Asphericity of the anterior human cornea with different corneal diameters

José Manuel González-Méijome, OD, MSc, César Villa-Collar, OD, MSc,
Robert Montés-Micó, OD, PhD, Antonio Gomes, OD

PURPOSE: To measure the anterior corneal asphericity (Q) with different corneal diameters.

SETTING: Department of Physics (Optometry), University of Minho, Braga, Portugal.

METHODS: Thirty-six eyes of 36 patients were evaluated using a videokeratoscope, and the Q-values were recorded. Topographic data were also analyzed using Vol-CT 6.89 software (Sarver & Associates, Inc) to obtain the Q-values with different corneal diameters (3.0 mm, 4.0 mm, 5.0 mm, 6.0 mm, and 7.0 mm). Variable Q models of corneal sagittal height were compared against models assuming constant Q-values obtained with the Medmont E300 videokeratoscope (Medmont Pty. Ltd.) and a standard Q model of −0.26.

RESULTS: The peripheral rate of change in corneal Q with different corneal diameters increased as corneal astigmatism increased. As a result, differences in the sagittal height between the constant model and variable model were evident beyond the central 3.0 mm area. There were significant differences between low and high astigmatic corneas in Q-values measured by the Medmont along the flattest meridian ($P = .004$) and Q-values obtained with Vol-CT software with a 7.0 mm corneal diameter ($P = .026$).

CONCLUSIONS: There were differences in sagittal corneal height calculations considering constant or variable models of Q. Concern arises when surgical interventions depend on corneal Q-values to predict the outcomes. Surgeons should be aware which procedure is behind Q computing by different corneal topographers and that a constant Q-value cannot reflect the actual shape of the cornea as significant departures from the actual sagittal height can arise depending on which Q-value is assumed.

J Cataract Refract Surg 2007; 33:465–473 © 2007 ASCRS and ESCRS

Interest in corneal topography in clinical and research activity has increased in the past decade with the development of computerized corneal topography assessment. Computerized corneal topographers provide full knowledge of the anterior corneal curvature, information that is applicable to current clinical practice (ie, contact lens fitting and management,[1,2] eye modeling and ocular aberration analysis,[3,4] corneal refractive surgery,[5,6–8] and detection and follow-up of corneal pathological conditions[9–11]).

Various aspheric mathematical models to describe the complex shape of the anterior corneal surface have been proposed.[12–15] It is currently believed that the human corneal contour is closely modeled by a conic section that is fully described by the asphericity (Q) and the apical radius of curvature (r_0) (Figure 1). The normal anterior corneal surface is prolate,[16] and it could be described as conic (flattening of the radius of curvature from the apex toward the periphery). The results of previous studies support this assumption.[6,14,17,18] Those studies report that the normal anterior corneal Q-value ranges from −0.01 to −0.80. Currently, the most commonly accepted value in a young adult population is approximately −0.23 ± 0.08.[19]

Recent studies found that human cornea Q-values vary significantly with age (slight peripheral thinning of the cornea)[20] and the degree of ametropia; that is, hyperopic eyes tend to have higher (less negative) Q-values than myopic eyes.[21] Obviously, significant changes in corneal Q are expected to occur after corneal laser refractive surgery.[22] However, most current videokeratoscopes mainly consider Q a unique parameter. Meridian differences in Q have been pointed out using Scheimpflug imaging,[20] and some corneal topographers and autokeratometers provide different Q-values for the main corneal meridians.[23] Significant variability in Q-values between different corneal

© 2007 ASCRS and ESCRS
Published by Elsevier Inc.
0886-3350/07/$—see front matter

doi:10.1016/j.jcrs.2006.11.004

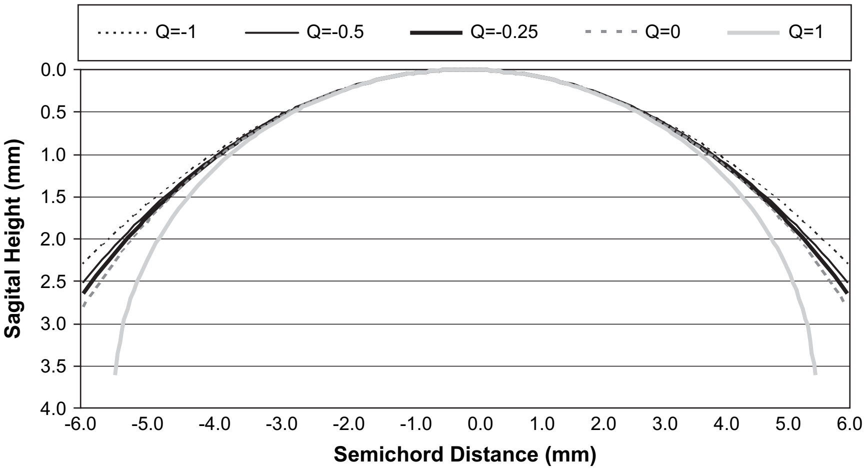

Figure 1. Different corneal sagittal profiles for different values of Q.

topographers is expected; the values depend on where the peripheral reference points are taken and how many meridians are involved in the calculation. Recently, Read et al.,[24] using a method that combines several corneal topography images to provide a full cornea topography map, observed marked differences in corneal Q depending on the annular area taken as reference. They also found that the conic section is a poor estimator of the peripheral cornea, which agrees with an earlier premise of Patel et al.[25] Patel et al.'s analysis of the corneal shape within the apical zone of operated eyes and normal eyes suggests that the corneal contour would be better defined using different conic sections with different shape factors depending on the corneal region to be represented.

