Validity of Axial Length Measurements for Monitoring Myopic Progression in Orthokeratology

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PURPOSE. To investigate the short-term effect of orthokeratology (ortho-k) lens wear on the anterior segment length for validating the use of axial length for monitoring myopic progression after ortho-k treatment.

METHODS. Thirty-seven and 39 subjects (ages: 7–10 years) were randomly assigned to wear ortho-k and single-vision spectacles, respectively. Central corneal thickness (CCT), anterior chamber depth (ACD), crystalline lens thickness (LT), and anterior segment length (ASL: summation of CCT, ACD, and LT) were measured before and 6 months after the treatment under cycloplegia. Changes in these parameters were evaluated and compared between the two groups of subjects.

RESULTS. There were no significant between-group differences in the baseline data ($P > 0.37$). After 6 months of lens wear, in the ortho-k group, CCT was significantly reduced by 0.009 ± 0.009 mm ($P < 0.001$), whereas ACD and LT remained unchanged ($P > 0.15$). In the spectacle group, ACD was significantly increased by 0.01 ± 0.03 mm ($P = 0.008$), whereas CCT and LT remained unchanged ($P > 0.06$). In both groups of subjects, ASL did not appreciably change but axial length was significantly increased by 0.10 ± 0.10 mm and 0.20 ± 0.11 mm in the ortho-k and the spectacle groups, respectively ($P < 0.001$).

CONCLUSIONS. Eyeball elongation occurred in children wearing both ortho-k and single-vision spectacles. Since ASL was not affected by ortho-k treatment, axial length measured reflects the true growth of the eyeball and is a valid parameter for monitoring myopic progression in ortho-k treated eyes. (ClinicalTrials.gov number, NCT00962208.) (*Invest Ophthalmol Vis Sci.* 2013;54:1613–1615) DOI:10.1167/iovs.12-10434

Orthokeratology (ortho-k) has been shown to be effective in slowing myopic progression in children.[1-6] Because the refractive error is reduced after ortho-k treatment, myopic progression after ortho-k is commonly evaluated by change in axial length (AL). AL is the distance from the anterior cornea to the retina, that is, the anterior segment length (ASL) plus the vitreous chamber depth (VCD) and ASL is the summation of central corneal thickness (CCT), anterior chamber depth (ACD), and crystalline lens thickness (LT). In ortho-k, CCT is thinned and central corneal curvature is flattened.[7,8] These have led to some concerns that ortho-k may affect ACD, which in turn may affect the AL measurements.[9,10] It may imply that axial elongation in ortho-k–treated eyes may be underestimated (or the efficacy of myopic control may be overestimated) due to a possible decrease in ACD from ortho-k lens wear, and thus shorter AL, and misinterpreted as a slower myopic progression compared with non-ortho-k–treated eyes. However, since ACD is only one component of ASL, to investigate if AL measurements are affected by ortho-k lens wear, investigation should focus on the change in ASL rather than the change in ACD alone. The current short-term study aimed at investigating the validity of using AL for monitoring myopic progression after ortho-k treatment by comparing the changes in individual components of and the overall change in ASL in subjects undergoing ortho-k and those wearing single-vision spectacles over a period of 6 months.

METHODS

The short-term effect of ortho-k lens wear was analyzed by evaluating the changes in CCT, ACD, LT, ASL, and AL before and after the stabilization of the treatment, which is usually within 3 months after lens wear. We used the first 6 months of data from 78 subjects (ages: 7–10 years) participating in a randomized clinical trial on myopic control using ortho-k (ClinicalTrials.gov number, NCT00962208).[6] These subjects, who had a low to moderate amount of myopia (0.75–4.00 diopters [D]) and with-the-rule astigmatism (≤1.25 D), were randomly assigned to wear either ortho-k lenses or single-vision spectacles. For the ortho-k subjects, their refractive error was close to full correction such that they had good unaided vision (monocular unaided visual acuity better than 0.18 logMAR) and low refractive error (residual myopia/astigmatism not exceeding 0.50 D) after the stabilization of the treatment. The myopic control study followed the Declaration of Helsinki and was approved by the ethic committee of The Hong Kong Polytechnic University. Consent was obtained from all subjects and their parents when they enrolled in the myopic control study.

