

# The Longitudinal Orthokeratology Research in Children (LORIC) in Hong Kong: A Pilot Study on Refractive Changes and Myopic Control

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**ABSTRACT** *Purpose:* Myopia is a common ocular disorder, and progression of myopia in children is of increasing concern. Modern overnight orthokeratology (ortho-k) is effective for myopic reduction and has been claimed to be effective in slowing the progression of myopia (myopic control) in children, although scientific evidence for this has been lacking. This 2 year pilot study was conducted to determine whether ortho-k can effectively reduce and control myopia in children. *Methods:* We monitored the growth of axial length (AL) and vitreous chamber depth (VCD) in 35 children (7–12 years of age), undergoing ortho-k treatment and compared the rates of change with 35 children wearing single-vision spectacles from an earlier study (control). For the ortho-k subjects, we also determined the changes in corneal curvature and the relationships with changes of refractive errors, AL and VCD. *Results:* The baseline spherical equivalent refractive errors (SER), the AL, and VCD of the ortho-k and control subjects were not statistically different. All the ortho-k subjects found post-ortho-k unaided vision acceptable in the daytime. The residual SER at the end of the study was  $-0.18 \pm 0.69$  D (dioptré) and the reduction (less myopic) in SER was  $2.09 \pm 1.34$  D (all values are mean  $\pm$  SD). At the end of 24 months, the increases in AL were  $0.29 \pm 0.27$  mm and  $0.54 \pm 0.27$  mm for the ortho-k and control groups, respectively (unpaired *t* test;  $p = 0.012$ ); the increases in VCD were  $0.23 \pm 0.25$  mm and  $0.48 \pm 0.26$  mm for the ortho-k and control groups, respectively ( $p = 0.005$ ). There was significant initial corneal flattening in the ortho-k group but no significant relationships were found between changes in corneal power and changes in AL and VCD. *Conclusion:* Ortho-k can have both a corrective and preventive/control effect in childhood myopia. However, there are substantial variations in changes in eye length among children and there is no way to predict the effect for individual subjects.

**KEYWORDS** myopia reduction, orthokeratology, eye elongation, axial length, myopia progression

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## INTRODUCTION

Myopia, one of the most commonly occurring ocular disorders, is increasing in prevalence, particularly in the Far East.<sup>1–7</sup> This is of concern because myopia causes blurred distance vision, and high degrees of myopia are associated with increased risk of retinal and vitreous detachments, and associated conditions such as glaucoma and macular degeneration,<sup>8,9</sup> bringing increased healthcare costs and ocular-related morbidity.

Myopic progression is due to elongation of the axial length (AL), and this is primarily in elongation of the vitreous chamber depth (VCD) of the eye;<sup>1,10–13</sup> changes in these parameters are best quantified using a-scan ultrasonography.

For years, researchers and clinicians have been searching for ways to control the progression of myopia.<sup>14–21</sup> “Control” means a slowing of the progression of myopia,<sup>4,18,21</sup> whereas “reduction” refers to a decrease in the already existing amount of myopia. Methods used for myopic control have included the use of rigid contact lenses,<sup>3,18,22,23</sup> bifocal spectacle lenses,<sup>20,24,25</sup> and multifocal spectacle lenses.<sup>21,26,27</sup> Researchers are also examining the use of pharmaceutical agents such as atropine and pirenzepine,<sup>28–31</sup> although there are safety concerns regarding regular and long-term use of such agents by young children.

Many earlier studies of the effect of rigid contact lenses and spectacle lenses on myopic control suffered from design shortcomings,<sup>3,18,22,26</sup> while more recent studies have failed to show clinically significant effects.<sup>26,32</sup> Nevertheless, there is a great public demand for an effective myopic treatment, particularly in countries, such as Hong Kong, China, Singapore, and Taiwan, which report a high and increasing prevalence of myopia.<sup>1–3,5–7</sup>

Orthokeratology (ortho-k), a treatment where a contact lens is used to reshape the cornea to *reduce* myopia, was first introduced in the early 1960s,<sup>2</sup> but it did not gain widespread acceptance because of safety concerns and the unpredictability of the outcomes.<sup>33–35</sup> The last decade, however, has seen revived interest in ortho-k. Improved rigid gas permeable (RGP) contact lens materials have reduced the potential for corneal insult; new instrument and lens design technology has made the outcomes largely predictable, and overnight wear of lenses (allowing good daytime vision without contact lenses or spectacles) has improved patient acceptance. A number of recent reports have shown

overnight ortho-k to be effective in reducing myopia (up to 4.00D), although the effect is, in general, temporary and requires continued lens wear to maintain the effect.<sup>36–38</sup>