It is important to know the actual shape of the human cornea in many clinical applications, and there is a lack of updated information on the shape of the anterior corneal surface at different locations. Thus, this study assessed anterior corneal Q-values with different corneal diameters and compared them with values assessed by a commercial videokeratoscope.

SUBJECTS AND METHODS

Subjects

Thirty-six eyes of 36 university students (10 men, 26 women) were evaluated. The study followed the tenets of the Declaration of Helsinki. Informed consent was obtained from all subjects after the nature and possible consequences of the study had been explained. Exclusion criteria were corneal pathology or corneal scarring, contact lens wear, and corneal surgery.

Corneal topography and Q calculations

Topographic data were obtained with the Medmont E300 videokeratoscope (Medmont Pty. Ltd.). The corneal topographer was calibrated before data acquisition according to the manufacturer's recommendations. The calibration was considered successful if the value was within ±0.01 mm of that reported by the manufacturer for the 4 calibration surfaces. During the initial setup, measurements in each eye were repeated until a well-focused and aligned image was obtained. Corneal videokeratographic data were downloaded onto floppy disks in ASCII file format, which contained information about corneal elevation, curvature, and power and the position of the pupil.

Videokeratographic data included simulated K-values for the 3.0 mm central area and eccentricity (e) [$Q = -e^2$] along the steepest and flattest corneal meridians. The Q-value was calculated with different corneal diameters (3.0 mm, 4.0 mm, 5.0 mm, 6.0 mm, and 7.0 mm) using the calculations feature of Vol-CT 6.89 software (Sarver & Associates Inc.).

Accepted for publication November 15, 2006.

From the Department of Physics–Optometry (González-Méijome), School of Sciences, University of Minho, Braga, Portugal; Clinica Oftalmologica Novovision S.L. (Villa-Collar), Madrid, Department of Optics (Montés-Micó), University of Valencia, Valencia, and a private practice (Gomes), Braga, Portugal.

No author has a financial or proprietary interest in any material or method mentioned.

Supported in part by grant 8281/2002 from the Science, and Technology Foundation, Ministry of Science, and a grant from the Superior Education and the European Social Funding (González-Méijome).

Corresponding author: José Manuel González-Méijome, OD, Department of Physics (Optometry), Campus de Gualtar, University of Minho, 4710-057 Braga, Portugal. E-mail: jgmeijome@fisica.uminho.pt.

Repeatability of Q calculations using the Vol-CT

Intrasession and intersession repeatability of Q-values obtained with the Vol-CT from 3 repeated topographic readings were assessed in a subset of 7 eyes of 7 subjects. These subjects were measured on 3 separate days at the same hour to avoid the influence of diurnal changes. On each occasion, 3 repeated measurements were obtained. The 3 measurements at the first day and the first measurement on each day were considered to calculate intrasession and intersession variability.

Comparisons of Q calculations between the videokeratoscope and Vol-CT

Corneal Q-values obtained with the Medmont E300 videokeratoscope in the flattest and steepest meridians were compared by correlation analysis with values given by the Vol-CT software.

Estimation of corneal height based on Q-Values

The Q-values obtained with different corneal diameters with the Vol-CT software were used to calculate the corneal sagittal height (sag_C) data using equation 1. A theoretical cornea of apical radius $r_0 = 7.8$ mm was considered.

$$sag_C = \frac{r_0 - \sqrt{r_0^2 - y_2p}}{p} \qquad (1)$$

where y is the distance to corneal center at the point where sag is calculated (chord diameter 7.0 mm in 0.1 mm steps) and p is the shape factor of the cornea ($p = 1 - e^2$ or $1 + Q$).

Comparison of corneal height between the constant and variable Q models

Different models of constant Q were assumed for height calculations. The first considered the average values of Q obtained in the present study from the Medmont E300 videokeratoscope along the flattest and steepest corneal meridians. The second considered a unique average value of −0.26 obtained from Yebra-Pimentel et al.[19] using the EyeSys videokeratoscope in a population of 109 young adults. Calculations of corneal height over a 7.0 mm diameter zone were carried out and compared against those derived from the variable Q-values previously obtained from Vol-CT software by changing the corneal diameter to 3.0 mm, 4.0 mm, 5.0 mm, 6.0 mm, and 7.0 mm. Comparisons are presented separately for eyes with low astigmatism (<−1.00 diopter [D]), eyes with moderate astigmatism (−1.00 to −3.00 D), and eyes with high astigmatism (>−3.00 D).

Statistical analysis

Data were analyzed using the SPSS statistical package (version 14.0, SPSS, Inc.). Q-values were analyzed in eyes with different degrees of corneal astigmatism (low, moderate, and high). Differences between Q-values obtained with the Vol-CT software or Medmont videokeratoscope between eyes with different astigmatism were analyzed using analysis of variance with Bonferroni post hoc correction. The level of significance was set at $\alpha = 0.05$. Normal distribution of variables was assessed by the Kolmogorov-Smirnov normality test. Correlations between the videokeratoscope and the Vol-CT Q-values were assessed by Pearson correlation analysis.

