Corneal Changes and Wavefront Analysis after Orthokeratology Fitting Test

IANE GONÇALVES STILLITANO, MARIA REGINA CHALITA, PAULO SCHOR, EDUARDO MAIDANA, MARCELO MASTROMONICO LUI, CESAR LIPENER, AND ANA LUISA HOFLING-LIMA

• PURPOSE: To evaluate corneal changes and ocular aberrations during an orthokeratology test.

• DESIGN: A prospective, nonrandomized cohort study.

• METHODS: Fourteen myopic patients (26 eyes) underwent an orthokeratology fitting test with the BE contact lens (Ultravision Pty, Ltd, Brisbane, Australia). Best spectacle-corrected visual acuity (BSCVA), uncorrected (Ultravision Pty, Ltd, Brisbane, Australia) visual acuity (UCVA), subjective cycloplegic refraction, biomicroscopy, corneal topography, optical pachymetry, and aberrometry were performed at baseline and one and eight nights orthokeratology. The short-term effect of orthokeratology using corneal topography, tomography, and ocular aberrations was evaluated.

• RESULTS: The mean spherical equivalent changed from −2.24 ± 0.98 diopters (D) at baseline to 0.15 ± 0.76 D after the eight nights of lens wear ($P = .001$). All patients had an UCVA of 20/30, 69.2% with 20/20. Changes in central corneal pachymetry were not observed. There was a statistically significant increase in the temporal corneal thickness from night one, without any difference between nights one and eight ($P > .001$). A significant increase of higher-order root mean square values was observed from baseline (0.42 ± 0.16 μm), night one (0.81 ± 0.24 μm), and night eight (1.04 ± 0.24 μm). Increases in coma (Z7+Z8) and spherical aberration (Z12) were observed. Positive horizontal (Z8) coma increased in right eyes, and negative horizontal (Z8) coma increased in left eyes ($P < .001$).

• CONCLUSIONS: Myopia reduction resulting from rapid central corneal flattening and improvement of UCVA occurred after orthokeratology. Higher-order aberrations (HOAs), particularly spherical aberration and coma, increased significantly during the orthokeratology test. An increase of temporal pachymetry and differences in coma direction induced between the eyes may be related to the subclinical lens decentration temporally. (Am J Ophthalmol 2007;144:378–386. © 2007 by Elsevier Inc. All rights reserved.)

Accepted for publication May 18, 2007.

From the Contact Lens & Refractive Surgery Sectors, Department of Ophthalmology, Federal University of São Paulo/Paulista School of Medicine UNIFESP/EPM, São Paulo, Brazil.

Inquiries to Iane Gonçalves Stillitano, Rua Botucatu, 822, São Paulo-SP, Brazil 04023062; e-mail: ianestillitano@oftalmol.epm.br

ORTHOKERATOLOGY, ALSO KNOWN AS CORNEAL refractive therapy (CRT), was introduced approximately 40 years ago as a method for the temporary reduction of myopia.[1] Orthokeratology is a reversible procedure that uses rigid contact lenses to change the curvature of the cornea to correct refractive errors.[2] Orthokeratology proved to be inefficient and unpredictable within the first two decades of use, losing credibility as a viable option for the correction of myopia.[3–5] However, the advent of corneal topography coupled with recent advances in the contact lens designs have increased the precision of this technique significantly.[6,7] For example, the introduction of reverse-geometry rigid gas-permeable contact lenses with high oxygen transmissibility allows overnight use for greater patient comfort and faster reduction of refractive error.[8,9]

Reverse-geometry lens wear for myopia alters the prolate corneal shape to make it spherical or mildly oblate, causing a flatter 5- to 6-mm central circular zone and steeper mid-periphery.[10] Several theories have been proposed to explain the mechanism behind orthokeratology. These include changes in the anterior and posterior corneal surface and the induction of spherical aberration (Z12). The refractive effect is explained by two different theories. The first theory postulates that changes in the central and paracentral corneal thickness contribute to changes in the anterior corneal surface, causing refractive change. The second theory postulates that anterior and posterior corneal surface modulation results in full-thickness changes in corneal curvature.[11] Swarbrick and associates found significant central corneal thinning and mid-peripheral thickening in a group of subjects who wore reverse-geometry orthokeratology lenses.[10] From these observations, they concluded that the induced corneal change was the result of the redistribution or remodeling of anterior corneal tissue, rather than an overall bending of the cornea.[10] Alharbi and Swarbrick confirmed these observations in a study on human subjects,[12] and Choo and associates demonstrated these changes in an animal model.[13] Although there is consensus that the central cornea thins, the effect on the mid-periphery is still debated.[9] Furthermore, the response of the back corneal surface after orthokeratology is still controversial.[14] The changes in the corneal surface can be monitored using corneal tomography systems, and the resulting optical changes can be quantified in vivo using aberrometry.

0002-9394/07/$32.00
doi:10.1016/j.ajo.2007.05.030

Quantification of the induced wavefront aberrations resulting from any refractive procedure, including orthokeratology, is important because of the impact on visual acuity and visual quality. An increase in ocular and corneal higher-order aberrations (HOAs) has been reported using various reverse-geometry orthokeratology contact lenses.[15–19] A diminution of low-contrast best-corrected visual acuity (BCVA) resulting from induced HOAs using CRT (Paragon Vision Sciences, Mesa, Arizona, USA) has been reported.[16] Additionally, the fitting characteristics of orthokeratology lenses have been reported to induce specific types of HOAs.[18]

A number of orthokeratology lens are commercially available; one such lens, the Mountford lens (BE lens), purportedly differs from other orthokeratology lens designs. The BE lenses are designed from the periphery in, commencing with the tangent periphery, an outer curve that depends largely on the measured value of corneal eccentricity, rather than starting with base curve selection. Furthermore, the refractive changes are brought about by the manipulation of squeeze film forces generated by differing pressure gradients beneath the lens.[20] The BE trial lens parameters are calculated using corneal topography and a computer program provided by the manufacturer. To date, there are no peer-reviewed publications reporting ocular wavefront analysis with the BE lens.

