29 ± 0.18

Abbreviations: Q value, corneal asphericity; SD, standard deviation; n, number of eyes in each category; SE, spherical equivalent; D, diopters. Note: *P*-values < 0.05 are shown in bold; refractive errors were categorized based on the magnitude of SE [7] (calculated as spherical + half cylindrical components of refraction of manifest refraction) as follows: high hyperopia (SE ≥ + 4 diopters [D]), moderate hyperopia (+ 4 D > SE ≥ + 2 D), low hyperopia (+ 2 D > SE > + 0.25 D), emmetropia (+ 0.25 D ≥ SE ≥ - 0.25 D), low myopia (- 0.25 D > SE > - 3 D), moderate myopia (- 3 D ≥ SE > - 6 D), and high myopia (SE ≤ - 6 D).

Table 5. Correlation between corneal asphericity and each refractive error category

Refractive error category		Q value							
		Anterior Surface	Posterior Surface	Nasal Quadrant	Temporal Quadrant	Superior Quadrant	Inferior Quadrant	Horizontal Meridian	Vertical Meridian
High hyperopia	Correlation Coefficient	NA	NA	NA	NA	NA	NA	NA	NA
	P-value	NA	NA	NA	NA	NA	NA	NA	NA
Moderate hyperopia	Correlation Coefficient	r = + 0.02	r = + 0.22	r = - 0.31	r = - 0.29	r = - 0.04	r = + 0.18	r = - 0.23	r = - 0.06
	P-value	*P* = 0.957	*P* = 0.522	*P* = 0.358	*P* = 0.381	*P* = 0.904	*P* = 0.607	*P* = 0.494	*P* = 0.871
Low hyperopia	Correlation Coefficient	r = + 0.63	r = - 0.04	r = + 0.46	r = + 0.16	r = + 0.21	r = + 0.54	r = + 0.56	r = + 0.39
	P-value	*P* = 0.129	*P* = 0.939	*P* = 0.294	*P* = 0.728	*P* = 0.645	*P* = 0.210	*P* = 0.195	*P* = 0.383
Emmetropia	Correlation Coefficient	r = + 0.50	r = - 0.50	r = + 0.50	r = - 0.50	r = + 0.50	r = + 0.50	r = + 0.50	r = + 0.50
	P-value	*P* = 0.667	*P* = 0.667	*P* = 0.667	*P* = 0.667	*P* = 0.667	*P* = 0.667	*P* = 0.667	*P* = 0.667
Low myopia	Correlation Coefficient	r = - 0.07	r = + 0.05	r = + 0.01	r = + 0.08	r = + 0.01	r = - 0.14	r = + 0.03	r = - 0.10
	P-value	*P* = 0.318	*P* = 0.477	*P = 0.841*	*P = 0.214*	*P = 0.852*	***P = 0.031***	*P = 0.648*	*P = 0.137*
Moderate myopia	Correlation Coefficient	r = - 0.08	r = - 0.05	r = - 0.11	r = + 0.02	r = - 0.11	r = - 0.09	r = - 0.06	r = - 0.09
	P-value	*P* = 0.264	*P* = 0.438	*P* = 0.115	*P* = 0.735	*P* = 0.112	*P* = 0.194	*P* = 0.357	*P* = 0.194
High myopia	Correlation Coefficient	r = - 0.12	r = - 0.04	r = - 0.42	r = - 0.34	r = + 0.14	r = + 0.01	r = - 0.40	r = + 0.12
	P-value	*P* = 0.653	*P* = 0.885	*P* = 0.091	*P* = 0.184	*P* = 0.591	*P* = 0970	*P* = 0.108	*P = 0.645*

Abbreviations: Q value, corneal asphericity; NA, not applicable; SE, spherical equivalent; D, diopters. Note: *P*-values < 0.05 are shown in bold; ; refractive errors were categorized based on the magnitude of SE [7] (calculated as spherical + half cylindrical components of refraction of manifest refraction) as follows: high hyperopia (SE ≥ + 4 diopters [D]), moderate hyperopia (+ 4 D > SE ≥ + 2 D), low hyperopia (+ 2 D > SE > + 0.25 D), emmetropia (+ 0.25 D ≥ SE ≥ - 0.25 D), low myopia (- 0.25 D > SE > - 3 D), moderate myopia (- 3 D ≥ SE > - 6 D), and high myopia (SE ≤ - 6 D).

