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Myopia control in the 21st century: A review of optical methods (2000–2019)

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Background: Without appropriate interventions, simple or low myopia can progressively get worse and lead to high myopia. Patients with high myopia are at a greater risk of developing retinal detachment, myopic macular degeneration, glaucoma and eventual blindness in some cases, and hence the reason for the global call for myopia control. Consequently, myopia in the 21st century is not only treated as a refractive error but an ocular disorder with potential negative consequences. Myopia control strategies include optical, pharmacological and behavioural methods. In this report, the effectiveness of optical methods of myopia control was reviewed.

Aim: The aim of the review is to evaluate and summarise existing knowledge on myopia control and provide recommendations to guide future studies.

Method: The review was conducted using online search engines including PubMed and Google Scholar. Articles published between 2000 and 2019 were included.

Results: For the optical methods of myopia control, under-correction has been found to be largely ineffective. However, a recent study shows that myopic children without correction had slower myopia progression (−0.75 D) than fully corrected children (−1.04 D) indicating a 28% reduction. Evidence from various studies indicates that bifocals and progressive addition lenses are not as effective as soft dual focus contact lenses or extended depth of focus contact lenses. Clinical trials indicate that single vision rigid gas permeable lenses did not slow myopic progression. Peripheral defocus lenses and orthokeratology were found to be approximately 50% effective across studies reviewed.

Conclusion: Peripheral defocus lenses and multifocal contact lens designs offer the most effective myopia control. Orthokeratology is equally effective but future designs should consider ways of minimising risks of complications with lens wear. More studies would be needed to better understand how under-corrected myopic eyes tend to progress faster, whereas myopic eyes without correction tend to progress slower. A holistic approach and combination of methods may offer the best form of myopia control in the 21st century considering the increase in near work activities and use of digital devices among the most vulnerable groups.

Keywords: myopia control; under-correction; bifocals; progressive addition lenses; contact lenses; orthokeratology.

Introduction

The nurture theory on myopia development indicates excessive reading and near work activities during childhood as risk factors of abnormal axial length (AL) elongation, yet its onset and development is not clearly understood.[1] Myopia, depending on its severity, can impair both distance and intermediate or near vision, and high myopia (≤ −5 D [dioptre]) is a cause of preventable blindness and vision impairment from myopic pathologies such as myopic macular degeneration, cataract, glaucoma, retinal tear as well as retinal detachment.[2]

The prevalence of myopia ranges between 1% and 78.4% across studies[3,4,5,6,7,8,9,10] reported in the 21st century. Although myopia is more prevalent in East Asia than other parts of the world (Table 1)[10], reports show that the world prevalence has grown from 1406 million in 2000 and could reach 4758 million by 2050 (50% of the world population) if proper control measures are not implemented.[10] The increasing prevalence of myopia could be related to the considerable increase in the use of smartphones and computers since the beginning of the 21st century. In the United States, for example, a survey reveals that 41% of children spend three or more hours daily using digital devices and 66% of children have their own smartphone or tablet.[11] This increased near

TABLE 1: Estimated prevalence of myopia between 2000 and 2050.

Region	Prevalence (%) in each decade					
	2000	2010	2020	2030	2040	2050
Andean Latin America	15.2	20.5	28.1	36.2	44.0	50.7
Asia-Pacific, high income	46.1	48.8	53.4	58.0	62.5	66.4
Australasia	19.7	27.3	36.0	43.8	50.2	55.1
Carribean	15.7	21.0	29.0	37.4	45.0	51.7
Central Africa	5.1	7.0	9.8	14.1	20.4	27.9
Central Asia	11.2	17.0	24.3	32.9	41.1	47.4
Central Europe	20.5	27.1	34.6	41.8	48.9	54.1
Central Latin America	22.1	27.3	34.2	41.6	48.9	54.9
East Africa	3.2	4.9	8.4	12.3	17.1	22.7
East Asia	38.8	47.0	51.6	56.9	61.4	65.3
Eastern Europe	18.0	25.0	32.2	38.9	45.9	50.4
North Africa and Middle East	14.6	23.3	30.5	38.8	46.3	52.2
North America, high income	28.3	34.5	42.1	48.5	54.0	58.4
Oceania	5.0	6.7	9.1	12.5	17.4	23.8
South Asia	14.4	20.2	28.6	38.0	46.2	53.0
Southeast Asia	33.8	39.3	46.1	52.4	57.6	62.0
Southern Africa	5.1	8.0	12.1	17.5	23.4	30.2
Southern Latin America	15.6	22.9	32.4	40.7	47.7	53.4
Tropical Latin America	14.5	20.1	27.7	35.9	43.9	50.7
West Africa	5.2	7.0	9.6	13.6	19.7	26.8
Western Europe	21.9	28.5	36.7	44.5	51.0	56.2
Global	22.9	28.3	33.9	39.9	45.2	49.8

Source: Adapted from Holden BA, Fricke TR, Wilson DA, et al. Global prevalence of myopia and high myopia and temporal trends from 2000 through to 2050. Ophthalmology. 2016;123(5):1036–1042. https://doi.org/10.1016/j.ophtha.2016.01.006.

work has been implicated in the development of myopia by some authors, while others argued that it is because of the fact that time on these devices keeps children inside and deprives them of time outdoors.[12]

The importance of research to control myopia cannot be overemphasised when one considers the potential complications of high myopia, increasing cost of health care and global loss of productivity associated with it.[2,13] There is a need to reduce its onset and progression particularly in children younger than 14 years of age and a good understanding of myopia control methods is deemed necessary. The aim of this review is to evaluate and summarise existing knowledge on myopia control and provide recommendations to guide future studies. The objectives are:

- to determine the most commonly used study design for myopia control
- to determine the most effective optical methods for myopia control based on the existing literature
- to document the limitations of previous studies
- to make recommendations for future studies

In this report, the effectiveness of optical methods of myopia control was reviewed in the context of increased research and development in this space.

Methods

The review of literature on optical myopia control strategies in the 21st century was conducted using online search engines including PubMed and Google Scholar. The identified copies were retrieved from online journals or from hard copies as appropriate. Furthermore, some articles were identified from other articles' reference lists and retrieved accordingly. Articles published in the English language with the keyword 'myopia control' and medical subject heading (MeSH) terms 'contact lenses' (CLs), 'spectacles' and 'prevention' were used. Articles published between 2000 and 2019 were considered. A total of 2507 studies were generated and 69 studies were used for analysis. Male and female genders (age 6–25 years) were included in the review. Studies reviewed include randomised control trials, population and school-based surveys. Animal studies were excluded from the review.

Ethical considerations

This article followed all ethical standards for research without direct contact with human or animal subjects.

Myopia control

Myopia progression extends through childhood until the late teenage years. However, the rate of myopic progression differs considerably from one child to another.[14] The creation of a myopigenic environment in urban cities in recent times cannot be dissociated from the increased prevalence of myopia across the world. The use of computers, phones, tablets and computer games has become more popular among children of today.[11] Prolonged reading on computers and near work has been associated with myopia.[15,16] This deprives children of spending quality time outdoors.[12] Research suggests that increased levels of exposure to outdoor light significantly reduce the incidence of myopia in school children. This is possibly related to the restrictive role of dopamine on eye growth and myopia development.[17,18] However, it was reported that it only has a significant effect on the incidence of myopia with little effect on myopic progression.[19,20,21] Consequently, efforts have been made to encourage more outdoor play in children to reduce the incidence of myopia.[22,23] In spite of other forms of myopia control (such as pharmacological agents) indicating a 50% reduction in myopia progression in children, optical aids remain a viable means of control because they are a common form of myopia correction. This article reviews only the optical methods. The optical interventions reviewed include under-correction with single vision lenses (SVLs), bifocals, progressive addition lenses (PALs), CLs and orthokeratology (Ortho-K).

