Optical Interventions for Myopia Control

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Key Points

- Optical intervention for myopia control can slow down myopia progression by 50–60%.
- Simultaneous myopic defocus and refractive error correction have been proved to be effective in myopia control.
- Different myopia control methods and their pros and cons aid clinicians to select the best treatment for patients.

14.1 Introduction

A variety of clinical methods are currently utilized for retarding myopia progression. However, none of the methods have been proven to cease the development or progression of myopia completely and they may not work for some individuals. As described in previous chapters, the main clinical interventions for myopia control currently include optical lenses, pharmaceutical agents and outdoor activities. This chapter provides an overview of the various types of optical interventions for slowing down myopia progression. The findings of the clinical trials of these methods are summarized and the relative effectiveness of these methods in myopia control is compared. In general, the optical methods for myopia control in children can be summarized into two categories: spectacle lenses and contact lenses.

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14.2 Spectacle Lenses

14.2.1 Under-Correction of Myopia

Studies using animals, such as chicks and mammals, have shown that the use of optical lenses to impose myopic defocus inhibits myopic eye growth in developing eyes [1–5]. These studies have led to the hypothesis that under-correction of myopia, that is, prescribing spectacles for distance vision that does not fully correct the myopic refraction, may be a viable method for slowing myopia progression in humans. As near work and accommodation were proposed as key factors for the development and progression of myopia, in theory, under-correction could reduce accommodative demand during near viewing, thereby halting the myopia progression of myopia.

Contrary to the animal studies, two clinical trial studies showed that under-correction actually accelerates myopia development and progression in myopic humans [6, 7]. In a randomized study by Chung et al. [6], children in the experimental group were assigned to wear spectacle lenses that were under corrected by 0.50–0.75 D to achieve distance visual acuity of 6/12, while children in the control group were prescribed their full correction. After 2 years, the under-correction group had greater myopia progression of −1.00 D as compared to the control group who progressed by −0.77 D. A retrospective study investigating clinical data from a private optometric practice also found that under-correction resulted in greater myopia progression compared to full correction [7].

One recent study in Beijing reported that children with no spectacle correction had slower myopia progression and less axial elongation than those given a full spectacle correction over 2 years [8]. In this study, myopia progression decreased significantly with an increasing amount of under-correction, but the effect on slowing myopia progression was slowed by only 0.27 D over 2 years, which is not clinically meaningful. In view of these conflicting results, there is no convincing evidence to indicate that under-correction should be used for slowing myopia progression in children.

14.2.2 Bifocal or Multifocal Spectacles

Over the past decades, numerous studies have assessed the effect of bifocal, multifocal, and progressive addition lens (PALs) spectacles on myopia progression. Table 14.1 summarizes the clinical trials of using the different spectacle lens types. Bifocals and PALs allow the wearers to clearly see objects in the distance through the upper part of the glasses by providing correction of distance refractive error. The bottom part of the lens consists of an addition power that may retard myopia progression by reducing accommodative effort and lag at near in a similar way as under-correction.

The majority of these studies have shown that PALs have an insignificant effect on slowing myopia progression rate (less than 0.2 D per year) overall (Table 14.1)

