

Evaluation of Refraction in a Statistically Significant Sample: Changes According to Age and Strabismus

Carlo Chiesi, MD; Laura Chiesi, MD; Gian Maria Cavallini, MD

ABSTRACT

Purpose: To assess possible refractive changes according to age and strabismus in a statistically significant cohort.

Methods: A population-based sample of 12,534 subjects 0.5 to 20 years old, examined between 2004 and 2006, was tested. Each subject received a complete orthoptic examination, including spherocylindrical streak retinoscopy in cycloplegia. Patients were divided into those with orthophoria (7,784) and those with strabismus (4,750), and the latter group was further divided into those with esodeviation (3,026) and those with exodeviation (1,724). A statistical analysis of the spherical equivalent, astigmatism, and anisometropia was performed with an independent samples *t* test or one-way analysis of variance.

Results: The percentage of patients with a mean spherical equivalent within ± 1 and ± 2 standard deviations was greater than 68% and 95%, respectively. The mean spherical equivalent of the total sample was 1.62 diopters (D) (± 2.88). The mean spherical equivalent was 1.10 ± 2.94 D in the orthophoria group, 3.22 ± 2.29 D in the

esodeviation group, and 1.13 ± 2.50 D in the exodeviation group (one-way analysis of variance; $P = .000$). Age-related changes in the mean spherical equivalent showed a clear and steady myopic shift, reaching mean myopic refraction at 12 to 14 years in both the total sample and the orthophoria and exodeviation groups. It assumed a more constant trend, with no myopic swing, in the esodeviation group ($P = .000$). Mean astigmatism was less in patients with less than 1.00 D anisometropia (0.83 ± 0.92 D) than in those with 1.00 D or greater anisometropia (1.42 ± 1.18 D) (*t* test; $P = .0001$).

Conclusion: Both the age-related trend in the spherical equivalent and the high hyperopic values of the distribution peak in patients with esodeviation confirm the importance of the hypermetropic refractive component. The statistically significantly higher incidence of astigmatism in patients with 1.00 D or greater ametropia highlights its incidence in amblyopia.

[J Pediatr Ophthalmol Strabismus 2009;46:266-272.]

INTRODUCTION

The literature includes studies of age-related refractive evolution,¹⁻¹⁵ but only a few have addressed the presence and type of strabismus.¹⁶⁻²⁴ The age range of study subjects is often limited to a few years^{10-13,25-33}; moreover, refraction is measured with an autorefractometer²⁶⁻³⁴ or isotropic photorefrac-

tion³⁵ and not always in cycloplegia.^{36,37} The presence of high values of hyperopia in patients with esotropia and the absence of refractive dependence in those with exotropia have been well known for a long time,^{18,21,22} but age-related changes have not been studied in depth. In recent years, data on patients with orthopia have been computerized, in-

From the Department of Ophthalmology, Modena & Reggio Emilia University, Modena, Italy.

Originally submitted December 9, 2007. Accepted for publication June 16, 2008.

The authors have no proprietary or financial interest in the materials presented herein.

Address correspondence to Carlo Chiesi, MD, Department of Ophthalmology, Modena & Reggio Emilia University, Via Del Pozzo, 71, 41100 Modena, Italy.

Group	No. of Patients	Mean Age (Y)	Median Age (Y)	Sex	
				Female	Male
Total	12,534	6.48 ± 4.12	5.93	6,441	6,093
Orthophoria	7,784	6.57 ± 4.22	6.00	3,998	3,786
Strabismus	4,750	6.33 ± 3.96	5.82	2,488	2,262
exotropia	1,724	6.55 ± 3.87	6.00	884	840
esotropia	3,026	6.21 ± 4.00	5.99	1,575	1,451