RESULTS

Subjects

The study comprised 10 men and 26 women with a mean age of 21 years ± 2.46 (SD) (range 19 to 27 years). The mean corneal astigmatism was −1.06 ± 0.64 D (range −0.30 to −3.60 D).

Q Calculations and comparisons between the videokeratoscope and Vol-CT

Table 1 and Table 2 show keratometry values and Q-values obtained with the Medmont videokeratoscope

Table 1. Values for keratometry (simulated keratometry) and asphericity (Q) obtained with the Medmont E300 videokeratoscope for the main meridians.

	Mean ± SD					
	Keratometry (SimK)			Asphericity (Q)		
Group	Flat	Steep	Astigmatism	Flat	Steep	Average
<1.00 D (n = 16)	42.63 ± 1.31	43.29 ± 1.31	0.66 ± 0.19	−0.42 ± 0.16	−0.27 ± 0.21	−0.34 ± 0.13
1.00–3.00 D (n = 13)	42.05 ± 1.55	43.48 ± 1.57	1.42 ± 0.33	−0.51 ± 0.13	−0.27 ± 0.17	−0.39 ± 0.11
>3.00 D (n = 7)	42.10 ± 1.16	45.62 ± 1.40	3.52 ± 0.96	−0.67 ± 0.15	−0.26 ± 0.19	−0.46 ± 0.15

n = number of eyes; SimK = simulated keratometry

Table 2. Values for asphericity obtained with the Vol-CT software at different corneal diameters for a 7.0 mm pupil.

	Corneal Diameter (mm)				
Group	3.0	4.0	5.0	6.0	7.0
<1.00 D (n = 16)					
Mean	−0.13 ± 0.12	−0.13 ± 0.12	−0.13 ± 0.12	−0.13 ± 0.12	−0.13 ± 0.12
Range	−0.40 to 0.14	−0.40 to 0.12	−0.39 to 0.10	−0.39 to 0.07	−0.40 to 0.04
1.00–3.00 D (n = 13)					
Mean	−0.10 ± 0.11	−0.12 ± 0.10	−0.15 ± 0.08	−0.18 ± 0.07	−0.20 ± 0.08
Range	−0.32 to 0.10	−0.30 to 0.06	−0.28 to 0.01	−0.30 to −0.05	−0.34 to −0.10
>3.00 D (n = 7)					
Mean	−0.15 ± 0.30	−0.20 ± 0.27	−0.23 ± 0.24	−0.29 ± 0.19	−0.34 ± 0.17
Range	−0.69 to 0.13	−0.68 to 0.02	−0.63 to −0.01	−0.58 to −0.14	−0.65 to −0.17

and the Vol-CT software, respectively, for corneas with different degrees of astigmatism. The Q-values obtained with the Medmont videokeratoscope for the steep meridian were similar in the 3 astigmatism groups. However, differences were observed between groups along the flattest meridian, with more astigmatic corneas having higher Q-values ($P = .004$). The Vol-CT Q-values were statistically significantly different between the 3 astigmatic groups with the largest corneal diameter, 7.0 mm ($P = .03$).

Intrasession standard deviation for the Q-value obtained with the Vol-CT was 0.015 with a 7.0 mm pupil, with a trend toward a decrease with larger corneal diameters. The behavior of the intersession Q determinations was similar, with a mean standard deviation of 0.040 with a 7.0 mm pupil; there was also a decrease as the reference point for computing became more peripheral. Despite slightly larger standard deviations, similar trends were present for data derived with a 5.0 mm and a 6.0 mm pupil for intrasession and intersession standard deviations. However, with smaller pupils, the Q-values derived from the software were highly inconsistent, with standard deviation of repeated records largely exceeding the average Q-values.

Table 3 shows the correlation between Medmont E300 videokeratoscope Q-values and Vol-CT Q-values with different corneal diameters for corneas with different degrees of corneal astigmatism. Values determined by the 2 methods achieved a maximum correlation for the most peripheral Q-value of the Vol-CT. Significant differences in these correlations existed between corneas with low to moderate astigmatism and corneas with high astigmatism. Stronger and significant correlations were only observed between Q-values obtained with the 2 techniques in the high astigmatism group. In the remaining 2 groups, despite a trend toward an increasing correlation for most peripheral locations, associations between Q-values were not statistically significant.

A comparison of corneas with different degrees of astigmatism showed that the Medmont Q-values were different between the low and high astigmatism groups only along the flattest meridian (mean difference 0.25) ($P = .003$). With the Vol-CT, a difference between the low and high astigmatism groups was detected only with a 7.0 mm diameter (mean difference 0.15) ($P = .026$).