Table 14.1 Myopia control studies using PALs, bifocal and multifocal spectacles

Authors and years	Study duration (years)	Design	Age (years), ethnicity	Subject Rx range, diopters (D)	Interventions and sample size (*n*)	Treatment effect in slowing myopia progression during study period, D (%)
Fulk et al. (2000) [15]	2.5	Randomized, masked	6–13	−0.50 to −6.00 (under 9 years old) or −8.00 (9 years old or older)	SV, $n = 40$ Bifocals with 1.50 D add, $n = 42$	0.25 (20%)
Edward et al. (2002) [9]	2	Randomized, double masked	7–10.5, Chinese	−1.25 to −4.50	SV, $n = 132$ PAL (1.5 D add), $n = 121$	0.14 (11%)
Gwiazda et al. (2003) [10]	3	Randomized, masked	6–11, diverse ethnicity	−1.25 to −4.50	SV, $n = 233$ PAL (2 D add), $n = 229$	0.20 (14%)
Yang et al. (2009) [11]	2	Randomized, masked	7–13, Chinese	−0.50 to −3.00	SV, $n = 75$ PAL (1.5 D add), $n = 74$	0.26 (17%)
COMET2 (2011) [12]	3	Randomized, masked, multicenter	8–12, diverse ethnicity	−0.75 to −2.50	SV, $n = 58$ PAL (2 D add), $n = 52$	0.28 (24%)
Sankaridurg et al. (2011) [17]	1	Randomized	6–16, Chinese	−0.75 to −3.50	Type I, III lenses, SV, $n = 50$ each group Type II, $n = 60$	Type III lens: 0.29 (30% only in a subgroup of children with myopic parents)
Berntsen et al. (2012) [13]	1	Randomized, masked, all subjects worn SV in 2nd year	6–11	−0.75 to −4.50	SV, $n = 42$ PAL (2 D add), $n = 41$	0.18 (35%)
Hasbe et al. (2014) [14]	1.5	Randomized, masked, cross-over	6–12, Japanese	−1.25 to −6.00	SV, $n = 44$ PAL (1.5 D add), $n = 42$	1st period: 0.31 (18%) 2nd period: 0.02 (2%)
Cheng et al. (2014) [16]	3	Randomized, masked	8–13, Chinese	−1 to −5.50	SV, $n = 41$ BF (1.5 D add), $n = 48$ PBF (1.5 D add, 3ΔBI), $n = 46$	BF: 0.81 (39%) PBF: 1.05 (51%)
Lam et al. (2019) [19]	2	Randomized, masked	8–13, Chinese	−1.00 to −5.00	SV = 90 DIMS = 93	0.44 (52%)

COMET2 and PEDIG Correction of Myopia Evaluation Trial 2 Study Group and the Paediatric Eye Disease Investigator Group, *SV* single vision spectacle lens, *PAL* progressive addition lens, *BF* bifocal spectacle lens, *PBF* prismatic bifocal lens, *DIMS* defocus incorporated multiple segments spectacle lens

[9–14]. Some myopic children with esophoria and accommodative lag may benefit from PALs, but the retardation effect is not clinically significant.

For bifocal spectacles, an early randomized trial performed by Fulk et al. [15] found that bifocals with +1.5 D add slowed myopia progression by 20% in the children with esophoria. The clinical trial by Cheng et al. [16] found that both executive top bifocals with and without 3Δ base-in prism have shown a more meaningful myopia control effect in a selected group of fast progressing myopic children when compared with single vision spectacles. The myopia progression rate was reduced by approximately 40–50% over 3 years, with the effect being more prominent among those with low accommodative lag. The inclusion of base-in prism in the experimental lenses was an attempt to reduce fusional vergence demand to enhance the treatment effects of the bifocals. A positive effect of myopia control was exhibited as changes in spherical equivalent refraction in the study. Axial length changes were similar between those with and without base-in prism in their bifocals; it is rather unclear whether there is a benefit in having base-in prism in the bifocal lens. This option may also not be preferable for some children having anisometropia, and it results in poor cosmesis.

Another hypothesis is that the correction or reduction of relative peripheral hyperopia may have an effect on myopia progression [17, 18]. Sankaridurg et al. [17] performed a clinical trial to test this hypothesis by using three custom-designed spectacle lenses that reduced peripheral hyperopic defocus while maintaining clear central vision. After 12 months of lens wear, no significant reduction in myopia progression was found between the treatment groups and the control group. Only one type of the treatment lenses showed 30% reduction of myopia progression in a subgroup of the children whose parents were myopes. A similar clinical trial in soft contact lens [18], based on the same hypothesis, exhibited meaningful effects and will be discussed later in the section on soft multifocal contact lenses.

More recently, a specially designed bifocal spectacle lens, called Defocus Incorporated Multiple Segments (DIMS) spectacle lens (also known as multisegment of myopic defocus (MSMD) spectacle lens), has been used for myopia control in a randomized trial by Lam et al. [19]. DIMS lens design is based on the principle of simultaneous vision with myopia defocus for myopia control where it comprises a central optical zone for correcting refractive error and multiple segments of constant myopic defocus (+3.50 D) surrounding the central zone. This enables the lens to provide clear vision and myopic defocus simultaneously for wearers regardless of whether they are looking at distance, intermediate or near objects. The results from the clinical trial showed that the children wearing DIMS lenses had 52% less myopia progression and 62% less axial elongation when compared with children wearing single vision spectacle lenses over 2 years. Moreover, about 20% of the DIMS lens wearers had no myopia progression during the study period. Further studies in other study populations are required to validate these promising results.