CCT, ACD, and LT were determined using an anterior segment tomographer (Pentacam, software version 1.14; Oculus, Wetzlar, Germany) after cycloplegia. The 25-scan mode was selected to facilitate image capturing in children. The first three good images captured were saved and the average data from the three images were used for data analysis. AL was determined using a commercial optical biometer (IOLMaster; Zeiss Humphrey, Dublin, CA). The first five readings with a difference of <0.02 mm and with signal-to-noise ratio above 3.5 were saved. The average was used for data analysis. All measurements were taken 30 minutes after instillation of one drop of 0.5% proparacaine, followed by one drop of 1.0% tropicamide, and one drop of 1.0% cycloplentolate, each drop 5 minutes apart. Pupil reaction and accommodation were checked prior to the tests to ensure full pupil

TABLE 1. Demographic Data and the Ocular Parameters of the 76 Subjects at the Baseline Visit

Variable	Ortho-k, $n = 37$	Control, $n = 39$
Age, y (range)	9 (7–10)	9 (7–10)
Sex	18F/19M	17F/22M
Spherical equivalent, D	−2.29 ± 0.74	−2.47 ± 0.94
Axial length, mm	24.52 ± 0.71	24.41 ± 0.87
Central corneal thickness, mm	0.576 ± 0.024	0.577 ± 0.032
Anterior chamber depth, mm	3.39 ± 0.21	3.36 ± 0.20
Lens thickness, mm	3.29 ± 0.19	3.31 ± 0.17
Anterior segment length, mm	7.25 ± 0.24	7.25 ± 0.26

TABLE 2. Changes in the Anterior Segment Components and Eyeball Length after 6 Months

Variable	Ortho-k, $n = 37$	Control, $n = 39$	P
Central corneal thickness, mm	−0.009 ± 0.009*	0.001 ± 0.008	*<0.001*
Anterior chamber depth, mm	−0.01 ± 0.04	0.01 ± 0.03*	*0.025*
Lens thickness, mm	0.01 ± 0.06	−0.02 ± 0.05	*0.018*
Anterior segment length, mm	0.00 ± 0.07	0.00 ± 0.06	0.917
Axial length, mm	0.10 ± 0.10*	0.20 ± 0.11*	*<0.001*

P: statistical significance on between-group difference using independent *t*-tests. Regular: statistically insignificant; italic: statistically significant.

* Changes were significantly different from zero (one-sample *t*-tests, $P < 0.05$).

dilation and relaxation of the ciliary muscles. Only data from the right eyes were reported.

Statistical Analysis

Except for age, distributions of the initial refractive error (spherical equivalent), CCT, ACD, LT, ASL, and AL and their changes were not significantly different from normal (Kolmogorov–Smirnov tests, $P > 0.41$). Therefore, nonparametric tests (χ^2 or Mann–Whitney U tests) were used to compare the differences in age and sex between the two groups at the baseline, whereas parametric tests (independent *t*-tests) were used to compare the initial refractive errors and ocular parameters in the two groups. Two-way repeated-measures ANOVAs were used to compare CCT, ACD, LT, ASL, and AL at baseline and the 6-month visits in the two groups of subjects. Independent *t*-tests were used if any significant main effect or interaction was found.

RESULTS

Data were excluded from two subjects in the control group because of poor image quality ($n = 1$) and missing data ($n = 1$). A total of 37 subjects (18 females and 19 males) and 39 participants (17 females and 22 males) were in the ortho-k and control groups, respectively. Table 1 shows the demographic data and the ocular parameters of these subjects. There were no significant differences in age, sex, refractive errors, or the ocular parameters between the two groups of subjects at the baseline visit ($P > 0.37$). The median age was 9 years and the initial mean ± SD spherical equivalent was −2.38 ± 0.84 D. Table 2 shows changes in CCT, ACD, LT, ASL, and AL during the study period. In the ortho-k group, CCT was significantly reduced by 0.009 ± 0.009 mm ($P < 0.001$), whereas ACD and LT remained unchanged ($P > 0.15$). In the control group, ACD was significantly increased by 0.01 ± 0.03 mm ($P = 0.01$), whereas CCT and LT remained unchanged ($P > 0.06$). However, ASL showed no changes ($P > 0.05$) in either group of subjects. AL significantly increased in both groups of subjects ($P < 0.001$) and the rate of axial elongation was faster in the control group (0.20 ± 0.11 mm) compared with that in the ortho-k group (0.10 ± 0.10 mm). Significant between-group differences in the changes in CCT, ACD, LT, and AL ($P < 0.02$) were observed, but not in ASL ($P = 0.92$).

