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Long-term follow-up of school-age children on the effectiveness of myopia correction with contact lenses

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Abstract

Introduction and purpose. Early use of contact correction for congenital myopia and astigmatism in children and adolescents contributes to their social rehabilitation. The myopia correction with contact lenses provides sustainability of correction and absence of periods of blurred retinal images, which are experienced with the use of glasses. **The purpose** of the study was to determine, through long-term follow-up, the extent to which contact lens correction improves uncorrected and maximally corrected visual acuity in school-age children with myopia and myopic astigmatism. **Material and methods**. We followed up for three years 84 children (168 eyes) aged 6–16 years with myopic manifest refraction and astigmatism, who used soft silicone hydrogel aspherical contact lenses to correct ametropia. In the early and late follow-up, these patients were examined for visual acuity, objective and subjective clinical refraction, axial eye length, corneal thickness and diameter, keratometry, and phorometric data (accommodation, vergence, disparate areas, and oculomotor apparatus and their interaction). **Results**. In course of long-term monitoring of myopia and myopic astigmatism correction with contact lenses in school-age children, the statistically significant results were recorded after three years of observation, namely: an increase in uncorrected visual acuity by 47% (t=5.2; p<0.01), corrected acuity vision by 8% (t=9.3; p<0.01), the spheroequivalent by 17% (t=3.7; p<0.01), anteroposterior segment of the eye by 4% (t=7,1; p<0.01), amplitude of accommodation by 27% (t=14.6; p<0.01), negative part of relative accommodation by 17% (t=7.3; p<0.01), positive part of relative accommodation by 32% (t=7.1; p<0.01), flexibility of accommodation by 35% (t=14.2; p<0.01), the ratio of accommodation convergence to accommodation by 19% (t=3.4, p<0.01), stereovision acuity by 56% (t=4.1; p<0.01), as well as a decrease in keratometry index in the strong meridian by 2% (t=5.2; p<0.01), delays in accommodative responses by 33% (t=14.2; p <0.01), distance phoria by 16% (t=10.1; p<0.01), near phoria by 16% (t=11.3, p<0.01). **Conclusions.** The study has shown that the use of contact lenses by school-aged children with myopia and myopic astigmatism can increase uncorrected and maximum corrected visual acuity. The increase of the spheroequivalent and anteroposterior axis (APA) of the eye indicates progression of myopia, but the use of soft contact lenses (SCL) leads to changes of the anterior corneal surface: an increase of the thickness in the central zone, and its flattening. Improvement of accommodation, vergence, disparate parts of the oculomotor apparatus, and their interaction was also observed. The results obtained indicate deceleration of myopia progression.

Keywords: **myopia; astigmatism; contact correction; phorometry; APA: anteroposterior axis; SCL: soft contact lens; WTW: white-to-white; NRA: negative relative accommodation; PRA: positive relative accommodation.**

Introduction

Refraction anomalies account for 33–75% of the structure of detected ophthalmic pathology in children and adolescents, and myopia accounts for 80% of all refraction anomalies. Myopia is the leading cause of visual impairment in children in all developed countries in Europe and America. According to the literature, myopia occurs in 33% of the young population of Western countries [1, 2, 3]. Myopic refraction occurs in 4–6% of children under 1 year, and in preschool-age, the incidence of myopia does not exceed 2–3%. Weak myopia is more common in preschool children. Myopia, which is found in children before the time of entering school, is more often congenital [4].

To stabilize progressive myopia, proper optical correction is important. The means of optical correction for myopia include glasses, progressive correction, as well as a correction with soft (spherical and bifocal) and orthokeratological lenses. Lack of full-fledged vision correction during the development of the visual system leads to severe functional impairment of vision.

Nowadays, spectacles are still the most common way to correct myopia, but they have some disadvantages: cosmetic, limited field of view, effect on the size of the retinal image, distortion of size and contours of objects, prismatic effect, limitations when correcting anisometropia, and changes in-depth perception [5, 7].

Contact lenses are free of the above disadvantages and in ophthalmopediatrics have a few undeniable advantages over spectacles. Primarily the cosmetic effect, no restrictions on physical activity, and no effect on the size of the retinal image [7]. In the conservative treatment of high refractive errors, congenital myopia, myopic anisometropia, there is no alternative to contact lenses, which not only improve the quality of vision but also contribute to the proper development of the visual analyzer in children [5]. The advantages of contact lenses also include sustained correction of ametropia, the absence of periods with a blurred retinal image, which is observed with the use of glasses. Soft silicone hydrogel contact lenses provide adequate oxygen supply to the cornea, which reduces hypoxic complications, is more comfortable than hard contact lenses, and allows children to play sports. Early use of contact correction of congenital myopia and astigmatism in children and adolescents contributes to social rehabilitation [8].

Purpose

The study was targeted to determine, through long-term follow-up, the extent to which contact lens correction improves uncorrected and maximally corrected visual acuity in school-age children with myopia and myopic astigmatism.

Material and methods

We followed up for three years 84 children (168 eyes) aged 6–16 years with myopic manifest refraction and astigmatism, who used soft silicone hydrogel aspherical contact lenses to correct ametropia. In the early and late follow-up, these patients were examined for visual acuity, objective and subjective clinical refraction, axial eye length, corneal thickness and diameter, keratometry, and phorometric data (accommodation, vergence, disparate areas, and oculomotor apparatus and their interaction).