Figure 14.1 presents a comparison of the percentage myopia progression that slowed down from PALs, bifocals, and prismatic bifocals use as well as other types of multiple spectacle lenses [9–16].

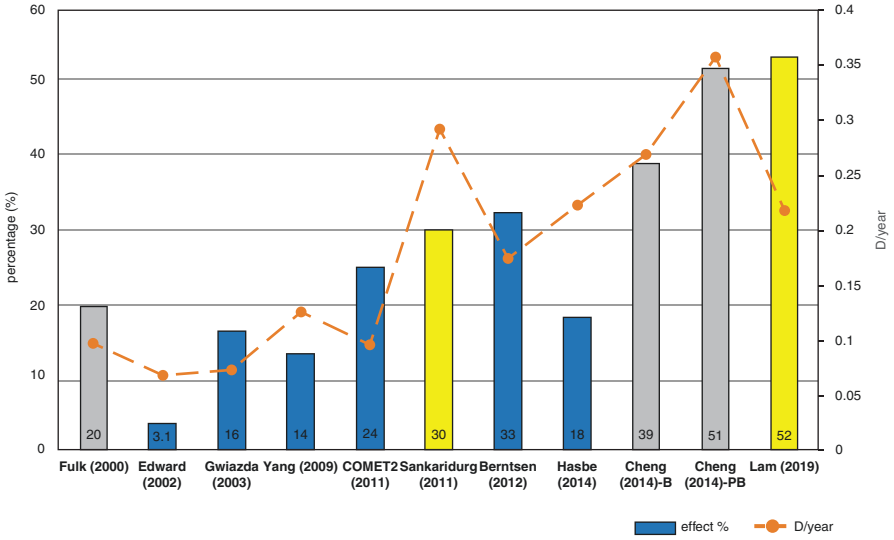

Fig. 14.1 The effect on slowing of myopia progression, in terms of percentage within the study period (effect %) and diopter per year (D/year), reported by various controlled clinical studies using bifocal or multifocal spectacles. The bars represent effect % using bifocals (gray), progressive addition lenses (blue) and other types of multifocal spectacle lenses (yellow). The value of effect % is indicated in the bar. The dotted line represents treatment effect in D/year (*B* bifocals, *PB* prismatic bifocals)

14.3 Contact Lenses

14.3.1 Rigid Gas Permeable Contact Lenses

Several studies in the later part of the twentieth century investigated whether daytime wear of rigid gas permeable (RGP) contact lenses slowed myopia progression, but all those studies had various limitations in their study designs, such as subject criteria outside the expected age of progression, lack of randomization, and unequal loss to follow-up [20–22]. Two randomized clinical trials [23, 24] showed that RGP contact lenses did not retard axial eye growth. However, Walline et al. [23] reported significant slower myopia progression in the group of RGP lenses compared with soft contact lenses. Despite that no differences were found in axial elongation between the groups. The proposed reason for a treatment effect on the refractions may be due to the changes in corneal curvature. As wear of RGP contact lenses is likely to induce only temporary changes in corneal curvature, the retardation of myopia progression may be transient. Therefore, the authors concluded that RGP lens wear does not slow myopia progression.

14.3.2 Orthokeratology

Orthokeratology (Ortho-K) lenses are specially designed RGP contact lenses that are worn overnight to reshape the cornea and thereby temporarily correct low to

moderate myopia. It has become a popular modality for controlling myopia in children in the last few decades. In addition to the enhancement of unaided vision at daytime, Ortho-K is also able to control myopia progression.

Modern Ortho-K lens designs include four zones, namely the central optic zone, the reverse zone, the alignment zone and the peripheral zone [25, 26]. The central optic zone helps to flatten the central cornea and is used for refractive correction. The reverse zone, which has a steeper curvature than the central zone, enhances the corneal reshaping to maximize the myopic reduction. The alignment zone, usually aspherical or tangent, plays a very important role in optimizing the lens centration, while the peripheral curve promotes tear exchange. Apart from spherical designs, toric lenses are also available commercially and are recommended for use in patients with more than 1.50 D astigmatism. Fitting of Ortho-K is simple nowadays with manufacturers providing trial lens sets or computer software that directly calculates the most suitable and precise parameters based on the corneal topography. Although many different Ortho-K lens designs are available on the market, Tahhan et al. [27] found no significant variation on the clinical efficacy between the different lens designs.