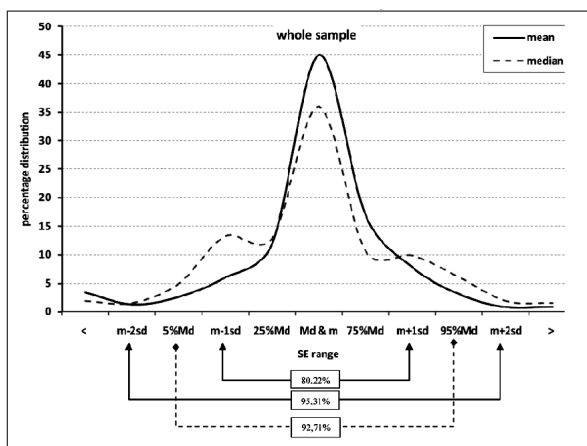


Figure 1. Curves and values of percentage distribution in the total sample in a ± 2 standard deviation mean spherical equivalent range and between the 5th and 95th percentiles of the median. m = mean; sd = standard deviation; Md = median.

cluding refractive types, and this has permitted analysis of a wide and statistically significant cohort of patients. In particular, the current study investigated refractive changes according to age and attempted to determine whether they differ with regard to the presence and type of strabismus.

PATIENTS AND METHODS

In a retrospective study, data were extracted from the case records of 12,534 patients examined at the Orthoptic Service of the Ophthalmological Department of Modena University between 2004 and 2006. Each patient was examined by an ophthalmologist, who confirmed the data obtained by orthoptic staff (visual acuity, ocular motility, and sensorial status); performed specific evaluations, such as spherocylindrical streak retinoscopy in cycloplegia (cyclopentolate 1% every 15 minutes AQ2 three times before examination), ophthalmoscopy, and biomicroscopy; and then assumed responsibility for possible therapy. Exclusion criteria included

ocular pathology, such as cataract, glaucoma, coloboma, optic atrophy, and stage 3 or worse retinopathy of prematurity. The following factors were considered: the spherical equivalent (mean of the refractive values of the vertical and horizontal meridians), astigmatism (difference between the vertical and horizontal refractive values), and anisometropia (difference between the spherical equivalent of the two eyes).

Patients were divided into orthophoria (7,784) and strabismus (4,750) groups. The strabismus group was then divided into esodeviation (3,026) and exodeviation (1,724) groups. Esodeviation was defined as esotropia or esophoria of more than 4 prism diopters, and exodeviation was defined as exotropia or exophoria of more than 8 prism diopters. Statistical analysis of data was performed with an independent samples *t* test or one-way analysis of variance.

The mean age of all subjects was 6.48 years (± 4.12 years), with a median value of 5.93 years (range: 0.5 to 20 years). Ages were similar in the subgroups. There was a slight prevalence of girls in both the total sample (6,441 girls and 6,093 boys) and the subgroups (Table 1).AQ3

RESULTS

Patient Distribution

The percentage of patients with a spherical equivalent within ± 1 and ± 2 standard deviations (SD) from the mean was greater than 68% (80.22%) and 95% (95.31%), respectively. The distribution within ± 2 SD of the refractive range was similar in all subgroups, but there was no statistical significance (one-way analysis of variance; $P = 1.000$). Even if the refractive range included the 5th and 95th percentiles of the median, the percentage distribution of subjects was similar to that in relation to mean and SD (Fig. 1).

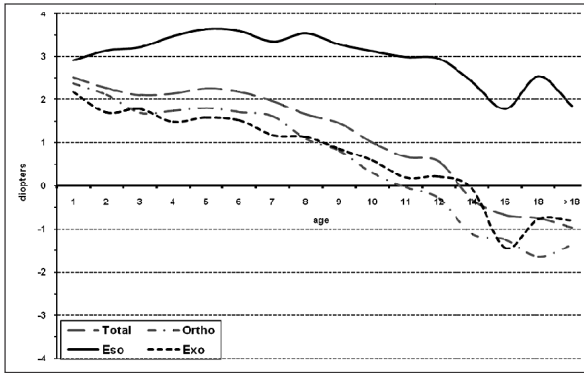


Figure 2. Variations of age-related spherical equivalent in the total sample and subgroups. eso = esodeviation; Ortho = orthophoria; exo = exodeviation.