The mean values of the variable (M) and standard deviation (±Ϭ) were calculated to represent quantitative data. Student's *t*-test was used to determine the statistical significance of differences between the mean values in the two independent groups. The null hypothesis of no effect was excluded, and the differences between the indices were considered statistically significant at the $p < 0.05$ significance level.

Results

***Initial examination.* 84 patients (168 eyes)**

Uncorrected visual acuity 0.01–0.06 was in 32 eyes (19.05%), 0.08–0.2 in 60 eyes (35.7%), 0.3–0.6 was in 76 eyes (45.2%) and the mean was 0.19 ± 0.11 (range 0.01 to 0.6). The maximum visual acuity with correction was 0.92 ± 0.08. The spheroequivalent was –4.2 ± 1.6 diopters (D), the mean keratometry was 44.02 ± 1.2 D in the weak and 44.9 ± 1.2 D in the strong meridian. The central corneal thickness was 539.9 ± 29.95 µm. The mean of APA was 24.65 ± 1.0 mm, and the horizontal corneal white-to-white (WTW) diameter was 11.8 ± 0.3. The mean of accommodation amplitude was 9.54 ± 1.23 D, the negative relative accommodation (NRA) was +1.26 ± 0.44 D, and positive relative accommodation (PRA) was –0.92 ± 0.14 D, with the accommodative lag found as +1.86 ± 0.28 D, the mean of monocular accommodation flexibility was 7.51 ± 0.32 cycles/min. The distance phoria averaged exo 5.29 ± 1.78 prism diopters, the near phoria was exo 9.25 ± 0.35 prism diopters. The ratio of accommodation convergence to accommodation was 2.3 ± 0.36 prism diopters. The sharpness of stereoscopic vision averaged 153.63 ± 7.07 arc seconds.

***1-month follow-up.* 84 patients (168 eyes)**

Uncorrected visual acuity 0.01–0.06 was in 32 eyes (19.05%), 0.08–0.2 was in 60 eyes (35.7%), 0.3–0.6 was in 76 eyes (45.2%) and the mean was 0.19 ± 0.14 (range 0.01 to 0.6). The maximum visual acuity with correction was 0.94 ± 0.06. The spheroequivalent was –4.1 ± 1.4 D, the mean keratometry was 44.06 ± 1.2 D in the weak and 44.8 ± 1.2 D in the strong meridian. The central corneal thickness was 537.9 ± 26.46 µm. The mean of APA was 24.59 ± 1.0 mm, and the horizontal corneal WTW diameter was 11.7 ± 0.2. The mean of accommodation amplitude was found to be 9.63 ± 1.28 D, the NRA was + 1.29 ± 0.46 D, the PRA was –0.96 ± 0.16 D, the accommodation lag was + 1.83 ± 0.24 D, and the mean of monocular accommodation flexibility was 7.6 ± 0.34 cycles/min. The distance phoria averaged exo 5.27 ± 1.58 prism diopters with the near phoria being exo 9.21 ± 0.33 prism diopters. The ratio of accommodation convergence to accommodation was 2.4 ± 0.29 prism diopters. The sharpness of stereoscopic vision averaged 152.44 ± 6.12 arc seconds.

***6-month follow-up.* 84 patients (168 eyes)**

Uncorrected visual acuity 0.01–0.06 was in 32 eyes (19.05%), 0.08–0.2 was in 60 eyes (35.7%), 0.3-0.6 was on 76 eyes (45.2%) and averaged 0.18 ± 0.16 (from 0.01 to 0.6). The maximum visual acuity with correction was 0.95 ± 0.06. The spheroequivalent was –4.2 ± 1.5 D, the mean of keratometry was 44.08 ± 1.3 D in the weak and 44.7 ± 1.2 D in the strong meridian. The central corneal thickness was 538.6 ± 34.5 µm. The mean of APA was 24.62 ± 1.2 mm, and the horizontal corneal WTW diameter was 11.7 ± 0.4. The mean of accommodation amplitude was found to be 9.66 ± 1.24 D, the NRA was + 1.31 ± 0.48 D, the PRA was –0.98 ± 0.17 D, the accommodation lag was + 1.80 ± 0.22 D, and the mean of monocularly accommodation flexibility was 7.81 ± 0.28 cycles/min. The distance phoria averaged exo 5.20 ± 1.62 prism diopters with the near phoria being exo 9.12 ± 0.41 prism diopters. The ratio of accommodation convergence to accommodation was 2.7 ± 0.42 prism diopters. The sharpness of stereoscopic vision was averaged 149.78 ± 6.08 arc seconds.

