AMERICAN ACADEMY® OF OPHTHALMOLOGY
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Influence of Ocular Wavefront Aberrations on Axial Length Elongation in Myopic Children Treated with Overnight Orthokeratology

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Purpose: To determine ocular optical parameters that affect axial length elongation in myopic children undergoing overnight orthokeratology.

Design: Prospective, noncomparative study.

Participants: Fifty-nine subjects who met the inclusion criteria were enrolled in this study.

Methods: Axial length and ocular wavefront aberration were assessed before and 1 year after the start of orthokeratology. Corneal topography was performed, and then corneal multifocality was calculated for a 4-mm pupil. After evaluating simple correlations between axial elongation and optical parameters, multiple linear regression analysis was performed to identify explanatory variables with a statistically significant contribution to axial elongation.

Main Outcome Measures: Axial length and ocular wavefront aberration before and 1 year after the start of orthokeratology.

Results: Fifty-five subjects completed the 1-year follow-up examinations. At baseline, their age ranged from 7.2 to 12.0 years. The manifest spherical equivalent refractive error ranged from −3.50 to −0.75 diopters. The mean axial length significantly increased from 24.20 mm at baseline to 24.43 mm 1 year after treatment. The axial elongation showed significant simple correlations with the change in C_2^0, change in second-order aberration, change in coma-like aberration, change in spherical-like aberration, change in total higher-order aberrations, change in corneal multifocality, baseline age, and baseline spherical equivalent refractive error, but not C_4^0. Multiple linear regression analysis showed that the change in coma-like aberration was the most relevant variable.

Conclusions: Asymmetric corneal shapes, rather than concentric and radially symmetric shapes, have a considerable effect on retardation of axial elongation, suggesting that the inhibitory effect of orthokeratology on myopia progression is caused by mechanisms other than the reduction in peripheral hyperopic defocus. *Ophthalmology 2014;■:1–8 © 2014 by the American Academy of Ophthalmology.*

Uncorrected refractive error is the second leading cause of blindness worldwide.[1,2] According to previous epidemiologic studies, the prevalence of myopia is estimated to be between 20% and 50% in Europe,[3] Oceania,[4] and the United States,[5,6] and a higher prevalence has been reported in some Asian countries.[7–9] In addition, a number of studies indicate that the prevalence of not only common but also high myopia has increased significantly over recent years.[8–11] Of particular concern is the fact that patients who are initially diagnosed at a younger age are more likely to develop severe myopia-associated complications later in life, such as glaucoma, chorioretinal degeneration, and retinal detachment.[10,12] It is also known that the associated risk of developing these complications increases with the severity of myopia and axial length elongation.[6,13] Myopia is a significant public health problem, which places a substantial socioeconomic burden on society.[14,15] Thus, the prevention or retardation of myopic progression is of notable significance.

In recent years, numerous studies have confirmed the potential of overnight orthokeratology for slowing the progression of myopia.[16–21] Among them, a noteworthy 2-year randomized clinical trial with a sophisticated design was conducted by Cho and Cheung[19] in myopic children aged 6 to 10 years, which showed that subjects wearing orthokeratology lenses experienced a slower increase in axial elongation by 43% than that of subjects wearing single-vision glasses. Although the mechanism underlying the role of orthokeratology in retarding axial length elongation has not been elucidated, almost all researchers supported the hypothesis that axial length elongation is suppressed by orthokeratology-induced improvement in peripheral hyperopic

Published by Elsevier Inc.
http://dx.doi.org/10.1016/j.ophtha.2014.07.042
ISSN 0161-6420/12

defocus. This theory is based on the evidence that among all the factors that affect visual inputs, peripheral defocus plays an important role in the progression of axial myopia in primates[22,23] and humans.[24,25] Myopes, compared with emmetropes and hyperopes, usually have greater relative hyperopia in the periphery with respect to axial refraction.[24,25] This peripheral hyperopic retinal blur has been proposed to trigger axial elongation and myopia progression ("peripheral refraction theory").[22,23,26,27] Orthokeratology lenses reshape corneas with a flattened central area and steeper midperiphery, leading to a reduction in relative peripheral hyperopia in myopic eyes, which is considered to reduce the visual feedback for eye elongation, resulting in slower myopic progression.[28−30] This type of corneal morphology, with the annular ring of steepened area in the midperiphery surrounding the central flattened cornea (oblate-shaped cornea), usually creates large amounts of higher-order aberrations, notably positive spherical aberration.[31,32] If the aforementioned hypothesis regarding the retardation of myopia progression is valid, there is a strong possibility that the inhibitory effect of orthokeratology on axial length elongation in myopic children is associated with changes in optical quality, particularly positive spherical aberration.