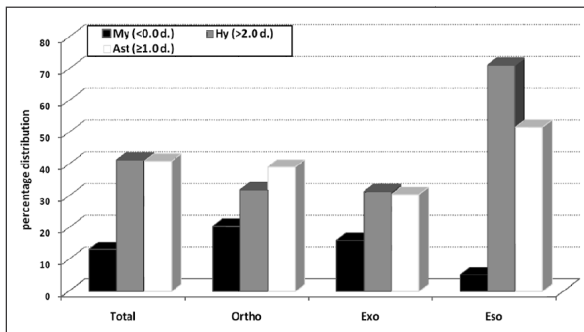


Figure 3. Percentage distribution of myopia (< 0 D), hyperopia (> 2 D), and astigmatism (> 1 D) in the total sample and subgroups. My = myopia; Ast = astigmatism; Hy = hypermetropia; Ortho = orthophoria; exo = exodeviation; eso = esodeviation.

Spherical Equivalent

The mean spherical equivalent of the total sample was 1.62 (\pm 2.88) D (median: 2.00), whereas in the orthophoria and strabismus subgroups, it was 1.10 (\pm 2.94) D (median: 1.75 D) and 2.46 (\pm 2.57) D (median: 2.50 D), respectively. In the esodeviation and exodeviation subgroups, the mean spherical equivalent was 3.22 (\pm 2.29) D (median: 3.25 D) and 1.13 (\pm 2.50) D (median: 1.63D), respectively. Statistical significance among the refractive data in the orthophoria, esodeviation, and exodeviation subgroups was emphasized (one-way analysis of variance; $P = .000$).

In the total sample, age-related changes in the mean spherical equivalent (from 5 months to 20 years) showed a clear and steady myopic shift, reaching a mean myopic refraction at approximately 12 to 14 years (+2.51 D at the 1st year and -0.97 D after the 18th year). This age-related myopic shift was confirmed in patients with orthophoria (+2.38 to -1.87 D) and in those with exodeviation (+2.18 to -0.81 D). It assumed a more constant trend, with no myopic swing, in those with esodeviation (+2.91

Table 2
Percentage Distribution of Myopia, Hyperopia, and Astigmatism in the Total Sample and Subgroups

Group	Myopia (< 0.00 D)	Hyperopia (> 2.00 D)	Astigmatism (> 1.00 D)
Total	16.24%	41.43%	41.03%
Orthophoria	20.55%	32.03%	39.20%
Strabismus	9.18%	56.82%	44.04%
exotropia	16.13%	31.44%	30.57%
esotropia	5.22%	71.28%	51.72%

D = diopters.

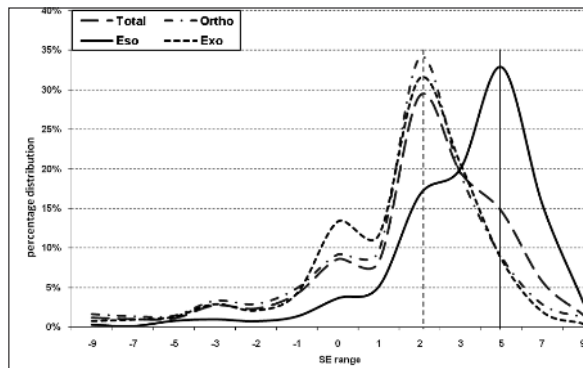


Figure 4. Percentage distribution of patients in a ± 9 D spherical equivalent range in the total sample and subgroups. eso = esodeviation; Ortho = orthophoria; exo = exodeviation; Se = spherical equivalent.

to +1.86 D). Statistical significance was seen with one-way analysis of variance ($P = .000$) (Fig. 2).

The percentage of subjects with a myopic (spherical equivalent < 0.00 D) and hypermetropic (spherical equivalent > +2.00 D) spherical equivalent was similar in the total sample and in the orthophoria and exodeviation subgroups, whereas it differed in those with esodeviation. Similar findings were noted with regard to the distribution of patients with 1.00 D or greater astigmatism, considered as an absolute value (Table 2 and Fig. 3).