The main hypothesis of myopia control using Ortho-K is the introduction of myopic defocus on the peripheral retina [27]. It is proposed that after Ortho-K treatment, the corneal shape changes to an oblate shape, which results in a peripheral refraction that has less hyperopic defocus [28]. Another hypothesis of the mechanism behind the myopia control effect of Ortho-K is that the changes in lag of accommodation may be due to increasing positive spherical aberration and changes in choroidal thickness [29, 30]. It seems that further investigation is required in order to determine the actual mechanism for the efficacy of Ortho-K.

Various clinical studies have demonstrated the effectiveness of inhibiting myopic progression with Ortho-K. Table 14.2 summarizes recent clinical trials using Ortho-K for myopia control in children. The effect of slowing axial length elongation ranges from 32% to 63% [31–38]. The overall treatment effect is around 50%. Figure 14.2 shows a comparison of the effect on retarding axial elongation using Ortho-K among different studies [31–37].

A recent study by Swabrick et al. [39] used a contralateral eye cross-over study design to investigate the effects of Ortho-K on axial length growth over 1 year. The results revealed that there were no changes in axial length at each 6-month phase of Ortho-K wear, while significant increases in axial length were found in the control group who wore daytime gas permeable lenses.

To the best of our knowledge, there is no research investigating the maximum power of myopia reduction with overnight Ortho-K, and most studies use −4.00 D as the exclusion criteria. Charm et al. investigated the myopic control effect of Ortho-K by partial reduction to the power of −4.00 D as the target in children with high myopia (spherical equivalent refraction at least −5.75 D and myopia ≥−5.00 D). The remaining refractive error was corrected by single vision spectacles. The myopia control effect was comparable to other studies of Ortho-K in low–moderate myopic subjects over 2 years [37]. As the risk of having corneal staining and lens decentration increases with the amount of myopia correction [39], partial reduction of myopia might be a better option in high myopes instead of the full correction.

Table 14.2 Myopia control studies using Ortho-K lenses

Authors and years	Study design	Study duration (years)	Control group	Mean change in AL (mm)		Treatment effect in retarding axial length elongation, mean difference in mm (%)
				Ortho-K	Control	
Cho et al. (2005) [31]	Self-selected prospective	2	SV	0.29	0.54	0.25 (46)
Walline et al. (2009) [32]	Prospective, historical controls	2	SVCL	0.25	0.57	0.32 (56)
Kakita et al. (2011) [33]	Self-selected retrospective	2	SV	0.39	0.61	0.22 (36)
Cho and Cheung (2012) [34]	Randomized, single-masked	2	SV	0.36	0.63	0.27 (43)
Hiraoka et al. (2012) [35]	Self-selected retrospective	5	SV	0.99	1.41	0.42 (30)
Santodomingo-Rubido et al. (2012) [36]	Self-selected prospective	2	SV	0.47	0.69	0.22 (32)
Charm and Cho (2013) [37]	Randomized, single-masked	2	SV	0.19	0.51	0.32 (63)
Chen et al. (2013) [38]	Self-selected prospective	2	SV	0.31	0.64	0.33 (52)

SV single vision spectacle lens, *SVCL* single vision soft contact lens

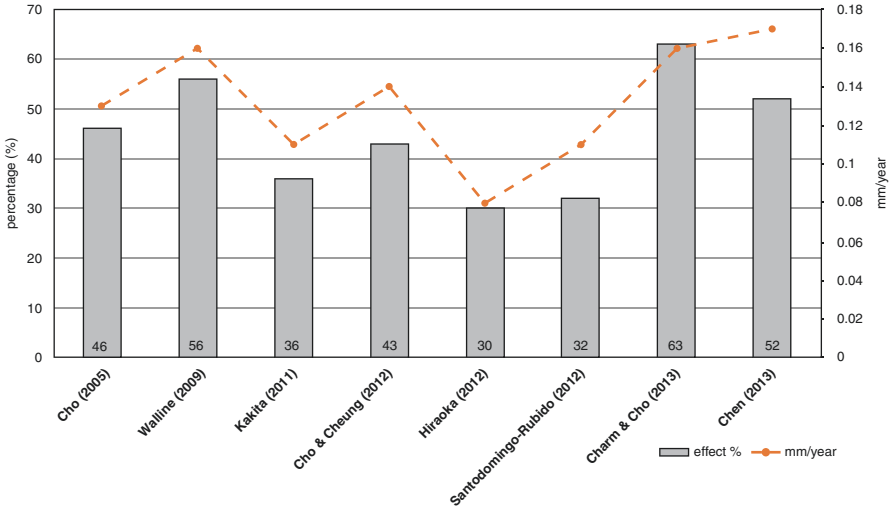

Fig. 14.2 Effect on slowing axial elongation reported by various studies using orthokeratology. The bar represents the treatment effect within the study period in terms of percentage (%) as compared to controls. The dotted line represents reduction in changes of axial length per year (mm/year)

