Changes in optical biometry throughout childhood and adolescence for orthokeratology patients

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Research Article

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Abstract

Background

Orthokeratology has been shown to supress progressive myopia in some children. We examine the changes in optical biometry parameters in orthokeratology (Ortho-K) patients, in a retrospective longitudinal study at a tertiary eye care center in Ann Arbor, MI USA.

Methods

Optical biometry measurements obtained with the Lenstar LS 900 (Haag-Streit USA Inc, EyeSuite software version i9.1.0.0) were aggregated from 170 patients who had undergone Ortho-K for myopia correction between 5 and 20 years of age. Pre-intervention biometry measurements were compared with follow up measurements done 6–18 months after initiation of Ortho-K. Linear mixed models were used to quantify associations in biometry changes with age of intervention allowing for correlation between measurements on two eyes of the same patient.

Results

A total of 91 patients were included in the study. Axial length increased through the age of 15.7 ± 0.84 years for Ortho-K patients at our center. The growth curve in our Ortho-K population was comparable to previously published normal growth curves in Wuhan and Shandong populations. Corneal thickness and keratometry decreased at a stable rate regardless of age of intervention (-7.9 mm 95% CI [-10.2, -5.7], p < 0.001).

Conclusion

In our population, Ortho-K did not appear to slow axial length progression, despite showing a previously described reduction in corneal thickness. As Ortho-K has been shown to have varying effects that differ from individual to individual, it continues to be important to reassess its effects on new populations to better understand its ideal uses.

Background

Almost half of postnatal eye growth is believed to occur within the first 12–16 months of life. The second half continues throughout various stages of childhood, adolescence, and adulthood.[1] These growth patterns are affected by many factors including genetics,[2, 3] environmental factors such as urban versus rural setting,[4] sunlight exposure,[2, 5] near work,[6, 7] and level of education.[8] Various interventions have been explored to slow the progression of myopia. In orthokeratology (Ortho-K), reverse geometry gas-permeable contact lenses are worn overnight to apply pressure to the cornea, temporarily
flattening the central cornea and altering the corneal power.[9, 10] Ortho-K is also believed to steepen the peripheral cornea, thereby reducing peripheral hyperopia. The association of peripheral hyperopia with globe elongation has been the rationale for the study of Ortho-K as a potential method for slowing progression of axial myopia in children.[9]

Ocular biometric data during eye growth and development is needed to understand the process of emmetropization and to describe the development of refractive errors such as progressive myopia.[11] Progressive myopia due to axial elongation increases the risk of many vision-threatening eye diseases such as myopic maculopathy, retinal detachment, glaucoma, and cataract formation. The accelerated growth of axial length can also lead to retinal tears and premature vitreous detachment in adolescence. These complications are related to progressively longer axial lengths.[12] Accordingly, identifying safe treatment options to effectively slow the progression of myopia in children is important. Currently, there does not exist a definitive treatment regimen for progressive myopia in children, although studies have shown some efficacy in the use of low dose atropine to prevent myopic progression. There is however concern regarding the potential for myopic rebound after treatment is discontinued. [13]

Studies have shown that Ortho-K can slow down axial length progression in myopic children to varying degrees [9, 14–16] with a potentially greater effect when initiated at an early age (6–8 years).[9, 14] When compared to spectacle correction, Ortho-K has shown a 40% − 60% mean reduction in axial length growth in various studies.[14, 15] However, these results vary from individual to individual, with some patients showing little or no myopic progression, and others progressing significantly with Ortho-K.

Ortho-K has also been shown to affect other components of the eye such as the cornea and the lens.[17] Since the effects of Ortho-K vary from individual to individual, it can be valuable to investigate its effects in new populations using modern techniques such as optical biometry. We present here a study looking at the effects of Ortho-K on eye growth (as measured by optical biometry) in North American children who underwent Ortho-K for their progressive myopia.