Variations in corneal Q with the Vol-CT with different corneal diameters

A trend toward an increase in Q for more peripheral reference locations was observed, with changes more evident as astigmatism increased ($P < .001$). Figure 2 shows a regression analysis of Q-values derived from the Vol-CT against the distance from the corneal center used for Q calculations for corneas with low astigmatism and corneas with moderate astigmatism. Numerical data of these plots are shown in Table 2. Relationships followed a linear model with a high coefficient of determination for corneas with low astigmatism ($r^2 = 0.993$), with moderate astigmatism ($r^2 = 0.995$), and with high astigmatism ($r^2 = 0.991$). However, the slope of the regression lines differed substantially, with more astigmatic corneas showing more rapid changes in corneal Q as the peripheral point of reference departed from the corneal center.

Differences in corneal height calculations between constant Q models and variable Q-Values by the Vol-CT for a standard cornea

Figure 3 shows how corneal sagittal height calculation changed when a model of a constant Q is assumed as opposed to a model of a variable Q, as obtained in the present study with the Vol-CT. As seen in Figure 3, bias increased when the point of reference departed from the corneal center by more than 1.5 mm of semichord distance. Beyond this point, the main fact of bias

Table 3. Pearson correlations between the Vol-CT and the Medmont E300 videokeratoscope asphericity values (Q) in eyes with different degrees of corneal astigmatism.

		Correlation (*P* value)				
		Vol-CT Asphericity (7.0 mm Pupil)				
Medmont Asphericity	Astigmatism (D)	Q_{3mm}	Q_{4mm}	Q_{5mm}	Q_{6mm}	Q_{7mm}
Q_{flat}	<1.00	0.149	0.174	0.206	0.263	0.296
		NS	NS	NS	NS	NS
	1.00–3.00	0.249	0.291	0.349	0.440	0.497
		NS	NS	NS	NS	NS
	>3.00	0.845	0.836	0.843	0.755	0.535
		(.017)*	(.019)*	(.017)*	(.05)*	NS
Q_{steep}	<1.00	0.158	0.183	0.261	0.325	0.373
		NS	NS	NS	NS	NS
	1.00–3.00	−0.440	0.379	−0.272	−0.115	0.139
		NS	NS	NS	NS	NS
	>3.00	0.822	0.866	0.868	0.879	0.733
		(.023)*	(.012)*	(.011)*	(.009)*	NS
$Q_{average}$	<1.00	0.214	0.248	0.328	0.412	0.470
		NS	NS	NS	NS	NS
	1.00–3.00	−0.186	0.113	0.006	0.185	0.417
		NS	NS	NS	NS	NS
	>3.00	0.949	0.972	0.977	0.940	0.737
		(.001)†	(<.001)†	(<.001)†	(.002)†	NS

NS = not significant
*Correlation significant at the 0.05 level (2−tailed)
†Correlation significant at the 0.01 level (2−tailed)

in corneal height determination was the value assumed as constant Q (in this case, steepest versus flattest Q-values). Differences observed as a function of the degree of corneal astigmatism were not as high, particularly using Q-values obtained with the Medmont along the steepest meridian. Moreover, because of the similar Q-values provided by the Medmont and Vol-CT (with 7.0 mm) for corneas with moderate

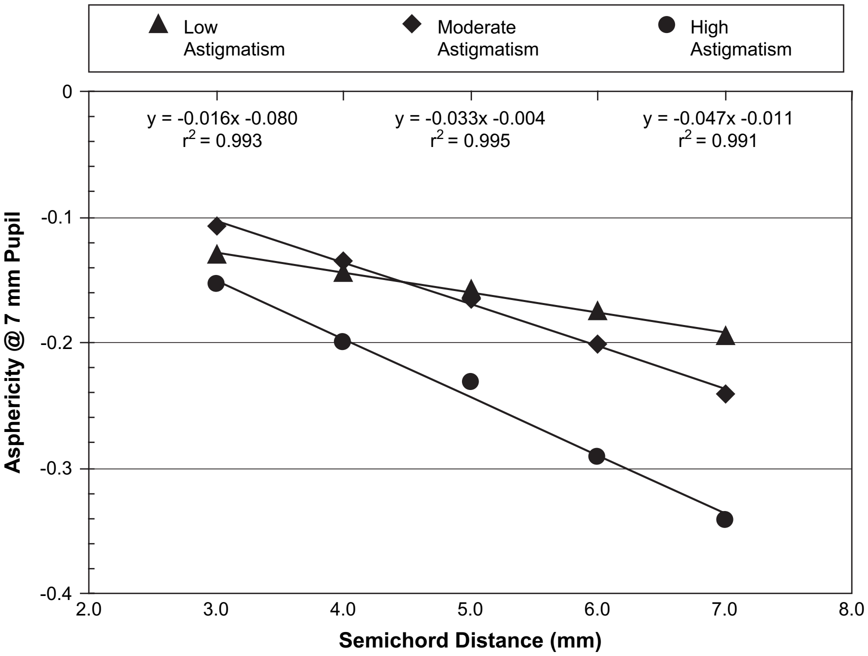

Figure 2. Regression analysis of the Vol-CT corneal Q as a function of distance to the center of corneas with different degrees of astigmatism.