Although Ortho-K is useful for myopic control in numerous studies, all the results were reported as an average value. Lipson et al [26] evaluated the axial length change over 3 years in children receiving Ortho-K treatment. Around 65% of the children had 0.5 mm or less axial elongation, while axial eye growth of more than 1.0 mm was seen in 15% of the children. Hence, the myopic control effect of Ortho-K lenses shows a large variation among individuals. Some researchers believed that the age at which Ortho-K is started, baseline myopia, cornea profile, and pupil size may be possible factors affecting the effectiveness of myopic control among Ortho-K wearers [26, 31, 34, 35, 40].

Interestingly, a recent study in Japan [41] showed that the combination of Ortho-K and low-concentration atropine (0.01%) eye drops was more effective in slowing axial elongation over 12 months than Ortho-K treatment alone in myopic children. More research is needed to show if this effect can be sustained in the longer term.

Although hypoxic reactions are rarely seen with Ortho-K wear due to the use of highly oxygen permeable materials, the need to wear contact lenses overnight may remain a concern for clinicians, as this type of lens wear pattern is associated with a higher risk of infectious keratitis [42–44]. A review of 50 cases of microbial keratitis done by Watt and Swarbrick [44] revealed that the majority of microbial keratitis cases are related to contamination of lenses due to patient non-compliance, such as improper lens handling or cleaning. A detailed systematic review on the safety of Ortho-K wear by Liu and Xie [45] also suggested that the training of practitioners and wearers, appropriate fitting procedures, compliance to lens care regimens and follow-up schedule are all factors affecting the incidence of microbial keratitis. A recent retrospective study compared the adverse events in Ortho-K wearers versus soft contact lens wearers over a 10-year period. The number of corneal complications such as keratitis and infiltrates were found to be significantly higher in the Ortho-K group, but no infectious keratitis was reported [46]. Bullimore et al. [47] found that there was no significant difference in the risk of getting microbial keratitis with Ortho-K wear compared to other overnight contact lens wear. This shows that with appropriate fitting and lens care, Ortho-K is a safe myopic control method. However, practitioners should always emphasize the importance of patient compliance, especially in lens care and follow-up visits, to reduce the risk of microbial keratitis [45].

Corneal staining is the most common complication in Ortho-K treatment. Studies confirmed the frequency and severity of staining associated with overnight lens wear [44]. Lens binding is one of the causes of creating central staining. Optimizing lens fitting, adding fenestration on lens and using artificial tears before lens removal could reduce the possibility of lens adhesion. Clinicians should be cautious if persistent or recurrent corneal staining is observed.

14.3.3 Soft Bifocal and Multifocal Contact Lenses

Soft contact lenses in the form of bifocal and multifocal have been designed to slow myopia progression in children, and there has been a rising interest in this area over

the recent decade. These lenses are worn during the daytime. Compared to spectacles, contact lenses are more cosmetically acceptable and are more convenient for daily activities of some children, especially during sports activities [48, 49]. Also, they are generally able to be competently handled and worn by children [48]. For most of eye care practitioners, the fitting procedures of soft bifocal contact lenses are relatively simpler than those of Ortho-K.

Table 14.3 and Fig. 14.3 summarize recent clinical trials using soft bifocal contact lenses for myopia control [18, 50–56]. Generally, two main approaches are employed for the design of soft contact lenses for myopia control. Both lens designs incorporate a central distance zone to correct myopia. One design manipulates the peripheral lens curvature in order to lower peripheral hyperopic defocus. The other design uses concentric rings of alternating myopia defocus using addition (plus) powers and myopia correction powers in the periphery. This design is sometimes called 'dual power or dual focus' contact lenses in the literature. Both approaches allow the lens wearers to have good vision in their daily life and receive therapeutic optical defocus at the same time.