Under-correction with single vision lenses

Under-correction is a method of deliberately reducing the full myopic prescription in order to slow myopic progression. Adler et al.[24] under-corrected 25 myopic children (age 6–15 years). Twenty-three of them were fully corrected, while 25 of them were under-corrected by 0.50 D. The baseline myopia was −1.06 D to −4.5 D (mean −2.82 D) for the fully corrected group and −1.37 D to −5.30 D (mean −2.95 D) for the under-corrected group. The results for both groups indicate that myopes with −3.00 D or more at baseline had faster progression of myopia than those less than −3.00 D. After 18 months, the progression of myopia was 4.4% in the children who were under-corrected but this difference was not statistically significant.

Li et al.[25] followed 1769 Chinese children (age 12 years) for 1 year. Out of 253 myopic children with spectacles, 47.4% were under-corrected by at least two lines of visual acuity and 52.6% were fully corrected. It was reported that the under-correction group had higher baseline myopia than the full correction group and the result did not show any significant difference in myopia progression or AL elongation. A limitation to the study was the 1-year follow-up which may not be enough to notice a significant change in progression. A study by Chung et al.[26] in Malay and Chinese children (aged 9–14 years) indicated an increase in myopia progression of 0.23 D over a 2-year period. They reported similar baseline data including a mean myopic refractive error of −2.68 D in both under-corrected and fully corrected groups. The distance refraction in juvenile myopic patients was under-corrected by 0.75 D and it resulted in a rapid increase in myopia progression (30%) which correlated with changes in AL and confirms that under-correction increases progression.

However, a recent study by Sun et al.[27] investigated the effect of no correction and full correction in Chinese myopic children with an average age 12.7 years. The children without correction had slower myopia progression (27%) than fully corrected children after two years. Baseline myopia with cycloplegic refraction was −3.03 D for full correction and −1.31 D for uncorrected. Myopia progression decreased significantly with an increasing amount of under-correction in all children. Studies by Li et al.[25] and Sun et al.[27] are similar in terms of age group and both studies involved Chinese children. The other studies[24,26] reviewed involved a younger population. Although Sun et al.[27] reported selection bias and differences in some baseline characteristics that may affect their results, the amount of under-correction in their study was greater (1.31 D) than the under-correction in other studies by Adler et al.[24] and Chung et al.[26] (0.50 D and 0.75 D, respectively). Besides, the purpose of the study by Sun et al.[27] is the effect of no correction on myopia progression. It was explained that the larger the amount of under-correction, the slower the myopic progression based on myopic defocus theory.[27] As Adler et al.[24] reported that higher myopic error at the baseline leads to faster progression, more studies with similar baseline characteristics would be needed to monitor the rates of myopia progression and the amount of under-correction given the conflicting results.

Bifocals

Bifocal glasses may make up for the reduced accommodative response commonly observed in esophoric myopic children.[28] In a randomised trial of the effect of SVLs versus bifocal lenses (BFLs) in children (age 6–12.9 years), Fulk et al.[29] demonstrated that BFLs reduced myopia progression by 0.25 D compared to SVLs in a period of 30 months. Myopia progression was reduced by 20% with BFLs compared to SVLs and the use of bifocals in myopic esophoric children slows progression by a slight degree. Their study suggests that BFLs only show a weak effect on myopia control.

Cheng et al.[30] noted that executive BFLs with a larger add area than normal BFLs might be more effective at reducing myopia progression. In addition, large segment executive BFLs produced a myopic shift in the peripheral image zone for the inferior field and the central field.[30] The addition of base-in prism to BFLs did not make a significant difference.[31] In a 3-year randomised clinical trial, Cheng et al.[30] randomly assigned Chinese–Canadian children (age 8–13 years) to three groups (SVLs, +1.50 D executive BFLs and +1.50 D executive BFLs with a 3 prism dioptre). The Howell–Dwyer near phoria card was used to measure near horizontal phoria through the distance correction. The rationale for using add +1.50 D and 3 prism dioptre was based on the outcome of a previous study[32] where a graphical method was used to determine the best lens and prism power that neutralises the lag of accommodation (LA) and phoria. With a mean baseline myopia of −3.08 D, the average myopia progression over 3 years was reported as a spherical equivalent (SE) of −2.06 D in the SVL group, an SE of −1.25 D in the BFL group and an SE of −1.01 D in the prismatic BFL group, indicating a 39% and 51% reduction in myopic progression in the BFL and prismatic BFL groups, respectively, as compared to the SVL group. The study concluded that bifocal spectacles can reduce myopia progression with an annual progression rate of approximately 0.50 D after 3 years. Myopic children with low lags of accommodation benefitted more from the use of prismatic bifocals possibly because of the reduction in convergence and lens-induced exophoria by the addition of a base-in prism.

Progressive addition lenses

Progressive addition lenses feature a progressive change in power from the distant, intermediate to near viewing portions without demarcations. In 469 subjects (age 6–11 years), Gwiazda et al.[33] investigated the effect of PALs (with +2.00 add) compared to SVLs on myopic progression. The baseline myopia was −2.40 D (mean SE) for PALs and −2.37 D (mean SE) for SVLs. Cycloplegic refraction was conducted over a period of 3 years and the mean increase in myopia was 1.28 D (PAL) and 1.48 D (SVL). There was a modest statistically significant difference of 0.20 D (13.5%) between PALs and SVLs only in the first year which remained the same in subsequent years.[33] The authors, however, noted that the difference may not make a meaningful impact in clinical practice.

Hasebe et al.[34] in a randomised, double-masked, crossover trial in Japanese children (age 6–12 years) concluded that the use of PALs compared to SVLs slowed myopia progression statistically but with a clinically non-significant treatment effect of 0.17 D for 18 months and a mean reduction rate of 15%. Baseline myopia (mean SE) was −3.17 D for the PAL group and −3.31 D for the SVL group. It was noted that early application of PALs could be more beneficial at lower degrees of myopia and a younger age. In another study,[35] they compared positively aspherised PALs (+1.00 add and +1.50 D add) with SVLs in Chinese and Japanese children (age 6–12 years). The baseline myopia was −2.55 D (SVL), −2.52 (add +1) and −2.80 (add +1.5). Myopia significantly progressed in three groups. Mean myopia progression was −1.38 D (SVL group), −1.32 D (+1.00 D add group) and −1.19 D (+1.50 D add group). The treatment effect with positively aspherised PALs with +1.50 D add was 31% (0.24 D). Reduction in myopia progression mostly occurred in the first 12 months with no significant efficacy in the second year. The high positive aspherisation of the distance zone added to PALs does not improve their therapeutic efficacy as compared to the conventional PALs with the same addition of power.