However, there is a clinical impression among many ortho-k practitioners that myopia also progresses more slowly in children receiving overnight ortho-k treatment to reduce their myopia, i.e. that the treatment also has a myopic control effect.<sup>39,40</sup> It has been suggested that wearing rigid contact lenses may decrease anterior chamber depth because of a backward displacement of the cornea, affecting the AL measurement and thus giving a misleading impression, when monitoring AL changes, that myopic progression is reduced.<sup>41</sup> In this study, we have also measured the VCD, the major component of AL that is unaffected by corneal flattening or backward corneal displacement. If there is a real decrease in the rates of eye elongation with ortho-k lens wear, the effect should be reflected in both the AL and the VCD measurements.

There being no published evidence that ortho-k can, or has the potential to, decrease myopic progression at the time of this study, on ethical grounds, we were unable to justify recommending children for overnight ortho-k lens wear, as this would place them at unnecessary risk compared to spectacle wear without adequate justification; for this reason, instead of a randomized study, a pilot study was conducted. Hence, we only recruited children whose parents were seeking ortho-k treatment for them in private practice.

The primary purpose of this pilot study was to determine whether ortho-k is effective for myopic reduction and control through a 2-year study monitoring AL and VCD changes in children undergoing ortho-k treatment and comparing the rates of change in AL and VCD with children wearing single-vision spectacles from an earlier study.<sup>21</sup> For the ortho-k subjects, findings of corneal curvature changes and refractive changes, relationships between curvature changes and baseline spherical equivalent refractive errors (SER), and changes in SER, AL, and VCD are also presented for completeness.

## METHODS

### Subjects

Parents presenting at optometric practices in Hong Kong seeking overnight ortho-k treatment for their children were invited to participate in this study if the

children satisfied our eligibility criteria. Forty-three children were recruited for the ortho-k group. All subjects were 7 to 12 years of age, had SER of  $-0.25$  D to  $-4.50$  D, astigmatism less than  $-2.00$  D, and visual acuity of at least 0.06 logMAR (about  $6/6^{-2}$  Snellen equivalent). They had no ocular or systemic conditions that might affect refractive development and no contraindications for contact lens use. None of the subjects was taking any medication, and the parents of these subjects were willing to bring them to the Optometry Clinic of The Hong Kong Polytechnic University for a number of visits for data collection. The tenets of the Declaration of Helsinki were followed, and we obtained ethical clearance from the approving committee of The Hong Kong Polytechnic University. Recruitment of subjects was carried out with the help of eight private practitioners who satisfied the following requirements:

- had a minimum of 2 years experience in fitting overnight ortho-k lenses;
- had prescribed at least 30 pairs of ortho-k lenses.

Control (single-vision spectacle-wearing) subjects were selected from the control group of a previous progressive lens study by Edwards et al.<sup>21</sup> to match the age, gender, and baseline SER of the ortho-k subjects who completed this study, and their data were retrieved for comparison in this study. No data collection was carried out for the control group in this study.

We sought 80% power to detect a 0.25 mm (about 0.50 D) difference in eye elongation between the treatment and control groups with a significance level of 0.05 (2-tailed); the number of subjects required to complete the study in each group was 31.

## Flow of Visits and Procedures for the Ortho-k Subjects

Ortho-k lens fitting, delivery, and aftercare services were provided by the optometrists as per their normal routine. Before commencing the study, informed consent was obtained from the parent(s) after detailed explanation of the benefits and risks of the study. Baseline AL and VCD measurements were made before commencing lens wear, and subsequent data collection visits were carried out after the subjects had worn the ortho-k lenses for 6, 12, 18, and 24 months. All measurements were performed by the same examiner who was unaware of the original refractive error and parameters of the ortho-k lenses prescribed to the subjects.

Non-cycloplegic subjective refraction and visual acuity assessments were performed before the measurements of AL and VCD. Corneal curvatures (steep and flat keratometry readings) were measured using Canon RK5 Autorefractor & Autokeratometer (Tokyo).