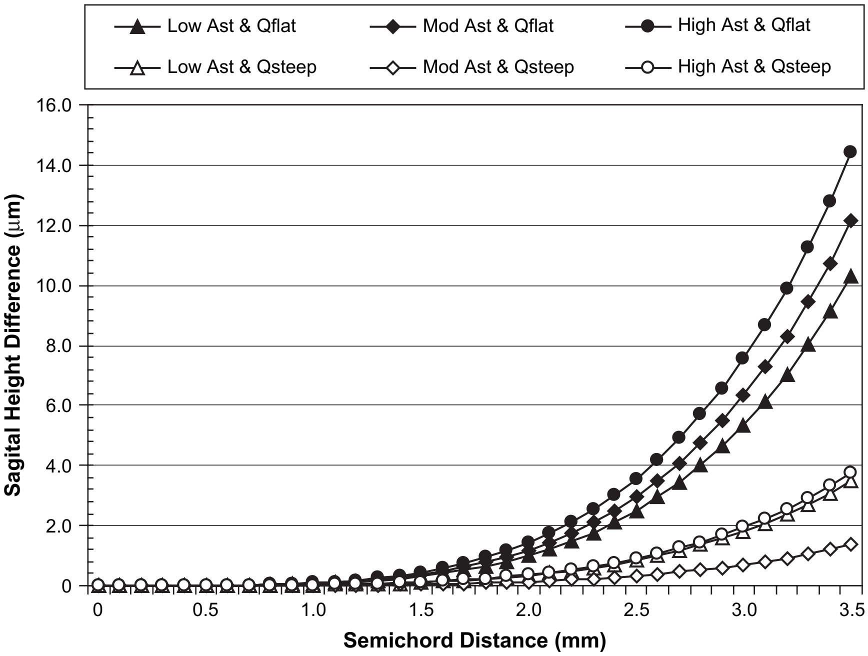

Figure 3. Difference in corneal sagittal height calculations for corneas with different degrees of astigmatism (low, moderate, high) between models assuming a constant Q (solid shapes = flat meridian obtained from Medmont E300; open shapes = steep meridian obtained from Medmont E300) and models assuming variable Q according to values in Table 2 and Figure 2 with a constant apical radius of 7.8 mm.

astigmatism, bias between constant and variable models in these corneas reached the lowest values. However, differences in corneal height at the most peripheral locations between the variable Q model and a model using Q-values obtained with Medmont along the flattest corneal meridian were more evident, reaching 10 to 14 µm at 3.5 mm semichord distance depending on the corneal astigmatism.

Figure 4 shows the differences in corneal height calculations between a model of a constant Q-value of −0.26 and the corresponding models of a variable Q-value in the 3 groups of corneal astigmatism. The similarity between values of the standard Q-values assumed for the constant model (Q = −0.26) and the Vol-CT Q-values with a 7.0 mm diameter for moderately astigmatic corneas resulted in the lowest values of

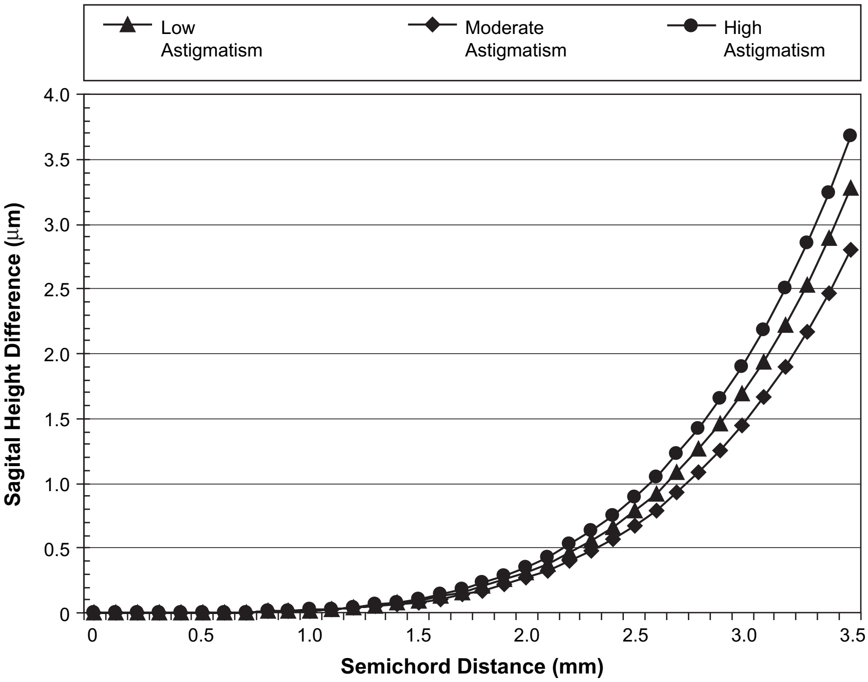

Figure 4. Difference in corneal height calculations for corneas with different degrees of astigmatism (low, moderate, high) between models assuming a constant Q of −0.26 and models assuming a variable Q according to values in Table 2 and Figure 2 with a constant apical radius of 7.8 mm.

sagittal height difference for this astigmatism group. Overall, differences departed from zero beyond the 1.5 mm area (central 3.0 mm of the cornea), increasing rapidly toward the periphery, where differences up to 3.5 µm are expected at the most peripheral locations for more astigmatic corneas.

