Keratoconus and Contact Lens-Induced Corneal Warpage Analysis Using the Keratomorphic Diagram

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**Purpose.** Videokeratography of early keratoconus may be difficult to distinguish from contact lens-induced corneal warpage, even by experienced examiners. Furthermore, topographic irregularity may be judged inconsistently if quantitative standards are not applied. Quantitative measures based on videokeratographic data were developed and evaluated to determine if improved corneal topographic classification can be achieved.

**Methods.** The Corneal Irregularity Coefficient (CIC) and Corneal Power Coefficient (CPC) were derived from multiple measures of mean corneal power and its variance for 207 videokeratographs of normal, warped, keratoconus, and keratoconus-suspect corneas. CIC was plotted against CPC, creating a distribution of points representing all maps that tended to be grouped according to surface conditions (the Keratomorphic Diagram). Normal, steep, abnormal, and warped zones were defined by CIC and CPC cutoff values chosen to distinguish normal from keratoconus corneas graphically.

**Results.** Seventy of 76 normal corneas were grouped in the normal zone and 6 in the steep zone; 84 of 84 keratoconus corneas were grouped in the abnormal zone; 35 of 35 contact lens-induced warpage cases were grouped in the warped zone; and 10 of 12 keratoconus-suspect corneas were grouped in the warped zone, with 2 in the abnormal zone. Serially plotted data of keratoconus progression and warpage regression demonstrated that the vector displacement of CIC and CPC values may provide a potentially useful means of distinguishing contact lens-induced warpage from keratoconus-suspect corneas.

**Conclusion.** The Keratomorphic Diagram aids in classifying and comparing corneal shape by plotting indices along axes with easily recalled scales. The diagram may become a useful tool to assess presurgical corneal surface instability and postoperative progression of corneal shape change due to healing. Invest Ophthalmol Vis Sci. 1994;35:4192-4204.
TABLE 1. Summary Statistics of Corneal Groups

<table>
<thead>
<tr>
<th>Group</th>
<th>n</th>
<th>CIC Mean ± SD</th>
<th>CPC Mean ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>76</td>
<td>0.46 ± 0.30</td>
<td>45.18 ± 1.63</td>
</tr>
<tr>
<td>Contact lens warpage</td>
<td>35</td>
<td>1.31 ± 0.24*</td>
<td>44.64 ± 1.38</td>
</tr>
<tr>
<td>Keratoconus</td>
<td>84</td>
<td>2.22 ± 0.53*</td>
<td>58.38 ± 7.25*</td>
</tr>
<tr>
<td>Keratoconus suspect</td>
<td>12</td>
<td>1.44 ± 0.20*</td>
<td>46.40 ± 1.92</td>
</tr>
</tbody>
</table>

CIC and CPC values in all categories were normally distributed (P > 0.05), Kolomogorov-Smirnov test with Lilliefors’ correction. CIC = corneal irregularity coefficient; CPC = corneal power coefficient; SD = standard deviation. * Statistically different from the normal group (P < 0.05); Student-Newman-Keuls test.

Only includes analysis of the inner 10 rings of the videokeratograph image, thereby missing potentially important early indicators of keratoconus in the periphery. Furthermore, SRI was developed to predict the optical performance of the cornea, and it was never intended to describe surface shape directly. Rabinowitz and McDonnell developed a keratoconus detection process using corneal topographic data from superior and inferior locations on the cornea (I-S values), but this method was not designed as a general classification scheme to distinguish a variety of corneal topographies. In this study, two new corneal topography indices were developed using dioptric power data from virtually the entire extent of the videokeratograph image. Although either index may be used alone, the usefulness of these measures is enhanced by plotting the functional relationship between the indices as a single point in a population distribution. This diagrammatic technique retains a precise, quantitative analysis, yet it provides an easily visualized, qualitative comparison of maps from corneas with various topographic conditions.

MATERIALS AND METHODS

Group Selection

TMS-I and CMS (Computed Anatomy, New York, NY) videokeratograph dioptric power data files were collected from 207 corneal topography maps obtained from patient records at the Louisiana State University Eye Center Clinic. Table 1 lists the categorical distribution of these corneas. Data selection was limited to maps that could be strictly classified as normal, contact lens-induced corneal warpage, keratoconus, or keratoconus-suspect corneas by an ophthalmologist. Selection was based on medical records or, in a few cases in the normal group, from information obtained directly from the subject. Categorization was not made exclusively from assessment of the videokeratographs, except for keratoconus-suspect corneas. Videokeratograph images that were poorly aligned, improperly digitized, or unfocused, were not used. The procedures in this study conformed with the tenets of the Declaration of Helsinki.

