Original Article

A correlation analysis of cone characteristics and central keratometric readings for the different stages of keratoconus

Alvin Jeffrey Munsamy, Vanessa Racquel Moodley

Background: Knowledge of the cone characteristics for the different stages of keratoconus may potentially assist practitioners in diagnosing and managing keratoconic patients. **Aim:** This study aims to determine if any correlation exists between the central keratometric readings and the cone characteristics for the different stages of keratoconus. **Setting:** A university eye clinic. **Materials and Methods:** In this retrospective study, a saturated sample of 190 eyes from 106 cases of previously diagnosed keratoconic patient files was analyzed. The stage of keratoconus and cone characteristics, namely, cone location, cone decentration, topographical patterns, and morphology were analyzed using an Oculus 3M corneal topographer. **Results:** Analysis revealed a correlation between cone decentration and stage of keratoconus ($P = 0.007$). The association was found to exist when central K-readings were between 45D and 52D and with an apical cone decentration of 3–4 mm. No correlations were obtained for the stage of keratoconus and the cone location; topography and morphology. **Conclusion:** It can be concluded that cone apices are not central in all stages. Practitioners should consider the peripheral cornea when diagnosing and managing keratoconic patients. No correlation between stage, morphology or topography was respectively revealed.

Key words: Cone decentration, cone location, cone morphology, keratoconus, topographical patterns

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Keratoconus is an ectatic degeneration that primarily affects the center of the cornea.[1-3] The diagnosis of keratoconus is based on numerous signs and symptoms presenting at varying stages. The biomicroscopic findings of corneal thinning, striae, Fleischer's ring, Munson's sign, and eventually corneal hydrops primarily confirm the diagnosis of keratoconus.[4] Clinicians measure both the physical profile and the optics of the central cornea when diagnosing and managing the condition.

Keratoconus has previously been classified mainly according to its keratometric readings, distorted mires and the size of the cone.[5] The stages of keratoconus may be classified according to central corneal steepening and cone morphological and topographical patterns, using different corneal topography maps. Corneal topography analyses the curvature, shape and elevation of the cornea and is represented on a color-coded scale with a map alongside it.[6] Topography alone cannot lead to a direct diagnosis of keratoconus, as it must be collaborated with clinical signs, symptoms and/or thickness optical coherence tomography scans. These diagnostic tools help to differentially distinguish and diagnose keratoconus from cases of normal irregular astigmatism and corneal dystrophies.[5,7] As the condition progresses through the different stages, practitioners routinely monitor changes in the physical and optical characteristics which are utilized to classify the severity of the condition. The research question that arises is whether any association exists between the physical corneal profile changes and the severity of the condition?

Cone characteristics that are observed during various stages of keratoconus can be categorized as either topographical or morphological. Topographical characteristics include cone location, apex decentration, and topographical corneal patterns. The location of the cone may be either central (located within the central 3 mm zone) or paracentral (located out of the central 3 mm zone).[8] McMahon[9] revealed that the cone can be found in any location on the cornea. Mandell, however, reported that the apex of the cone is near-central in any direction, or more often, displaced downward from the line of sight.[4,10] Greenstein *et al*.[11] who found cones within the central 3 mm and paracentrally within the 3–5 mm zone in two samples. Demirbas and Pflugfelder agreed partially with Mandell as they found the majority of apices in the inferotemporal quadrant.[12] McMahon *et al*. found that the mean distance of the apex from center by gender was 1.90 and 1.63 mm for males and females respectively.[13] It is thus evident that studies are only in agreement with the fact that the cone is decentered, but not on the direction of decentration. The stage of the keratoconus, however, has not been accounted for in the aforementioned studies. To date, Abu Ameerh *et al*.[14] found a correlation between central K-readings and cone displacement >1 mm and further stated that although patterns cannot be associated with the severity of keratoconus, the vertical displacement of the cone from the pupil axis was significantly associated with the severity of keratoconus.[14]

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There are various corneal topographical patterns as shown in Fig. 1. Distinguishing the topographical pattern allows the progression of incipient cases of keratoconus to be detected early and differentiated from common misdiagnosed cases of Pellucid marginal degeneration and Terrien's marginal degeneration, particularly incipient cases and unilateral cases in the sister's eye.[15,16] Our study attempted to correlate a relationship between the various patterns to a particular stage of the disease.