Several lens types, with a design to reduce peripheral hyperopia, have been reported to be promising in retarding myopia progression. Examples include a lens type used in a study by Sankaridurg et al. [18] and a multifocal contact lens used in a study by Walline et al. [50]. The former was reported to retard myopia progression by 34% over 1 year and the latter by 50% over 2 years. Paune et al. [51] carried out a study using 'soft radial refractive gradient' (SRRG) contact lens, which corrects the central refraction while producing peripheral myopic defocus that increases gradually from the central optical axis towards the periphery. After 2 years, children wearing the SRRG contact lens had retardation in myopia progression by 43%. Cheng et al. [52] developed a soft contact lens for myopia control that included a positive spherical aberration (+SA) in the optical design to shift retinal hyperopic defocus in the opposite direction, resulting in the reduction of relative peripheral hyperopia. The greatest effect of myopia control (56%) was observed during the first 6 months, and it decreased greatly to 20% by 12 months. The overall treatment effects of these contact lenses were better than ophthalmic lenses that used a similar approach [17]. This may be due to the soft contact lenses moving with the eye, and hence the optical correction remains centered for all viewing gazes.

Anstice and Phillips [53] investigated the use of a concentric bifocal power (also called dual-focus or dual power) soft contact lens with 2D of myopic defocus in retarding myopia progression in children. Children participating in their study were randomly assigned to wear the treatment lens in one eye and an ordinary single vision contact lens in the fellow eye for 10 months. The lens types were then switched between the eyes and the lenses were worn for another 10 months. On average, the eyes with the bifocal contact lenses showed about 45% less myopia progression than the eyes with single vision contact lenses. Several randomized clinical trials showed that concentric bifocal contact lenses exhibited meaningful effects on myopia control. Lam et al. [54] reported that the use of Defocus Incorporated Soft Contact (DISC) lens for at least 7 hours a day resulted in more effective myopia control, reaching nearly 60% reduction in myopia progression and

Table 14.3 Myopia control studies using soft bifocal and multifocal contact lenses

Authors and years	Study duration (months)	Study design	Age (years old), ethnicity	Subject Rx range (D)	Interventions and sample size (*n*)	Effect in slowing myopia progression in study period, D (%)
Anstice and Phillips (2011) [53]	20	Randomized, paired eye control, cross-over	11–14, diverse ethnicity	−1.25 to −4.50	DF (2 D add), *n* = 40 SVCL, *n* = 40	1st 10-month: 0.25 (37%) 2nd 10-month: 0.2 (54%)
Sankaridurg et al. (2011) [18]	12	Randomized	7–14, Chinese	−0.75 to −3.50	RPH CL, *n* = 45 SV, *n* = 40	0.29 (34%)
Walline et al. (2013) [50]	24	Matched study	8–11, diverse ethnicity	−1.00 to −6.00	Proclear multifocal D (2 D add), *n* = 40 Matched SVCL, *n* = 40	0.52 (50%)
Lam et al. (2014) [54]	24	Randomized, double-masked	8–13, Chinese	−1.00 to −5.00	DISC (2.5 D add), *n* = 65 SVCL, *n* = 63	0.21 (25%) 0.44 (50%) > 6 h 0.54 (58%) > 7 h 0.53 (60%) > 8 h
Paune et al. (2014) [51]	24	Prospective, nonrandomized	9–16, Caucasian	−0.75 to −7.00	SRRG, *n* = 30 OK, *n* = 29 SV, *n* = 41	0.42 (43%)
Aller et al. (2016) [57]	12	Randomized, masked	8–18,	−0.50 to −6.00	BFSCL, *n* = 39 SVCL, *n* = −40	0.57 (72% in children with eso fixation disparities)
Cheng et al. (2016) [52]	24 (only 12-month data)	Randomized, double-masked	8–11	−0.75 to −4.00	+SA, *n* = 64 SVCL, *n* = 63	6-month: 0.21 (56%) 12-month: 0.12 (20%)
Chamberlain et al. (2018) [55]	36	Randomized, double-masked	8–12	−0.75 to −4.00	DF (2 D add), *n* = 70 SVCL, *n* = 74	0.73 (59%)
Ruiz-Pomeda et al. (2018) [56]	24	Randomized, double-masked, multicenter	8–12	−0.75 to −4.00	DF (2 D add), *n* = 46 SVCL, *n* = 33	0.29 (39%)

DF dual focus contact lens, *SVCL* single vision contact lens, *RPH CL* contact lens designed to reduce relative peripheral hyperopia, *SV* single vision spectacle lens, *DISC* Defocus Incorporated Soft Contact lens, *SRRG* soft radial refractive gradient contact lens, *OK* Ortho-K, *BFSCL* bifocal soft contact lens, *+SA* soft contact lens with positive special aberration