The normal category was comprised of subjects with emmetropia and correctable forms of regular ametropia, including myopia, hyperopia, and regular forms of astigmatism (<4.5 D of cylinder). The normal group excluded individuals recovering from contact lens-induced corneal warpage and those exhibiting signs of chronic warpage, such as irregular astigmatism.

The corneal warpage group was composed of maps from contact lens-wearing subjects who had clinically diagnosed warpage at the time of their initial videokeratograph examination. Topography maps acquired after the first examination were not included in this group because warpage typically regresses with discontinued lens wear.

The keratoconus group was composed of maps from individuals with clinically diagnosed keratoconus, which included at least one clinical sign other than the topographic appearance of the map. These signs included, among others, slit lamp findings of stromal thinning, Vogt's striae, Fleischer ring, and Munson's sign. Within this group, 52 corneas had apical power less than 50 D, 27 had apical power between 50 and 60 D, and 5 had apical power greater than 60 D. Apical power was determined from the average corneal power in the first three rings of the videokeratograph. Eighteen corneas (21.4%) had centrally located cones and 66 (78.6%) had peripheral cones, based on definitions used by Wilson et al.

The keratoconus-suspect group was composed of maps from corneas that could not be diagnosed with any clinical sign of keratoconus but did have a map indicative of either an area of local steepening or irregular corneal astigmatism (asymmetric bow-tie pattern). Three corneas (25%) had central steep regions, and 9 (75%) had peripheral steep regions. This group included one cornea in which keratoconus was clinically diagnosed in the fellow eye. To eliminate the possibility of confusing contact lens-induced corneal warpage with keratoconus, contact lens wearers were not included in the keratoconus-suspect group. Within the suspect group, eight corneas had apical power below 45 D, and four had apical power between 45 D and 50 D.
Data Reduction

Videokeratograph diopter files were converted from computer code to ASCII text with two decimal places of precision using the file conversion utility program accessed through the TMS-1 software menu. A separate program was written and compiled in TurboBASIC language and was used to analyze each ASCII data file by extracting various statistical and parametric measurements. Finally, two new indices, the Corneal Irregularity Coefficient (CIC) and the Corneal Power Coefficient (CPC), were calculated using the extracted measurements and were recorded. The CIC value was designed to evaluate the variability of corneal power throughout the map, whereas the CPC value was used to evaluate specific features of power, such as the amplitude of power asymmetry, the magnitude of central power, and the power magnitude of a localized region of steepness. The terms used in deriving the equations for CIC and CPC were selected by trial and error analysis of various statistical parameters to determine the best correlation to corneal surface irregularity and power. The origin of these terms are described in the next paragraph and are indicated partially in Figure 1.

Semimeridian dioptic power values were computed at 256 points along each ring, yielding data at approximately every 1.4° of angular subtense. Data were acquired from rings 1 to 25, and points with interpolated data were not used in calculations. If data from more than 10 points along any given semimeridian were interpolated, warning messages were printed with the CIC and CPC values. For the categories in this study, only the keratoconus group had interpolated data that elicited a warning, and these were all from the most advanced cases (16 out of 84, or 19%, of the examinations). Next, the mean dioptic power and its standard deviation were computed along each of the semimeridians as shown in Figure 1. The maximum mean power of any semimeridian (α) and the maximum standard deviation value for mean power in any semimeridian were found (G). The standard deviation of the mean powers for all semimeridians (A), the mean standard deviation of the standard deviations for mean power in all semimeridians (C), and the standard deviation of the standard deviations for mean power in all semimeridians (E) were calculated. To aid in the acquisition of surface asymmetry information, the difference in the mean dioptic power between the semimeridian with the highest mean power and the opposite semimeridian was computed (I). Next, the power difference was computed between the lowest mean power semimeridian and the opposite semimeridian value (J). Similar measures of mean power as a function of ring value and its variance were then made in the orthogonal direction along each of the rings (B, D, F, and H). To determine power information localized to the central cornea, the mean of the mean dioptic power of each of the first three rings was calculated (γ). Finally, the peak dioptic power value at any point on the cornea was determined to establish a maximum power value, irrespective of location (β).
Figure 2 shows the functional appearance of mean dioptic power plotted against semimeridian angle for normal, astigmatic, and keratoconic corneas. The smaller inset graphs show the mean dioptic power as a function of the ring value out to ring 15, although data for numerical analysis was collected out to ring 25. These plots show features unique to specific corneal categories, which suggests that measurement of these features may be useful for topographic discrimination analysis.