A morphological characteristic of the keratoconic cone involves analyzing the apex of the cone, which is the point of the maximal corneal protrusion. It is divided into three categories, nipple, oval and globus cones. A nipple cone is a small, near-central cone of 5 mm or less in diameter, resembling a circular shape in the paracentral region of the cornea, inferior nasally.[6,15] Oval cones have corneal displacement of the apex below the midline, resulting in a cone located mid-peripherally, with a diameter >5 mm usually in the inferior temporal location.[6,15] According to Armitage *et al*., oval cones are most likely located more eccentrically than nipple cones.[17] The globus cone has a diameter ≥75% of the diameters of the cornea.[6,15]

In an attempt to correlate central keratometric readings, this study further investigated the severity of keratoconus with the aforementioned cone characteristics. The specific objectives were to analyze corneal topography maps to determine the stage of keratoconus, locate the cone position, analyze the amount of decentration from the center of the cornea and ultimately establish if a relationship existed between the central K-readings and different cone characteristics in keratoconus.

Research methods and design[18]

Study population and sample strategy

Patient record files from an urban Eye Clinic between the years 2010 and 2014 underwent a descriptive retrospective analysis. Patients diagnosed with keratoconus during investigation, whose clinical records contained good quality corneal topography maps on the Oculus 3M were included in the study sample, resulting in 106 cases or 190 eyes.

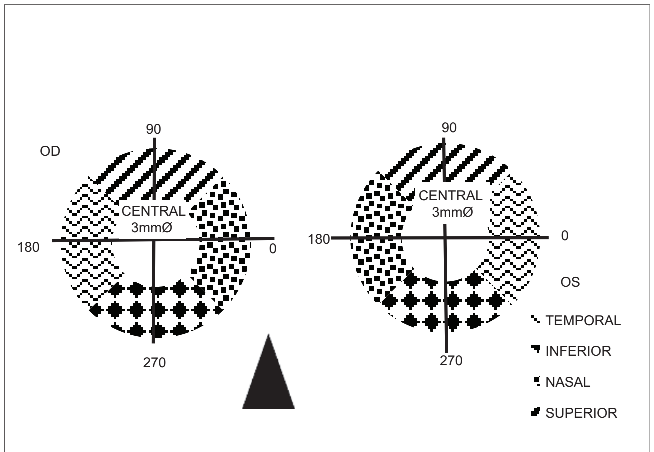

Figure 1: Graphical representation of the degree scale used for the location of the cone for the right eye and left eye when using a Fourier topographical map

Materials and Methods

Corneal topography maps of the subject's most recent visit were analyzed to classify the stage of keratoconus and to locate the apex and position of the cone. The maps were also used to determine the topographical and morphological characteristics of the cone.

The placido topographer is based on the reflection system, in which a placido disc image is projected on the cornea, and a camera captures the reflected image. The corneal topographer used in this study was the Oculus 3M.

Staging of keratoconus[18]

The stage of keratoconus of each eye was classified, in diopters according to the Collaborative Longitudinal Evaluation of Keratoconus (CLEK) study grading system [Table 1], one of many ways used to classify the stages of keratoconus. Studies[2,19] have used the CLEK grading classification for staging keratoconus. The K-readings were obtained directly from the topographer (from an axial map) and grouped into mild, moderate, or advanced based on steepest K-reading.

Cone location[18]

Fourier and axial topography maps for each keratoconic eye were analyzed to identify the cone location. Fourier maps show the location of the cone in degrees and the decentration of the steepest part of the cone in millimeters from the center of the cornea. Axial topography maps were used simultaneously with the Fourier map to locate the apex of the cone. The cone location was grouped into five categories namely central, inferior, superior, nasal, and temporal for each eye respectively as shown in Fig. 1. According to Mandell,[4] the cornea comprises a central spherical zone called the corneal cap which was utilized in this study as a marker to locate central cones. Thus, cone location was classified as central if the steepest meridian was positioned within the central 3 mm and paracentral if the steepest meridian was located out of the central 3 mm zone. The paracentral cones were further classified as shown in Fig. 1.

Cone decentration[18]

Cone decentration refers to the distance between the center of the cornea and the apex of the cone. It does not localize cone apex and direction. To find the maximum decentration of the cone, a tangential map was used. A reference point was marked in the center of the cornea and a second reference point was marked at the apex of the cone. A value in millimeters was thereafter obtained. Each map was separately analyzed by three researchers to ensure accuracy in the results.

Topographical patterns[18]

The topographical pattern of the cone was visually analyzed using the tangential map of the Oculus topographer. The patterns were qualitatively assessed by observing the steepest portion of

Table 1: Collaborative Longitudinal Evaluation of Keratoconus classification of keratoconus using the steepest K-reading[2]

Grading/stage of keratoconus	K-readings
Mild	≤45.00D
Moderate	45.00D-52.00D
Advanced	≥52.00D

the cornea, that is the two "warmest" colors of the given map and deciding on the "best-fit" pattern from ten templates.[20] Practically, three researchers analyzed the topographic patterns and collectively agreed on a pattern from the templates [Fig. 2].

