Evaluation of relationships among refractive and topographic parameters

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ABSTRACT

Purpose: To examine the relationships among several refractive and topographic parameters.

Setting: Cullen Eye Institute Department of Ophthalmology, Baylor College of Medicine, Houston, Texas, USA.

Methods: Using computerized videokeratography (EyeSys Corneal Analysis System™), 287 corneas of 150 patients were retrospectively analyzed. The Holladay Diagnostic Summary (HDS) refractive maps were used to evaluate relationships among variables of the HDS and refractive error.

Results: Myopic spherical equivalent refraction ($P = .0003$) and more negative asphericity (Q-values) ($P = .0119$) were correlated with steeper corneas. The Q-values were less negative in eyes with moderate myopia (2.0 to 6.0 diopters [D]) than in those with hyperopia (1.0 D or greater). The Q-values below −0.3 were correlated with less favorable values for predicted corneal acuity and corneal uniformity index values. Mean corneal curvature measurements obtained by computerized videokeratography and standard keratometry showed a strong degree of correlation ($P = .0001$).

Conclusion: As the degree of myopia and negative asphericity increased, the corneal radius of curvature decreased. Corneal Q-values less than −0.3 were associated with reduced optical performance of the cornea. *J Cataract Refract Surg 1999; 25: 814–820 © 1999 ASCRS and ESCRS*

Until the middle of the 1800s, the cornea was believed to be spherical. Mandell[1] first demonstrated that the normal human cornea is aspheric and that it progressively flattens toward the periphery (prolate − negative asphericity).[2] However, some corneas are oblate (positive asphericity), increasing in curvature toward the limbus.[1,3,4] The negative asphericity of the normal cornea decreases the spherical aberration.[5] A cornea with abnormal asphericity may cause excessive aberration with resultant monocular diplopia, reduced visual acuity, and impaired contrast sensitivity and glare acuity in low mesopic and scotopic conditions.[6]

Many studies have defined the asphericity of the normal human cornea.[3,7–18] These studies used central or peripheral keratometric or keratoscopic ring measurements to quantify differences in curvature across the cornea. As the shape of normal corneas is neither symmetrical nor spherocylindrical, it is desirable to calculate asphericity using data obtained in all meridians. These data are available from computer-assisted videokeratographic (CVK) devices.

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In this study, we examined computerized videokeratographs of emmetropic, myopic, and hyperopic eyes to determine the relationships among the refractive spherical equivalent, mean keratometric power, and asphericity.

Patients and Methods

This retrospective analysis comprised 287 corneas of 150 patients being evaluated for excimer laser myopic photorefractive keratectomy, holmium:YAG laser thermal keratoplasty, or contact lens fitting. Criteria for entry in the study included (1) no history or slitlamp evidence of ocular trauma, ocular surgery, or corneal disease including tear film abnormalities; (2) lack of ocular pathology such as glaucoma, cataract, and macular disease; (3) no use of systemic corticosteroids, antimetabolites, or immunosuppressants; (4) best spectacle-corrected visual acuity of 20/40 or better; (5) regular keratometer mires; and (6) discontinuation of soft contact lenses for at least 2 weeks and of rigid gas-permeable contact lenses for at least 5 weeks with stable manifest refraction and CVK measurements obtained 2 weeks apart. Clinical examination included demographic and ocular history; slitlamp biomicroscopy; manifest refraction; keratometry (Bausch & Lomb, Inc.); CVK (EyeSys Corneal Analysis System™ [ECAS], version 3.2, Premier Laser Systems, Inc.).[19]

Computerized videokeratographs were obtained by having the patient fixate on the green fixation light of the ECAS. Quality of images was assessed, and maps with incomplete imaging of the central 6.0 mm circle were discarded. Holladay Diagnostic Summary (HDS)[20–22] refractive maps were obtained for each eye, and the relationships among refractive error and different variables from the HDS were evaluated.