***1-year follow-up*. 84 patients (168 eyes)**

Uncorrected visual acuity 0.01–0.06 was in 32 eyes (19.05%), 0.08–0.2 was in 60 eyes (35.7%), 0.3–0.6 was in 76 eyes (45.2%) and the mean was 0.18 ± 0.16 (range 0.01 to 0.6). The maximum visual acuity with correction was 0.95 ± 0.02. The spheroequivalent was –4.3 ± 1.5 D, the mean keratometry was 44.02 ± 1.3 D in the weak and 44.5 ± 1.3 D in the strong meridian. The central corneal thickness was 539.7 ± 29.5 µm. The mean of APA was 24.64 ± 1.3 mm, and the horizontal corneal WTW diameter was 11.8 ± 0.6. The mean of accommodation amplitude was found to be 9.97 ± 1.34 D, the NRA was +1.36 ± 0.46 D, the PRA was –1.06 ± 0.18 D, the accommodation lag was +1.78 ± 0.24 D, and the mean of monocular accommodation flexibility was 7.94± 0.28 cycles/min. The distance phoria averaged exo 5.14 ± 1.45 prism diopters with the near phoria being exo 8.98 ± 0.27 prism diopters. The ratio of accommodation convergence to accommodation was 2.87 ± 0.31 prism diopters. The sharpness of stereoscopic vision averaged 139.89 ± 6.17 arc seconds.

***1.5-year follow-up*. 84 patients (168 eyes)**

Uncorrected visual acuity 0.01–0.06 was in 31 eyes (18.45%), 0.08–0.2 was in 61 eyes (36.3%), 0.3–0.6 was in 76 eyes (45.2%) and the mean was 0.21 ± 0.18 (range 0.01 to 0.6). The maximum visual acuity with correction was 0.95 ± 0.06. The spheroequivalent was –4.6 ± 1.6 D, the mean keratometry was 44.02 ± 1.2 D in the weak and 44.5 ± 1.4 D in the strong meridian. The central corneal thickness was 537.6 ± 34.6 µm. The mean of APA was 24.9 ± 0.9 mm, and the horizontal corneal WTW diameter was 11.7 ± 0.5. The mean of accommodation amplitude was found to be 10.02 ± 1.45 D, the NRA was +1.35 ± 0.45 D, the PRA was –1.05 ± 0.16 D, the accommodation lag was +1.77 ± 0.31 D, and the mean of monocular accommodation flexibility was 7.95± 0.21 cycles/min. The distance phoria averaged exo 5.16 ± 1.38 prism diopters with the near phoria being exo 8.97 ± 0.22 prism diopters. The ratio of accommodation convergence to accommodation was 2.86 ± 0.32 prism diopters. The sharpness of stereoscopic vision averaged 137.71 ± 4.6 arc seconds.

2-year follow-up. **80 patients (160 eyes)**

Uncorrected visual acuity 0.01–0.06 was in 31 eyes (19.37%), 0.08–0.2 was in 61 eyes (38.13%), 0.3–0.6 was in 68 eyes (42.5%) and the mean was 0.24 ± 0.16 (range 0.01 to 0.6). The maximum visual acuity with correction was 0.97 ± 0.04. The spheroequivalent was –4.8 ± 1.7 D, the mean keratometry was 44.01 ± 1.2 D in the weak and 44.4 ± 1.6 D in the strong meridian. The central corneal thickness was 537.9 ± 34.8 μm. The mean of APA was 25.1 ± 0.9 mm, and the horizontal corneal WTW diameter was 11.7 ± 0.6. The mean of accommodation amplitude was found to be 10.02 ± 1.31 D, the NRA was +1.38 ± 0.46 D, the PRA was –1.08 ± 0.14 D, the accommodation lag was +1.80 ± 0.24 D, and the mean of monocular accommodation flexibility was 8.01± 0.36 cycles/min. The distance phoria averaged exo 5.01 ± 1.72 prism diopters with the near phoria being exo 8.25 ± 0.31 prism diopters. The ratio of accommodation convergence to accommodation was 2.6 ± 0.34 prism diopters. The sharpness of stereoscopic vision averaged 121.54 ± 7.14 arc seconds.

2.5-year follow-up. **80 patients (160 eyes)**

Uncorrected visual acuity 0.01–0.06 was in 31 eyes (19.37%), 0.08–0.2 was in 61 eyes (38.13%), 0.3–0.6 was in 68 eyes (42.5%) and the mean was 0.25 ± 0.16 (range 0.01 to 0.6). The maximum visual acuity with correction was 0.98 ± 0.04. The spheroequivalent was –4.8 ± 1.6 D, the mean keratometry was 43.98 ± 1.8 D in the weak and 44.2 ± 1.5 D in the strong meridian. The central corneal thickness was 542.9 ± 41.1 μm. The mean of APA was 25.62 ± 1.08 mm, and the horizontal corneal WTW diameter was 11.7 ± 0.6. The mean of accommodation amplitude was found to be 11.4 ± 1.38 D, the NRA was +1.39 ± 0.44 D, the PRA was –1.09 ± 0.19 D, the accommodation lag was +1.84 ± 0.26 D, and the mean of monocular accommodation flexibility was 8.04± 0.28 cycles/min. The distance phoria averaged exo 5.03 ± 1.65 prism diopters with the near phoria being exo 8.11 ± 0.32 prism diopters. The ratio of accommodation convergence to accommodation was 2.52 ± 0.37 prism diopters. The sharpness of stereoscopic vision averaged 113.84 ± 6.24 arc seconds.