Some studies[36,37] have identified LA as a risk factor for the progression of myopia, although other studies[38,39,40] reported contrary findings. A possible reason is that higher LA presents with higher accommodative demands in myopes who exhibit the tendency to have sustained periods of retinal defocus consequently leading to AL elongation.[36] Myopic defocus (creation of images in front of the retina) inhibits eye growth and it is the major principle behind some optical myopia control strategies.[41] Hence, the reason PALs are introduced to help reduce retinal defocus during near tasks. Reports also indicate that the more esophoric a myope is, the more the addition needed to reduce myopic progression, hence the reason esophoric myopes benefit more from myopia control trials with PALs. However, a major limitation of studies involving PALs for myopia control is the tendency of children to avoid reading through the near add.[42,43] Nevertheless, the phoria status of myopic children needs to be considered for near additions to be effective.

Schilling et al.[44] compared LA in myopes (age 18–25 years) wearing SVLs and four different designs of PALs at different near viewing distances (25 cm, 33 cm and 40 cm). The designs differ in near zone width and the horizontal power gradients around the near zone. The LA was measured with subjects fixating a near card. A formula from a previous study[45] was used to calculate the LA (LA = accommodative demand – accommodative response). Their results indicated that there was no significant difference in LA between PALs with narrow and wide segments. The LA was more reduced with the negative horizontal mean power gradient PALs. Therefore, the designs of the reading portion of PALs should consider the additional power and the distribution of the peripheral power in the reading portion which may play a significant role in myopia control. Leads of accommodation observed with bifocal CLs in some myopes could be responsible for their beneficial effects on myopia control.[46] However, Weizhong et al.[47] assume that the effectiveness of bifocal or multifocal lenses on myopia progression is an improvement in accommodative accuracy which consequently reduced the near lag. Their findings suggest that reducing the amount of near lag in myopes has no clinical significance.

Peripheral defocus spectacle lenses

A new myopia control lens, defocus-incorporated multiple segments (DIMS®), was launched by Hoya Vision Care and Hong Kong Polytechnic University (HKPU) in 2018. The lens works on the theory of myopia defocus by projecting images on and in front of the retina simultaneously.[48,49] From clinical research with Chinese children (age 8–13 years) and the myopia range from −1.00 D to −5.00 D, Lam et al.[41] used a myopic defocus of +3.50 D and DIMS® lenses which were found to reduce myopic progression by 52% compared to children wearing single vision (SV) spectacle lenses over two years.[41] The mean baseline myopia was similar in both groups (−2.93 D for DIMS and −2.70 D SVL). The authors reported a lower dropout rate (13%) and an improvement in wearing time of the DIMS lens (up to 15 hours per day) compared to the Defocus-Incorporated Soft Contact Lens (DISC CL) (42% dropout rate, 8 hours per day) used in a previous study. The obvious difference is the ease of wear of spectacles over CLs.

Contact lenses

Contact lenses may produce better myopia control than single vision spectacle lenses. One possible reason is that the optical treatment area of CLs affects a larger part of the visual field than the peripheral treatment area of spectacle lenses.[50] In addition to the flattening of the cornea that may reduce myopic refractive error, CLs follow the eye movement and ensure a sustained therapeutic effect unlike spectacle lenses where the eye movements may result in a loss of the therapeutic effect.[51,52] However, a randomised clinical trial by Katz et al.[53] in Singaporean children (age 6–12 years) concluded that rigid gas permeable (RGP) CLs did not make a significant difference in myopia progression, even among regular users. Cycloplegic subjective refraction was used to assess children for refractive errors (spherical equivalent refraction [SER] from −1.00 D to −4.00 D). The children assigned to RGP contacts remained more myopic by 3.7% than those in the spectacle group. The AL increased by 0.84 mm in the CL group and 0.79 mm in the spectacle group indicating a 6% increase in AL. The CL and myopia progression study in a 3-year trial compared the effect of RGPs and soft CLs in slowing the progression of moderate myopia. There was a clinically significant difference. The RGP lenses offer more control because of the corneal flattening, a phenomenon similar to the effect obtained with the use of Ortho-K but this was not maintained after cessation of RGP wear.[51,54]

Soft bifocal or dual focus CLs create a myopic peripheral defocus to slow the progression of myopia by approximately 50% across the studies reviewed.[55,56,57] In a randomised control trial of 40 myopic children with similar baseline characteristics (mean SER of −2.71 D, age 11–14 years), Anstice et al.[55] compared a dual focus CL (concentric design of +2.00 D peripheral portion) with a single vision distance CL between two eyes of the same subject for 10 months. The same procedure was repeated for the other eye for another 10 months. The results indicate approximately 30% reduction of myopia in 70% of the eyes wearing the dual focus lens. There was no significant difference in the contrast sensitivity and visual acuity with both lenses during the trial. This suggests that the sustained myopic defocus with bifocal CLs can reduce myopia progression without affecting visual function.

Walline et al.[57] fitted children (age 8–11 years) with soft multifocal CLs (SMCLs) with +2.00 D add and concluded that SMCL wear resulted in a 50% reduction in myopia progression as compared to a historical single vision CL control group. Sankaridurg et al.[56] fitted novel CL with progressive increase in addition on Chinese children (age 7–14 years). The estimated progression in spherical myopia was 34% less than with spectacle lenses. They concluded that reducing peripheral hyperopia can have a significant effect on central refractive development and consequently slows myopic progression.

Moore et al.[58] investigated the effect of a commercially available spherical soft CL on peripheral defocus of young adult myopic eyes (mean age: 24 years). There were differences in peripheral defocus profiles in different brands (designs) of CLs. The four brands of soft CLs used caused a negative change in spherical aberration. The CLs inducing less negative spherical aberration changes were associated with a less hyperopic change in relative peripheral defocus. Although the result did not reveal how much myopic change in peripheral defocus is needed to cause a clinically meaningful change in myopia progression, it can be inferred that higher power CLs increased peripheral myopic defocus and soft CLs provide better peripheral defocus than spectacle lenses. In other words, the type and design of CL (including aspheric optics and optic zone diameter) would significantly influence the role of peripheral defocus on myopia progression.

Peripheral defocus contact lenses

The DISC CL (DISC®) is a novel bifocal CL with a concentric rings pattern to allow myopic retinal defocus (with add +2.50 D) and at the same time maintain clear vision through the central portion.[59] Lam et al.[59] in a 2-year double blind randomised control trial (RCT) on Hong Kong Chinese children (age 8–13 years) compared the DISC® with SVCL group. Children enrolled had myopia of −1.00 D to −5.00 D. The mean baseline myopia was −2.86 D and −2.79 D in the DISC® and SVCL groups, respectively. The DISC® reduced myopia progression by 25% and AL by 31% in 2 years. Wearing time is a major factor influencing myopia-controlling property of the DISC® with increased wearing time indicating up to 50% reduction for subjects wearing the CL 5 h or more per day. More studies will be needed to explore the benefits of the DISC® lens on a large scale as a high dropout rate (42%) was a major limitation of the study.

In a more recent study comprising 508 Chinese children (age 7–13 years), with cycloplegic autorefraction (SER from −0.75 to −3.50 D), Sankaridurg et al.[60] used novel CLs that induced retinal myopic defocus. Compared to SVCLs in compliant wearers (at least 6 days a week), there was a 26% – 43% reduction in myopic progression. The mean baseline myopia was −2.29 D for the control group which was not significantly different from the four groups of test peripheral defocus contact lenses (PDCLs) with different lens designs. Beside the difference in relative peripheral plus power (+1.50 D, +2.50 D) of the test PDCLs, some were also designed to create myopic defocus over a large area. There was no significant control effect across the four test PDCLs.