The variables are defined as follows: The effective refractive power (Eff RP) is the refractive power of the anterior corneal surface within the central 3.0 mm of the topographic map. Total astigmatism is the difference between the flat refractive power (RP) and steep RP within the 3.0 mm pupil zone. Regular astigmatism is the amount of astigmatism that can be neutralized with a spherocylindrical correction within the 3.0 mm pupil zone. The difference between total astigmatism and regular astigmatism is a measure of irregular astigmatism (ΔA). Asphericity (Q-value) is the corneal asphericity within the central 4.5 mm diameter zone. Previous studies determining corneal asphericity have used areas of the cornea ranging from 4.5 to 10.0 mm diameter, resulting in differences for normal values.[3,9,10,12,15,16] The corneal uniformity (CU) index is a measure of the uniformity of the corneal surface within the 3.0 mm pupil zone and is expressed as a percentage; a CU index of 100% indicates that the optical quality of the anterior corneal surface is uniform. It may be uniformly bad (e.g., microcystic edema) or uniformly good. The predicted corneal (PC) acuity quantifies the optical quality of the cornea within the central 3.0 mm zone in Snellen visual acuity units, ranging from 20/10 to 20/200. The PC acuity is thus the estimate of the patient's visual acuity when the cornea is the limiting factor in the visual system; Snellen visual acuities were changed to LogMAR units to calculate this parameter.[23] To simplify analysis of the relationship between refractive map variables and spherical equivalent refractive error and the Q-value, patients were grouped according to their spherical

Table 1. Results according to spherical equivalent refraction.

Spherical Equivalent (D)	Eyes	Mean ± SD				
	Number (%)	Eff RP (D)	ΔA*	Q-Value	CU Index (%)	PC Acuity
≥1.0	77 (26.8)	43.35 ± 1.60†*	0.06 ± 0.22	−0.10 ± 0.26§	94.93 ± 7.71	−0.11 ± 0.13
≤−2.0 to <+1.0	56 (19.5)	43.86 ± 1.58	0.03 ± 0.04	−0.02 ± 0.23	97.32 ± 13.68	−0.19 ± 0.127
≤−6.0 to <−2.0	113 (39.4)	43.80 ± 1.66†	0.04 ± 0.12	0.01 ± 0.21§	97.87 ± 6.60	−0.18 ± 0.13
<−6.0	41 (14.3)	44.67 ± 1.80†,‡	0.05 ± 0.18	−0.07 ± 0.25	97.80 ± 5.25	−0.16 ± 0.12

*Irregular astigmatism, defined as difference between total astigmatism and regular astigmatism
†Statistically significant differences; $P < .05$
‡Statistically significant differences; $P < .05$
§Statistically significant differences; $P < .05$

Table 2. Demographic and refractive data for 287 eyes.

Characteristic	Mean ± SD	Range
Age (years)	40.67 ± 12.39	8 to 71
Spherical equivalent (D)	−2.41 ± 3.70	−20.00 to 6.87
Mean keratometric power (D)*	43.86 ± 1.65	38.14 to 50.00
Eff RP (D)†	43.81 ± 1.69	38.28 to 50.52
Refractive astigmatism (D)	0.57 ± 0.65	0 to 4.50
Total astigmatism (D)	0.87 ± 0.66	0.11 to 6.68
Regular astigmatism (D)	0.84 ± 0.67	0.07 to 6.68
Irregular astigmatism (D)	0.04 ± 0.16	0 to 2
Asphericity	−0.03 ± 0.23	−0.90 to 0.82
CU index (%)	99.96 ± 8.62	60 to 100
PC acuity		
LogMAR	−0.16 ± 0.13	−0.30 to 0.30
Snellen	20/13.8	20/10 to 20/40

*Mean keratometric power using standard keratometer
†Mean corneal power within the 3.0 mm pupillary zone in Holladay Diagnostic Summary

equivalent refraction as well as their Q-value (Tables 1 and 2).

Statistical Analysis

Data were entered into an Excel database and then converted for statistical analysis using SAS statistical software. Spearman rank correlation analysis was done to determine correlation among ΔA, the Q-value, the CU index, and PC acuity (LogMAR values); among refractive astigmatism, total astigmatism, and regular astigmatism; and among asphericity, spherical equivalent refraction, and Eff RP. Differences among selected ranges of spherical equivalent refraction values (Table 1) for the Q-value and Eff RP and among selected ranges of asphericity for the CU index and PC acuity were compared by analysis of variance (ANOVA, General Linear Models), which was also performed to evaluate the effects of the type of refractive correction (contact lens or not) on Q-value, ΔA, Eff RP, the CU index, and PC acuity (LogMAR values). To define the normal range, ±2 standard deviation (SD) values were calculated for Q, the CU index, and PC acuity.