Morphological characteristics[18]

Morphological patterns were classified into three categories: Nipple, oval and globus,[16,21] A tangential map of the topographer was selected to best distinguish the three cones [Fig. 3].[16] The cones were identified and then measured in millimeters using the two predominant colors indicating corneal steepening, which was then marked as the two reference points when analyzing the size of the cone. Three researchers evaluated each map and measured the size independently.

Results

This retrospective study involved the analysis of 106 patient record files (190 eyes), all of which contained a clinical diagnosis of keratoconus. The sample distribution revealed 10 eyes for Stage 1, 61 eyes for Stage 2 and 119 eyes for Stage 3 keratoconus. Eighty-three of the 109 patients presented with bilateral keratoconus. The average patient age was 25.17 ± 11.42 years, ranging from 10 to 60 years old. Gender and ethnicity were not indicated in all patient files thereby excluding its use in analysis.

The association between stage, decentration, morphology, location and topographical patterns was assessed using Spearman's rho. Statistical significance was defined as a $P < 0.05$. Correlations found are presented in Table 2.

The hypothesis test for a correlation was found between the stage of keratoconus and the decentration of the cone apex yielding a $P = 0.034$. The association between stage and decentration was then further analyzed using the statistical analysis system (SAS) log-linear model. This revealed the greatest residual value ($R = 3.006$) to be when K-readings were between 45D and 52D (Stage 2) for the apical cone decentration between 3 and 4 mm.

The hypothesis test for a correlation between the stage of keratoconus and the location of the cone yielded a $P = 0.377$. It is thus concluded that the stage of keratoconus and the location of the cone were not correlated.

The hypothesis test for a correlation between the stage of keratoconus and the topography of the cone yielded a $P = 0.564$. It is thus concluded that the stage of keratoconus and the topography of the cone were not correlated.

The hypothesis test for a correlation between the stage of keratoconus and the morphology of the cone yielded a $P = 0.14$. It is thus concluded that the stage of keratoconus and the morphology of the cone were not correlated.

Discussion

The correlation analysis in our study revealed an association between the stage of keratoconus and cone apical decentration for moderate keratoconus with a value of 3–4 mm off corneal center. Therefore, for central K-reading measurements between 45D and 52D, the cone will be expected to be located outside the central 3 mm zone of the cornea.

Various studies[12-14] agree with our finding despite the lack of staging and correlation analysis in their methodologies. Mild did not correlate with apical decentration which could be due to the CLEK staging criteria of <45D, which is very similar to normal central keratometry. Conversely, advanced keratoconus (>52D) lacks an upper limit, poses a difficulty of finding an association for apical decentration.

Practitioners who determine the base curve of the contact lens using the central keratometric readings will need to note that for Stage 2 of keratoconus the cone will not necessarily lie centrally, but will most likely be located paracentrally. If the central keratometric reading only is taken for Stage 2 keratoconic eyes, it will generally be flatter than the actual cone profile as the cone will have decentered and the reading will be taken in the more flatter corneal portion superior to the cone. This will result in the lens of the first choice being much

Table 2: Spearman's correlation for stage of keratoconus and cone characteristics

Cone characteristic correlation with stage	*P*	*n* (eyes)	Correlation
Stage versus apical decentration	0.043	190	✓
Stage versus location	0.320	190	×
Stage versus morphology	0.567	190	×
Stage versus topographical patterns	0.069	190	×

×: Implies no correlation exists, ✓: Implies a correlation exists

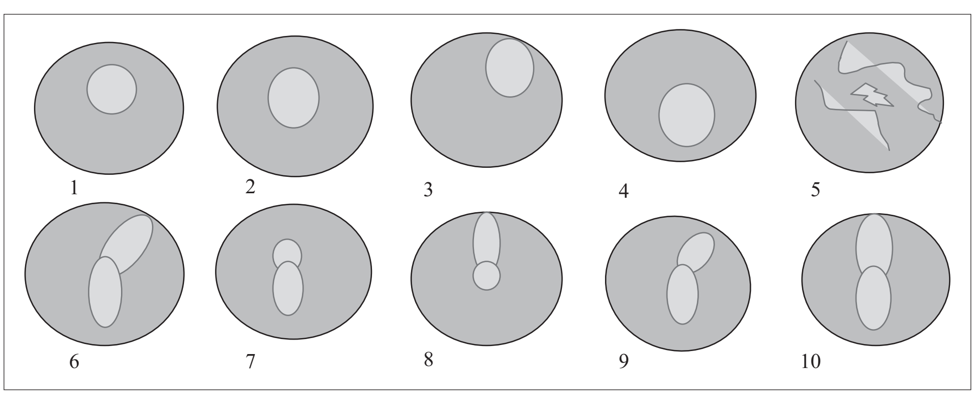

Figure 2: Illustration of the ten different topographical patterns reproduced from a template by Rabinowitz,[19] (1 – Round, 2 – Oval, 3 – Superior steepening, 4 – Inferior steepening, 5 – Irregular, 6 – Symmetric bowtie with skewed radial axis, 7 – Asymmetric bowtie with inferior steepening, 8 – Asymmetric bowtie with superior steepening, 9 – Asymmetric bowtie with skewed radial axis, 10 – Symmetric bowtie)