3-year follow-up. **78 patients (156 eyes)**

Uncorrected visual acuity 0.01–0.06 was in 29 eyes (18.58%), 0.08–0.2 was in 60 eyes (38.46%), 0.3–0.6 was in 67 eyes (42.94%) and the mean was 0.28 ± 0.2 (range 0.01 to 0.6). The maximum visual acuity with correction was 0.99 ± 0.01. The spheroequivalent was –4.92 ± 1.7 D, the mean keratometry was 43.95 ± 1.9 D in the weak and 44.06 ± 1.8 D in the strong meridian. The central corneal thickness was 544.3 ± 44.1 μm. The mean of APA was 25.64 ±

1.12 mm, and the horizontal corneal WTW diameter was 11.8 ± 0.5. The mean of accommodation amplitude was found to be 12.1 ± 1.22 D, the NRA was +1.48 ± 0.46 D, the PRA was –1.21 ± 0.16 D, the accommodation lag was +1.4 ± 0.14 D, and the mean of monocular accommodation flexibility was 10.12± 0.17 cycles/min. The distance phoria averaged exo 4.58 ± 0.98 prism diopters with the near phoria being exo 7.98 ± 0.31 prism diopters. The ratio of accommodation convergence to accommodation was 2.74 ± 0.26 prism diopters. The sharpness of stereoscopic vision averaged 98.76 ± 4.87 arc seconds.

Table 1 shows dynamics of visual acuity and spheroequivalent index in the short- and long-term follow-up of the school-age children with myopia and astigmatism after the use of soft silicone-hydrogel aspherical contact lenses (M ± Ϭ).

Table 1. Dynamics of visual acuity and spheroequivalent index in the short- and long-term follow-up of the school-age children with myopia and astigmatism after the use of soft silicone-hydrogel aspheric contact lenses (M ± Ϭ)

Follow-up (number of eyes)	Uncorrected visual acuity	Maximum corrected visual acuity	Spheroequivalent index, D
Initial examination (n=168)	0.19 ± 0.11	0.92 ± 0.08	–4.2 ± 1.6
1-month follow-up (n=168)	0.19 ± 0.14	0.94± 0.06*	–4.1 ± 1.4
6-month follow-up (n=168)	0.18 ± 5.1	0.95± 0.06**	–4.2 ± 1.5
1-year follow-up (n=168)	0.18 ± 0.16	0.95 ± 0.02**	–4.3 ± 1.5
1.5-year follow-up (n=168)	0.21 ± 0.18*	0.95 ± 0.06**	–4.6 ± 1.6*
2-year follow-up (n=160)	0.24 ± 0.16**	0.97 ± 0.04**	–4.8 ± 1.7**
2.5-year follow-up (n=160)	0.25 ± 0.16**	0.98 ± 0.04**	–4.8 ± 1.6**
3-year follow-up (n=156)	0.28 ± 0.2**	0.99 ± 0.1**	–4.92 ± 1.7**
	$t_{1mth\ follow\text{-}up}=0$ $t_{6mth\ follow\text{-}up}=1.0$ $t_{1yr\ follow\text{-}up}=1.0$ $t_{1.5yr\ follow\text{-}up}=2.0$ $t_{2yr\ follow\text{-}up}=3.0$ $t_{2.5yr\ follow\text{-}up}=3.6$ $t_{3yr\ follow\text{-}up}=5.2$	$t_{1mth\ follow\text{-}up}=2.3$ $t_{6mth\ follow\text{-}up}=3.5$ $t_{1yr\ follow\text{-}up}=3.4$ $t_{1.5yr\ follow\text{-}up}=3.5$ $t_{2yr\ follow\text{-}up}=6.0$ $t_{2.5yr\ follow\text{-}up}=7.3$ $t_{3yr\ follow\text{-}up}=9.3$	$t_{1mth\ follow\text{-}up}=0.3$ $t_{6mth\ follow\text{-}up}=0$ $t_{1yr\ follow\text{-}up}=0.5$ $t_{1.5yr\ follow\text{-}up}=2.0$ $t_{2yr\ follow\text{-}up}=3.0$ $t_{2.5yr\ follow\text{-}up}=3.1$ $t_{3yr\ follow\text{-}up}=3{,}7$

*The level of significance of differences compared to the initial examination data; $p < 0.05$ calculated by Student's t-test

** The level of significance of differences compared to the initial examination data; $p < 0{,}01$ calculated by Student's t-test

Table 1 shows that the use of contact correction for the school-age children allowed attaining a statistically significant increase in uncorrected visual acuity by 11% after 1.5 years of follow-up ($t = 2.0$; $p < 0.05$), after 2 years by 26% = 3.0; $p < 0.01$), after 2.5 years by 32% ($t = 3.6$; $p < 0.01$), after 3 years by 47% ($t = 5.2$; $p < 0.01$).

There is also a statistically significant increase in corrected visual acuity by 2% after 1 month of the follow-up ($t = 2.3$; $p < 0.05$), after 6 months, 1 year and 1.5 years by 3% ($t_{6mth} = 3.5$; $t_{1yr} = 3.4$; $t_{1.5yr} = 3.5$; $p < 0.01$), after 2 years by 5% ($t = 6.0$; $p < 0.01$), after 2.5 years by 7% ($t = 7.3$; $p < 0.01$), after 3 years by 8% ($t = 9.3$; $p < 0.01$).

Notwithstanding the use of contact correction, there was a statistically significant increase in the spheroequivalent index by 10% after 1.5 years of the follow-up ($t = 2.0$; $p < 0.05$), after 2 and 2.5 years by 14% ($t_{2yr} = 3.0$; $t_{2.5yr} = 3.1$; $p < 0.01$), after 3 years by 17% ($t = 3.7$; $p < 0.01$).