Orthokeratology

Orthokeratology is a rigid CL (also known as corneal refractive therapy) usually worn overnight to reduce or correct myopia by flattening the anterior portion of the cornea and taken off during the day.[61] Orthokeratology significantly reduces eye growth and can produce corrective and control effects on myopia. This is largely attributed to a relative peripheral myopic defocus that slows the progression of myopia significantly but there could be variations in changes in AL among myopic children.[62,63] Santodomingo-Rubido et al.[64] conducted cycloplegic autorefraction and compared AL growth between white European children wearing Ortho-K and SVL (age 6–12 years, SER from −0.75 D to −4.00 D) over two years. The baseline myopia was similar in both the Ortho-K (SER −2.15 D, AL 24.4 mm) and SV (SER −2.08 D, AL 24.22 mm) groups. The increase in AL in the Ortho-K group was 0.47 mm and the SVL group was 0.69 mm. The study indicated that Ortho-K wear reduces AL elongation by a significant amount (32%) when compared to SVLs. In a similar study, Kakita et al.[65] also reported 36% reduction in AL.

Cho et al.[66] in a single-masked randomised clinical trial in children (age 6–10 years) randomly assigned to wear Ortho-K or SVLs for two years concluded that Ortho-K slows AL elongation by 43% compared to SVLs. Average AL elongation was 0.36 mm in the Ortho-K group and 0.63 mm in the control group. Myopic progression was significantly greater in younger children (7–8 years) than older children (9–10 years) in both groups. Chen et al.[67] also reported a 52% reduction in AL compared to controls in myopic children (age 6–12 years) with moderate-to-high astigmatism.

Cho et al.[68] compared changes in AL elongation spanning a period of 14 months in subjects (age 8–14 years) who discontinued and later resumed Ortho-K with those who wore spectacles after a 2-year myopia control study. It was reported that discontinuation of Ortho-K wear at or before the age of 14 years could lead to a more rapid elongation of AL and the resumption of spectacles after stopping Ortho-K for 6 months significantly reduced AL elongation. A combination of partial reduction (PR) Ortho-K and SVLs (daytime wear) was used by Charm et al.[69] in myopic children (age 8–11 years). The Ortho-K was a custom-made four-zone design and the residual refractive errors were corrected with SVLs. Results indicated that PR Ortho-K slowed myopic progression by a significant amount. The AL elongation was 63% slower in the PR Ortho-K group than the SVL group. A study by Lin et al.[54] compared Ortho-K with atropine 0.125%. There was an increase in myopia of 0.28 D in the Ortho-K group and 0.34 D per year in the atropine group indicating a 17.6% increase. High myopes benefitted more from Ortho-K and atropine than low myopes.

Zhu et al.[61] compared the effect of Ortho-K and spectacles on myopia progression in Chinese children (age 7–14 years).

The mean refractive error for the Ortho-K group after two years was −1.05 D compared to −5.60 D in the spectacle group (81% increase). The increase in AL was 51% slower in the Ortho-K group than the spectacle group after 24 months. Axial length elongation was slower by 49% in low myopes, 59% in moderate myopes and 46% in high myopes. Myopic progression was much slower (61%) in younger myopes than older myopes (35%). It can be inferred from this study that Ortho-K significantly reduces myopia progression as compared to SVLs. However, most of the studies reported above are short-term studies with an average span of two years.

To further assert the effectiveness of Ortho-K, a long-term study (seven years) compared the AL growth in white European children (aged 6–12 years, SER −0.75 to −4.00 D) wearing Ortho-K to children wearing SV spectacle lenses and revealed a 42% reduction in AL for the Ortho-K group after 12 months, 41% after 24 months and 33% after 84 months.[70] Although the mechanism by which Ortho-K reduces myopic progression is not clear, there is a flattening of the central corneal area that simultaneously steepens the mid-peripheral zone. This results in the creation of peripheral myopic defocus which may reduce the visual feedback for AL elongation.[71,72,73]

Discussion

In this report, the optical methods of myopia control were reviewed including under-correction, bifocals, PALs, multifocal CLs and Ortho-K. Progression with the under-correction method is not clearly understood. Studies by Adler et al.[24] and Chung et al.[26] reveal an increase in myopic progression with under-correction. A possible reason is that under-correction will make myopic eyes experience relative peripheral hyperopia which may contribute to myopia progression. Under-correction may also change the viewing behaviour of children which may make them participate less in distant vision tasks and spend less time outdoors. Spending less time outdoors has been indicated as a risk factor in the development of myopia.[19,20,22] This has been linked to the restrictive role of the neurotransmitter dopamine on eye growth and myopia development[17,18] which implies that lack of outdoor light leads to lesser dopamine secretion.

Studies by Gwiazda et al.,[33] Hasebe et al.[34,35] and the Correction of Myopia Evaluation Trial (COMET 2) [74] that used PALs for myopia control found a reduction in myopia progression of about 30% in the first year of the trial when compared to SVLs, but the effect was reduced in subsequent years. A common limitation of some studies reviewed is the assumption that a particular power (addition) for PALs exerts the same myopia control effect on all children. Research shows that esophoric myopes could benefit from more power (addition) than exophoric myopes to control myopia.[40]

For bifocal CLs, a study by Aller et al.[52] shows a large difference (myopia control rate of 72%) compared to previous studies (average control rate of 50%), a possible limitation of the study is that the generalisability of the findings was limited as most participants had esophoric fixation disparity at close focus.[52] Further studies beyond 12 months should be carried out which could validate their findings. Other studies reviewed[55,56,57] show that dual focus CLs or SMCLs are more effective in controlling myopia progression than spectacles (including PALs) possibly because CLs are more likely worn throughout the day than spectacles, thus improving compliance. The addition in SMCLs is also constant in all angles of gaze.[52] However, recent research involving the DIMS® lens indicates reduced myopic progression by 52% compared to SV spectacle lenses. The low dropout rate and improvement in wearing time of the DIMS® spectacle lens made it a more attractive option than the DISC® CL. The implication of this in clinical practice is that the spectacle form of control with peripheral defocus lenses could offer a better adaptability than their CL counterpart when it becomes commercially available. As the DIMS® lens is a new innovation, further clinical trials involving peripheral defocus spectacle lenses (PDSLs) in other ethnic groups and high myopes (from −5.00 D) would be needed to ascertain its effectiveness in reducing myopia progression.