Table 1 summarizes the Q values per age group. There were statistically significant differences in Q values among age groups anteriorly, nasally, temporally, inferiorly, horizontally, and vertically (all $P < 0.05$), but not superiorly or posteriorly (both $P > 0.05$) (Table 1). Pairwise comparisons revealed only more prolate anterior, inferior, and horizontal Q values in the group aged ≤ 19 years than in the group aged 40 – 49 years, anterior and inferior Q values in the group aged 20 – 29 years than in the group aged 40 – 49 years, and inferior Q values in the group aged 30 – 39 years than in the group aged 40 – 49 years (all $P < 0.05$). However, the Q values in other locations did not differ significantly between age groups (all $P > 0.05$; Table 2).

Table 3 indicates that there were no statistically significant differences between sexes in the mean (SD) Q values of the anterior or posterior surface; the nasal, temporal, superior, or inferior quadrant; and the horizontal or vertical meridian (all $P > 0.05$).

The mean (SD) (range) SE of our sample was - 2.96 (1.76) (- 8.63 to + 4.75) D. Table 4 lists the mean (SD) anterior, posterior, nasal, temporal, superior, inferior, horizontal, and vertical Q values per refractive error category. Table 5 indicates that there was no significant correlation between each category of refractive error and the anterior, posterior, nasal, temporal, superior, inferior, horizontal, or vertical Q value (all $P > 0.05$), except for a significant negligible inverse correlation between low myopia and inferior Q value (r = - 0.14; $P = 0.031$) (Table 5).

There was a trend in the temporal (r = + 0.19; $P < 0.001$) and inferior (r = + 0.10; $P = 0.022$) quadrants toward a more prolate shape with increasing myopia. We observed no significant correlation between anterior (r = + 0.08; $P = 0.095$) or posterior (r = - 0.08; $P = 0.092$) Q value and SE and between anterior Q value and central corneal radius (r = + 0.02; $P = 0.673$). However, there was a significant negligible inverse correlation between posterior Q value and central corneal radius (r = - 0.18; $P < 0.001$).

The mean (SD) central corneal radius for the entire sample was 7.86 (0.25) mm. The mean (SD) (range) central corneal radius was 7.94 (0.25) (7.40 – 8.81) mm for men and 7.81 (0.24) (7.16 – 8.64) mm for women, being significantly flatter among men ($P < 0.001$). Moreover, we observed a linear trend of decreasing central corneal radius with increasing age ($P = 0.017$).

DISCUSSION

We reported the mean Q values of the anterior and posterior corneal surfaces, the four anterior quadrants, and two meridians in the general Saudi population. We observed that the anterior cornea was significantly more prolate than the posterior, the nasal quadrant than the temporal, the superior quadrant than the inferior, and the horizontal meridian than the vertical. The anterior, nasal, temporal, inferior, horizontal, and vertical Q values differed significantly among age groups, but not the superior or posterior Q value. The cornea became less prolate with increasing age; however, Q values were comparable between the sexes. There was no significant correlation between anterior or posterior Q value and SE, yet a significant trend was detected in the temporal and inferior quadrants toward more prolate shape with increasing myopia. There was a significant negligible correlation between posterior Q value and central corneal radius but no significant correlation between anterior Q value and central corneal radius.

Average corneal asphericity has been calculated and analyzed in different populations, including those of China [2, 3, 8, 9, 13], Egypt [14], Germany [1], the Netherlands [10], India [15], and the USA [5, 7, 16]. These studies used various topographers [3, 7, 8, 10, 15], included different age groups, and had various sample sizes [3, 7, 8, 10, 15] (Table 6).