The equations for CIC and CPC were arrived at by a series of systematic computations using combinations of the terms described above to determine the maximum possible distribution of the CIC and CPC values across the entire data set. CIC was defined as:

$$\text{CIC} = \log \left( \frac{A + B + C + D + E + F + G + H}{I + J} \right) - 0.18$$  \hspace{1cm} (1)

where the constant $-0.18$ shifted the CIC scale to separate the normal and keratoconus groups at an easily recalled cutoff value of 1.00. CPC was defined as:

$$\text{CPC} = \frac{a + b + c + d + e + f + g + h}{3}$$  \hspace{1cm} (2)

The intraobserver repeatability of the CIC and CPC measures was assessed by averaging three examinations acquired at a single session by an experienced examiner for a spherical calibration surface and a normal human cornea. For the spherical surface, mean CIC was $-0.46 \pm 0.04$ SD and mean CPC was $43.56 \pm 0.02$ SD. With the human cornea, mean CIC was $-0.31 \pm 0.07$ SD, and mean CPC was $44.65 \pm 0.31$ SD. These standard deviations are approximately delineated by the diameter of a data point symbol shown in Figure 3.

RESULTS

Cross-Sectional Data Analysis

When the corneal irregularity coefficient is plotted as a function of the corneal power coefficient, a Keratomorphic Diagram is generated (Fig. 3). The term "keratomorphic" denotes the form of a corneal surface, and the diagram displays all possible corneal maps. Because of the relationship among the terms used to determine CIC and CPC, there tends to be a functional distribution for naturally occurring corneal surfaces. Data from the normal, keratoconus-suspect, and keratoconus groups could be described by the equation:

$$\text{CIC} = \left[ 4.18 \log (\text{CPC} - 35.85) \right] - 3.45$$  \hspace{1cm} (3)

which is indicated by the solid, curved line in Figure 3.

Table 1 provides the summary statistics for the corneal categories plotted in the Keratomorphic Diagram. All groups passed the Kolomogorov–Smirnov test for a gaussian distribution at a $P > 0.05$ level. For the normal group, the 5th and 95th percentiles for the CIC measure were $-0.06$ and 0.88, respectively, and the 5th and 95th percentiles of the CPC distribu-

FIGURE 3. The Keratomorphic Diagram. Normal corneas (°), corneas with clinically diagnosed keratoconus (◇), corneas with contact lens-induced corneal warpage (▽), and keratoconus-suspect corneas (◇) are plotted for cross-sectional data. The distribution of data from the normal, keratoconus-suspect, and keratoconus corneas was used to fit the function: $\text{CIC} = (4.18 \log (\text{CPC} - 35.85)) - 3.45$ (solid curved line). Dotted lines at CIC = 1.00 and CPC = 48.00 separate the diagram into four quadrants: normal, steep, abnormal, and warped zones. Reference surfaces have been plotted, including a 43-D calibration sphere (●), a spherocylinder with orthogonally oriented axes of 45 D and 43 D (□), an oblate spheroid with 43-D apical power (▲), and a prolate spheroid with 43-D apical power (▼). Note that oblate and prolate surfaces, whose power varies from the center to the periphery, have higher CIC values than the sphere and the spherocylinder, whose power remains constant along any given semimeridian. CIC = corneal irregularity coefficient; CPC = corneal power coefficient.

FIGURE 4. Corneal irregularity coefficient (CIC) plotted as a function of cylinder power for the normal test group. Cylinder power was obtained from the TMS-I videokeratograph measurement. No significant relationship is noted.

The distribution of CIC and CPC values were 43.10 and 48.54, respectively. A CIC cutoff of 1.00 corresponded well to the normal group mean CIC value ± 2 SD and to the 95th percentile value, and it completely separated the normal and keratoconus groups. Similarly, a CPC cutoff value of 48.00 was chosen to aid in separating the normal from the keratoconus groups. These cutoff values also divided the Keratomorphic Diagram into four zones.