For myopic subjects with astigmatism, reports indicate that the presence of astigmatism could increase the chances of myopic progression.[75,76] Internal astigmatism (IA) has been identified as a stimulus factor for AL growth.[76] A study[77] indicates that toric Ortho-K can reduce corneal astigmatism by 48.1% (from 2.35 D to 1.22 D), whereas spherical Ortho-K resulted in a 10.5% decrease (2.29 D – 2.05 D). In moderate-to-high astigmatism, toric Ortho-K also gave better myopia control effect of 55.6% when compared to spherical Ortho-K. A 10-year follow-up study[78] revealed that the increase in AL was more in younger children with a high baseline myopia and that Ortho-K control stabilises after seven years, although a decelerating effect was reported in AL elongation in the early years.[78] An important feature of Ortho-K is that it can create large optical treatment effect in moderate-to-high myopia unlike other forms of optical treatment. Orthokeratology is also comparable to low-dose atropine in reducing myopia progression.[63,79] However, Ortho-K has its disadvantages that include the risk of infectious keratitis, the risk of corneal damage, wear discomfort and high cost.[78]

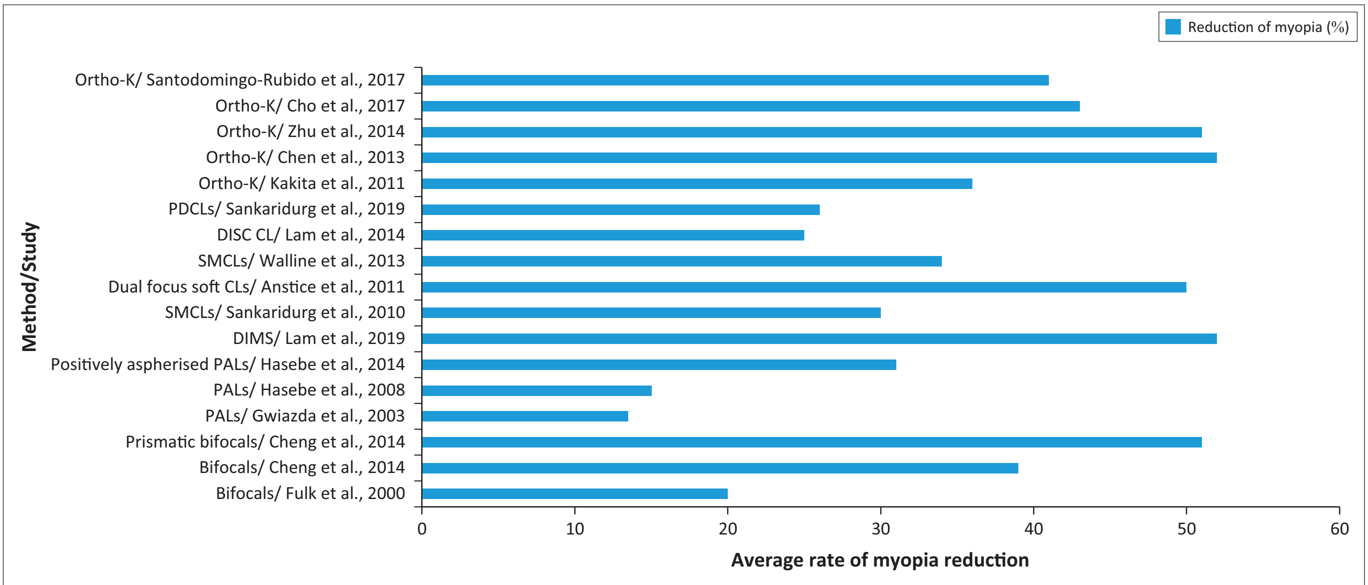
In all the optical methods reviewed, PALs and bifocals appear to be the least effective. Dual focus CL, novel peripheral defocus lenses (PDLs) and Ortho-K give moderate myopia control and seemed to be the most effective optical methods of myopia control (Figure 1 and Table 2). The PDLs showed promise for the future. Reports[33,80] indicate higher prevalence and faster progression of myopia in Asians as compared to Europeans. As most of the studies reviewed on myopia control involve Chinese children as displayed in Table 2, there is a need for more research duplicating some of the studies on individual interventions as well as comparing different ethnicities. Before concluding that ethnic differences exist, the study design needs to control for the lifestyle differences that exist between ethnicities in different locations.

TABLE 2: Effect of optical methods on myopia progression.

Study	Age (years)	Ethnicity	Method	Treatment effect
Adler et al.[24]	6–15	Jewish	Under-correction (glasses)	Increased myopia progression by 4.4%
Chung et al.[26]	9–14	Malay and Chinese	Under-correction (glasses)	Increased myopia progression by 30%
Li et al.[25]	12	Chinese	Under-correction (glasses)	Under-correction or full correction did not show significant difference in myopic progression
Sun et al.[27]	12.7	Chinese	No correction or full correction (glasses)	Slowed myopic progression by 28%
Cheng et al.[30]	8–13	Chinese Canadian	Bifocals (glasses)	Reduced myopia by 39%
Cheng et al.[30]	8–13	Chinese Canadian	Prismatic bifocals (glasses)	Reduced myopia by 51%
Gwiazda et al.[33]	6–11	Diverse	PALs (glasses)	Reduced myopia by 13%
Hasebe et al.[34]	6–12	Japanese	PALs (glasses)	Reduced myopia by 15%
Hasebe et al.[35]	6–12	Chinese & Japanese	Positively asphperised PALs (glasses)	Reduced myopia progression by 31%
Schilling et al.[44]	18–25	†	PALs (glasses)	PALs with more negative horizontal power gradients are more effective in reducing lag of accommodation
Lam et al.[41]	8–13	Chinese	DIMS® (glasses)	Reduced myopia progression by 52%
Katz et al.[53]	6–12	Singaporean	RGPCLs	Increased myopia progression by 3.7%
Anstice et al.[55]	11–14	Diverse	Dual focus soft CLs	Reduced myopia progression by 30%
Walline et al.[57]	8–11	Americans	SMCLs	Reduced myopia progression by 50%
Lam et al.[59]	8–13	Chinese	DISC® (CL)	Reduced myopia progression by 25% – 50% depending on duration of wear
Sankaridurg et al.[60]	7–13	Chinese	PDCLs	Reduced myopia progression by 26% – 43% in compliant wearers
Moore et al.[58]	24	Americans	Soft CLs	Soft CLs provide better peripheral defocus than spectacle lenses
Santodomingo-Rubido et al.[64]	6–12	White Europeans	Ortho-K	Reduced AL by 41%
Zhu et al.[61]	7–14	Chinese	Ortho-K	Reduced AL by 51%
Cho et al.[68]	8–14	Chinese	Ortho-K	Stopping Ortho-K before 14 years could lead to a more rapid AL elongation
Lin et al.[54]	7–17	Asians	Ortho-K	Comparable with atropine 0.125%.

SMCLs, soft multifocal contact lenses; PALs, progressive addition lenses; DIMS, defocus-incorporated multiple segments; DISC, defocus-incorporated soft contact; PDCLs, peripheral defocus soft contact lenses; RGPCLs, rigid gas permeable contact lenses; Ortho-K, orthokeratology.

†, Not reported.



SMCLs, soft multifocal contact lenses; PALs, progressive addition lenses; DIMS, defocus-incorporated multiple segments; CL, contact lens; DISC, defocus-incorporated soft contact; PDCLs, peripheral defocus soft contact lenses; Ortho-K, orthokeratology.

FIGURE 1: Bar chart showing the average reduction rates (%) of optical methods of myopia control. Under-correction was not included as the studies reviewed indicate an increase in myopic progression. Studies by Lam et al. (2019) (DIMS®) and Chen et al. (2013) (orthokeratology) indicate the best control (52%), while progressive addition lenses and bifocal lenses indicate the weakest (13% and 20%, respectively).

Recommendations

A combination of methods (such as partial Ortho-K and full correction with SVLs) could be more effective in reducing myopic progression. The baseline myopia for most of the studies reviewed ranged from −1.00 D to −5.00 D, higher magnitude myopia tends to progress faster than lower magnitude. Control measures should be implemented from −1 D and the phoria status has also to be considered as lower power (addition) is needed for less esophoric children. The near addition for PALs should be tailored to meet the individual needs of the patient. Clinicians should consider the use of peripheral defocus lenses particularly the spectacle form (52% effective and easier to wear than CLs) for myopia control as commercial availability becomes more accessible.