**Methods**

Biometry measurements captured between August 25, 2015, and June 27, 2019 were retrieved from Lenstar LS900 optical biometers (Haag-Streit USA Inc, EyeSuite software version i9.1.0.0) at University of Michigan’s Kellogg Eye Center. Institutional review board approval was obtained for the study, and it was determined that informed consent was not required because of its retrospective nature and the anonymized data utilized in this study. The study was carried out in accordance with the tenets of the Declaration of Helsinki. Patients under the age of 20 undergoing orthokeratology at the University of Michigan Kellogg Eye Center were included. As part of standard of care for Ortho-K at our institution, patients were assessed pre-orthokeratology and approximately 1 year after treatment initiation with optical biometry. Measurements were obtained by providers without a “washout” period in order to avoid the need for alternative correction for patients. Within-patient changes in axial length (AL), lens thickness (LT), central corneal thickness (CCT), and flat and steep keratometry (K1 and K2, respectively) were
analyzed. In this cohort analysis, linear mixed models were used to investigate the association between changes in biometry measurements and age, allowing for correlation between measurements on two eyes of the same patient. Statistical analysis was done in R (v 4.1.0, R Foundation for Statistical Computing, Vienna, Austria).

Results

Table 1
Patient demographics at time of pre-Ortho-K intervention.

<table>
<thead>
<tr>
<th>Overall, n</th>
<th>91</th>
</tr>
</thead>
<tbody>
<tr>
<td>Female, n (%)</td>
<td>49 (54%)</td>
</tr>
<tr>
<td>Male, n (%)</td>
<td>42 (46%)</td>
</tr>
<tr>
<td>Patient/Family-Identified Race, n (%)</td>
<td></td>
</tr>
<tr>
<td>White</td>
<td>7 (8%)</td>
</tr>
<tr>
<td>Asian</td>
<td>81 (89%)</td>
</tr>
<tr>
<td>Unknown</td>
<td>3 (3%)</td>
</tr>
<tr>
<td>Age (years) at first scan, mean (SD)</td>
<td>12.0 (2.5)</td>
</tr>
<tr>
<td>Years between scans, mean (SD)</td>
<td>1.1 (0.2)</td>
</tr>
</tbody>
</table>

A total of 91 patients meeting the aforementioned criteria were included in the study. At our institution, patients undergoing Ortho-K tended to be of Asian descent. The average age of intervention in our study sample, as seen in Table 1, was 12 years old (6–17 years old), with an average of 1.1 years between initiating Ortho-K (Table 2) and the post-initiation biometry measurement.

Table 2
Average biometry measurements taken at pre-Ortho-K intervention.

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Axial Length (mm)</td>
<td>24.84</td>
<td>0.87</td>
</tr>
<tr>
<td>Lens Thickness (mm)</td>
<td>3.37</td>
<td>32.61</td>
</tr>
<tr>
<td>Central Corneal Thickness (microns)</td>
<td>544</td>
<td>32.6</td>
</tr>
<tr>
<td>K1 Parameter (D)</td>
<td>42.5</td>
<td>1.54</td>
</tr>
<tr>
<td>K2 Parameter (D)</td>
<td>43.8</td>
<td>1.75</td>
</tr>
</tbody>
</table>
Table 3
Average change in biometry measurements from pre-Ortho-K measurement to 1 year after Ortho-K measurement

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Axial Length (mm)</td>
<td>0.14</td>
<td>0.22</td>
</tr>
<tr>
<td>Lens Thickness (mm)</td>
<td>0.05</td>
<td>0.13</td>
</tr>
<tr>
<td>Central Corneal Thickness (microns)</td>
<td>-7.95</td>
<td>12.23</td>
</tr>
<tr>
<td>K1 Parameter (D)</td>
<td>-2.26</td>
<td>1.54</td>
</tr>
<tr>
<td>K2 Parameter (D)</td>
<td>-2.26</td>
<td>1.75</td>
</tr>
</tbody>
</table>

The average change in axial length from initiation of Ortho-K to 1-year post-initiation appeared to be linearly associated with age of intervention (p < 0.05) and increased for all patients, as seen in Table 3. Eyes with Ortho-K intervention done at younger ages exhibited a greater increase in axial length 1 year after initiation of Ortho-K, with an average increase of 0.4 mm at 6 years old, as seen in Fig. 1. This increase in axial length continued until the age of 15.5 years (95% CI: [13.9, 17.0]), at which point axial length was found to be stationary.