DISCUSSION

Our results agreed with previous studies that CCT was thinned,[7,8] whereas ACD remained unchanged after ortho-k.[11,12] However, these studies did not investigate the effect of ortho-k on ASL. We found that ASL remained unchanged during 6 months of wearing ortho-k lenses compared with wearing single-vision spectacles. Previous studies on ocular biometry in

children mainly focused on corneal power, ACD, LT, VCD, and AL.[13–18] Although these studies have reported changes in each component of ASL, to our knowledge none actually analyzed overall change in ASL.

It is well known that changes in CCT, ACD, LT, and VCD in children can be related to the normal growth of the eyeball and, thus, affect the refractive status of the eye. Among these parameters, change in CCT stabilizes at the age of 3 years.[17,18] From the ages of 6 to 14 years, there is a mean increase of 0.73, 0.19, and 0.61 mm in AL, ACD, and VCD, respectively, and a mean decrease of 0.06 D, 0.07 mm, and 2.11 D in corneal power, LT, and crystalline lens power, respectively, in emmetropes.[13] That is, during emmetropization in young children, the eyeball continues to grow and the refractive status of the eye is compensated by change in the crystalline lens power rather than the change in corneal power to allow the eyes to remain emmetropic. Myopes tend to have longer AL, ACD, and VCD, but shorter LT than emmetropes and hyperopes.[14,15]

By deriving ASL from adding ACD to LT or subtracting VCD from AL using data available from previous literature,[1,2,13–16] we found that there was a small increase in ASL in children over time and longer ASL was associated with age, refractive error, and sex. Cross-sectional studies showed that ASL increased by 0.11 mm from 6 to 14 years of age.[16] The extent of change in ASL over time was minimal compared with the change in AL (1.15 mm). ASL was 0.2 mm longer in myopic children when compared to hyperopic children[14] and 0.1 mm longer in boys compared to girls.[15,16] Data from longitudinal studies also showed minimal increase in ASL over 2 years, from 0.02 mm in emmetropic children[13] to 0.06 mm in myopic children wearing single-vision spectacles[1] and 0.11 mm in those wearing single-vision soft lenses.[2] The effect of ortho-k on change in ASL was insignificant. The 2-year changes in ortho-k subjects were +0.06 mm in the LORIC study[1] and −0.01 mm in the CRAYON study.[2] In the current study, we found no significant changes in ASL in both the ortho-k and control subjects over a period of 6 months.

In this study, subjects in both groups showed axial elongation but they had a small but significantly different behavior in the change in ACD. The behavior in the changes in ACD and AL in the spectacle-wearing subjects followed normal growth in myopic eyes (i.e., ACD increased with axial elongation; ACD increased by 0.01 mm, whereas AL increased by 0.20 mm in 6 months). However, there was no change in ACD in ortho-k subjects despite the increase in AL.

It should be noted that a change in any individual component of ASL may affect the refractive power of the

eye. In theory, a 1-mm forward displacement of the crystalline lens into the anterior chamber can increase the myopia of the eye by 1.40 D, if all the other ocular components remain unchanged.[19] In an ortho-k–treated eye, the overall refractive change can be complicated because the treatment appears to affect all components of AL, including ASL. Thus, a change in corneal power in an ortho-k–treated eye may not necessarily reflect the overall change in the refractive power of the eye.[20] The current study focused only on the change in dimension and did not consider ocular power. Further studies are warranted to investigate the effect of the change in the ocular biometry on the refractive system of the eye after ortho-k. Future research on myopic control treatment based on axial elongation may also consider including the assessment of ASL and its individual components.

As mentioned earlier, there are concerns that myopic control effect using ortho-k may be overestimated due to the shortening of ACD, because of the backward displacement of the cornea or thinning of CCT with rigid lens wear leading to an apparent shortening of AL.[9,10] Despite the thinning of CCT, our results rejected this speculation in that we did not find any associated changes in ACD, LT, and ASL after the treatment.

In conclusion, our study showed that although ortho-k lens wear affected CCT, the change was negligible compared with the change in AL. The treatment itself did not affect the ACD, LT, and ASL; thus, AL is a valid parameter for monitoring myopic progression. Changes in ocular biometry during eyeball elongation are the result of the modification of growth in response to ortho-k lens wear.

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