The current study analyzed the efficacy and corneal changes induced by overnight orthokeratology fitting test using the BE lens design. Given the lack of wavefront data and the apparently differing mechanism of action, it is important to determine whether the BE lens induces similar or different wavefront aberrations compared with those reported for other orthokeratology lenses. We believe that wavefront analysis aids in understanding the underlying short-term biomechanical and optical response of the eye after orthokeratology and allows for further refinements in lens design.

METHODS

• **SUBJECTS:** This was a prospective study of 26 eyes of 14 myopic patients (seven women and seven men) who underwent overnight orthokeratology fitting tests with the BE lens. This study was conducted at the Contact Lens Sector of the Vision Institute of the Federal University of São Paulo/Paulista School of Medicine (UNIFESP/EPM). The inclusion criteria for this study included myopia up to −4.50 diopters (D) with or without against-the-rule astigmatism of up to −0.75 D and with-the-rule astigmatism of up to −1.50 D. Any patient with ophthalmic disease or who had undergone previous ocular surgery was excluded from this study. Soft contact lenses had to be removed for one month before the beginning of the study. There were no rigid contact lens wearers participating in this study.

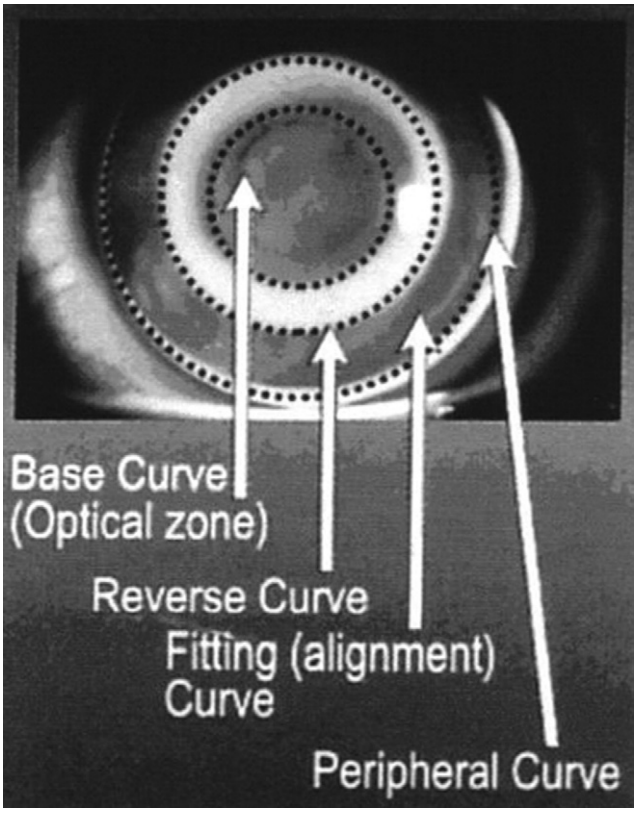

FIGURE 1. Schematic design of the reverse geometry contact lens used for orthokeratology.

All but two subjects were fitted with the BE orthokeratology contact lenses in both eyes. All patients underwent a baseline examination and follow-up examinations after one and eight nights after orthokeratology. All examinations included the measurement of best spectacle-corrected visual acuity (BSCVA), uncorrected visual acuity (UCVA), subjective cycloplegic refraction, biomicroscopy, corneal topography and tomography (including optical corneal pachymetry and posterior corneal surface mapping), and ocular aberrometry.

• **ORTHOKERATOLOGY CONTACT LENS FITTING PROCEDURE:** Patients were fitted with the BE standard contact lenses for testing (UltraVision Pty, Ltd., Brisbane, Australia), Boston XO material (DK = 100×10^{-11} [cm^2/s] [ml O_2/ml × mm Hg, ISO/Fatt]; Bausch & Lomb, Rochester, New York, USA), manufactured by Mediphacos, a Brazilian enterprise (Mediphacos Ltda, Belo Horizonte, Brazil). The BE Retainer is designed using topographical data only. Each retainer is individually designed specific to the patient's corneal topography. The BE lens is designed to control the fluid forces in the tear layer to allow controlled and predictable corneal shape and refractive change.

These lenses have a similar design to reverse geometry lenses (Figure 1): posterior central curve, reverse curve,

tangential curve, and peripheral curve. The parameters include a 11-mm chord diameter, 6.0- to 6.5-mm optical zone, 0.02- to 0.24-mm center thickness, and 7.70- to 9.35-mm base curve with proprietary secondary and peripheral curves. The BE lens was fitted using a trial set and a scientifically validated predictive computer program version 1.1.3 (BE Enterprises Studio, Vancouver, Canada) that relates corneal shape to refractive change. The BE trial lens were fitted according to the manufacturer's recommended fitting procedure described by Mountford, which includes the determination of baseline refractive error, average apical radius (R0), sagittal height or corneal elevation (sag), horizontal visible iris diameter (HVID), and interpretation of the post-fit corneal topography.[7] The elevation data of R0 and sag were determined over a chord length of 9.35 mm as directed for BE lenses. These data were entered into the BE Enterprises computer program to identify the trial lens base curve.

Subjects were instructed to wear the lenses overnight during sleep and to return the next morning within one hour of waking with the lenses in situ. If the first overnight trial was unsuccessful, a second trial was performed after a minimum of 72 hours. If an unacceptable topographic map showing small or decentered treatment zone was present after the eighth night of wear, the lens parameters were changed and another fitting test was performed after two weeks of discontinuing lens wear. The criteria to define a successful overnight trial were the following: presence of bull's-eye corneal topography pattern on the first and eighth nights, tendency to a bull's-eye pattern on the first night, and absence of keratitis or other complications that could affect the corneal response.