Before a-scan AL and VCD measurements (using a SONOMED A-5500, Sonomed, Inc., New York, USA), one drop of 0.4% benoxinate was instilled; and one minute later, one drop of cyclopentolate HCl 0.5% was instilled for cycloplegic retinoscopy (see next paragraph). A-scan ultrasonography was performed after the cornea had been desensitized. Five readings (the maximum capacity of the biometer) with a standard deviation less than 0.1 mm were obtained for each eye (as per the manufacturer's recommendations) and the mean value used for analysis. The cornea was examined using a slit lamp biomicroscope and fluorescein dye, both before and after these measures to ensure normal corneal integrity. Subjects with more than mild corneal staining were referred back to their own practitioners and asked to return a few days later to resume data collection as necessary. All the subjects were wearing four to five-zone reversed geometry lenses made of Boston XO or HDS 100 material.

Apart from the above tests, corneal topography and ocular changes of the ortho-k subjects were also assessed using non-invasive tests before A-scan ultrasonography. Tests for these evaluations were corneal integrity, corneal topography, corneal thickness, intra-ocular pressure, corneal endothelial morphology, cycloplegic autorefractometry, and retinoscopy. Results of these tests (ocular changes) will be reported in detail elsewhere.

All data were collected by the same examiner. For post-ortho-k data collections, ortho-k subjects wore their lenses the night before the day of data collection.

## Treatment of Data

The distributions of age, steep and flat keratometry readings, SER, AL, and VCD were not significantly different from a normal distribution (Kolmogorov-Smirnov D tests,  $p > 0.05$ ). The distributions of changes for steep and flat keratometry readings, SER, AL, and VCD were also not significantly different from a normal distribution (Kolmogorov-Smirnov D tests,  $p > 0.05$ ). Hence, parametric statistical tests were used to analyse the data. Unpaired *t* tests were used to compare the baseline data between the two groups of subjects and between male and female subjects.

**TABLE 1** Reasons for Withdrawal of 8 Subjects

Reasons for withdrawal	Number of subjects	Last examination
Concern about safety (frightened by bad publicity about ortho-k)	1	6th-month visit
Corneal complications (recurrent corneal staining)	2	Baseline/12th-month visit
(inflammation)	2	Baseline
Lens damage	1	18th-month visit
No longer in Hong Kong (further study overseas)	1	18th-month visit
(migrated)	1	18th-month visit

The mean  $\pm$  SD age of these subjects (4 male, 4 female) was  $9.3 \pm 1.7$  years with mean  $\pm$  SD baseline SER of  $-3.22 \pm 0.60$  D.

Repeated measures analysis of variance (ANOVAs) were used to compare the change in SER and corneal curvature over time in the ortho-k subjects. If significant differences were found, paired *t* tests with Bonferroni corrections were performed to compare the differences in SER and corneal curvature.

To determine myopic progression, Repeated measures ANOVAs were used to compare the changes (from baseline) in the AL and VCD over time and between the two study groups; interactions between time and groups were also assessed. If repeated measures ANOVA showed significant results between groups and significant interaction between time and groups, unpaired *t* tests were used to test for differences in AL and VCD changes between the two groups after the

24-month monitoring period, and plots of the changes were used to illustrate trends. Where appropriate, Bonferroni corrections were used to take account of *post-hoc* comparisons.

Pearson correlations were also performed to study the relationship between baseline SER and VCD changes and between corneal curvature changes and SER, AL, and VCD changes.

Only the data from the right eyes are reported here; however, similar results were observed in the left eye, since findings between ocular variables are highly correlated.<sup>42</sup>

## RESULTS

Three subjects dropped out of the study after the baseline visits, two dropped out after 6 months, one after 12 months, and another two after 18 months. Thus, 35 subjects completed the study, giving a dropout rate of about 19%. Table 1 shows the reasons for withdrawal. The mean  $\pm$  SD age of the 35 ortho-k subjects (16 male, 19 female) who completed the study was  $9.6 \pm 1.5$  years, and the mean SER was  $-2.27 \pm 1.09$  D. The mean  $\pm$  SD age for the 35 control subjects (16 male, 19 female) was  $9.6 \pm 0.69$  years, and the mean  $\pm$  SD SER was  $-2.55 \pm 0.98$  D.

There were no statistically significant differences in baseline values between the two groups of subjects in age, SER, AL, or VCD (unpaired *t* tests,  $p > 0.05$ ; see Table 2). The number of male and female subjects was the same in the groups, and there were no significant differences in the baseline data between male and female subjects in each group (unpaired *t* tests,  $p > 0.05$ ; see Table 2).