When compared to semi-parametric models of healthy axial length growth curves comprising both corrected myopic and non-myopic (Fig. 2) our study population more closely match studies with a predominantly Asian population.[18, 19] The high degree of overlap between the normal growth curves found in Diez et al. (Fig. 2, blue curve) with the standard error of our study (Fig. 2, red curve) indicates that in this population Ortho-K did not have significant effect on axial length progression.

Our results, shown in Fig. 3, show very limited changes in lens thickness between baseline and 1 year after Ortho-K intervention (0.05mm, 95% CI: [0.03, 0.076]). This points to a very small change in lens thickness across adolescence. Furthermore, the age at which the Ortho-K intervention was started did not appear to affect the change in lens thickness post-intervention (p = 0.38).

The change in central corneal thickness between baseline and follow up for patients with Ortho-K intervention did not appear to vary with age of intervention (p = 0.80), as seen in Fig. 4. When modeled without age of intervention as a variable, change between baseline and 1 year after Ortho-K intervention appeared to decrease by 7.95mm (95% CI: [-10.2, -5.7]).

Similarly, mean keratometry changes between baseline and 1 year after orthokeratology demonstrated a small but constant reduction in corneal power regardless of age of intervention, as seen in Fig. 4. An average 1-year post-intervention change of about - 2.26 D (95% CI [-2.5, -1.94]) and - 2.26 D (95% CI [-2.61, -1.91]) was seen for K1 and K2, respectively.

Discussion
Biometry measurements throughout childhood can provide an understanding of the growth patterns of the human eye. Orthokeratology has been proposed as a treatment option for highly progressive myopia. Understanding the patterns associated with eye development and growth during Ortho-K treatment provides ophthalmologists with key pieces of information when assessing and treating pediatric patients.

In our study, patients undergoing orthokeratology treatment exhibited axial length growth at rates comparable to published growth patterns in populations with similar ethnic make-up. Previous studies have established that axial length increases throughout childhood, and to account for normal growth patterns, we compared the growth curves from our Ortho-K population with growth curves for normal healthy axial length growth in children. Diez et al. in 2019 and Truckenbrod et al. in 2020, performed large-scale longitudinal studies to examine axial length progression for healthy schoolchildren in China and Germany, respectively. When comparing our Ortho-K data to the data from Diez et al., we found that the age-matched rate of growth of axial length for healthy eyes matched the rate of growth for the Ortho-K patients we studied. Our Ortho-K patients demonstrated higher rates of axial length growth than those in the Truckenbrod study. A possible explanation for this is that our patient population was primarily of Asian descent, which closely matched the ethnicity of the study done by Diez et al. in China, but differed significantly from the primarily Caucasian population studied by Truckenbrod et al. This supports the conclusion that Ortho-K treatment did not appear to significantly slow axial length growth for the studied patients.

Previous studies looking at axial length progression in Ortho-K patients found a reduction in the progression of axial length growth of about 0.23mm and 0.36mm when compared to controls prescribed single-vision spectacles after 1 year, and 2 years of Ortho-K treatment, respectively. In a study axial length growth in children undergoing Ortho-K was compared to children wearing soft contact lenses. Axial length progression appeared to be 0.16 mm per year less for Ortho-K wearers than soft contact lens wearers. However, this study suffered from high dropout rate of 30%, which may have resulted in a biased representation of the effect of Ortho-K. An additional concern with reported reductions in axial length growth for Ortho-K patients, is Ortho-K's effect on thinning the cornea, a component of axial length. This likely leads to an overestimation of axial length growth suppression in Ortho-K patients.

For our population, Ortho-K appeared to have little effect on age related axial length growth when compared to normal growth patterns. The lack of a control group not undergoing Ortho-K in our study, however, limits our ability to draw this conclusion from the available data. Further studies to further evaluate this finding using a control group within the same population would be of value.

Given the previously published observational reports and case series of infectious keratitis with Ortho-K, clarifying patient populations in which Ortho-K may not affect axial length growth may offer a way to limit risk to patients.