It is important to understand the role of orthokeratology in slowing myopia progression; however, no study has investigated the relationship between axial elongation and optical quality changes. If the primary factor that regulates myopia progression in children treated with orthokeratology can be clarified, the method could be optimized to be more effective, and the rationale could be applied to other modalities such as spectacles and contact lenses. Therefore, we conducted this prospective study to explore the relationship between axial elongation and optical properties and to determine the optical parameters that affect axial elongation in myopic children wearing orthokeratology lenses.

Methods

This study was conducted at Kakita Eye Clinic between December 2010 and January 2013. Fifty-nine patients (22 boys and 37 girls) who met the inclusion criteria (Table 1) were enrolled. The study was conducted in accordance with the tenets of the Declaration of Helsinki and approved by the Ethics Committee of Kakita Eye Clinic. Written informed consent was obtained from all the participants and their guardians after an explanation of the nature and possible consequences of the study.

The orthokeratology lenses used in this study were 4-zone reverse geometry lenses (αORTHO-K; Alpha Corp., Nagoya, Japan), with a nominal Dk of 104×10^{-11} (cm^2/s) (ml O_2/ml×mmHg) (ISO/Fatt). The patients were fitted with the lenses according to the manufacturer's fitting recommendations. After lens dispensing, the patients were advised to wear their orthokeratology lenses every night for at least 7 consecutive hours.

The patients returned for follow-up examinations every 3 months and underwent slit-lamp examination in case of an adverse event. The fit of the orthokeratology lens, visual acuity, and refraction were evaluated at each visit. Throughout the course of the study, the lens design was modified in case of reduction in visual acuity by more than 0.30 logarithm of the minimum angle of resolution (logMAR) units or poor topographic changes.

The axial length was evaluated by noncontact optical biometry (IOLMaster; Carl Zeiss Meditec, Dublin, CA) by a single examiner before and 1 year after orthokeratology therapy commenced. At each visit, 10 successive measurements were taken, and their average was used as a representative value. The patients were requested to undergo the examinations from 7 to 10 hours after removal of the lens, and the measurements were obtained between 3 and 6 o'clock in the afternoon to minimize the influence of diurnal variation.

Ocular higher-order aberrations for a 4-mm pupil were measured with a Hartmann−Shack wavefront analyzer (KR-9000 PW; Topcon Co., Tokyo, Japan) through a natural pupil, without the use of dilating drugs. Corneal topography was performed simultaneously by using a Placido disk attached to the Hartmann−Shack aberrometer.[33] The acquired data sets were expanded with the normalized Zernike polynomials. The magnitudes of the coefficients of the Zernike polynomials were represented as the root mean square (RMS; in micrometers) and used to indicate wavefront aberrations. The second-order aberration corresponds to the conventional refractive error (sphere and cylinder), which can be corrected by spherocylindrical lenses, whereas third- and higher-order aberrations cannot. The RMS of the third-order Zernike coefficients was used to denote coma-like aberration, and the RMS of the fourth-order coefficients was used to indicate spherical-like aberration. Total higher-order aberrations were calculated as the RMS of the third- and fourth-order coefficients. In addition, we investigated each Zernike coefficient: C_2^{-2}, C_2^0, C_2^2, C_3^{-3}, C_3^{-1}, C_3^1, C_3^3, C_4^{-4}, C_4^{-2}, C_4^0, C_4^2, and C_4^4. The measurements were repeated at least 5 times for each eye, and the 3 best-focused images were selected and averaged. The averaged values were used for subsequent analyses.

Table 1. Inclusion Criteria

1. Age 7−12 yrs at baseline
2. No history of orthokeratology or contact lens use
3. Noncycloplegic autorefraction (spherical equivalent) from −4.00 to −0.75 D in both eyes
4. Astigmatism (noncycloplegic autorefraction) ≤1.50 D in both eyes
5. Anisometropia (noncycloplegic autorefraction) ≤1.50 D
6. Corrected distance visual acuity ≥0.00 logMAR units in both eyes (Snellen equivalent to 20/20)
7. No strabismus by a cover-uncover test with or without refractive correction
8. Birth weight ≥1500 g
9. No known ocular, systemic, or neurodevelopmental deviations that might affect refractive development
10. No use of medications that might affect refractive development

D = diopter; logMAR = logarithm of the minimum angle of resolution.