**TABLE 2** Baseline Data (Mean  $\pm$  SD) of the Right Eyes of 35 Orthokeratology and 35 Control Subjects

	Age (years)	Spherical equivalent refractive error (D)	Axial length (mm)	Vitreous chamber depth (mm)
Orthokeratology				
Male ( $n = 16$ )	$9.44 \pm 1.71$	$-2.32 \pm 1.03$	$24.53 \pm 0.69$	$17.17 \pm 0.70$
Female ( $n = 19$ )	$9.68 \pm 1.25$	$-2.22 \pm 1.16$	$24.47 \pm 0.74$	$17.25 \pm 0.67$
<i>p</i>	0.626	0.782	0.800	0.723
Control				
Male ( $n = 16$ )	$9.65 \pm 0.66$	$-2.48 \pm 0.98$	$24.74 \pm 0.69$	$17.43 \pm 0.72$
Female ( $n = 19$ )	$9.51 \pm 0.73$	$-2.62 \pm 1.00$	$24.56 \pm 0.48$	$17.41 \pm 0.59$
<i>p</i>	0.555	0.675	0.363	0.909
Orthokeratology (all)	$9.57 \pm 1.46$	$-2.27 \pm 1.09$	$24.50 \pm 0.71$	$17.21 \pm 0.67$
Control (all)	$9.58 \pm 0.69$	$-2.55 \pm 0.98$	$24.64 \pm 0.58$	$17.42 \pm 0.64$
<i>p</i> *	0.988	0.256	0.342	0.193

*p* = probability values for differences between male and female subjects using unpaired *t* tests.

*p*\* = probability values for differences between orthokeratology and control subjects using unpaired *t* tests.

For the ortho-k subjects, there was significant reduction in the SER with time ( $F(4, 31) = 41.752, p < 0.001$ ), and *post-hoc* test showed that compared to the baseline value the residual (post-ortho-k) SER was significantly reduced at all subsequent visits ( $p < 0.001$ ). However, there were no significant differences in residual SER among subsequent visits ( $0.10 < p < 1.0$ ), indicating that significant SER reduction occurred before 6 months of wear. The residual SER at the end of the study was  $-0.18 \pm 0.69$  D and the mean  $\pm$  SD SER reduction was  $2.09 \pm 1.34$  D (see Table 3). Considering the myopia only, the percentage reduction in the ortho-k subjects was  $100 \pm 42\%$ , whereas for SER, the percentage reduction was  $80 \pm 78\%$  ( $90 \pm 42\%$  if one outlier was omitted).

There was a significant slowing of eye growth in the ortho-k group, which was reflected both in AL measures ( $F(1, 67) = 30.862, p < 0.001$ ) and VCD measures ( $F(1, 66) = 34.03, p < 0.001$ ). General growth was of course reflected in the main effect of time in both measures (AL:  $F(3, 65) = 39.105, p < 0.001$ ; VCD:  $F(3, 64) = 31.314, p < 0.001$ ). The differential growth in the two measures was reflected in significant interactions of (time\*group) for the AL measures ( $F(3, 65) = 5.289, p = 0.003$ ) and VCD measures ( $F(3, 64) = 9.661, p < 0.001$ ).

At the end of the 24-month study period, the AL and VCD of the ortho-k subjects were significantly shorter than those of the control group (unpaired *t* tests: AL,  $p = 0.012$ ; VCD,  $p = 0.005$ ). (It is recognized that these two variables are related, however, applying a corrected