All study subjects were instructed to take appropriate care of the lenses, including regular disinfection and deproteinization using Unique Ph (Alcon Laboratories, Inc, Forth Worth, Texas, USA). Compliance with the maintenance and disinfection protocol was confirmed and reiterated at all follow-up visits.

At all follow-up visits, biomicroscopy was used to evaluate fit of the lenses, to assess the anterior segment, and to monitor the effects of lens wear. Sodium fluorescein patterns and alignment were evaluated with the lens in situ. Criteria for an acceptable symmetric fit were a bull's-eye fluorescein pattern with a 4- to 5-mm central bearing zone and a 2-mm wide mid-peripheral tear reservoir with a 1- to 2-mm edge lift. One to 2 mm of movement in a well-centered lens was imperative for an acceptable fit. Corneal staining was graded from zero through four, and the proportion of area covered with stain within each of five zones (central, nasal, temporal, inferior, and superior) also was evaluated.

• **CORNEAL TOPOGRAPHY AND TOMOGRAPHY:** Central anterior corneal curvature was measured using the Medmont corneal topographer E300 version 3.6 (Medmont International Pty, Ltd., Victoria, Australia). The Medmont corneal topographer uses a 32-ring small placido cone with more than 15,000 measurement points. At baseline, four optimal images of each eye with a score of more than 99, based on optimal centering, focusing, and no eye movement during acquisition, were captured automatically and were averaged. Parameters obtained included HVID, R0, corneal eccentricity (e), sag, flat keratometry (flat k), steep keratometry (steep k), and the difference in apical corneal power between baseline and the day one and day eight follow-up visits using axial difference maps. After lens removal at each follow-up visit, the axial, refractive, and tangential difference maps were obtained for analysis of refractive changes, treatment zone diameter, and lens position, respectively. Topographic patterns defined by the manufacturer were used to determine the success of the fitting test. A bull's-eye pattern indicated an ideal corneal shape change corresponding to the desired refractive response. A smiling face pattern indicated an inadequate corneal response corresponding to a flat fit. The presence of a central island indicated a steeper fit than desired. Other patterns deemed inadequate were a smiling face with a fake central island, a frowning face, and central divots.

The bull's-eye pattern indicates ideal apical clearance between the BE lens and cornea that results in a large consistent spherical treatment zone. Ideally, this treatment zone should match the photopic pupil diameter. This treatment zone appears as a deep blue pool centered over the corneal apex on axial curvature difference maps. All patients in this study obtained a bull's-eye topographic pattern. In the cases that did not achieve the bull's-eye pattern initially, the base curve of the trial lens was altered as recommended by the fitting software. A retrial was performed only after the cornea achieved normal curvature.

All patients were classified as good candidates for the orthokeratology fitting test based on the following relationship: therapy target − BE retainer potential (indicated by adjustment value <-1.00 D or any positive value). Corneal tomography was performed using the Orbscan IIz (Bausch & Lomb, Rochester, New York, USA). One map was obtained at baseline and after the first and eighth overnight orthokeratology fitting test. The Orbscan IIz provides anterior and posterior corneal elevation maps and optical pachymetry based on Scheimpflug slit-scanning technology.

The numerical values of the highest and lowest points corresponding to the posterior float map were recorded, in addition to the nasal, central, and temporal pachymetry. Average nasal and temporal pachymetry values were calculated between 5 to 7 mm from the corneal center, corresponding to the corneal mid-periphery.

Aberrometry. Ocular aberrometry was performed to gain an understanding of the optical effects of the change in corneal shape induced by orthokeratology. Ocular aberra-

TABLE 1. Mean and Pattern Deviation of the Measurements of Apical Radius, Sagittal Height, Eccentricity, and Keratometry from the Medmont Corneal Topographer in 26 Eyes That Underwent Orthokeratology

	Baseline	Night 1	Night 8	*P* value
R0 (mm)	7.82 ± 0.25	8.00 ± 0.25	8.20 ± 0.24	.001*
Sag (mm)	1.50 ± 0.05	1.50 ± 0.05	1.50 ± 0.05	.279
e (mm)	0.69 ± 0.17	0.46 ± 0.24	0.30 ± 0.21	.001*
steep K (D)	44.17 ± 1.11	43.18 ± 1.11	42.28 ± 1.08	.001*
flat K (D)	43.01 ± 1.21	42.06 ± 1.08	41.44 ± 1.18	.001*

D = diopters; e = corneal eccentricity; flat K = flat keratometry; R0 = apical curvature radius; Sag = corneal sagittal height; steep K = steep keratometry;

Night 1 denotes pachymetry after the first night of lens wear.

Night 8 denotes pachymetry after the eight night of lens wear.

*Denotes statistical significance.

TABLE 2. Mean and Pattern Deviation of the Measurements in Millimeters of Higher and Lower Elevation Points of the Posterior Float Map from Orbscan IIz Corneal Tomography in 26 Eyes That Underwent Orthokeratology

Posterior Float	Baseline	Night 1	Night 8	*P* value
Higher elevation point	0.03 ± 0.01	0.03 ± 0.01	0.03 ± 0.01	.576
Lower elevation point	−0.05 ± 0.01	−0.04 ± 0.01	−0.05 ± 0.01	.235

Night 1 denotes pachymetry after the first night of lens wear.

Night 8 denotes pachymetry after the eight night of lens wear.

tions were measured using the LADARWave Hartmann-Shack aberrometer (Alcon Laboratories, Inc). The root mean square (RMS) values of the normalized Zernike polynomials were to used analyze change in ocular aberrations. All wavefront data are presented for a 6.5-mm pupil diameter and correspond to the Optical Society of America standards for reporting optical aberrations.[21]

Measurements were obtained approximately 30 minutes after instillation of one drop of 1% tropicamide. All measurements were performed by an experienced examiner (I.G.S.) who ensured the patients' line of sight was coaxial to the optical axis and fixation target of the aberrometer. The subjects were instructed to blink once and remain still, and five images were acquired after stabilization of the tear film as seen on the sensor spot pattern (generally within two seconds after blinking).