Conclusion

Myopia control measures can be easily incorporated into spectacles and CLs because they are common forms of correction. This underlines the importance of this review. Randomised controlled trials are the most commonly used study designs for myopia control. Peripheral defocus lens (either of concentric rings or progressive in nature) and multifocal CL designs based on myopic defocus theory offer the most effective myopia control. Orthokeratology is equally effective but future designs should consider ways of minimising risks of complications with lens wear. For the newer methods (PDCLs and PDSLs), studies that involve PDSLs reported lower dropout rates and easier adaptability than PDCLs. This implies that the PDSLs could be more useful and feasible in clinical practice as a form of myopia control. Under-correction is not considered an option based on available evidence. More studies would be needed to better understand how under-corrected myopic eyes tend to progress faster, whereas myopic eyes without correction tend to progress slower. A holistic approach and combination of methods may offer the best form of myopia control in the 21st century considering the increase in near work activities and use of digital devices among the most vulnerable groups.

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Competing interests

K.N. in addition to being a researcher with African Vision Research Institute (AVRI) at the University of KwaZulu-Natal is employed by Essilor (which sells optical lenses) as Vice President (VP) of Inclusive Business, Philanthropy and Social Impact.

Authors' contributions

T.R.A. was responsible for writing the article and K.S.N. and S.O.W. were responsible for the review and editing of the article.

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Data availability statement

Data sharing is not applicable to this study as no new data were created or analysed in this study.

Disclaimer

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References

1. Zadnik K, Mutti DO. Incidence and distribution of refractive anomalies. In: Benjamin WJ, editor. Borish's clinical refraction. 2nd ed. St Louis, MO: BH Elsevier; 2006:35–55.
2. Cooper J, Schulman E, Jamal N. Current status on the development and treatment of myopia. Optometry. 2012;83(5):179–199.
3. Atowa UC, Munsamy AJ, Wajuihian SO. Prevalence and risk factors for myopia among school children in Aba, Nigeria. Afr Vision Eye Health. 2017;76(1):a369. https://doi.org/10.4102/aveh.v76i1.369
4. Wajuihian SO, Hansraj R. Refractive error in a sample of black high school children in South Africa. Optom Vis Sci. 2017;94(12):1145–1152. https://doi.org/10.1097/OPX.0000000000001145
5. Azizoglu S, Junghans BM, Barutchu A, Crewther SG. Refractive errors in students form Middle Eastern backgrounds living and undertaking schooling in Australia. Clin Exp Optom. 2011;94(1):67–75. https://doi.org/10.1111/j.1444-0938.2010.00563.x
6. O'Donoghue L, McClelland JF, Logan NS, Rudnicka AR, Owen CG, Saunders KJ. Refractive error and visual impairment in school children in Northern Ireland. Br J Ophthalmol [serial online]. 2010; 94(9):1155–1159. [cited 2017 Oct 18]. Available from: www.bjo.bmj.com.
7. Congdon N, Wang Y, Song Y, et al. Visual disability, visual function and myopia among rural Chinese secondary school children: The Xichang Pediatric Refractive Error Study (X-PRES) – Report 1. Invest Ophthalmol Vis Sci. 2008;49(7):2888–2894. https://doi.org/10.1167/iovs.07-1160
8. Junghans BM, Crewther SG. Prevalence of myopia among primary school children in Eastern Sydney. Clin Exp Optom. 2003;86(5):339–345. https://doi.org/10.1111/j.1444-0938.2003.tb03130.x
9. Sun JT, An M, Yan XB, Li GH, Wang DB. Prevalence and related factors for myopia in school-aged children in Qingdao. J Ophthalmol [serial online]. 2018 [cited 2019 Jul 12]. Available from: www.hindawi.com, https://doi.org/10.1155/2018/9781987
10. Holden BA, Fricke TR, Wilson DA, et al. Global prevalence of myopia and high myopia and temporal trends from 2000 through 2050. Ophthalmology. 2016;123(5):1036–1042. https://doi.org/10.1016/j.ophtha.2016.01.006
11. American Optometric Association. American Eye-Q Survey [homepage on the Internet]. c2015 [cited 2018 April 12]. Available from: www.aoa.org.
12. Lee YY, Lo CT, Sheu SJ, Lin JL. What factors are associated with myopia in young adults? A survey study in Taiwan military conscripts. Invest Ophthalmol Vis Sci. 2013;54(2):1026–1033. https://doi.org/10.1167/iovs.12-10480
13. Contreras AB, Ackland P. Spectacle coverage report. London, UK: International Agency for the Prevention of Blindness; 2017.
14. Goss DA. Development of the ametropias. In: Benjamin WJ, editor. Borish's clinical refraction. 2nd ed. St Louis, MO: BH Elsevier; 2006.
15. Ip JM, Saw SM, Rose KA, et al. Role of near work in myopia: Findings in a sample of Australian school children. Invest Ophthalmol Vis Sci. 2008;49(7):2903–2910. https://doi.org/10.1167/iovs.07-0804
16. Rose KA, Morgan IG, Ip J, et al. Outdoor activity reduces the prevalence of myopia in children. Ophthalmology. 2008;115(8):1279–1285. https://doi.org/10.1016/j.ophtha.2007.12.019
17. Wu PC, Chen CT, Lin KK, et al. Myopia prevention and outdoor light intensity in a school-based cluster randomized trial. Ophthalmology. 2018;125(8):1239–1250. https://doi.org/10.1016/j.ophtha.2017.12.011
18. Li HH, Sun YL, Cui DM, Wu J, Zeng JW. Effect of dopamine on bone morphogenesis protein-2 expression in human retinal pigment epithelium. Int J Ophthalmol. 2017;10(9):1370–1373. https://doi.org/10.18240/ijo.2017.09.06
19. Wu PC, Tsai CL, Wu HL, Yang YH, Ruo HK. Outdoor activity during class recess reduces myopia onset and progression in school children. Ophthalmology. 2013;120(5):1080–1085. https://doi.org/10.1016/j.ophtha.2012.11.009
20. He M, Xiang F, Zeng Y, et al. Effect of time spent outdoors at school on the development of myopia among children in China: A randomized clinical trial. JAMA. 2015;314(11):1142–1148. https://doi.org/10.1001/jama.2015.10803
21. Guo Y, Liu LJ, Tang P, et al. Outdoor activity and myopia progression in 4-year follow-up of Chinese primary school children: The Beijing Children Eye Study. PLoS One. 2017;12(4):e0175921. http://doi.org/10.1371/journal.pone.0175921
22. Dirani M, Tong L, Gazzard G, et al. Outdoor activity and myopia in Singapore teenage children. Br J Ophthalmol. 2009;93(8):997–1000. https://doi.org/10.1136/bjo.2008.150979
23. Jones LA, Sinott LT, Mutti DO, Mitchell GL, Moeschberger ML, Zadnik K. Parental history of myopia, sports and outdoor activities, and future myopia. Invest Ophthalmol Vis Sci. 2007;48(8):3524–3532. https://doi.org/10.1167/iovs.06-1118
24. Adler D, Millodot M. The possible effect of undercorrection on myopic progression in children. Clin Exp Optom. 2006;89(5):315–321. https://doi.org/10.1111/j.1444-0938.2006.00055.x
25. Li SY, Li SM, Zhou YH, et al. Effect of undercorrection on myopia progression in 12-year old children. Graefes Arch Clin Exp Ophthalmol. 2015;253(8):1363–1368. https://doi.org/10.1007/s00417-015-3053-8
26. Chung K, Mohidin N, O'Leary DJ. Undercorrection of myopia enhances rather than inhibits myopia progression. Vision Res. 2002;42(22):2555–2559. https://doi.org/10.1016/S0042-6989(02)00258-4
27. Sun YY, Li SM, Li SY, et al. Effect of uncorrection versus full correction on myopia progression in 12-Year old children. Graefes Arch Clin Exp Ophthalmol. 2017;255(1):189–195. https://doi.org/10.1007/s00417-016-3529-1
28. Kading D, Mayberry A. Slowing myopia progression in children. Rev Optom [serial online]. c2012 [cited 2017 Feb 27]. Available from: www.reviewofoptometry.com.
29. Fulk GW, Cyert LA, Parker DE. A randomized trial of the effect of single vision vs bifocal lenses on myopia progression in children with esophoria. Optom Vis Sci. 2000;77(8):395–401. https://doi.org/10.1097/00006324-200008000-00006
30. Cheng D, Woo GC, Drobe B, Schmid KL. Effect of bifocal and prismatic bifocal spectacles on myopia progression in children: Three-year results of a randomized clinical trial. JAMA Ophthalmol. 2014;132(3):258–264. https://doi.org/10.1001/jamaophthalmol.2013.7623
31. Cheng D, Woo GC, Schmid KL. Bifocal lens control of myopic progression in children. Clin Exp Optom. 2011;94(1):24–32. https://doi.org/10.1111/j.1444-0938.2010.00510.x
32. Cheng D, Schmid KL, Woo GC. The effect of positive-lens addition and base-in prism on accommodation accuracy and near horizontal phoria in Chinese myopic children. Ophthalmic Physiol Opt. 2008;28(3):225–237. https://doi.org/10.1111/j.1475-1313.2008.00560.x