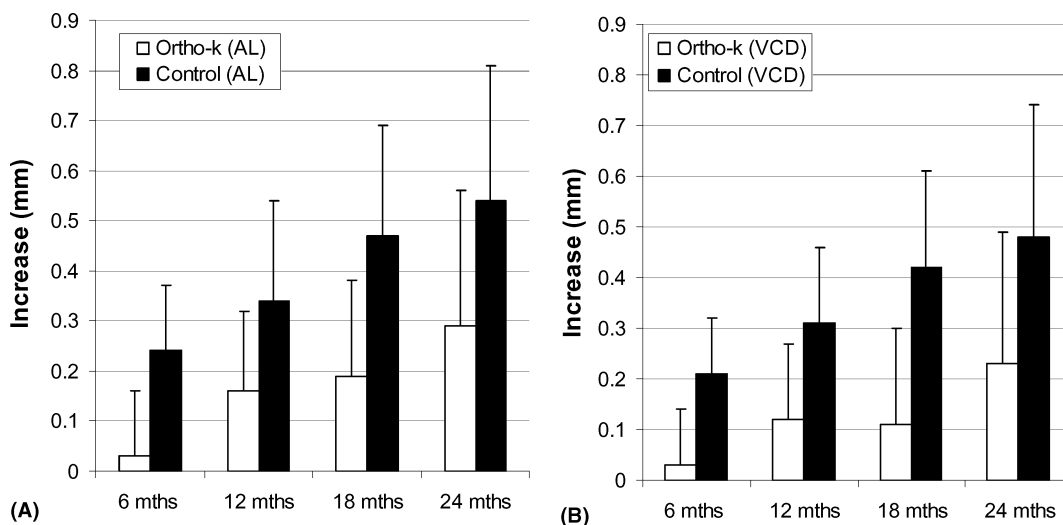
value for alpha of 0.025 still results in a statistically significant difference.) Figure 1 and Table 3 show the AL and VCD change (from baseline) at each stage of the study for the two groups of subjects. At the end of 24 months, the AL and VCD increases were about half the increases in the control group. The mean  $\pm$  SD increases in AL and VCD after 24 months were  $0.29 \pm 0.27$  mm and  $0.23 \pm 0.25$  mm, respectively, for the ortho-k group, and  $0.54 \pm 0.27$  mm and  $0.48 \pm 0.26$  mm, respectively, for the control group. A statistically significant relationship was found between changes in VCD and baseline SER for both groups of subjects. For the ortho-k group, a positive correlation was found (Pearson's  $r = 0.53, p = 0.001$ ) (see Figure 2A), showing that the more myopic ortho-k subjects showed less eye growth. For the control group, the reverse was true—a negative correlation was found (Pearson's  $r = -0.59, p < 0.001$ ) (see Figure 2B), indicating that less myopic spectacle-wearing subjects showed smaller increases in VCD with time. (AL also showed similar results.)

There was significant corneal flattening, shown as decreases in corneal power [flat keratometry reading:  $F(4, 31) = 48.121, p < 0.001$ ; steep keratometry reading:  $F(4, 31) = 34.567, p < 0.001$ ], and the *post-hoc* test showed that compared to the baseline value the cornea was significantly flattened at all subsequent visits ( $p < 0.001$ ); no significant differences in keratometry readings were found among subsequent visits ( $0.187 < p < 1.0$ ), indicating that significant flattening occurred before 6 months of wear. The mean  $\pm$  SD flattening in the flat and steep keratometry readings at the end

**TABLE 3** Changes (Mean  $\pm$  SD) (from Baseline) of the Spherical Equivalent Refractive Error, Keratometry Readings, Axial Length, and Vitreous Chamber Depth at Each Stage of the Study (Right Eye Only) of 35 Orthokeratology and Control Subjects

	6 months	12 months	18 months	24 months
Spherical equivalent refractive error (D)				
Orthokeratology	$2.40 \pm 1.10$	$2.29 \pm 1.20$	$2.19 \pm 1.23$	$2.09 \pm 1.34$
Control	$-0.48 \pm 0.36$	$-0.62 \pm 0.35$	$-0.88 \pm 0.50$	$-1.20 \pm 0.61$
K readings (orthokeratology subjects only)				
Steep K	$-1.06 \pm 1.07$	$-1.08 \pm 0.91$	$-1.06 \pm 0.74$	$-1.35 \pm 0.86$
Flat K	$-1.24 \pm 0.76$	$-1.17 \pm 0.66$	$-1.30 \pm 0.79$	$-1.51 \pm 0.72$
Axial length (mm)				
Orthokeratology	$0.03 \pm 0.13$	$0.16 \pm 0.20$	$0.19 \pm 0.22$	$0.29 \pm 0.27$
Control	$0.24 \pm 0.13$	$0.34 \pm 0.16$	$0.47 \pm 0.19$	$0.54 \pm 0.27$
<i>p</i>	<0.001	<0.001	<0.001	<0.001
Vitreous chamber depth (mm)				
Orthokeratology	$0.03 \pm 0.13$	$0.12 \pm 0.19$	$0.11 \pm 0.20$	$0.23 \pm 0.25$
Control	$0.21 \pm 0.11$	$0.31 \pm 0.15$	$0.42 \pm 0.19$	$0.48 \pm 0.26$
<i>p</i>	<0.001	<0.001	<0.001	<0.001

*p* = probability values for differences between orthokeratology and control subjects using unpaired *t* tests.



**FIGURE 1** Changes in the (A) axial length (AL) and (B) vitreous chamber depth (VCD) at each stage of the study of 35 orthokeratology (Ortho-k) and 35 spectacle-wearing (Control) subjects. Each vertical bar represents 1SD.

of 24 months were  $1.51 \pm 0.72$  D and  $1.35 \pm 0.86$  D respectively (Table 3).