Data from the five maps were averaged automatically and subsequently were analyzed for changes between baseline and the first and eighth nights after orthokeratology. Total aberrations (total RMS), HOAs (HOA RMS), lower-order aberrations (defocus-Z4 and astigmatism-Z3+Z5), coma RMS (Z7+Z8), and spherical aberration RMS (Z12) values were analyzed. Horizontal (Z8) and vertical (Z7) coma values were analyzed separately for right and left eyes.

Statistical Analysis. Data were analyzed for each patient's eye independently using Microsoft Excel 2000 version 9.0.2720 (Microsoft Corp, Redmond, Washington, USA). Spherical equivalent (SE) was analyzed using the Student *t* test. A *P* value less than .001 was considered statistically significant.

Corneal pachymetry, keratometry, R0, sag, corneal eccentricity, and wavefront aberrations were compared at baseline, night one, and night eight using the repeated-measures analysis of variance. The Bonferroni multiple comparative test was used to determine pair-wise differences: baseline × night one, baseline × night eight, and night one × night eight. The mixed linear model, with a Toeplitz heterogeneous variance–covariance structure, was used to perform the comparative analysis of horizontal and vertical coma changes between right and left eyes of all patients. The reduction in myopia was defined as the reduction in defocus immediately after the eighth night measured using the LADARWave aberrometer (Alcon Laboratories Inc, Orlando, Florida, USA). A *P* value less than .05 was considered statistically significant.

RESULTS

THE MEAN AGE OF THE PATIENTS WAS 31.0 ± 8.43 YEARS (range, 14 to 52 years). Before orthokeratology, 30.7% of the patients had an UCVA between 20/200 and 20/400, 42.2% between 20/150 and 20/100, and 26.9% between 20/60 and 20/40. At the end of the night eight of BE lens wear, 100% of patients had an UCVA equal to or better

TABLE 3. Corneal Pachymetry in Micrometers at Nasal, Central, and Temporal Locations in 26 Eyes That Underwent Orthokeratology

	Nasal	Central	Temporal
Baseline	631.84 ± 25.15	527.84 ± 27.09	590.74 ± 23.89
Night 1	638.37 ± 30.25	531.00 ± 28.93	604.32 ± 31.19
Night 8	635.47 ± 30.78	530.12 ± 24.24	602.47 ± 26.74

Night 1 denotes pachymetry after the first night of lens wear.
Night 8 denotes pachymetry after the eight night of lens wear.

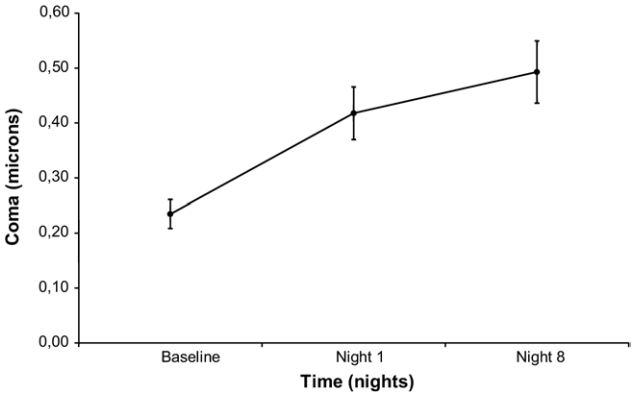

FIGURE 2. Graph showing the change in coma during the orthokeratology fitting test (n = 26 eyes; $P < .001$).

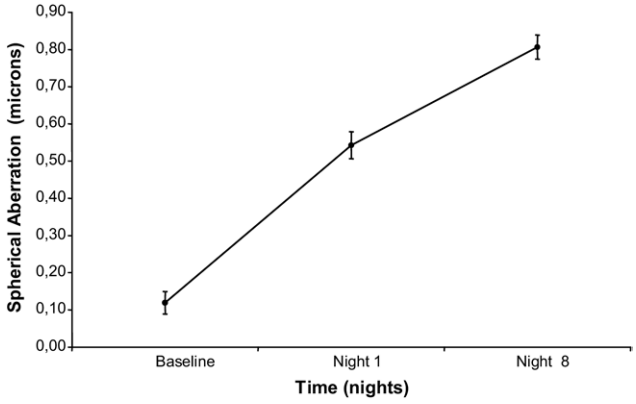

FIGURE 3. Graph showing the change in spherical aberration during the orthokeratology fitting test (n = 26 eyes; $P < .001$).

than 20/30, of which 69.2% saw 20/20 or better. The mean UCVA changed from +0.90 ± 0.31 logarithm of minimum angle of resolution units (20/160 Snellen) at baseline examination to +0.04 ± 0.09 logarithm of minimum angle of resolution units (20/20 Snellen) after orthokeratology. The BSCVA at baseline was 20/15 in 38.46% of the patients, 20/20 in 57.69% of the patients, and 20/25 in 3.84% of the patients. After the orthokeratology fitting test, the BSCVA was 20/15 in 23.00% of the patients, 20/20 in 65.38% of the patients, and 20/25 in 11.50% of the patients.

The mean baseline SE ranged from −1.00 to −4.25 D. The SE changed from −2.24 ± 0.98 D at baseline to 0.15 ± 0.76 D after orthokeratology ($P < .001$). There were statistically significant changes from baseline to night one and night eight in R0, steep k, flat k, and e ($P = .001$; Table 1). There was no statistically significant change in back surface elevation in the highest point ($P = .576$) or the lowest point ($P = .235$; Table 2).

Significant changes in central and nasal pachymetry between baseline and night one, baseline and night eight, and between night one and night eight were not observed. There was a 13.58-μm increase in temporal corneal thickness from baseline to the first night, and no differences between the first and eighth nights ($P = 1.000$; Table 3).