Normal corneas tend to occupy the Normal Zone in the lower left-hand quadrant of the diagram (70 out of 76 maps), whereas keratoconic corneas with irregular surfaces and high power occupy the Abnormal Zone in the upper right hand quadrant of the diagram (84 out of 84 maps). Although some subjects in the normal group with high-cylinder astigmatism do possess a CIC value approaching 1.00, there was no obvious correlation between CIC and cylinder power (Fig. 4). Six steep normal corneas with high CPCs occupied the upper left portion of the Steep Zone.

Note that...
much of the steep zone is vacant because few human corneas will be both high powered and highly regular.

Ten of 12 keratoconus-suspect corneas occupied the Warped Zone in the upper left-hand quadrant, and two were located in the abnormal zone (Fig. 3). One of the corneas in the abnormal zone was later found to have a stromal scar in the inferior periphery that elicited a strong topographic resemblance to mild keratoconus without the traditional clinical signs of keratoconus. The second cornea was just beyond the CPC cutoff, with a value of 48.14. This cornea may be at the threshold of clinical diagnosis, and reexamination at a later date would help to resolve how to categorize this map (see Serial Data Analysis, below).

Thirty-five of 35 incidences of contact lens-induced corneal warpage were plotted in the warped zone (Fig. 3), occupying virtually the same location in the Keratomorphic Diagram as the keratoconus-suspect group. However, contact lens-warped corneas appear to have a tendency for lower CPC values than the keratoconus-suspect corneas. Using Student’s t-test, the difference in the means of the two groups for the CPC values was greater than would be expected by chance ($P = 0.001$), whereas the difference in the means for the CIC values was not significantly different ($P = 0.093$). Even though the CPC measure helps to differentiate the warpage group from the suspect group, it is clear that there is insufficient information to distinguish lens-induced warpage from subclinical keratoconus based on a single measure. Therefore, serially acquired examinations would be useful in establishing the basis of abnormal corneal shape.

**Serial Data Analysis: Contact Lens Wear**

Serial examinations of specific patients were selected to determine how changes in topography appear over time in the Keratomorphic Diagram and whether this information can be used to distinguish contact lens-warped corneas from keratoconus-suspect corneas. Continued wear of contact lenses that induce corneal warpage causes fluctuation of the plotted data within the warped zone and in the upper portion of the normal zone (Fig. 5). When contact lens wear is discontinued, a drop in CIC usually occurs within the first month (Fig. 6). However, one cornea may respond with a greater reduction in CIC than its fellow cornea for a given period of time. This is dramatically shown in Figure 6—the right cornea dropped 1.4 units in CIC, whereas the left cornea dropped by only 0.3 units during the first month (point A to point B). We do not know why the right cornea exhibited such a highly regular shape only 1 month after lens wear was discontinued; theoretically, it could be attributed to retained central corneal molding from the contact lens, combined with the relatively more rapid regression of peripherally situated warpage.

Warped corneas appear to return to the normal zone within 2 months after lens removal. Corneal remodeling, however, may continue for 3 or more months, as demonstrated by continued instability of the CIC and CPC values. Figure 7A shows serial corneal power maps corresponding to the data for the left eye in Figure 7B. Note the qualitative sense of correspondence between the maps and the keratomorphic data as irregularity (CIC) rises and falls. Also note the reduction of CPC, indicating a regression of localized, high-powered features. The corneal map at point F appears to indicate a small amount of residual inferior steepness, but the CIC and CPC values place the map in the normal quadrant. This steep area appeared to be overemphasized by the binning process used in mapping the contours.

By the fifth month after cessation of contact lens wear, CIC and CPC values become relatively stable within the normal zone. Some corneas, though, may exhibit a rebound effect during the remodeling period (Fig. 6).

**Serial Data Analysis: Keratoconus and Keratoconus-Suspect Corneas**

In Figure 8, the right cornea exhibits fully developed keratoconus at the beginning of the series, whereas the left cornea shows a typical keratoconus-suspect pattern (map A in Fig. 8A). Disregarding the information obtained from the keratoconic right cornea, the left cornea was only suspected of having keratoconus because no clinical signs of the disease were present. Note that this map pattern can be confused with contact lens-induced corneal warpage (Fig. 7A), which clearly indicates the need for additional follow-up. Because this patient did not wear contact lenses, the location of the map in the warped zone strongly suggests the possible development of keratoconus.