Results

Of the 150 patients, 45% were men (130 eyes) and 55%, women (157 eyes). Mean spherical equivalent refraction was −2.41 diopters (D) ± 3.70 (SD) and mean keratometric power, 43.86 ± 1.65 D (Table 2). The mean Q-value was −0.03 ± 0.23 (Table 2); 8.4% of eyes had Q-values less than −0.30 (Table 3). One hundred two eyes (35.6%) had contact lens correction, 24 (8.4%) with rigid gas-permeable lenses and 78 (27.2%) with soft contact lenses. No statistically significant differences were found between contact lens wearers and other patients in Q-values, ΔA, Eff RP, keratometric mean power, the CU index, and PC acuity (LogMAR values) ($P > .05$, ANOVA). Values outside a 2 SD range were 0.44 to −0.51 for Q-values, lower than 79.72% for the CU index, and worse than 20/25 for PC acuity (Table 4).

More positive Q-values were correlated with higher ΔA ($P = .02$), better PC acuity ($P = .002$), and higher CU index ($P = .009$) values (Table 5), although all r values were less than 0.2. Corneas with Q-values less than −0.3 had the lowest scores for PC acuity and the CU index (Table 3). Higher CU index scores strongly

Table 3. Results according to asphericity value.

Asphericity (Q-value)	Eyes Number (%)	Mean ± SD Spherical Equivalent (D)	Eff RP (D)	ΔA*	CU Index	PC Acuity
<−0.30	24 (8.4)	−2.59 ± 5.89	44.56 ± 2.13	0.01 ± 0.12	93.75 ± 8.75†	−0.09 ± 0.14‡,§
−0.30 to 0	149 (51.9)	−2.08 ± 3.79	43.81 ± 1.59	0.04 ± 0.19	96.37 ± 10.47	−0.16 ± 0.13‡
≥0	114 (39.7)	−2.83 ± 2.9	43.67 ± 1.7	0.05 ± 0.12	98.42 ± 4.90†	−0.18 ± 0.13§

*Irregular astigmatism, defined as difference between total astigmatism and regular astigmatism
†Statistically significant differences; $P < .05$
‡Statistically significant differences; $P < .05$
§Statistically significant differences; $P < .05$

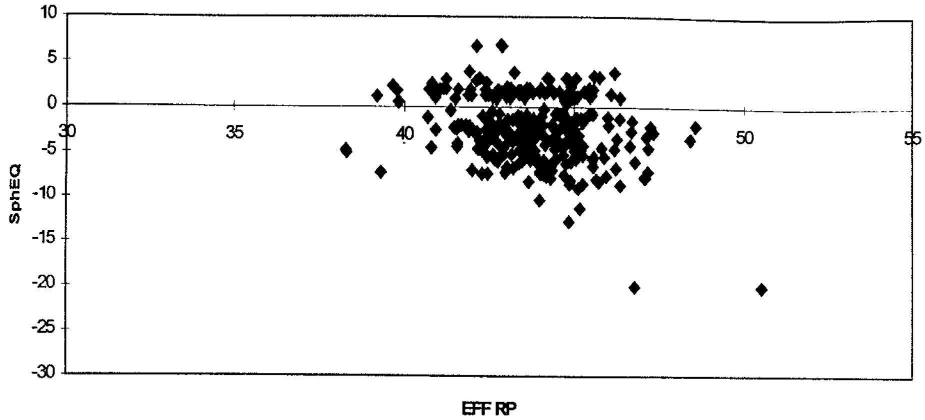

Figure 1. (Budak) Scattergram of effective refractive power (Eff RP) versus spherical equivalent refraction (SphEQ) (r = 0.21269).