The mean total RMS decreased from 3.90 ± 1.22 μm at the baseline examination to 3.32 ± 1.22 μm after night one to 2.63 ± 1.20 μm after night eight. There was a statistically significant increase of HOA RMS from 0.42 ± 0.16 μm at the baseline examination to 0.81 ± 0.24 μm after night one ($P = .006$) to 1.04 ± 0.24 μm after night eight ($P = .004$). Figure 2 plots the increase of coma (Z7+Z8) from baseline through the follow-up period. Orthokeratology induced positive spherical aberration in all eyes. Figure 3 plots the increase of spherical aberration (Z12) from baseline through the follow-up period.

Analysis of the right and left eyes separately shows a distinct pattern for horizontal coma [Z8] (Figure 4). Horizontal coma increased in a positive direction in right eyes and in a negative direction in left eyes ($P < .001$; Figure 4). Figures 5 and 6 represent the Zernike plot of the right and left eyes, respectively. There was no statistically significant difference in vertical coma (Z7) between eyes. Two patients experienced central corneal erosion (Grade 4 staining) on night one after (non-recommended) extended overnight and daily use (12 hours). The patients were instructed to discontinue lens wear until the epithelium healed completely and the orthokeratology lens was refitted after one week.

DISCUSSION

A NUMBER OF STUDIES HAVE REPORTED THE EFFECTIVENESS of modern orthokeratology using a variety of different designs of reverse-geometry lenses.[22–24] The results of our

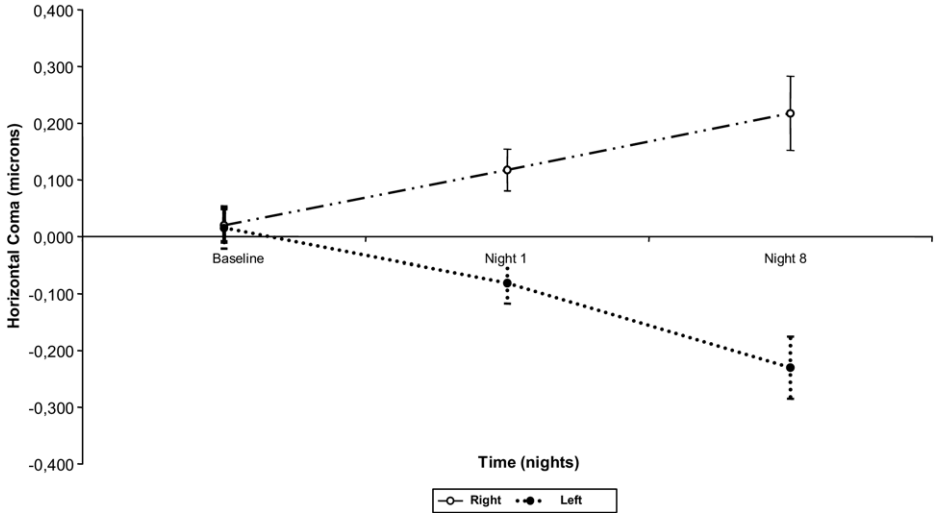

FIGURE 4. Graph showing the change in horizontal coma for right and left eyes during the orthokeratology fitting test (n = 26 eyes; $P < .001$).

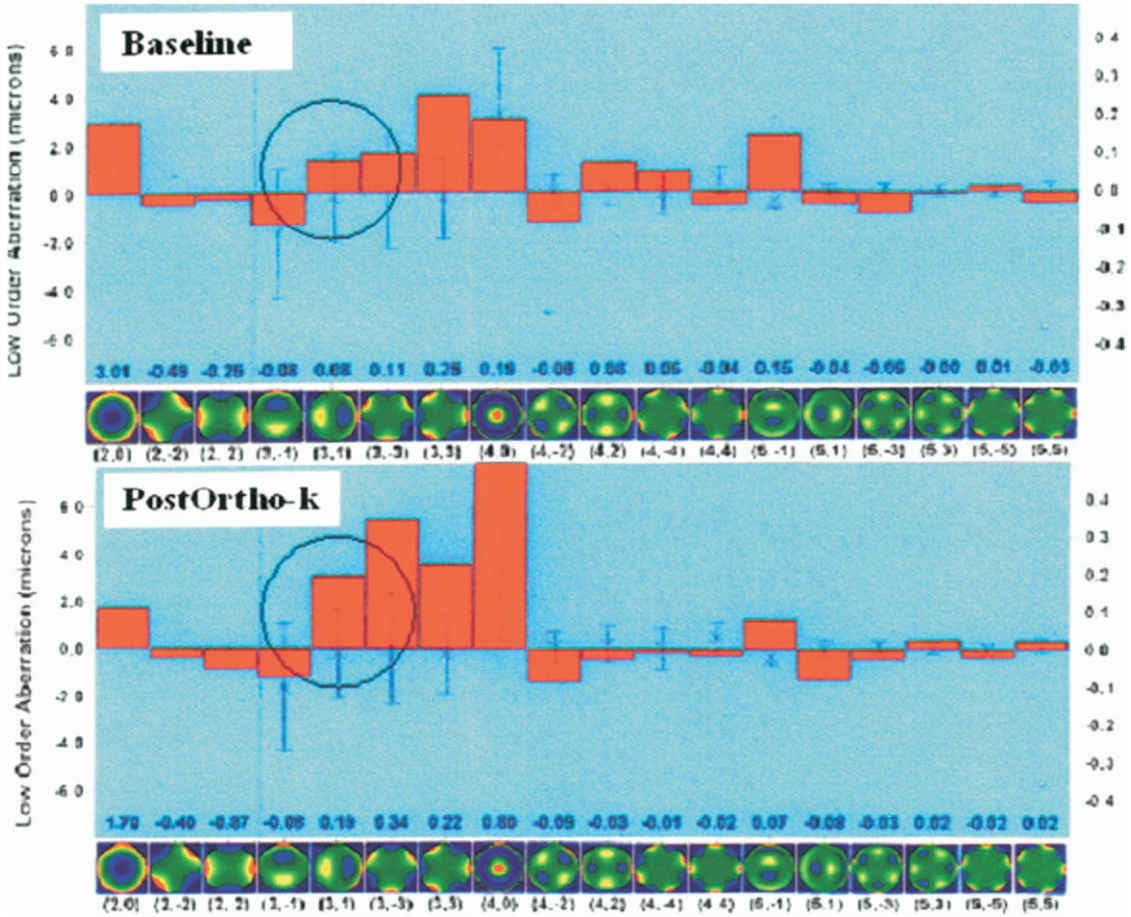

FIGURE 5. (Top) Baseline and (Bottom) post-orthokeratology Zernike plot of a right eye showing the increase of coma in the positive direction.