Reexamination after 5 months (map B, Fig. 8A) indicates that the corneal power map appearance suggests the possibility of keratoconus, with a more focal area of steepening of slightly greater magnitude than seen 5 months earlier. Even if this patient had worn contact lenses during this period, a clinician might be unable to distinguish the keratoconus pattern from potential lens-induced warpage based on the topography of the maps alone. However, use of the Keratomorphic Diagram illustrates that CIC and CPC values have shifted in 5 months from the warped zone (point A, left cornea) to the margin of the abnormal zone (point B). This vector direction is highly indicative of keratoconus development. Abatement of contact lens-induced warpage alone should direct the corneal data vector toward the normal region of the Keratomorphic Diagram and not toward the abnormal zone, unless keratoconus or a localized surface steepening defect was also present.
Serial data were acquired for the subject in Figure 8 for as long as 55 months for the right cornea and 46 months for the left cornea. The Keratomorphic Diagram shows the progression of the disease in the left cornea and the relatively stable topography of the right cornea, except for the last examination. Keratomorphic Diagrams of serial data collected from additional subjects indicate that keratoconus may show rapid progression for several weeks (Fig. 9), whereas other subjects exhibit relatively stable forms of keratoconus for years (Figs. 8, 10). The patient in Figure 10 is notable for having a central form of keratoconus of mild to moderate severity.

**DISCUSSION**

If one were only concerned about the relationship between retinal image quality and corneal topography, analysis of the corneal region associated with the entrance pupil of the eye would be appropriate. However, the peripheral topography also contains a wealth of information of immediate and future benefit to the clinician. For example, the earliest topographic indicators of some forms of keratoconus appear in peripheral regions of the cornea. Topography indices sensitive to these changes in peripheral shape would improve our understanding of the etiology of this disease. Rabinowitz has discussed the need for quantitative measures to evaluate the development and expression of keratoconus in family members as a means of elucidating the genetic transmission of the disease.

The Keratomorphic Diagram provides a consistent, quantitative corneal shape analysis by using CIC and CPC values to categorize and compare corneal topographies. Typically, human analysis of a topography map involves a heuristic approach that, among other features, considers the global average of corneal power; the regularity, number, shape, and orientation of contour patterns; and the localization of regions with powers higher or lower than the average power. CIC and CPC values extract and quantify several of the same features used by humans, with the exception of meridional orientation information that may unnecessarily complicate surface analysis. The CIC and CPC cutoff values were arbitrarily chosen to distinguish normal corneas from keratoconic corneas in the current data set. Therefore, at this time, the Keratomorphic Diagram should only be considered a research tool and should not be used as a conclusive diagnostic test without additional prospective evaluation.

The corneal surface also may be qualitatively de-
Keratomorphic Diagram

Figure 6. Keratomorphic Diagram of recovery from contact lens-induced corneal warpage. Note the different response in CIC magnitude for these fellow corneas, particularly during the first month after discontinuing lens wear. After 4 months, the corneas appear to stabilize near a CIC value of 0.30. CIC = corneal irregularity coefficient.

scribed using one of the four zones in the Keratomorphic Diagram: normal, steep, warped, and abnormal. One advantage to plotting data in the diagram is the ability to visually judge the relationship between a newly analyzed cornea to other corneas of known condition.20 Thus, the diagram generates a “corneal taxonomy” classification scheme of all possible corneal forms that could illustrate the evolution of a normal cornea into an abnormal form, or vice versa.

The Keratomorphic Diagram may be useful for screening patients before a keratorefractive procedure to disclose previously undiagnosed problems, such as subclinical keratoconus or unresolved contact lens-induced corneal warpage. Because many candidates for refractive surgery wear contact lenses and have possible lens-induced warpage, the need for a consistent, quantitative method for evaluating corneal shape is important to rule out underlying keratoconus and to determine when warpage regresses to a stable state. It should be recognized that the potential for residual, postoperative refractive error is increased whenever the presurgical corneal shape is in a state of flux with an unknown endpoint of stability. The diagram might also prove useful with postoperative videokeratography of photorefractive keratectomy and radial keratotomy to quantitate corneal stability and to document the direction and rate at which a cornea is being reshaped over time.