Our results show only very slight increases in lens thickness across adolescence and adulthood after treatment with Ortho-K; this differs from previous investigations done on healthy eyes. In a study examining changes in lens thickness, wherein 864 children were followed annually for three years, lens
thickness was found to decrease between the ages of 6–10, followed by a period of stabilization until the age of 14.[26] This difference could be attributed to Zadnik’s use of A-scan ultrasonography to measure biometry instead of the more precise optical biometry. Our results are consistent with those of a recent study that found lens thickness did not change 6 months after initiation of Ortho-K treatment when compared to initial pre-Ortho-K measurements.[27]

Central corneal thickness and keratometry are clinically relevant for planning surgical procedures to correct astigmatism and myopia. In healthy eyes, central corneal thickness (CCT) appears to be stable after 1.5 years of age in children.[28] For patients undergoing Ortho-K, our results point to a 7.9 micron (95% CI: [-10.2, -5.7]) reduction 1 year post-Ortho-K initiation. This change also appears to not be influenced by the age of orthokeratology initiation. Recent studies have also shown a reduction in CCT after Ortho-K initiation in as little as 1 week unrelated to age.[29, 30] This reduction has been demonstrated in prior studies to be confined to the corneal epithelial layer.[31, 32]

There is limited research on corneal keratometry changes post Ortho-K. Khan et al. in a study comparing baseline keratometry K1 and K2 parameters before initiating Ortho-K and 12 weeks after initiation, found a reduction in K1 and K2 of 1.50 D (95% CI [0.49, 2.52]) and 1.68 D (95% CI [0.49, 2.87]), respectively.[33] Our results point to a similar but slightly amplified decrease in both flat and steep keratometry values by 2.26 D (95% CI [-2.5, -1.94]). It is important to note that these changes were observed without a washout period of Ortho-K lens wear. As such, these changes in keratometry are unlikely to be persistent.

**Conclusion**

Axial length, lens thickness, and corneal thickness change throughout childhood until stabilization in young adulthood. Orthokeratology has been shown to affect these parameters, in our population, Ortho-K did not appear to affect axial length progression when compared to normal patient growth curves. Using optical biometry to understand growth patterns during orthokeratology treatment and how they compare to normal growth patterns in different populations may aid in the study and understanding of axial length progression in children.

**List Of Abbreviations**

Orthokeratology (OrthoK), Axial length (AL), lens thickness (LT), central corneal thickness (CCT), flat keratometry (K1), steep keratometry (K2)

**Declarations**

**Ethics approval and consent to participate:** Institutional review board approval (University of Michigan's Human Research Protection Program (HRPP)) was obtained for the study from the Institutional review board of University of Michigan. Additionally, Institutional review board of University of Michigan has waived informed consent for the study because of its retrospective nature and the anonymized data
utilized in this study. The study was carried out in accordance with the tenets of the Declaration of Helsinki

**Consent for publication:** Not applicable

**Availability of data and materials:** The datasets generated and/or analyzed during the current study are not publicly available to protect patient privacy but are available from the corresponding author on reasonable request.

**Competing interests:** None

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**Authors contributions:** OM, NN, CA analyzed the data and interpreted results, TS, NN, SN contributed to study design, OM, NN, CA were major contributors in writing the manuscript, all authors read, edited and approved the manuscript.

**Acknowledgements:** Not applicable

**References**


Figures
Figure 1

Difference in axial length, in mm, between the first and second measurements taken approximately a year apart stratified by age at first measurement. A positive value at a certain age indicates patients of that age on average experienced an increase in axial length between the measurements.
Figure 2

Comparison of semi-parametric model of yearly change in axial length, in mm, against age of intervention for Ortho-K patients or age of first measurement in healthy children (Blue: Diez, et al. 2019, Green: Truckenbrod et al 2021, Red: Our study). A positive value at a certain age indicates patients of that age on average experience an increase in axial length between the measurements taken about a year apart.
Figure 3

Average difference in lens thickness, in mm, between the pre-Ortho-K intervention and a second measurement taken approximately 1 year after Ortho-K intervention stratified by age at first measurement. A positive value at a certain age indicates patients of that age on average experience an increase in lens thickness between the measurements taken about a year apart.
Figure 4

Average difference in central corneal thickness, in microns, between the pre-Ortho-K intervention and a second measurement taken approximately 1 year after Ortho-K intervention stratified by age at first measurement.