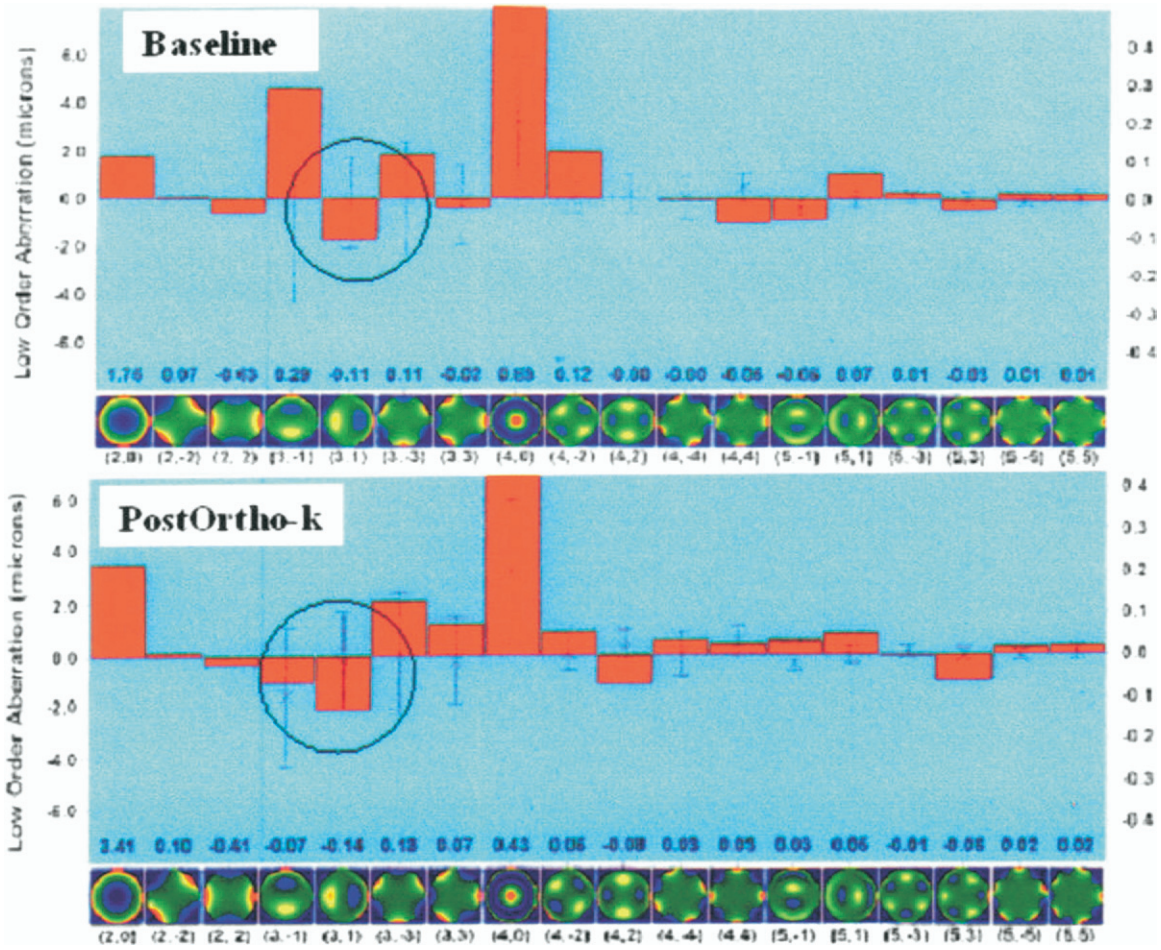

FIGURE 6. (Top) Baseline and (Bottom) post-orthokeratology Zernike plot of a left eye showing the increase of coma in the negative direction.

study show that the reduction in myopia by central corneal flattening and related improvement of UCVA occurred rapidly during orthokeratology fitting test with the BE lens. However, there were also associated changes in lower-order aberrations and HOAs and corneal thickness.

The refractive outcomes from this study concur with those of Alharbi and Swarbrick,[12] who reported a mean refractive change in SE of 2.63 D and improvement in the mean UCVA from 20/130 at baseline examination to 20/15 after orthokeratology in 18 eyes using the BE lens. We found a change of 2.39 D with an improvement in UCVA from 20/160 at baseline examination to 20/20 after orthokeratology.

The corneal topography changes seen in our study support the work of others[9,10,22] that elliptical form reorganization causes the refractive changes during overnight orthokeratology. For example, the reduction in R0, keratometry, and eccentricity all indicate that the cornea became flatter after orthokeratology (Table 1). Just one night of overnight orthokeratology lens wear induced significant changes in corneal curvature, myopia correction, and UCVA. These results support previous conclusions[23,25] that the corneal remodeling occurs very early during orthokeratology.