The results of plotting contact lens-induced warpage and keratoconus-suspect corneas indicate

Figure 7. Contact lens-induced corneal warpage followed by a period of recovery. (A, top) Videokeratography maps A to F correspond to the data for the left cornea in the plot in (B, bottom). The map contour pattern in the inferior periphery in maps A to D is similar to that seen with early or mild keratoconus. Maps E and F appear relatively normal. (B, bottom) Keratomorphic Diagram for the videokeratographs shown in (A, top). Note that this patient continued to wear contact lenses in both eyes for 2 to 3 months before their permanent removal at point C. After 2 additional months, the maps for both corneas can be plotted in the normal zone (point E). Further improvement is shown at point F. Data point F is missing for the right cornea.
Regression of PMMA-Induced Warpage

- Normal Cornea
- Clinical Keratoconus
- Keratoconus Suspect
- Right Cornea
- Left Cornea
  A) -2 Months
  B) -1 Month
  C) Lenses Off
  D) 1 Month
  E) 2 Months
  F) 3 Months

Corneal Irregularity Coefficient (CIC)

Corneal Power Coefficient (CPC)
Keratomorphic Diagram

**Normal Cornea**

**Clinical Keratoconus**

**Keratoconus Suspect**

- Right Cornea
  - A) 0 Months
  - B) 5 Months
  - C) 17 Months
  - D) 29 Months
  - E) 46 Months
  - F) 55 Months

**Corneal Power Coefficient (CPC)**

- Warped Zone
- Abnormal Zone
- Normal Zone
- Steep Zone

**Corneal Irregularity Coefficient (CIC)**
FIGURE 8. Development and progression of keratoconus in a subject during a 4-year period. (A, top) Videokeratographs of the left cornea, in which subclinical keratoconus (maps A and B) progresses to clinically diagnosed keratoconus (maps C to F). (B, bottom) Corresponding analysis and Keratomorphic Diagram of fellow corneas. Note the relative stability of the right corneal surface while the left cornea progresses to the abnormal zone. The left cornea data points correspond to the maps in (A, top). Data point F is missing for the right cornea.

that members of the two groups cannot be reliably distinguished from one another without future testing to generate a displacement vector in the diagram. However, there is a significant difference between the CPC mean values of the cross-sectional data of these two groups, indicating that the lens-warped corneas tend to be locally flatter than the keratoconus-suspect corneas. This CPC difference may have been greater if the keratoconus-suspect group had been limited to contain only examples of definite subclinical keratoconus. Further studies should demonstrate whether the warped zone can be subdivided into two separate zones. Because little is known about the dynamic properties of the development of keratoconus, the relatively few numbers of keratoconus-suspect corneas available for this study may be due to a lack of recognition of these corneas when analyzing videokeratography or the rapidity with which keratoconus may progress. Thus, the opportunities for recording preclinical keratoconus may be severely limited by the serendipitous timing of videokeratography. On the other hand, if the disease initially progresses at a relatively slow rate, the acquisition of maps during its earliest stages may be easily accomplished. Maguire and Bourne\textsuperscript{16} demonstrated that videokeratography captures map details indicative of keratoconus development similar to that shown in Figure 8A. With greater emphasis on videokeratography for screening and with the application of a technique such as the Keratomorphic Diagram, a clearer picture of the initial stages of keratoconus should emerge. If keratoconus is already known to exist, the rate of progression can be documented in the diagram, and it may become possible, with further study of this method, to predict when a relatively stable endpoint

FIGURE 9. Development of keratoconus in fellow corneas during a 3-week period. Note the large change in CPC during a 2-week period in the right cornea, indicative of the progression of a region of local steepening.
will be attained or to project when a corneal transplant may be necessary.

The Keratomorphic Diagram was designed to separate power maps of the normal cornea from corneas with keratoconus in our sample set. All keratoconus maps in the current sample were contained in the abnormal zone defined by a corneal irregularity coefficient >1.00 and a corneal power coefficient >48.00. Additional validation testing with larger data samples would further refine the CIC and CPC cutoff values. Normal corneas occupied either the normal zone or a small region of the steep zone, but they were not found in the warped or abnormal zones. The keratoconus-suspect group effectively filled in the region between the normal and keratoconic corneas, and, because the keratoconus-suspect group has no artificially induced warpage, these subjects probably reflect the natural distribution of CIC and CPC along a continuum. The warped zone contained the maps of contact lens-warped corneas and keratoconus-suspect corneas. The mean CPC values of these two groups, however, were significantly different. Further refinements to the Keratomorphic Diagram may lead to better discrimination between these groups. Using serial analysis, the regression of corneal warpage and the progression of keratoconus can be observed in the diagram and quantified by the change in CIC and CPC values.

**Key Words**

keratoconus, contact lens, corneal warpage, corneal topography, keratorefractive surgery

**References**