Table 2 shows the dynamics of keratometric indices in the short- and long-term follow-up of the school-age children with myopia and astigmatism after the use of soft silicone-hydrogel aspheric contact lenses (M ± Ϭ).

Table 2 shows that the use of contact correction in school-age children allowed a statistically significant decrease in the keratometry index in the strong meridian by 1% observed after 1, 1.5, and 2 years of the follow-up ($t_{1yr\ follow\text{-}up} = 2.5$; $t_{1.5yr\ follow\text{-}up} = 2.5$, $p < 0.05$; $t_{2yr\ follow\text{-}up} = 3.1$, $p < 0.01$) and by 2 % after 2.5 and 3 years of the follow-up ($t_{2.5yr\ follow\text{-}up} = 4.3$; $t_{3yr\ follow\text{-}up} = 5.2$, $p < 0.01$).

Table 3 shows the dynamics of corneal thickness in the central zone in the short- and long-term follow-up of the school-age children with myopia and astigmatism after application of soft silicone-hydrogel aspheric contact lenses (M ± Ϭ).

Table 3 shows that when using contact correction for school-age children, the follow-up after 2.5 and 3 years exposes a tendency in increasing the thickness of the cornea in the central area, but the data is not statistically significant ($t_{2.5\ yr} = 0.8$; $t_{3\ yr} = 1.1$; $p > 0.05$).

Table 4 shows the dynamics of APA in the short- and long-term follow-up of the school-age children with myopia and astigmatism after application of soft silicone-hydrogel aspheric contact lenses (M ± Ϭ).

Table 2. Dynamics of keratometric indices in the short- and long-term follow-up of the school-age children with myopia and astigmatism after the use of soft silicone-hydrogel aspheric contact lenses (M ± Ϭ)

Follow-up (number of eyes)	Keratometry index in the weak meridian, diopter	Keratometry index in the strong meridian, diopter
Initial examination (n=168)	44.02 ± 1.2	44.9 ± 1.2
1-month follow-up (n=168)	44.06 ± 1.2	44.8 ± 1.2
6-month follow-up (n=168)	44.08 ± 1.3	44.7 ± 1.2
1-year follow-up (n=168)	44.02 ± 1.3	44.5 ± 1.3*
1.5-year follow-up (n=168)	44.02 ± 1.2	44.5 ± 1.4*
2-year follow-up (n=160)	44.01 ± 1.2	44.4 ± 1.6**
2.5-year follow-up (n=160)	43.98 ± 1.8	44.2 ± 1.5**
3-year follow-up (n=156)	43.95 ± 1.9	44.06 ± 1.8**
	$t_{1mth\ follow\text{-}up} = 0.2$ $t_{6mth\ follow\text{-}up} = 0.3$ $t_{1yr\ follow\text{-}up} = 0.2$ $t_{1.5yr\ follow\text{-}up} = 0.2$ $t_{2yr\ follow\text{-}up} = 0.1$ $t_{2.5yr\ follow\text{-}up} = 0.2$ $t_{3yr\ follow\text{-}up} = 0.4$	$t_{1mth\ follow\text{-}up} = 0.6$ $t_{6mth\ follow\text{-}up} = 1.2$ $t_{1yr\ follow\text{-}up} = 2.5$ $t_{1.5yr\ follow\text{-}up} = 2.5$ $t_{2yr\ follow\text{-}up} = 3.1$ $t_{2.5yr\ follow\text{-}up} = 4.3$ $t_{3yr\ follow\text{-}up} = 5.2$

*The level of significance of differences compared to the initial examination data; $p < 0.05$ calculated by Student's t-test

** The level of significance of differences compared to the initial examination data; $p < 0,01$ calculated by Student's t-test

Table 3. Dynamics of corneal thickness in central zone in the short- and long-term follow-up of the school-age children with myopia and astigmatism after application of soft silicone-hydrogel aspheric contact lenses (M ± Ϭ)

Follow-up (number of eyes)	The thickness of the cornea in the central zone, μm
Initial examination (n=168)	539.9 ± 29.95
1-month follow-up (n=168)	537.9 ± 26.46
6-month follow-up (n=168)	538.6 ± 34.5
1-year follow-up (n=168)	539.7 ± 29.5
1.5-year follow-up (n=168)	537.6 ± 34.6
2-year follow-up (n=160)	537.9 ± 34.8
2.5-year follow-up (n=160)	542.9 ± 41.1
3-year follow-up (n=156)	544.3 ± 44.1
	$t_{1mth\ follow\text{-}up} = 0.5$ $t_{6mth\ follow\text{-}up} = 0.3$ $t_{1yr\ follow\text{-}up} = 0.1$ $t_{1.5yr\ follow\text{-}up} = 0.5$ $t_{2yr\ follow\text{-}up} = 0.5$ $t_{2.5yr\ follow\text{-}up} = 0.8$ $t_{3yr\ follow\text{-}up} = 1.1$

*The level of significance of differences compared to the initial examination data; p < 0.05 calculated by Student's t-test

** The level of significance of differences compared to the initial examination data; p < 0,01 calculated by Student's t-test

Table 4. The dynamics of APA in the short- and long-term follow-up of the school-age children with myopia and astigmatism after application of soft silicone-hydrogel aspheric contact lenses (M ± Ϭ)