DISCUSSION

Almost all measurements of anterior corneal Q for the sample analyzed in the present study displayed negative values ($-1<Q<0$) with both methods, corresponding to the most common normal corneal shape (prolate ellipse). These values are in the range of previously reported measurements in normal eyes: −0.01 to −0.81,[6] −0.01 to −0.64,[17] −0.04 to −0.72,[26] and −0.11 to −0.26.[18]

In our study, the mean Q-values for the steep meridian with the Medmont E300 videokeratoscope agree with the average Q-value of −0.26 reported by Budak et al.,[27] who reviewed several studies that offered mean values for Q-value on the range of −0.11 to −0.33. The same average value was found by Yebra-Pimentel et al.[19] in a group of young adults. No differences in corneal Q were observed between corneas with low astigmatism and corneas with moderate astigmatism along the steepest meridian, while significant differences were present between the 2 groups in the flat meridian, with more astigmatic eyes having higher Q-values along the flattest meridian.

That the highest correlation between Medmont E300 videokeratoscope and Vol-CT Q calculations was found at the most peripheral point obtained with the Vol-CT software suggests that the reference point used by the videokeratoscope is near the 3.5 mm location (7.0 mm chord area). In a recent study, Medmont E300 videokeratoscope Q-values showed good agreement with Q-values obtained with an autokeratometer whose peripheral readings were taken near this location in the vertical meridian.[23]

Differences in Q-values between the videokeratoscope and Vol-CT could be explained by the different flattening profile along the flattest and steepest corneal meridians. Although the Vol-CT software provides an estimation of corneal Q that is representative of all corneal meridians at a certain chord distance, the Medmont videokeratoscope gives 2 different values considering only 1 corneal meridian (steepest or flattest). More astigmatic corneas display different Q-values in their main corneal meridians. This could explain why more astigmatic corneas did not display as good an agreement as corneas with low astigmatism between Vol-CT Q and flat and steep videokeratoscope Q; conversely, better correlation was achieved when the mean of the videokeratoscope Q was compared with the Vol-CT Q (Table 3). The same reason could explain why the Q-value given by the videokeratoscope along the flattest meridian did not correlate with the Vol-CT Q-value.

In the present study, statistically significant differences in Q-values were found with different reference points from the central cornea, demonstrating that a single conic shape assuming a constant Q-value does not account for the actual corneal shape. Contrary to this common belief, the corneal flattening ratio changes as one goes from the central cornea in an almost linear fashion, with the cornea becoming more prolate as the corneal diameter increases. Both conclusions agree with those of Read et al.[24] In fact, the authors found a shift in Q to more negative values with larger corneal diameters in frequency distribution plots. Although the approach of Read et al. was different from the approach we used, to our knowledge, these are the 2 most recent studies highlighting the importance of a better understanding of peripheral corneal topography.

The first attempt to evaluate corneal shape within the pupillary area of normal subjects and after photorefractive keratectomy (PRK) was by Patel et al.,[25] who suggest that corneal contour, modeled by the interconnection of different conic sections where the shape factor will be dependent on the local corneal region to be analyzed, would reflect the actual corneal shape rather than the common mathematical definition approach based on a unique shape factor. Today, with powerful computerized corneal topographers and specific software, the approach can be reconsidered, as we did in this study.

Another interesting observation from our data is that for corneas with low astigmatism, the Q-value increased linearly the negative value by 10% to 11% with each millimeter of change in chord distance (half a millimeter on each side from the center of the cornea). The same change in peripheral reference points to compute Q in corneas with moderate astigmatism resulted in an increase of 20% to 25%, again in the negative direction, which was 2-fold that of the relative change in corneas with low astigmatism. In corneas with high astigmatism, this gradient ranged from 17% to 29% (Figure 3).

In previous studies, corneal Q was found to be different for myopia and hyperopia[21] and to change significantly with age.[20] Thus, it will be interesting to investigate how the changes in corneal Q found in our study might be affected by these 2 parameters. Our observations have obvious consequences in terms of sagittal corneal height calculations. Regarding bias in corneal height, we conclude that it depends on corneal astigmatism; however, most important, it depends on the value of the assumed corneal Q. When we assume the Q of the steepest corneal meridian, bias is almost insignificant. When we assume the Q along the flattest corneal meridian, bias increases significantly toward the periphery from a 3.0 mm central chord area of almost zero bias.

The implications of the present study should be considered in customized refractive surgery procedures. Benefits of custom laser ablations regarding quality of vision rely strongly on the ablation algorithm used. The main goal of such procedures, both in primary treatments or retreatments, is to reduce the increase in higher-order aberrations (HOAs) induced by standard ablations, instead of fully correcting them. Studies have found an increase in spherical aberration after primary laser in situ keratomileusis (LASIK) procedures with different systems.[28,29] Similar results were found in a recent comparative study of LASIK retreatments using standard algorithms and at a lower rate when wavefront-guided algorithms were used.[30] The same study found that although HOA and coma-like aberrations increased by a factor of ×1.5 in a group of standard LASIK retreatments, a small reduction in these aberrations was found in the custom LASIK group.