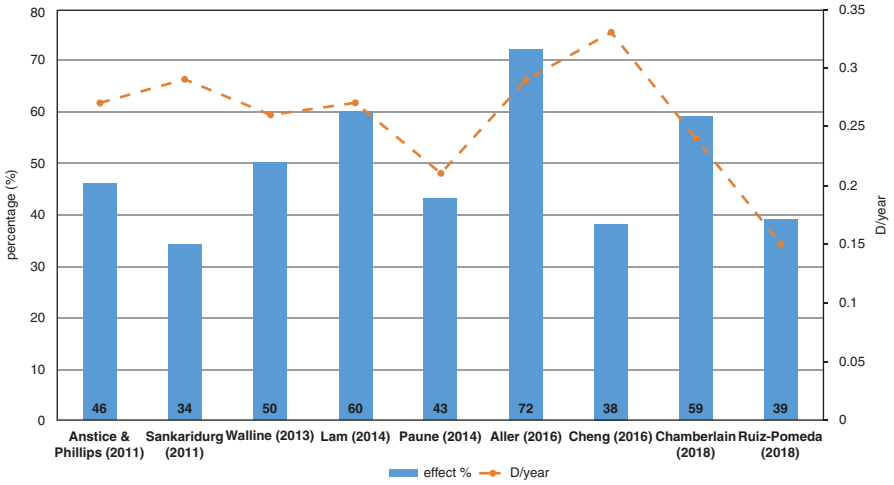

Fig. 14.3 Comparison of the treatment effect on slowing myopia progression among the studies using soft bifocal and multifocal contact lenses. The bar represents treatment effect within the study period in terms of percentage as compared with controls. The dotted line represents reduction of myopia progression per year (D/year)

axial length growth. The amount of myopic defocus used in the DISC lens was 2.50 D. Two more recent studies have indicated that a Dual-Focus 1-Day soft contact lens using 2D of myopic defocus also slows myopia progression in children. The multicenter study by Chamberlain et al. [55] has shown that the Dual-Focus 1-Day soft contact lens slows myopic progression and axial elongation in children by 59% and 52%, respectively, over 3 years. However, another study in Spain showed less myopia control effect, 39% and 36% in terms of refractive changes and axial growth, respectively [56]. A study by Aller et al. [57] reported the most promising effect of 70% with another type of bifocal soft contact lenses, but this was seen only for the children with eso fixation disparities at near.

Among the optical interventions for myopia control, Ortho-K lenses (45%), soft bifocal contact lenses (50%), prismatic bifocals (50%) and the very recent DIMS spectacle lenses (52%) have shown clinically significant treatment effects. However, the treatment effect of these methods is still inferior to that of pharmaceutical eye drops. The average reduction in myopia progression using regular dose (1%) of atropine is approximately 70% or above [58, 59]. Yet, the associated side effects, such as blurring of near vision, light sensitivity and possible allergic reactions and post-treatment rebound effects [58, 59], will be obstacles for the widespread application of atropine 1% in clinical practice. Lower doses of atropine (such as 0.5%, 0.02%, 0.01%) have been found to have minimal side effects, but long-term safety is unclear [60–62]. Atropine 0.01% has been found to have the least side effects with good myopia control and least rebound effects [61, 62]. However, optical treatment regimens are less invasive than those by pharmacological treatment and have been found to be more popular.

14.4 Others: Outdoor Activities and Violet Light Transmitting Lenses

Recent epidemiological studies have found that children who spend more time outdoors during daytime are less likely to become myopic and have less myopia progression, regardless of the amount of near work duration and parental history of myopia [63–65]. Some evidence for this relationship has been shown in young adults [63]. Outdoor time also appears to reduce the risk of myopia development in schoolchildren. A longitudinal study conducted in Taiwan found that children in a primary school who were encouraged to have outdoor activities during recess (outdoor group) were less likely to have myopia after a year compared to children in other schools who continued their normal recess routine (the control group) [64]. The proportion of children who had myopia onset after a year was significantly higher in the control group (18%) than in the intervention group (8%, $p < 0.001$).