33. Gwiazda J, Hyman L, Hussein M, et al. A randomized clinical trial of progressive addition lenses versus single vision lenses on the progression of myopia in children. Invest Ophthalmol Vis Sci. 2003;44(4):1492–1500. https://doi.org/10.1167/iovs.02-0816

34. Hasebe S, Ohtsuki H, Nonaka T, et al. Effect of progressive addition lenses on myopia progression in Japanese children: A prospective, randomized, double-masked, crossover trial. Invest Ophthalmol Vis Sci. 2008;49(7):2781–2789. https://doi.org/10.1167/iovs.07-0385

35. Hasebe S, Jun J, Varnas SR. Myopia control with positively aspherized progressive addition lenses: A 2-year multicenter, randomized controlled trial. Invest Ophthalmol Vis Sci. 2014;55(11):7177–7188. https://doi.org/10.1167/iovs.12-11462

36. Gwiazda JE, Hyman L, Norton TT, et al. Accommodation and related risk factors associated with myopia progression and their interaction with treatment in COMET children. Invest Ophthalmol Vis Sci. 2004;45(7):2143–2151. https://doi.org/10.1167/iovs.03-1306

37. Sreenivasan V, Aslakson E, Kornaus A, Thibos LN. Retinal image quality during accommodation in adult myopic eyes. Optom Vis Sci. 2013;90(11):1292–1303. https://doi.org/10.1097/OPX.0000000000000068

38. Berntsen DA, Mutti DO, Zadnik K. The effect of bifocal add on accommodative lag in myopic children with high accommodative lag. Invest Ophthalmol Vis Sci. 2010;51(12):6104–6110. https://doi.org/10.1167/iovs.09-4417

39. Berntsen DA, Sinnott LT, Mutti DO, Zadnik K. A randomized trial using progressive addition lenses to evaluate theories of myopia progression in children with a high lag of accommodation. Invest Ophthalmol Vis Sci. 2012;53(2):640–649. https://doi.org/10.1167/iovs.11-7769

40. Mutti DO, Mitchell GL, Hayes JR, et al. The CLEERE study group. Accommodative lag before and after the onset of myopia. Invest Ophthalmol Vis Sci. 2006;47(3):837–847. https://doi.org/10.1167/iovs.05-0888

41. Lam CSY, Tang WC, Tse DY, et al. Defocus incorporated multiple segments (DIMS) spectacle lenses slow myopia progression: A 2-year randomised clinical trial. Br J Ophthalmol [serial online]. 2019 [cited 2019 Jul 01]; Epub ahead of print. Available from: https://doi.org/10.1136/bjophthalmol-2018-313739

42. Bao J, Wang Y, Zhuo Z, et al. Influence of progressive addition lenses on reading posture in myopic children. Br J Ophthalmol. 2016;100(8):1114–1117. https://doi.org/10.1136/bjophthalmol-2015-307325

43. Jiang BC, Tea YC, O'Donnell D. Changes in accommodative and vergence responses when viewing through near addition lenses. Optometry. 2007;78(3):129–134. https://doi.org/10.1016/j.optm.2006.08.017

44. Schilling T, Ohlendorf A, Varnas SR, Wahl S. Peripheral design of progressive addition lenses and the lag of accommodation in myopes. Invest Ophthalmol Vis Sci. 2017;58(9):3319–3324. https://doi.org/10.1167/iovs.17-21589

45. Atchison DA, Varnas SR. Accommodation stimulus and response determinations with autorefractors. Ophthalmic Physiol Opt. 2017;37(1):96–104. https://doi.org/10.1111/opo.12340

46. Tarrant J, Severson H, Wildsoet CF. Accommodation in emmetropic and myopic young adults wearing bifocal soft contact lenses. Ophthal Physiol Opt. 2008;28(1):62–72. https://doi.org/10.1111/j.1475-1313.2007.00529.x

47. Weizhong L, Zhikuan Y, Wen L, Xiang C, Jian G. A longitudinal study on the relationship between myopia development and near accommodation lag in myopic children. Ophthal Physiol Opt. 2008;28(1):57–61. https://doi.org/10.1111/j.1475-1313.2007.00536.x

48. The Hong Kong Polytechnic University: Annual report on activities and advancement of knowledge transfer [homepage on the Internet]. c2018 [cited 2019 Jan 20]. Available from: https://www.ugc.edu.hk/doc/eng/ugc/activity/kt/PolyU17.pdf.

49. Asian scientist magazine: Lens shown to reduce myopia in children [homepage on the Internet]. c2011–2019 [updated 2018 May 01; cited 2019 Jan 20]. Available from: https://www.asianscientist.com/2018/05/health/myopia-children-eyeglasses-lens.