Zhang et al. [3] studied the right eyes of 1052 Chinese individuals aged 6 – 83 years using a computerized videokeratoscope (Wavelight-ALLEGRO Topographer, software version 1.59). Xiong et al. [8] studied the right eyes of 1683 Chinese individuals aged 30 – 107 years (average: 53.64 years) using the Bausch & Lomb Orbscan IIz (software version 3.12) [8]. Dubbelman et al. [10] studied the right eyes of 114 Dutch individuals aged 18 – 65 years (mean [SD]: 39 [14] years) using the Topcon SL-45 system Scheimpflug camera. Cheung et al. [13] studied the eyes of 63 Hong Kong-Chinese individuals aged 18 – 39 years (mean [SD]: 23 [24] years) using the Topographic Modeling System (version 1.61 TMS-1; Computed Anatomy, NY, USA). Horner et al. [15] studied the eyes of 48 Indians for 5 years, with initial ages of 11 – 13 years, and observed changes in corneal asphericity using a computerized videokeratoscope (EyeSys corneal topographer). Fuller and Alperin [7] studied anterior corneal asphericity of 160 right eyes of African American and White individuals using a high-resolution rotating Scheimpflug camera system, the Pentacam HR (Oculus). Budak et al. [16] studied 287 corneas of 150 patients in Texas, USA, using computerized videokeratography (EyeSys Corneal Analysis System).

Table 6. Summary of corneal asphericity values reported in the literature

Authors	Participants (age range)	Q value, Mean ± SD		Diameter(mm)
Zhang et al.(2011) [3]	1052 Chinese (6 – 83 y)	Anterior	- 0.30 ± 0.12	6
		Nasal	- 0.38 ± 0.16	
		Temporal	- 0.25 ± 0.13	
		Superior	- 0.34 ± 0.19	
		Inferior	- 0.30 ± 0.16	
		Horizontal	- 0.31 ± 0.11	
		Vertical	- 0.31 ± 0.15	
Xiong et al. (2017) [8]	1683 Chinese (30 – 107 y)	Anterior	- 0.28 ± 0.18	3
		Posterior	- 0.26 ± 0.22	
		Anterior	- 0.28 ± 0.18	5
		Posterior	- 0.26 ± 0.21	
		Anterior	- 0.29 ± 0.18	7
		Posterior	- 0.26 ± 0.22	
Dubbelmanet al (2006) [10]	114 Dutch (18 – 65 y) with an equivalent refractive error of - 6.88 and + 3.5 D	Anterior	0.87 ± 0.11	7.5
Horner et al (2000) [15]	48 Indian, myopic (11 – 13 y)	Mean of both meridians	- 0.08 ± 0.12	4.5
Fuller and Alperin (2013) [7]	80 African Americans (21 – 75 y)	Anterior	- 0.26 ± 0.19	6
		Nasal	- 0.43 ± 0.41	
		Temporal	- 0.19 ± 0.48	
		Superior	- 0.26 ± 0.49	
		Inferior	- 0.19 ± 0.20	
		Horizontal	- 0.29 ± 0.37	
		Vertical	0.08 ± 2.10	
	80 Whites (22 – 72 y)	Anterior	- 0.20 ± 0.12	
		Nasal	- 0.27 ± 0.23	
		Temporal	- 0.17 ± 0.12	
		Superior	- 0.26 ± 0.28	
		Inferior	- 0.13 ± 0.16	
		Horizontal	- 0.22 ± 0.14	
		Vertical	- 0.20 ± 0.16	

Abbreviations: Q value, corneal asphericity; SD, standard deviation; mm, millimeters; y, years; D, diopters.

Using the Pentacam HR, we studied 500 right eyes of Saudi individuals aged 18 – 58 years to determine and analyze the corneal Q value and its related factors, including age, sex, SE, and central corneal radius. The mean (SD) anterior Q value measured using Pentacam was - 0.24 (0.10). A similar result was observed for African Americans in the study of Fuller and Alperin [7] and for Dutch individuals in the study of Dubbelman et al. [17].