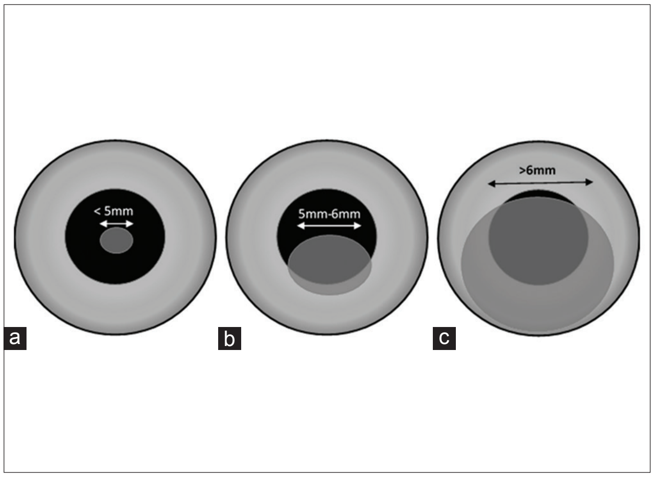

Figure 3: Graphical representation of the three types of cone morphology, a – Nipple, b – Oval, c – Globus

flatter than required, leading to a flat fit with the associated signs such as excessive lens movement or discomfort. The finding of an association between moderate keratoconus and cone apical decentration informs contact lens fitting procedures when addressing corneas with decentered cones. Practitioners managing keratoconus could consider larger diameter corneal lenses or scleral lenses for use with moderate stage keratoconic cases, thereby reducing chair time and the number of trial lenses used. The CLEK study[2] reported that >95% of its 1209 sample size had k-readings >45D. Our study isolated a correlation for k-reading and off-center apices in this category, highlighting the relevance of utilizing peripheral keratometry in diagnosing and managing keratoconus. A classification for keratoconus using peripheral keratometry does not exist. Thus, factoring peripheral keratometry for subclinical keratoconus may re-classify its severity.

The analysis of results in an attempt to find an association between the stage of keratoconus and cone topography were inconclusive. The cone becomes steeper as the disease progresses, suggesting a more irregular corneal surface, which may not conform to a specific topographical pattern for a specific stage of the disease. It may be impractical to predict which pattern would be expected as each keratoconic cornea has periods of progression as well as periods of remission.[15,21] Clinically, topographical patterns have been shown to be useful in diagnosing incipient stages and differentially diagnosing other forms of corneal ectasia.[16,20]

Our study found no association between the stage of keratoconus and cone morphology, a finding similar to that of Sinjab.[16] There may be several diseases such as rosacea, eczema, or allergic conjunctivitis with different pathophysiological mechanisms that produce the corneal changes we see present in keratoconus, hence a definite morphology for a specific stage proved challenging. In addition, corneal rubbing will cause epithelial injury and continuous keratocyte apoptosis, causing a decrease in keratocytes as well as releasing degradative enzymes.[15] Thus, if the cone begins with a nipple morphology, continuous eye rubbing will cause degradation of the epithelium resulting in a larger area of thinning, leading to a change in the corneal morphology.[21] The multifactorial etiology for the morphological changes of the cone may create an impediment for correlation.

The analysis of cone characteristics to the practitioner can be useful in enhancing the approach to management of the condition. The entire cone's location; topography and morphology appear to be too complex characteristics to find a linear association for the multifactorial etiological influences on the cone. Hence, the linear nature of the corneal apex decentration yielded a relationship with keratoconus progression.

Conclusion

This study of one hundred and ninety keratoconic eyes retrospectively analyzed on a Kwa-Zulu Natal, South African population, revealed a correlation in the decentration of the apex of the cone with the progression of keratoconus, with significance in the moderate stage and decentration of 3–4 mm from the center of the cornea. Practitioners should select contact lenses that will adequately align with corneas that have a decentered corneal apex outside the central 3 mm of the cornea for optimal lens stability and visual acuity.

Although no correlation was found to exist between the other cone characteristics, namely, location, topographical patterns, morphology, and the stage of keratoconus, it can be concluded that corneal topography maps are useful in evaluating the different cone characteristics for any stage of keratoconus. Evaluating peripheral keratometric readings are significant when choosing a management option when the cone is not centrally located.

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Conflicts of interest

There are no conflicts of interest.

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