There were no significant relationships between changes to the corneal power and changes to AL and VCD (Pearson's  $r$ ,  $-0.084 < r < 0.366$ ,  $p \geq 0.031$ ). However, there was a significant relationship between changes to the baseline SER and changes to flat keratometry reading at the end of 24 months of lens wear (Pearson's  $r = -0.679$ ,  $p < 0.001$ ). However, no such no correlation with the steep keratometry reading was found (Pearson's  $r = -0.409$ ,  $p = 0.015$ ) (after Bonferroni correction: alpha set at 0.003, i.e., 0.005/16).

## DISCUSSION

### Eye Elongation Over the 24-Month Monitoring Period

In the current study, the mean change in AL per year was 0.14 mm (equivalent to about 0.39 D) for the ortho-k subjects compared to 0.27 mm (equivalent to about 0.75 D) for the control subjects. That is, after wearing ortho-k lenses for 24 months, the mean changes in AL in the ortho-k group were about half the changes observed in the spectacle-wearing control group. Similar results were obtained for VCD. For spectacle-wearing subjects, eye elongation is faster in those with higher baseline SER (Figure 2B: those who were more myopic showed faster progression). In ortho-k treatment, subjects with higher baseline SER would benefit most as eye elongation is slower in these subjects than in those with lower baseline SER (Figure 2A: those who were more myopic showed a greater slowing of progression).

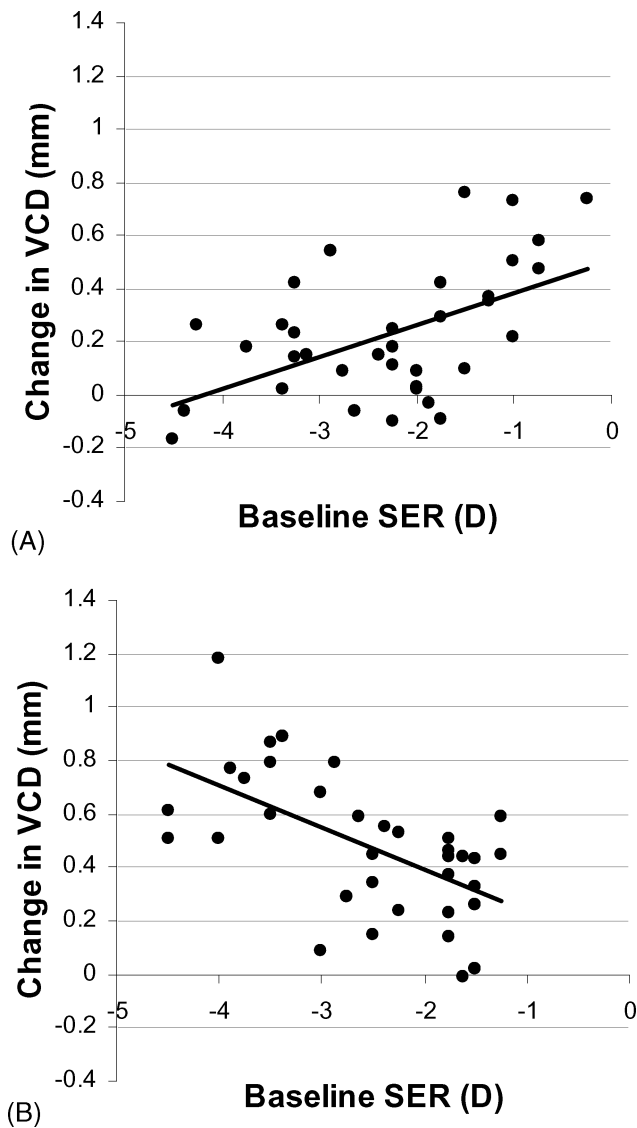
However, as with the control group, variability in the AL and VCD changes were quite large and so, while on average, eye elongation was significantly slowed in ortho-k lens wear, there is no way to predict the effect on any individual.