However, our findings contradict those of Owens and associates, who reported significant flattening of the posterior corneal surface.[14] In all cases, we found no changes in posterior corneal curvature after orthokeratology. This difference may be the result of the methods used to measure posterior curvature changes between studies. We used a tomography system that directly measures the posterior cornea, whereas Owens and associates used an indirect method based on the subjective measurement of arc length using Purkinje images.[14] Based on our findings, it seems that the posterior cornea is not modified during the initial period of overnight orthokeratology with the BE lens. There is increasing clinical evidence that the effect of orthokeratology is achieved by the sudden remodeling of the anterior layers,[10] rather than changes in corneal thickness. Some have theorized that localized differences in the tear film thickness under the contact lenses cause positive and negative pressure gradients that reduce corneal thickness and flatten it centrally, yet thicken the corneal mid-periphery.[12] In our short-term

study, contrary to the results of Alharbi and Swarbrick,[12] no reduction in central thickness was observed, which is likely related to induced overnight corneal edema (Table 3). However, we did find a significant increase in corneal pachymetry at the temporal mid-periphery immediately after night one that remained after night eight.

The underlying cellular and structural basis of the observed stromal thickness at the corneal mid-periphery have yet to be elucidated. It is possible that adaptation of the epithelium does occur. Some have speculated that the thickness is the result of residual stromal edema induced in some way by negative pressure generated under the reverse-curve orthokeratology lenses.[14] Alharbi and associates recently reported an unusual pattern of induced corneal edema after overnight orthokeratology wear.[26] In eyes that underwent overnight orthokeratology, Alharbi and associates found edema at the corneal mid-periphery, yet central corneal edema was significantly lower than that in controls eyes with no lenses.[26] This unusual edematous pattern has been confirmed by other authors.[27]

The correlation of corneal changes to induced optical aberrations allows an understanding of the effect of corneal remodeling on the optical system of the eye.[19] In this study, we found a significant reduction in total RMS resulting from the reduction in defocus (Z4) and an increase in HOA RMS after overnight orthokeratology. These observations are similar to those reported after radial keratotomy,[28,29] photorefractive keratectomy,[30,31] and laser in situ keratomileusis.[32,33] For example, we found significant increases in HOA, such as coma (Z7+Z8) and spherical aberration (Z12), even in eyes with a UCVA of 20/20 after orthokeratology. For the entire study population, mean coma (Z7+Z8) nearly doubled and mean spherical aberration (Z12) increased by 800%.

The apparent directionality of horizontal coma (Z8) observed between the right and left eyes represents a faster temporal wavefront in both eyes. Corneal topography shows that this is the result of a relative flattening of the temporal cornea after orthokeratology. Using corneal topography on a large sample of eyes that underwent orthokeratology, Yang and associates found that decentration of more than 0.50 mm mainly occurs in the temporal aspect of the cornea.[34] Although our biomicroscopy findings indicated that all lenses were centered adequately, the presence of horizontal coma indicates that a degree of subclinical decentration occurred. The lack of significant induction of vertical coma (Z7) indicates that vertical lens decentration did not occur. The temporal flattening induced by subclinical lens decentration did not seem to affect the outcomes of the treatment. We believe that the increase in temporal thickness was the result of greater negative pressure under the temporal aspect of the reverse-curve lens caused by a slight temporal displacement. However, Hiraoka and associates reported the induction of negative vertical coma (Z7) because of superior displacement using a different type of orthokeratology lens.[17] Perhaps the variation in coma (Z7+Z8) between studies is the result of the type of reverse-geometry design used in the lens.

Excellent centration during the orthokeratology fitting is imperative to avoid inducing HOAs, such as coma. It recently was demonstrated that various aberrations can affect visual performance differently.[35] For example, spherical aberration (Z12) can compensate for defocus (Z4), producing a less aberrated point spread function. Consequently, not all HOAs are deleterious to visual performance.[36] Bearing in mind the compensatory effect of spherical aberration, it is imperative to induce little to no asymmetrical aberrations, particularly coma in patients fitted with orthokeratology, to maintain visual quality.

Berntsen and associates reported reduced low-contrast BCVA as a result of increased HOAs during corneal reshaping with CRT.[16] Before the present study, we had no knowledge of whether there was a correlation between the induced HOAs resulting from orthokeratology and uncorrected visual function. Hence, we measured only high-contrast visual acuity. Further studies are necessary to evaluate the impact of induced HOAs on UCVA and mesopic visual quality.

Ocular wavefront analysis is necessary for future design, development, and improvement in fitting techniques for orthokeratology lenses. We believe that different lens design can induce different combinations of HOAs. Thus, it is important to determine how this method of corneal reshaping and orthokeratology lens models can be refined to maximize visual performance.

The two cases of adverse corneal erosion observed during this short-term trial healed without sequelae. There have been a number of reports of more serious corneal complications, such as Acanthamoeba and Pseudomonas infection, that warrant longer-term and larger-scale studies to assess this risk.

In summary, myopia reduction with rapid central flatening and improvement of the UCVA was obtained in the short-term with the BE overnight orthokeratology lens. An increase in HOAs was observed, particularly spherical aberration (Z12) and coma (Z7+Z8). There was also an increase in the temporal thickness, induction of positive horizontal coma (Z8) in the right eyes and negative in the left eyes, and temporal flattening of the cornea likely related subclinical decentration area.

THE AUTHORS INDICATE NO FINANCIAL SUPPORT OR FINANCIAL CONFLICT OF INTEREST. INVOLVED IN DESIGN OF STUDY (I.G.S., C.L., A.L.H.L.); conduct of study and collection (I.G.S., E.M., M.M.L.); management (C.L., A.L.H.L.); analysis (I.G.S., P.S.); and interpretation of the data and preparation, review, or approval of the manuscript (I.G.S., M.R.C., P.S., C.L., A.L.H.L.). The research protocol was

approved by the UNIFESP/EPM Medical Research Ethics Committee and was conducted in accordance with the tenets of the Declaration of Helsinki. Informed consent was obtained from all subjects.