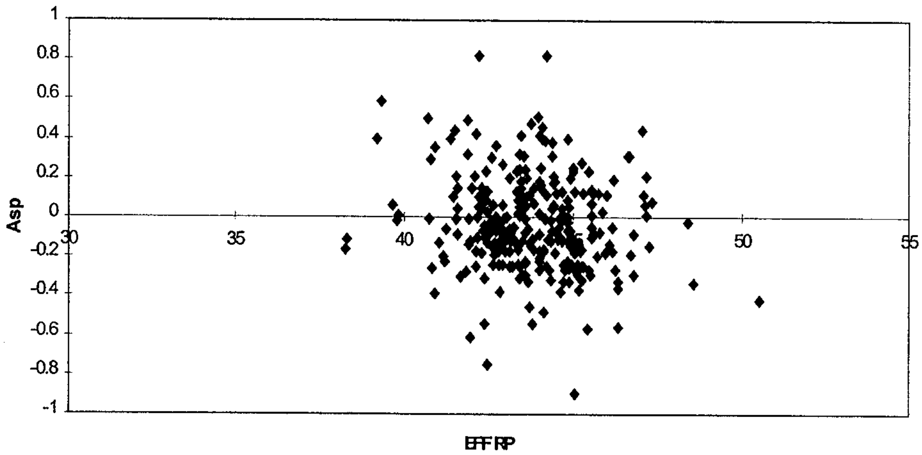

Figure 2. (Budak) Scattergram of effective refractive power (Eff RP) versus corneal asphericity (Asp), which is the Q-value (r = 0.14829).

power in myopia is almost 1.0 D greater than in emmetropia or hyperopia.

Similarly, in our study, we found a low correlation ($r = -0.21$) between increasing myopia and greater mean corneal refractive power (Eff RP) (Figure 1). In addition, mean corneal refractive power was higher in high myopia (greater than −6.0 D) by 1.3 D compared with hyperopia and by 0.8 D compared with moderate myopia (<−2.0 to ≥6.0 D).

The aspheric nature of the normal cornea is well established.[3–16] A negative Q-value (prolate) is defined as corneal flattening moving from center to periphery, whereas a positive Q-value (oblate) is defined as increasing corneal curvature moving from center to periphery.[14] The following parameters have been used to define the conicoid form: shape factor (P), eccentricity (e), and Q.[3,10,12,13,15,16,18,38] These variables are related as follows[10,38]:

$$P = 1 - e^2$$

$$P = 1 + Q$$

$$Q = -e^2$$

Kiely and coauthors[3] showed that the theoretical corneal Q-value for completely reducing the Seidel spherical aberration to zero is −0.528. Previous studies[3,9,10,12,15,16,35,39–41] reported mean Q-values in normal corneas of between −0.11 and −0.33 (converted to Q from P or e), with a mean of −0.26. This suggests that the cornea corrects approximately one-half of the eye's spherical aberration. Since most individuals have little refractive spherical aberration, the remaining spherical aberration must be reduced by the aspheric biconvex crystalline lens with a gradient index of refraction that is highest in the nucleus.

Sheridan and Douthwaite[12] found no significant difference in asphericity among those with emmetropia, myopia, or hyperopia. More recently, Carney and coauthors[35] observed that the corneal Q-value becomes more positive as the level of myopia increases; the corneal Q-value for eyes with high myopia (greater than 4.0 D) was significantly more positive than for those with emmetropia or low myopia. The mean corneal Q-value in our study (−0.03) was less negative than values found in previous studies.[3,9,10,12,15,16,35,39–41] In our series, there was no overall correlation between the Q-value and spherical equivalent refraction; however, in the subgroup analysis, those with moderate myopia had more positive Q-values than those with hyperopia. The same trend was not seen in high myopia or emmetropia.

Although the correlation between the corneal Q-value and corneal radius of curvature was not statistically significant in a study by Carney and coauthors,[35] Kiely and coauthors[3] found that lower Q-values correlated with higher mean keratometric values. We confirmed this finding in our analysis of Q-values and Eff RP.

We also observed that higher Q-values were weakly correlated with higher ΔA (i.e., more irregular astigmatism), better PC acuity, and higher CU index values. In addition, Q-values lower than −0.3 had the lowest values for PC acuity and the CU index. We cannot explain this finding, but only 24 eyes were in this category.