In previous studies on RGP lens wear, Perrigin et al.<sup>23</sup> reported an annual AL change of 0.16 mm in their RGP subjects (monitored over 3 years), and Khoo et al.<sup>3</sup> found a mean AL change of 0.22 mm per year in their RGP subjects. Katz et al.<sup>32</sup> reported a mean AL increase of 0.42 mm per year in children wearing RGP lenses compared to 0.40 mm per year in children wearing spectacles and concluded that RGP lens wear is unlikely to hold promise as an option for myopic control in children as lens wear did not slow myopic progression. However, the dropout rates of these three studies were about 44%, 47%, and 50%\* respectively, leading to differences in baseline severity of myopia between the contact lens and spectacle-wearing groups (more myopic in the contact lens groups). The high dropout rates are likely to have biased their findings toward the more myopic (and faster progressing) subjects in their initially selected groups. In the current study, we selected the control subjects to match the ortho-k subjects who completed the study, so we did not have this problem.

### Subjects Lost to Observation

In the assessment of the effectiveness of a treatment, it is very important that the subjects are compliant with

\*Considering only subjects who completed the initial pre-adaptation visit and those who remained in the study until the final visit.



**FIGURE 2** Plots showing changes in vitreous chamber depth after 24 months of study against the baseline spherical equivalent refractive error (SER) of (A) orthokeratology subjects, (B) spectacle-wearing control subjects.

the treatment schedule. High dropout rates suggest that the treatment is unlikely to be useful, irrespective of the outcome of the study. Some investigators are currently looking into how to minimize RGP dropouts in myopic progression studies using alternate study designs.<sup>43</sup>

The dropout rate for this study (19%) was relatively low compared to other myopic control studies. As mentioned earlier, the dropout rates reported in RGP studies ranged from 44% to 50%.<sup>3,23,32</sup> Wearing RGP lenses in the daytime has never been a popular choice in Hong Kong<sup>44</sup> because both practitioners and parents are concerned about the safety of children wearing daily wear RGP lenses for school and play and about the risks and discomfort of dislocated lenses. Indeed, the high

dropout rates reported by Khoo et al.<sup>3</sup> and Katz et al.<sup>32</sup> confirm the unpopularity of RGP lens wear. The better retention reported in the current study may have been because subjects only needed to wear the lenses to sleep and could usually enjoy clear vision during the day without need for any vision correction. All the subjects were compliant with regard to their wearing schedule, although not all the subjects were prescribed the same wearing schedule. Most of the subjects (25) were required to wear their lenses every night for at least 7 hours. Some subjects (3) were able to retain a myopic reduction effect for more than 1 or 2 days so they only wore their lenses every other night or wore the lenses for 2 consecutive nights and stopped for 1 night and so on. Seven subjects preferred to rest 1 night a week, during the weekend.

In the current study, the ortho-k patients did not receive any incentive to remain in the study to encourage them to return for data collection. (They were provided with complimentary contact lens solutions which were only adequate for normal consumption.) The treatment was costly and also time consuming, but the fact that the dropout rate was low indicated strong motivation and acceptance of the treatment.

### Optical Components Involved in Myopic Progression

A measured reduction in myopic refractive error over time can comprise both myopic reduction and myopic control. Measurement of refractive error cannot separate these effects, but measurement of the length of the eye can. The usual myopic reduction with ortho-k in young adults has been shown to be effected by corneal thinning and/or corneal flattening.<sup>45,46</sup> If a reduction in the elongation rate of the eye with time can also be shown to occur during the treatment in children, then this is myopic control. Our ortho-k subjects show significant flattening of the cornea after 6 months of lens wear, but no changes of corneal curvature thereafter. The significant correlation between changes to the corneal surface and changes to the baseline SER at the end of the 24-month study period indicates that the flattening of the cornea plays a role in the magnitude of the myopic reduction *by optical means*. However, the lack of correlations between changes to the corneal curvature and changes to the AL and VCD indicates that eye elongation is not affected by changes to the corneal curvature.

In view of the suggestions<sup>41</sup> that backward corneal displacement may lead to the impression of a shorter AL, we also measured and compared the VCD in this study to ensure that any difference in AL between the ortho-k and control groups was also reflected in the VCD measurements, and hence was not due to the flattening of the corneal surface. This was shown to be the case in our study: Changes in both AL and VCD were about half those of the spectacle-wearing controls in our ortho-k subjects.

## How Does Ortho-k Lens Wear Slow Myopic Progression?

Ortho-k lens wear has been shown to induce higher-order aberrations.<sup>47</sup> Collins et al.<sup>48</sup> have reported differences in monochromatic aberrations between emmetropic and myopic eyes, with myopic eyes showing lower fourth-order aberrations. They suggested that the differences observed between emmetropic and myopic eyes may be due to “optical effects associated with excessive eye growth in myopic eye or could contribute to the development of myopia, in line with the hypothesis that poor retinal image quality promotes excessive eye growth.” It is possible that changes in higher-order aberrations induced by ortho-k lens wear<sup>47</sup> may trigger mechanism(s) leading to a slowing of eye growth.