REFERENCES

1. Jessen G. Orthofocus techniques. Contacto 1962;6:200–204.
2. Pearson R. The concept of orthokeratology in which corneal lenses are fitted in order to temporarily reduce or eliminate a refractive error. Cont Lens Anterior Eye 2000;23:67.
3. Binder PS, May CH, Grant SC. An evaluation of orthokeratology. Ophthalmology 1980;87:729–744.
4. Coon LJ. Orthokeratology. Part II: Evaluating the Tabb method. J Am Optom Assoc 1984;55:409–418.
5. Polse KA, Brand RJ, Schwalbe JS, Vastine DW, Keener RJ. The Berkeley Orthokeratology Study, Part II: Efficacy and duration. Am J Optom Physiol Opt 1983;60:187–198.
6. Dave T, Ruston D. Current trends in modern orthokeratology. Ophthalmic Physiol Opt 1998;18:224–233.
7. Mountford J. An analysis of the changes in corneal shape and refractive error induced by accelerated orthokeratology. Int Contact Lens Clin 1997;24:128–143.
8. Sridharan R, Swarbrick H. Corneal response to short-term orthokeratology lens wear. Optom Vis Sci 2003;80:200–206.
9. Nichols JJ, Marsich MM, Nguyen M, Barr JT, Bullimore MA. Overnight orthokeratology. Optom Vis Sci 2000;77:252–259.
10. Swarbrick HA, Wong G, O'Leary DJ. Corneal response to orthokeratology. Optom Vis Sci 1998;75:791–799.
11. Swarbrick HA. Orthokeratology review and update. Clin Exp Optom 2006;89:124–143.
12. Alharbi A, Swarbrick HA. The effects of overnight orthokeratology lens wear on corneal thickness. Invest Ophthalmol Vis Sci 2003;44:2518–2523.
13. Choo J, Caroline P, Harlin D. How does the cornea change under corneal reshaping contact lenses? Eye Contact Lens 2004;30:211–213; discussion 218.
14. Owens H, Garner LF, Craig JP, Gamble G. Posterior corneal changes with orthokeratology. Optom Vis Sci 2004;81:421–426.
15. Mao XJ, Lu F, Qu J. Effects after orthokeratology on corneal topography and monochromic wavefront aberration. Zhonghua Yan Ke Za Zhi 2004;40:471–473.
16. Berntsen DA, Barr JT, Mitchell GL. The effect of overnight contact lens corneal reshaping on higher-order aberrations and best-corrected visual acuity. Optom Vis Sci 2005;82:490–497.
17. Hiraoka T, Matsumoto Y, Okamoto F, et al. Corneal higher-order aberrations induced by overnight orthokeratology. Am J Ophthalmol 2005;139:429–436.
18. Joslin CE, Wu SM, McMahon TT, Shahidi M. Higher-order wavefront aberrations in corneal refractive therapy. Optom Vis Sci 2003;80:805–811.
19. Joslin CE, Wu SM, McMahon TT, Shahidi M. Is "whole eye" wavefront analysis helpful to corneal refractive therapy? Eye Contact Lens 2004;30:186–188.
20. Lowe R. Corneal refractive therapy, uncorrected visual acuity, and "E" values: personal experiences. Eye Contact Lens 2004;30:238–241.
21. Thibos LN, Applegate RA, Schwiegerling JT, Webb R. Standards for reporting the optical aberrations of eyes. J Refract Surg 2002;18:S652–S660.
22. Rah MJ, Jackson JM, Jones LA, Marsden HJ, Bailey MD, Barr JT. Overnight orthokeratology: preliminary results of the Lenses and Overnight Orthokeratology (LOOK) study. Optom Vis Sci 2002;79:598–605.
23. Soni PS, Nguyen TT, Bonanno JA. Overnight orthokeratology: visual and corneal changes. Eye Contact Lens 2003;29:137–145.
24. Tahhan N, Du Toit R, Papas E, Chung H, La Hood D, Holden AB. Comparison of reverse-geometry lens designs for overnight orthokeratology. Optom Vis Sci 2003;80:796–804.
25. Soni PS, Nguyen TT, Bonanno JA. Overnight orthokeratology: refractive and corneal recovery after discontinuation of reverse-geometry lenses. Eye Contact Lens 2004;30:254–262.
26. Alharbi A, La Hood D, Swarbrick HA. Overnight orthokeratology lens wear can inhibit the central stromal edema response. Invest Ophthalmol Vis Sci 2005;46:2334–2340.
27. Wang J, Fonn D, Simpson TL, Sorbara L, Kort R, Jones L. Topographical thickness of the epithelium and total cornea after overnight wear of reverse geometry rigid contact lenses for myopia reduction. Invest Ophthalmol Vis Sci 2003;44:4742–4746.
28. Applegate RA, Hilmantel G, Howland HC. Corneal aberrations increase with the magnitude of radial keratotomy refractive correction. Optom Vis Sci 1996;73:585–589.
29. Oliver K, Hemenger R, Corbett M, et al. Corneal optical aberrations induced by photorefractive keratectomy. J Refract Surg 1997;13:246–254.
30. Oshika T, Klyce SD, Applegate RA, Howland HC, El Danasoury MA. Comparison of corneal wavefront aberrations after photorefractive keratectomy and laser in situ keratomileusis. Am J Ophthalmol 1999;127:1–7.
31. Schwiergerling J, Snyder RW. Corneal ablation patterns to correct for spherical aberration in photorefractive keratectomy. J Cataract Refract Surg 2000;26:214–221.
32. 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.
33. Marcos S, Barbero S, Llorente L, Merayo-Lloves J. Optical response to LASIK surgery for myopia from total and corneal aberration measurements. Invest Ophthalmol Vis Sci 2001;42:3349–3356.
34. Yang X, Gong XM, Dai ZY, Wei L, Li SX. Topographical evaluation on decentration of orthokeratology lenses. Zhonghua Yan Ke Za Zhi 2003;39:335–338.
35. Applegate RA, Sarver EJ, Khemsara V. Are all aberrations equal? J Refract Surg 2002;18:S556–S562.
36. Applegate RA, Marsack JD, Ramos R, Sarver EJ. Interaction between aberrations to improve or reduce visual performance. J Cataract Refract Surg 2003;29:1487–1495.