Follow-up (number of eyes)	APA, mm
Initial examination (n=168)	24.65 ± 1.0
1-month follow-up (n=168)	24.59 ± 1.0
6-month follow-up (n=168)	24.62 ± 1.2
1-year follow-up (n=168)	24.64 ± 1.3
1.5-year follow-up (n=168)	24.9 ± 0.9
2-year follow-up (n=160)	25.1 ± 0.9**
2.5-year follow-up (n=160)	25.62 ± 1.08**
3-year follow-up (n=156)	25.64 ± 1.12**
	$t_{1mth\ follow\text{-}up} = 0.5$ $t_{6mth\ follow\text{-}up} = 0.2$ $t_{1yr\ follow\text{-}up} = 0.1$ $t_{1.5yr\ follow\text{-}up} = 1.9$ $t_{2yr\ follow\text{-}up} = 3.3$ $t_{2.5yr\ follow\text{-}up} = 7.1$ $t_{3yr\ follow\text{-}up} = 7.1$

*The level of significance of differences compared to the initial examination data; $p < 0.05$ calculated by Student's t-test

** The level of significance of differences compared to the initial examination data; $p < 0,01$ calculated by Student's t-test

As evident from Table 4, despite the use of contact correction in school-age children, there is a statistically significant increase in the length of the anteroposterior segment of the eye. After two years, the length of the eye increases statistically significantly by 2% (t_{2yr} = 3.3; $p < 0.01$), after 2.5 and 3 years by 4% ($t = 7.1$; $p < 0.01$).

Table 5 shows the dynamics of accommodation in the short and long term of the follow-up in school-age children with myopia and astigmatism after the use of soft silicone-hydrogel aspherical contact lenses (M ± Ϭ).

As can be seen from Table 5, when using contact correction in school-age children, there is a statistically significant increase of accommodation amplitude after 1 and 1.5 years by 5% ($t_{1yr} = 2.4$, $p < 0.05$; $t_{1.5yr} = 2.7$, $p < 0.01$), after 2 years by 7% ($t = 2.8$, $p < 0.01$), after 2.5 years by 19% ($t = 9.9$, $p < 0.01$), after 3 years by 27% ($t = 14.6$, $p < 0.01$), the negative part of the relative accommodation after 1 and 1.5 years increases by 8% and 7% respectively ($t_{1yr} = 2.5$, $p < 0.05$; $t_{1.5yr}$ =2.4, $p < 0.05$), after 2 and 2.5 years by 10% ($t_{2yr} = 3.4$, $p < 0.01$; $t_{2.5yr} = 3.6$, $p < 0.01$), after 3 years by 17% ($t = 7.3$, $p <0.01$), and the positive part of the relative accommodation after 1 year by 15% ($t = 2.7$, $p < 0.01$), after 1,5 years by 14% ($t = 2.6$, $p < 0.01$), after 2 years by 17% ($t = 3.4$, $p <0.01$), after 2.5 years by 19% ($t = 3.6$, $p < 0.01$), after 3 years by 32% ($t = 7.1$, $p < 0.01$), accommodation flexibility after 1 and 1.5 years by 6% ($t_{1yr} = 2.5$, $p < 0.05$; $t_{1.5yr} = 2.6$, $p < 0.01$), after 2 and 2.5 years by 7% ($t_{2yr} = 2.9$, $p < 0.01$; $t_{2.5yr}$ = 3, 1, $p < 0.01$), after 3 years by 35% ($t = 14.2$, $p < 0.01$).

There was also a statistically significant decrease in accommodation response lag after 3 years by 33% ($t = 14.2$, $p < 0.01$).

Table 6 shows the dynamics of muscle balance in the short and long term of the follow-up in school-age children with myopia and astigmatism after the use of soft silicone-hydrogel aspherical contact lenses (M ± Ϭ).

Table 6 shows that under contact correction with lenses in school-age children, phoria at distance decreases statistically significantly after 2 years by 6% ($t = 3.1$, $p < 0.01$), after 2.5 years by 5% ($t = 2.9$, $p < 0.01$), after 3 years by 16% ($t = 10.1$, $p < 0.01$), phoria at near decreases after 2 years by 12% ($t = 5.2$, $p < 0.01$), after 2.5 years by 14% ($t = 6.4$, $p < 0.01$), and after 3 years by 16% ($t = 11.3$, $p < 0.01$).

There is also a statistically significant increase in the ratio of accommodation convergence to accommodation after 6 months by 17% ($t = 3.4$, $p < 0.01$), after 1 year by 25% ($t = 5.4$, $p < 0.01$), after 1.5 years by 24% ($t = 5.3$, $p < 0.01$), after 2 years by 13% ($t = 3.1$, $p < 0.01$), and after 3 years by 19% ($t = 3.4$, $p < 0.01$).