50. Sankaridurg P, Donovan L, Varnas S, et al. Spectacle lenses designed to reduce progression of myopia: 12-month results. Optom Vis Sci. 2010;87(10):802. https://doi.org/10.1097/OPX.0b013e3181fab730

51. Walline JJ, Jones LA, Mutti DO, Zadnik K. A randomized trial of the effects of rigid contact lenses on myopia progression. Arch Ophthalmol. 2004;122(12):1760–1766. https://doi.org/10.1001/archopht.122.12.1760

52. Aller TA, Liu M, Wildsoet CF. Myopia control with bifocal contact lenses: A randomized clinical trial. Optom Vis Sci. 2016;93(4):344–352. https://doi.org/10.1097/OPX.0000000000000808

53. Katz J, Schein OD, Levy B, et al. A randomized trial of rigid gas permeable contact lenses to reduce progression of children's myopia. Am J Ophthalmol. 2003;136(1):82–90. https://doi.org/10.1016/S0002-9394(03)00106-5

54. Lin HJ, Wan L, Tsai FJ, et al. Overnight orthokeratology is comparable with atropine in controlling myopia. BMC Ophthalmol. 2014;14:40. https://doi.org/10.1186/1471-2415-14-40

55. Anstice NS, Phillips JR. Effect of dual-focus soft contact lens wear on axial myopia progression in children. Ophthalmology. 2011;118(6):1152–1161. https://doi.org/10.1016/j.ophtha.2010.10.035

56. Sankaridurg P, Holden B, Smith E, et al. Decrease in rate of myopia progression with a contact lens designed to reduce relative peripheral hyperopia: One-year results. Invest Ophthalmol Vis Sci. 2011;52(13):9362–9367. https://doi.org/10.1167/iovs.11-7260

57. Walline JJ, Greiner KL, McVey M, Elizabeth JJ, Lisa A. Multifocal contact lens myopia control. Optom Vis Sci. 2013;90(11):1207–1214. https://doi.org/10.1097/OPX.0000000000000036

58. Moore KE, Benoit JS, Berntsen DA. Spherical soft contact lens designs and peripheral defocus in myopic eyes. Optom Vis Sci. 2017;94(3):370–379. https://doi.org/10.1097/OPX.0000000000001053

59. Lam CSY, Tang WC, Tse DYY, Tang YY, To CH. Defocus incorporated soft contact (DISC) lens slows myopia progression in Hong Kong Chinese schoolchildren: A 2-year randomised clinical trial. Br J Ophthalmol. 2014;98(1):40–45. https://doi.org/10.1136/bjophthalmol-2013-303914

60. Sankaridurg P, Bakaraju RC, Naduvilath, et al. Myopia control with novel central and peripheral plus contact lenses and extended depth of focus contact lenses: 2 year results from a randomised clinical trial. Ophthalmic Physiol Opt. 2019;39(4):294–307. https://doi.org/10.1111/opo.12621.

61. Zhu MJ, Feng HY, He XG, Zou HD, Zhu JF. The control effect of orthokeratology on axial length elongation in Chinese children with myopia. BMC Ophthalmol. 2014;14:141. https://doi.org/10.1186/1471-2415-14-141

62. Walline JJ, Jones LA, Sinnott LT. Corneal reshaping and myopia progression. Br J Ophthalmol. 2009;93(9):1181–1185. https://doi.org/10.1136/bjo.2008.151365

63. Cho P, Cheung SW, Edwards M. The longitudinal orthokeratology research in children (LORIC) in Hong Kong: A pilot study on refractive changes and myopic control. Curr Eye Res. 2005;30(1):71–80. https://doi.org/10.1080/02713680590907256

64. Santodomingo-Rubido J, Villa-Collar C, Gilmartin B, Gutierrez-Ortega R. Myopia control with orthokeratology contact lenses in Spain: Refractive and biometric changes. Invest Ophthalmol Vis Sci. 2012;53(8):5060–5065. https://doi.org/10.1167/iovs.11-8005

65. Kakita T, Hiraoka T, Oshika T. Influence of overnight orthokeratology on axial elongation in childhood myopia. Invest Ophthalmol Vis Sci. 2011;52(5):2170–2174. https://doi.org/10.1167/iovs.10-5485

66. Cho P, Cheung SW. Retardation of myopia in orthokeratology (ROMIO) study: A 2-year randomized clinical trial. Invest Ophthalmol Vis Sci. 2012;53(11):7077–7085. https://doi.org/10.1167/iovs.12-10565

67. Chen C, Cheung SW, Cho P. Myopia control using toric orthokeratology (TO-SEE study). Invest Ophthalmol Vis Sci. 2013;54(10):6510–6517. https://doi.org/10.1167/iovs.13-12527

68. Cho P, Cheung SW. Discontinuation of orthokeratology on eyeball elongation (DOEE), randomized controlled trial. Cont Lens Anterior Eye. 2017;40(2):82–87. https://doi.org/10.1016/j.clae.2016.12.002.

69. Charm J, Cho P. High myopia-partial reduction Ortho-K: A 2-Year randomized study. Optom Vis Sci. 2013;90(6):530–539. https://doi.org/10.1097/OPX.0b013e318293657d

70. Santodomingo-Rubido J, Villa-Collar C, Gilmartin B, Gutierrez-Ortega R, Sugimoto K. Long-term efficacy of orthokeratology contact lens wear in controlling the progression of childhood myopia. Curr Eye Res. 2017;42(5):713–720. https://doi.org/10.1080/02713683.2016.1221979.

71. Mathur A, Atchison DA. Effect of orthokeratology on peripheral aberrations of the eye. Optom Vis Sci. 2009;86(5):476–484. https://doi.org/10.1097/OPX.0b013e31819fa5aa

72. Kang P, Swarbrick H. Peripheral refraction in myopic children wearing orthokeratology and gas-permeable lenses. Optom Vis Sci. 2011;88(4):476–482. https://doi.org/10.1097/OPX.0b013e31820f16fb

73. Kanda H, Oshika T, Hiraoka T, et al. Effect of spectacle lenses designed to reduce relative peripheral hyperopia on myopia progression in Japanese children: A 2-year multicentre randomized controlled trial. Jpn J Ophthalmol. 2018;62(5):537–543. https://doi.org/10.1007/s10384-018-0616-3

74. Correction of Myopia Evaluation Trial 2 Study Group for the Pediatric Eye Disease Investigator Group. Progressive-addition lenses versus single-vision lenses for slowing progression of myopia in children with high accommodative lag and near esophoria. Invest Ophthalmol Vis Sci. 2011;52(5):2749–2757. https://doi.org/10.1167/iovs.10-6631

75. Czepita D, Filipak D. Role of astigmatism in the creation of myopia. Klinika Oczna. 2003;10(6):385–386.

76. Wu L, Weng C, Xia F, Wang X, Zhou X. Internal astigmatism and its role in the growth of axial length in school-age children. J Ophthalmol. 2018; Article ID 1686045:5 pages. https://doi.org/10.1155/2018/1686045

77. Zhang Y, Chen YG. Comparison of myopia control between toric and spherical periphery design orthokeratology in myopic children with moderate-to-high corneal astigmatism. Int J Ophthalmol. 2018;11(4):650–655.

78. Tarutta EP, Verzhanskaya TY. Stabilizing effect of orthokeratology lenses (ten-year follow up results). Russ Ann Ophthalmol. 2017; 133(1): 49–54. https://doi.org/10.17116/oftalma2017133149-54

79. Hiraoka T, Kakita T, Okamoto F, Takahashi H, Oshika T. Long-term effect of overnight orthokeratology on axial length elongation in childhood myopia: A 5-year follow-up study. Invest Ophthalmol Vis Sci. 2012;53(7):3913–3919. https://doi.org/10.1167/iovs.11-8453

80. Saw SM, Tong L, Chua WH, et al. Incidence and progression of myopia in Singaporean school children. Invest Ophthalmol Vis Sci. 2005;46(1):51–57. https://doi.org/10.1167/iovs.04-0565