We recognize that there are limits to generalizing the findings of our study. First, our patient cohort was limited largely to ametropic adults and was, therefore, not a random sampling of the population. Second, the zone used for calculating asphericity in our topographic device was 4.5 mm in diameter, and one must be cautious in comparing our Q-values with those calculated for larger or smaller diameters.

In summary, we found a higher mean Q-value than previously reported. Although we did not find a correlation between corneal Q-values and spherical equivalent refractive error, those with hyperopia had more positive Q-values than those with moderate myopia (−2.0 to −6.0 D). Corneal asphericity less than −0.3 was correlated with lower values of corneal optical performance. We also found that eyes with high levels of myopia have steeper central corneal curvatures. These findings provide a baseline of information for evaluating changes in corneal curvature produced by surgery and contact lens wear.

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Table 4. The ±2 SD range for the Q-value, CU index, and PC acuity.

Measurement	±2 SD
Q-value*	0.44 to −0.51
CU index (%)	79.72 to 100
PC acuity (Snellen)	20/25 to 20/10

*Asphericity

Table 5. Analysis of correlation (r*) among irregular astigmatism, asphericity (Q), PC acuity, and the CU index.

	Irregular Astigmatism (ΔA)	PC Acuity	CU Index
Q-value†			
r	.14	.18	.15
P	.0196	.0021	.0095
CU index			
r	.04	.66	—
P	.5024	.0001	—
PC acuity (LogMAR)			
r	.04	—	—
P	.4573	—	—

*r = correlation coefficient
†Asphericity

Table 6. Analysis of correlation (r*) among refractive, total, and regular astigmatism.

	Astigmatism	
Astigmatism	Total	Regular
Refractive		
r	.48	.49
P	.001	.0001
Regular		
r	.995	—
P	.0001	—

*r = correlation coefficient

correlated with better PC acuity scores ($P = .001$) (Table 5).

Refractive, total, and regular astigmatism were strongly correlated with one another (Table 6). Myopic spherical equivalent refraction (Figure 1) and more negative Q-values (Figure 2) were weakly correlated with higher mean Eff RP values. Further analysis revealed that eyes with myopia of more than −6.0 D had significantly higher mean Eff RP values than those with moderate myopia (<−2.0 to ≥−6.0 D) or hyperopia (+1.0 D or more) (Table 1) ($F = 5.7$, $P = .0008$; ANOVA).

There was no correlation between Q-values and spherical equivalent refraction ($P = .208$). However, after eyes were subdivided according to spherical equivalent values (Table 1), eyes with moderate myopia had more positive Q-values than those with hyperopia ($F = 4.34$, $P = .0032$; ANOVA). Mean corneal curvature measurements obtained by CVK and standard keratometry were strongly correlated ($r = 0.9856$, $P = .0001$).

Discussion

Accurate information about average corneal curvature and power is important for the diagnosis and treatment of various conditions. Obtaining and appropriately analyzing these data have become more critical as refractive surgical procedures continue to evolve and gain popularity. This process has stimulated renewed interest in corneal-shape analysis.

The anterior surface of the human cornea is the main refractive element of the eye, contributing approximately two thirds of the eye's total RP. The central corneal radius of curvature, as measured by keratometry, has been extensively documented. The range of radius values in normal eyes is 6.7 to 9.4 mm, with a mean of 7.7 to 7.8 mm.[24–26] Previous studies have shown that the mean keratometric value reaches the adult range of 43.0 to 44.0 D at age 3 years and changes only minimally thereafter.[27–29]

There have been conflicting reports regarding the relationship of myopia and corneal curvature. In a study by Pärssinen,[30] corneal curvature remained unchanged despite an increase in myopia and astigmatism. Two studies[31,32] found that an increase in myopia was accompanied by an increase in keratometric power in children and young adults, whereas Sorsby et al.[29] reported that some myopic eyes exhibit compensatory adaptations by corneal flattening. Stenström[33] found a correlation ($r = 0.18$) between higher myopia and corneal power, and Sheridan,[34] that myopic eyes have steeper central and peripheral corneal curvatures than emmetropic and hyperopic eyes. Other studies[35–37] have confirmed this, indicating that corneal