Table 5. The dynamics of accommodation in the short and long term of the follow-up in school-age children with myopia and astigmatism after the use of soft silicone-hydrogel aspherical contact lenses (M ± Ϭ)

Follow-up (number of eyes)	Accommodation parameters				
	Accommodation amplitude (diopter)	Negative part of relative accommodation (diopter)	Positive part of relative accommodation (diopter)	Accommodation response (diopter)	Flexibility of accommodation (cycles/min)
Initial examination (n=168)	9.54±1.23	+1.26±0.44	–0.92±0.14	+1.86±0.28	7.51±0.32
1mth follow-up (n=168)	9.63±1.28	+1.29±0.46	–0.96±0.16	+1.83±0.24	7.6±0.34
6mth follow-up (n=168)	9.66±1.24	+1.31±0.48	–0.98±0.17	+1.80±0.22	7.81±0.28
1yr follow-up (n=168)	9.97±1.34*	+1.36±0.46*	–1.06±0.18**	+1.78±0.24	7.94±0.28*
1.5yr follow-up (n=168)	10.02±1.45**	+1.35±0.45*	–1.05±0.16**	+1.77±0.31	7.95±0.21**
2yr follow-up (n=160)	10.2±1.31**	+1.38±0.46**	–1.08±0.14**	+1.8±0.24	8.01±0.36**
2.5yr follow-up (n=160)	11.4±1.38**	+1.39±0.44**	–1.09±0.19**	+1.84±0.26	8.04±0.28**
3yr follow-up (n=156)	12.1±1.22**	+1.48±0.46**	–1.21±0.16**	+1.4±0.14**	10.12±0.17**
	$t_{\text{1mth follow-up}}$= 0.5 $t_{\text{6mth follow-up}}$= 0.6 $t_{\text{1yr follow-up}}$= 2.4 $t_{\text{1.5yr follow-up}}$= 2.7 $t_{\text{2yr follow-up}}$ = 2.8 $t_{\text{2.5yr follow-up}}$ = 9.9 $t_{\text{3yr follow-up}}$ = 14.6	$t_{\text{1mth follow-up}}$= 1.2 $t_{\text{6mth follow-up}}$= 1.4 $t_{\text{1yr follow-up}}$= 2.5 $t_{\text{1.5yr follow-up}}$= 2.4 $t_{\text{2yr follow-up}}$ = 3.4 $t_{\text{2.5yr follow-up}}$ = 3.6 $t_{\text{3yr follow-up}}$ = 7.3	$t_{\text{1mth follow-up}}$= 0.7 $t_{\text{6mth follow-up}}$= 1.2 $t_{\text{1yr follow-up}}$= 2.7 $t_{\text{1.5yr follow-up}}$= 2.6 $t_{\text{2yr follow-up}}$ = 3.4 $t_{\text{2.5yr follow-up}}$ = 3.6 $t_{\text{3yr follow-up}}$ = 7.1	$t_{\text{1mth follow-up}}$= 0.6 $t_{\text{6mth follow-up}}$= 1.5 $t_{\text{1yr follow-up}}$= 1.6 $t_{\text{1.5yr follow-up}}$= 1.8 $t_{\text{2yr follow-up}}$ = 1.5 $t_{\text{2.5yr follow-up}}$ = 0.4 $t_{\text{3yr follow-up}}$ = 10.3	$t_{\text{1mth follow-up}}$= 0.6 $t_{\text{6mth follow-up}}$= 1.8 $t_{\text{1yr follow-up}}$= 2.5 $t_{\text{1.5yr follow-up}}$= 2.6 $t_{\text{2yr follow-up}}$ = 2.9 $t_{\text{2.5yr follow-up}}$ = 3.1 $t_{\text{3yr follow-up}}$ = 14.2

*The level of significance of differences compared to the initial examination data; $p < 0.05$ calculated by Student's t-test

** The level of significance of differences compared to the initial examination data; $p < 0,01$ calculated by Student's t-test

Table 6. Dynamics of muscle balance in the short and long term of follow-up in school-age children with myopia and astigmatism after the use of soft silicone-hydrogel aspherical contact lenses (M ± Ϭ)

Follow-up (number of eyes)	Phoria (prism diopters Exo)		The ratio of accommodative convergence to accommodation (prism diopters)
	at distance	at near	
Initial examination (n=168)	5.29 ± 1.78	9.25 ± 0.35	2.3 ± 0.36
1-month follow-up (n=168)	5.27 ± 1.58	9.21 ± 0.33	2.4 ± 0.29
6-month follow-up (n=168)	5.20 ± 1.62	9.12 ± 0.41	2.7 ± 0.42**
1-year follow-up (n=168)	5.14 ± 1.45	8.98 ± 0.27	2.87 ± 0.31**
1.5-year follow-up (n=168)	5.16 ± 1.38	8.97 ± 0.22	2.86 ± 0.32**
2-year follow-up (n=160)	5.01 ± 1.72**	8.25 ± 0.31**	2.6 ± 0.34**
2.5-year follow-up (n=160)	5.03 ± 1.65**	8.11 ± 0.32**	2.52 ± 0.37
3-year follow-up (n=156)	4.58 ± 0.98**	7.98 ± 0.31**	2.74 ± 0.26**
	$t_{1mth\ follow\text{-}up}$= 0.2 $t_{6mth\ follow\text{-}up}$= 1.0 $t_{1yr\ follow\text{-}up}$= 1.7 $t_{1.5yr\ follow\text{-}up}$= 1.4 $t_{2yr\ follow\text{-}up}$ = 3.1 $t_{2.5yr\ follow\text{-}up}$ = 2.9 $t_{3yr\ follow\text{-}up}$ = 10.1	$t_{1mth\ follow\text{-}up}$= 0.1 $t_{6mth\ follow\text{-}up}$= 0.6 $t_{1yr\ follow\text{-}up}$= 1.3 $t_{1.5yr\ follow\text{-}up}$= 1.4 $t_{2yr\ follow\text{-}up}$ = 5.2 $t_{2.5yr\ follow\text{-}up}$ = 6.4 $t_{3yr\ follow\text{-}up}$ = 11.3	$t_{1mth\ follow\text{-}up}$= 0.7 $t_{6mth\ follow\text{-}up}$= 3.4 $t_{1yr\ follow\text{-}up}$= 5.4 $t_{1.5yr\ follow\text{-}up}$= 5.3 $t_{2yr\ follow\text{-}up}$ = 3.1 $t_{2.5yr\ follow\text{-}up}$ = 1.9 $t_{3yr\ follow\text{-}up}$ = 3.4