In the future, another goal of custom ablation will be to improve quality of vision beyond the simple correction of refractive error without changing the aberration structure of the eye. Significant changes in corneal Q occur after refractive surgery,[31,32] and these changes explain the increase in spherical aberration and deterioration in the quality of monocular and binocular vision.[33,34] New algorithms for wavefront-guided ablations that attempt to reduce the level of aberration induced are available. However, at present, it seems as though they do not completely mitigate the impact on quality of vision.[30] Thus, new algorithms should be developed to create aspheric profiles of ablation in LASIK procedures to correct spherical aberration by intentionally increasing negative Q and creating larger optical zones. Such an approach requires changes in the current ablation depths, which could compromise the integrity of the cornea.[35] Theoretical calculations by Gatinel et al.[35] show that to maintain the same asphericity after LASIK and PRK procedures, the maximum depth of ablation will increase as the initial corneal Q becomes more positive (less prolate). When the purpose is to intentionally change corneal Q, the maximum ablation depth will increase as the intended change moves toward negative Q-values (more prolate). Also, the ablation depth increases as the intended optical zone diameter increases. Gatinel et al.[36] also evaluated the influence of adjusting corneal Q to a predefined value without changing the apical radius (same corneal power) for customized hyperopic treatments. They found that defocus and spherical aberration would decrease as Q becomes more negative (increased prolateness) and increase as Q becomes more positive (increased oblateness).

All these theoretical calculations play an important role in the peripheral ablation profile and require accurate estimation of corneal Q. However, to our knowledge, a constant Q-value is usually taken into account in such calculations, and it is common practice in today's ablation algorithms in standard and customized procedures. However, our results show that corneal Q changes in a linear fashion from the center toward the periphery in normal corneas, with larger differences for astigmatic corneas. Differences between the theoretical corneal profile calculated from a uniform Q-value and the actual variable Q-value could be of major importance when considering customized ablations with larger optical zones and smoother marginal or transition zones and when reflection losses of energy and non-normal incidence of the laser beam in the peripheral cornea (ie, the laser beam incidence is not perpendicular to the surface at that certain point) account for more reliable predictions of surgical outcomes.[31,37] In fact, differences between calculated and actual corneal ablation profiles are more accentuated at the corneal periphery.[38] Whether the results in our study could be used to correct for such differences in the future is to be investigated.

The significance of differences between corneal models assuming a constant Q-value and models assuming variable Q-values will be different depending on the topographer used to determine this value. Based on the present study, we can conclude that differences between the 2 models are small when average normal values are considered in constant Q models but they are statistically different from zero beyond the 3.0 mm central corneal zone. However these differences could be more significant when customized ablations for corneas with higher degrees of irregularity and more peripheral interventions (larger optical zones) are planned. Thus, studies evaluating these relationships with different instruments should be done to estimate the clinical significance when programming ablation depths. This would be of particular interest when programming customized ablations to enhance residual refractive errors or to improve the quality of vision by intentional changes to corneal Q.

The Q-values obtained with the Vol-CT software seem to be reliable and constant with larger pupil diameters (5.0 to 7.0 mm) when comparing readings taken during the same session or between different sessions. This is of primary importance for longitudinal studies that evaluate the changes in Q profiles at different corneal regions. We are planning to evaluate these effects in a larger sample; however, from our experience, we do not recommend using a pupil smaller than 5.0 mm to compute zonal Q-values using Vol-CT software.