The mechanism by which the outdoor activity could protect against myopia development is still unknown. However, there are a number of theories, such as relaxed accommodation for viewing distance receiving more myopic defocus in outdoor environments and higher light intensity in outdoor environments [65, 66]. The spectral composition of sunlight may also play a role in myopia control. Sunlight has a large portion of short-wavelength visible and non-visible light, such as blue light and ultraviolet light [67]. Animal studies have demonstrated that blue light has a suppressive effect against myopia [68, 69]. Recently, Torri et al. [70] proposed that violet light (VL) (which has a shorter wavelength than blue light), which is a missing light component in indoor environments, may play a role in the inhibition of myopia development and progression. They demonstrated that exposure to VL inhibited myopic shift and axial elongation in chicks. On the basis of the animal findings, they conducted a clinical trial in which myopic children were assigned to wear VL blocking eyeglasses, partially VL blocking contact lenses or VL transmitting contact lenses [70]. The results showed that children who wore VL transmitting contact lenses had significantly less axial length elongation compared to those wearing the other types of lenses over 1 year. These data provide evidence that VL may contribute to the protective effect against myopia progression. Further investigation is needed to determine whether VL transmitting lenses could slow myopia progression or prevent myopia in children.

14.5 Comparison of the Effectiveness on Myopia Control by Different Optical Interventions

Several studies have reviewed and compared the outcomes of the effect on myopia control using various treatments and methodologies [71–74]. In a review of nine randomized controlled trials that compared the effects of multifocal and single vision spectacle lenses, multifocals with add power ranging from +1.50 to +2.00 D were associated with a statistically significant decrease in myopia progression in school-age children compared with single vision lenses [74]. The effect was more prominent in children with a higher degree of myopia at baseline and could be

sustained for a period of 24 months or more. Asian children were found to have greater benefit from the interventions than Caucasian children. A study comparing the treatment effect of atropine, soft bifocal and Ortho-K contact lens indicated that both atropine and Ortho-K showed treatment effects reaching over 75%, while soft bifocals had effects up to 48% [71].

In another study, a meta-analysis was performed to determine and compare 16 interventions for myopia control in children using pharmaceuticals or optical methods [73]. Among the optical methods, spectacle lens, contact lenses and Ortho-K were included. They concluded that atropine, pirenzepine, Ortho-K, soft contact lenses with myopia control features and progressive addition spectacle lenses are effective at reducing myopia progression in terms of refraction or axial length. For the pharmaceutical treatment, the average treatment effects reported in the literature are around 50%. For spectacle treatments, the effects range from minimal in the PAL trials to moderately effective in a study on executive bifocals. The investigators also compare different interventions with single vision spectacle lenses/placebo [73]. Atropine was found to be the most effective as it can retard myopia progression by around 0.50–0.60 D per year.

14.6 Conclusions

In summary, under-correction of myopia is not recommended for myopia control as it is likely to speed up myopia progression instead. Among spectacles, PALs and multifocal lenses do not yield clinically meaningful effects on slowing myopia progression in children. One single center study using prismatic bifocals in children with rapid progressing myopia showed a moderate treatment effect. Ortho-K, soft bifocal contact lenses and the very recent DIMS spectacle lenses have all shown clinically significant treatment effects ranging from 45% to 60% reduction in myopia progression. These methods demonstrated that myopic defocus as natural optical signals can inhibit refractive eye growth and control myopia progression through different optical designs. Although the effectiveness of myopia control with atropine is relatively better than those of optical methods, the associated side effects, such as sensitivity to light and near blur, hinder its widespread clinical application. Optical interventions are less invasive, which will make it likely to become more popular compared to pharmaceutical treatments.

Although there are a number of clinical methods currently available for myopia control for children, none of them have been proven to definitely halt the development or progression of myopia. The treatment effect also varies among individuals. Each therapy has its advantages and limitations. The suitable choice of treatment for each patient can vary and should be determined by the eye care professionals based on age, parental history, myopic progression rate, corneal health and lifestyle of the children. More research is needed to enhance the treatment effects of myopia control, particularly to prevent myopia before its onset through improved designs of optical lenses or pharmaceuticals. Several clinical trials are also testing the possibility of better myopia control with combined treatments, for example, optical lenses (soft bifocals, Ortho-K or DIMS spectacle lenses) with ophthalmic pharmaceutical

(low-concentration atropine) or with other non-optical modalities (outdoor activities, intense bright light for near work). Also, there is still room for research on new myopia control methods, such as VL transmitting contact lenses or spectacles. When there is more evidence in the treatment effect, there is hope to reduce the prevalence of myopia and high myopia and its related ocular complications.

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