*The level of significance of differences compared to the initial examination data; p <0.05 calculated by Student's t-test

** The level of significance of differences compared to the initial examination data; p <0,01 calculated by Student's t-test

Table 7 shows the dynamics of stereo visual acuity in the short and long term of the follow-up in school-age children with myopia and astigmatism after the use of soft silicone-hydrogel aspherical contact lenses (M ± Ϭ).

Table 7. Dynamics of stereo visual acuity in the short and long term of the follow-up in school-age children with myopia and astigmatism after the use of soft silicone-hydrogel aspherical contact lenses (M ± Ϭ).

Follow-up (number of eyes)	Stereoscopic visual acuity, arc seconds
Initial examination (n=168)	153.63 ± 7.07
1-month follow-up (n=168)	152.44 ± 6.12
6-month follow-up (n=168)	149.78 ± 6.08
1-year follow-up (n=168)	139.89 ± 6.17
1.5-year follow-up (n=168)	137.71 ± 4.6
2-year follow-up (n=160)	121.54 ± 7.14*
2.5-year follow-up (n=160)	113.84 ± 6.24**
3-year follow-up (n=156)	98.76 ± 4.87**
	$t_{1mth\ follow\text{-}up}$= 0.1; $t_{6mth\ follow\text{-}up}$= 0.3; $t_{1yr\ follow\text{-}up}$= 0.9; $t_{1.5yr\ follow\text{-}up}$= 1.1; $t_{2yr\ follow\text{-}up}$ = 2.3; $t_{2.5yr\ follow\text{-}up}$ = 2.9; $t_{3yr\ follow\text{-}up}$ = 4,1.

*The level of significance of differences compared to the initial examination data; p < 0.05 calculated by Student's t-test

** The level of significance of differences compared to the initial examination data; p < 0,01 calculated by Student's t-test.

As can be seen from Table 7, when applying correction with contact lenses for school-age children, there is a statistically significant increase in stereo visual acuity after two years of the follow-up by 26% ($t = 2.3$; $p < 0.05$), after 2.5 years by 35% ($t = 2.9$; $p < 0.01$), after 3 years by 56% ($t = 4.1$; $p < 0.01$).

Discussion

The leading role in the set of measures to control myopia is given to the selection of full-fledged correction, which should create conditions for the development of the visual analyzer and ensure maximum visual acuity [9]. Contact lenses have a variety of advantages in this case, as they form a single optical system with the eye, transmit the image size without the distortion, and prismatic effect typical for spectacle lenses, especially with high refractive powers. Medical publications show that when correcting myopia above 6,00 D the average visual acuity is 1.6 times higher with contact lenses than with spectacles. It is also believed that contact lenses improve accommodation performance and some optical designs can compensate for insufficient accommodation [10].

Our three-year studies have established that the use of contact lens correction in school-aged children with myopia and myopic astigmatism can increase uncorrected and maximum corrected visual acuity. An increase of the spheroequivalent index and increase of the APA length of the eye is the evidence of progressing myopia, but the use of soft contact lenses leads to changes of the anterior corneal surface: increase of the thickness in the central zone, and its flattening. There are also observed improvements of accommodation, vergence, disparate areas of the oculomotor apparatus, and their interaction. The results obtained are indicative of the slowdown of myopia progression.

Conclusions

The three-year follow-up of contact correction in school-aged children with myopia and myopic astigmatism found the statistically significant increases in uncorrected visual acuity by 47% ($t = 5.2$; $p < 0.01$), corrected visual acuity by 8% ($t = 9.3$; $p < 0.01$), spheroequivalent index by 17% ($t = 3.7$; $p < 0.01$), the anteroposterior segment of the eye by 4% ($t = 7.1$ $p < 0.01$), the amplitude of accommodation by 27% ($t = 14.6$, $p < 0.01$), the negative part of the relative accommodation by 17% ($t = 7.3$, $p < 0.01$), the positive part of relative accommodation by 32% ($t = 7, 1$, $p < 0.01$), the accommodation flexibility by 35% ($t = 14.2$, $p < 0.01$), the accommodation convergence to accommodation ratio by 19% ($t = 3.4$, $p < 0.01$), and stereo acuity by 56% ($t = 4.1$ $p < 0,01$). We also observed a decrease of keratometry in the strong meridian by 2% ($t = 5.2$; $p < 0.01$), the decrease of accommodative lag by 33% ($t = 14.2$, $p < 0.01$), the decrease in phoria at distance by 16% ($t = 10.1$, $p < 0.01$), and the decrease in phoria at near by 16% ($t = 11.3$, $p < 0.01$).

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