Our study showed that 99.6% of the Saudi corneas were prolate anteriorly. Data for anterior and posterior corneal asphericity were not normally distributed. Fuller and Alperin [7] did not observe a normal distribution for Q value data in both African American and White individuals. Xiong et al. [8] observed that anterior and posterior Q values were not normally distributed but rather skewed to the left. Similar results were observed in other studies [16, 18, 19]. Conversely, Zhang et al. [3] observed a normal distribution among the Chinese population, and the anterior Q value was negative in 99.9% of participants.

We measured the Q values of each quadrant and meridian along with mean Q values of the anterior and posterior corneal surfaces. The corneal surface in the nasal and superior quadrants was significantly more prolate than in the temporal and inferior quadrants, respectively, indicating rapid flattening in the nasal and superior quadrants. The horizontal meridian was significantly more prolate than the vertical meridian. Similarly, Fuller and Alperin [7] and Zhang et al. [3] observed more negative Q values for the nasal and superior corneal quadrants than for the temporal and inferior quadrants; however, they observed no significant differences between Q values for the horizontal and vertical meridians [3].

In our sample, there were statistically significant differences in asphericity among age groups anteriorly, nasally, temporally, inferiorly, horizontally, and vertically, but not superiorly or posteriorly. The cornea became less prolate with increasing age. Xiong et al. [8] observed that the anterior corneal Q value became more negative and the posterior Q value less negative with increasing age. Zhang et al. [3], Scholz et al. [1], and Dubbleman et al. [20] observed no significant correlation between Q value and age.

Our study revealed that corneal Q values were comparable between sexes. Fuller and Alperin [7] and Cheung et al. [13] observed similar results. In contrast, Xiong et al. [8], Scholz et al. [1], Dubbelman et al. [10], and Chan et al. [9] observed a more prolate anterior corneal surface in female individuals.

Although we noted a trend in the temporal and inferior quadrants toward a more prolate shape with increasing myopia, no significant correlation was observed between anterior or posterior Q value and SE in our Saudi participants. Likewise, there was no significant correlation between each category of refractive error and the anterior, posterior, nasal, temporal, superior, inferior, horizontal, or vertical Q values, except for a significant negligible inverse correlation between low myopia and inferior Q value. Fuller and Alperin [7], Budak et al. [16], and Dubbelman et al. [10] observed no correlation of Q value with refractive error. Xiong et al. [8] observed a more prolate anterior corneal surface and less prolate posterior surface in an emmetropic group when compared to myopic and hyperopic groups. Carney et al. [21] observed that the anterior corneal Q value became more oblate as the level of myopia increased, and Llorente et al. [22] observed less negative Q values in hyperopic eyes.

We observed no significant correlation between anterior Q value and central corneal radius. However, there was a significant negligible inverse correlation between posterior Q value and central corneal radius. The mean central corneal radius was significantly flatter among men. Moreover, we observed a linear trend of decreasing central corneal radius with increasing age. Cheung et al. [13] and Carney et al. [21] observed no significant correlation with anterior asphericity and radius. Conversely, Zhang et al. [3] observed a weak but significant negative correlation between anterior corneal asphericity and radius, whereby the cornea became more prolate with increasing central corneal radius. Q values tended to be more negative and prolate with increased central corneal radius.

To our knowledge, this is the first study to report Q value-related factors in normal corneas within the healthy Saudi population. However, we failed to analyze other potentially related factors, such as anterior chamber depth, vitreous chamber depth, and horizontal visible iris diameter. Another limitation was that most participants (93.2%) were aged less than 40 years. Future studies in the same population, addressing these limitations, are required to provide clinical reference values for corneal asphericity.

CONCLUSIONS

Most corneas in this study were prolate in contour. Anterior corneal asphericity was positively correlated with age. However, corneal asphericity was not significantly related to sex, refractive error, or central corneal radius in the Saudi population. We aimed to establish clinical reference values for corneal asphericity that may be utilized in customized laser refractive surgery, intraocular lens design, calculation formulas, and contact lens design. However, further studies are needed to verify our preliminary findings.

ETHICAL DECLARATIONS

Ethical approval: The study adhered to the tenets of the Declaration of Helsinki and was approved at the departmental level; consent was obtained from all participants.
Conflict of interest: None.

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