## Novelty of Ortho-k for Myopic Control

While some practitioners prescribe overnight ortho-k lenses for children for myopic control, based on the clinical impression that these lenses tend to slow myopic progression, there are no reports of the clinical effectiveness of this treatment. All previous methods for myopic control require the children to continue to wear spectacles or other vision correction aids during the daytime.<sup>21,28,32,41</sup> However, overnight ortho-k allows children to wear the lenses at night during sleep and to be able to see clearly without aids after lens removal on awakening, and to continue to have acceptable unaided vision in the daytime. The convenience of not having to wear spectacles or other vision correction aids in the daytime is one of the main reasons for good compliance regarding wearing time and for children to remain on the treatment. The parent and the child have clear evidence that myopia is reduced as the child has acceptable unaided vision in the daytime, thus increas-

ing confidence in the treatment. In addition of course, the changes to corneal curvature are transient and reversible, should patient or parent find any aspect of the treatment unacceptable.

## Limitations of This Study and Further Studies

Although the randomised clinical trial (RCT) is considered to be the ‘gold standard’ design for evaluating the effect of a treatment, researchers and practitioners must also pay attention to the special ethical problems that may arise from RCTs.<sup>49</sup> At the time of this study, without evidence that ortho-k could control myopic progression, it would be ethically questionable to assign children to overnight contact lens wear because of the potential ocular risks that are absent in spectacle wear. Hence, in this study, the parents of all the ortho-k children had enrolled their children for ortho-k treatment, and so the children were not put under any added risk but gained the benefit of more careful attention and other non-routine monitoring (e.g., eye length and corneal thickness measurement,) provided by the research personnel of this study, while maintaining the routine aftercare services provided by their practitioners. Our study personnel maintained contact with the patient’s practitioner and coordinated any needed aftercare. Adverse findings were recorded and reported, and where necessary, subjects were referred back to their practitioner for re-education regarding proper insertion and removal technique and proper use of solutions.

The use of “historical” control subjects and nonrandomised study design is not uncommon in research studies.<sup>23,41</sup> The justification for using historical control subjects is that there is no reason to believe that this group of children, recruited 2 to 3 years earlier, should respond to spectacle wearing in a different manner than a new group of controls. Because of the nature of this study, with patients being recruited from independent ortho-k practitioners, we had no control over the lens fitting regimen they used for their particular patients. However, we had indirect indications of the adequacy of fitting, since we were able to assess residual refractive error, corneal integrity, corneal radius, and corneal topography of each patient over time. This source of variance would be expected to be controlled by use of standardised fitting procedures in a formally designed randomized clinical trial, which we now believe, based on our findings, to be ethical and justified.



The study was not masked—obviously the subjects cannot be masked; it was also difficult to mask the examiner because of the type of data collected. For example, from the assessment of the topographical maps, the examiner would be able to tell if the subject wore ortho-k lenses or not. Hence, at best, the examiner was not aware of the original refractive error of the subjects or the target of myopic reduction of each subject. The examiner was not provided with the information from the previous visit (6 months previously) and so, it would also be impossible to remember earlier measurements. However, a masked study design would be difficult and expensive in ortho-k research, involving a number of measurement stations, with non-communicating examiners. Given the promising nature of our findings, it may be justified.

Ortho-k has been confirmed to be effective for reduction of myopia of up to 4.00 D,<sup>37</sup> and our results are in agreement with recent published reports. However, it is also known that the individual has to continue to wear lenses at night to maintain the myopic reduction. So, is the effect of retardation of myopic progression found in the current study also a temporary effect? More research work is required to further investigate the effect on myopic progression with ortho-k.

In summary, our results confirmed the effectiveness of myopic reduction of up to 4.00 D; the mean  $\pm$  SD reduction (less myopic) in SER was  $2.09 \pm 1.34$  D and the mean  $\pm$  SD residual SER at the end of the study was  $-0.18 \pm 0.69$  D. Over 80% of our ortho-k subjects completed the study, and at the end of the 24-month monitoring period, the mean eye elongation in children wearing ortho-k lenses was about half that of children wearing spectacles. Hence, parents may consider ortho-k as an option for slowing the myopic progression in their children. However, there are substantial variations in the degree of eye elongation among children and there is currently no way to predict the degree of slowing for any individual.

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