REFERENCES

1. Bufidis T, Konstas AGP, Mamtziou E. The role of computerized corneal topography in rigid gas permeable contact lens fitting. CLAO J 1998; 24:206–209
2. Maeda N, Klyce SD, Hamano H. Alteration of corneal asphericity in rigid gas permeable contact lens induced warpage. CLAO J 1994; 20:27–31
3. Applegate RA, Hilmantel G, Howland HC, et al. Corneal first surface optical aberrations and visual performance. J Refract Surg 2000; 16:507–514
4. Holladay JT, Lynn MJ, Waring GO III, et al. The relationship of visual acuity, refractive error, and pupil size after radial keratotomy. Arch Ophthalmol 1991; 109:70–76
5. Patel S, Marshall J. Corneal asphericity and its implications for photorefractive keratectomy: a mathematical model. J Refract Surg 1996; 12:347–351
6. Holmes-Higgin DK, Baker PC, Burris TE, Silvestrini TA. Characterization of the aspheric corneal surface with intrastromal corneal ring segments. J Refract Surg 1999; 15:520–528
7. Patel S, Marshall J, Fitzke FW III. Model for predicting the optical performance of the eye in refractive surgery. Refract Corneal Surg 1993; 9:366–375
8. Gatinel D, Hoang-Xuan T, Azar DT. Determination of corneal asphericity after myopia surgery with the excimer laser: a mathematical model. Invest Ophthalmol Vis Sci 2001; 42:1736–1742
9. Chastang PJ, Borderie VM, Carvajal-Gonzalez S, et al. Automated keratoconus detection using the EyeSys videokeratoscope. J Cataract Refract Surg 2000; 26:675–683
10. Maguire LJ, Lowry JC. Identifying progression of subclinical keratoconus by serial topography analysis. Am J Ophthalmol 1991; 112:41–45
11. Dao CL, Kok JH, Brinkman CJ, van Mil CJ. Corneal eccentricity as a tool for the diagnosis of keratoconus. Cornea 1994; 13: 339–344
12. Lotmar W. Theoretical eye model with aspherics. J Opt Soc Am 1971; 61:1522–1529
13. Kiely PM, Smith G, Carney LG. The mean shape of the human cornea. Optica Acta 1982; 29:1027–1040
14. Mandell RB. The enigma of corneal contour; Everett Kinsey Lecture. CLAO J 1992; 18:267–273
15. Lindsay R, Smith G, Atchison D. Descriptors of corneal shape. Optom Vis Sci 1998; 75:156–158
16. Davis WR, Raasch TW, Mitchell GL, et al. Corneal asphericity and apical curvature in children: a cross-sectional and longitudinal evaluation. Invest Ophthalmol Vis Sci 2005; 46:1899–1906
17. Townsley MG. New knowledge of the corneal contour. Contacto 1970; 14(3):38–43
18. Eghbali F, Yeung KK, Maloney RK. Topographic determination of corneal asphericity and its lack of effect on the refractive outcome of radial keratotomy. Am J Ophthalmol 1995; 119:275–280
19. Yebra-Pimentel E, González-Méijome JM, Cerviño A, et al. Asfericidad corneal en una población de adultos jóvenes. Implicaciones clínicas. Arch Soc Esp Oftalmol 2004; 79:385–392
20. Dubbelman M, Sicam VADP, van der Heijde GL. The shape of the anterior and posterior surface of the aging human cornea. Vision Res 2006; 46:993–1001
21. Llorente L, Barbero S, Cano D, et al. Myopic versus hyperopic eyes: axial length, corneal shape, and optical aberrations. J Vision 2004; 4:288–298
22. Pop M, Payette Y. Correlation of wavefront data and corneal asphericity with contrast sensitivity after laser in situ keratomileusis for myopia. J Refract Surg 2004; 20:S678–S684
23. González-Méijome JM, Jorge J, Queiros A, et al. A comparison of the ARK-700A autokeratometer and Medmont E300 corneal topographer when measuring peripheral corneal curvature. Ophthalmic Physiol Opt 2004; 24:391–398
24. Read SA, Collins MJ, Carney LG, Franklin RJ. The topography of the central and peripheral cornea. Invest Ophthalmol Vis Sci 2006; 47:1404–1415
25. Patel S, Marshall J, Fitzke FW, Gartry DS. The shape of the corneal apical zone after excimer photorefractive keratectomy. Acta Ophthalmol (Copenh) 1994; 72:588–596
26. Mandell RB, St Helen R. Mathematical model of the corneal contour. Br J Physiol Opt 1971; 26:183–197
27. Budak K, Khater TT, Friedman NJ, et al. Evaluation of relationships among refractive and topographic parameters. J Cataract Refract Surg 1999; 25:814–820
28. Moreno-Barriuso E, Merayo Lloves J, Marcos S, et al. Ocular aberrations before and after myopic corneal refractive surgery: LASIK-induced changes measured with laser ray tracing. Invest Ophthalmol Vis Sci 2001; 42:1396–1403
29. Oshika T, Miyata K, Tokunaga T, et al. Higher order wavefront aberrations of cornea and magnitude of refractive correction in laser in situ keratomileusis. Ophthalmology 2002; 109: 1154–1158
30. Alió JL, Montés-Mico R. Wavefront-guided versus standard LASIK enhancement for residual refractive errors. Ophthalmology 2006; 113:191–197
31. Anera RG, Jiménez JR, Jiménez del Barco L, et al. Changes in corneal asphericity after laser in situ keratomileusis. J Cataract Refract Surg 2003; 29:762–768
32. Jiménez JR, Anera RG, Díaz JA, Pérez-Ocón F. Corneal asphericity after refractive surgery when the Munnerlyn formula is applied. J Opt Soc Am A Opt Image Sci Vis 2004; 21:98–103
33. Jiménez JR, Anera RG, Jiménez del Barco L. Equation for corneal asphericity after corneal refractive surgery. J Refract Surg 2003; 19:65–69
34. Jiménez Cuesta JR, Anera RG, Jiménez R, Salas C. Impact of interocular differences in corneal asphericity on binocular summation. Am J Ophthalmol 2003; 135:279–284
35. Gatinel D, Malet J, Hoang-Xuan T, Azar DT. Analysis of customized corneal ablations: theoretical limitations of increasing negative asphericity. Invest Ophthalmol Vis Sci 2002; 43: 941–948
36. Gatinel D, Malet J, Hoang-Xuan T, Azar DT. Corneal asphericity change after excimer laser hyperopic surgery: theoretical effects on corneal profiles and corresponding Zernike expansions. Invest Ophthalmol Vis Sci 2004; 45:1349–1359
37. Anera RG, Jiménez JR, Jiménez del Barco L, Hita E. Changes in corneal asphericity after laser refractive surgery, including reflection losses and nonnormal incidence upon the anterior cornea. Opt Lett 2003; 28:417–419
38. Anera RG, Villa C, Jiménez JR, et al. Differences between real and predicted corneal shapes after aspherical corneal ablation. Appl Opt 2005; 44:4528–4532

First author:
José Manuel González-Méijome, OD, MSc