When the spherical equivalent was -9.00 to +9.00 D, more than ± 2 SD from the mean, the highest concentration peak was superimposable in both the orthophoria and the exodeviation groups, stabilizing at approximately +2.00 D, whereas in the esodeviation group, it was clearly shifted toward higher hypermetropic values (approximately +5.00 D) (Fig. 4).

Furthermore, in the first 5 years of life, patients with esodeviation had a positive yearly variation in the spherical equivalent (+0.15 D), whereas in

Age (Y)	Total	Orthophoria	Exodeviation	Esodeviation
0 to 5	-0.050	-0.116	-0.118	+0.144
6 to 10	-0.250	-0.300	-0.200	-0.102
11 to 15	-0.294	-0.296	-0.258	-0.205
16 to 20	-0.102	-0.138	-0.054	-0.047

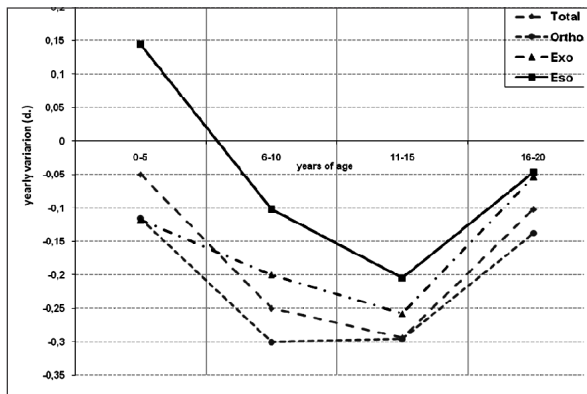


Figure 5. Variation per year of spherical equivalent at different ages in the total sample and the subgroups. D = diopters; Ortho = orthophoria; exo = exodeviation; eso = esodeviation.

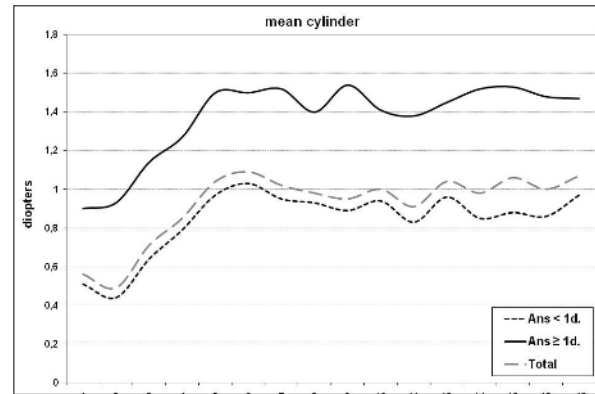


Figure 6. Age-related trend of mean astigmatism in the total sample and in patients with anisometropia less than 1 D versus patients with anisometropia of 1 D or greater. D = diopters; Ans = anisometropia

other groups, the variation was negative (-0.118 D). Beyond the fifth year of life, yearly variations were similar in all study groups (Table 3 and Fig. 5).

Astigmatism and Anisometropia

Mean astigmatism did not show any significant differences among the various subgroups (total group: 0.90 D [\pm 0.97]; orthophoria group: 0.89 D [\pm 0.97]; strabismus group: 0.92 D [\pm 0.97]; esodeviation group: 1.01 D [\pm 0.96]; exodeviation group: 0.72 D [\pm 0.94]). Age-related changes showed an increasing trend in the first 5 to 6 years of life, followed by stabilization (Fig. 6). In accordance with the literature, fewer patients showed 1.00 D or greater against-the-rule astigmatism than with-the-rule astigmatism (8.10% and 31.16%, respectively). These values did not differ statistically in the various subgroups (Table 4).

The percentage of subjects with 1.00 D or greater anisometropia was similar in all subgroups (total group: 12.98%; orthophoria group: 14.27%; strabismus group: 10.86%; exodeviation group: 10.27%; esodeviation group: 11.20%).

Mean astigmatism was less in patients with less than 1.00 D anisometropia (0.83 D [\pm 0.92]) than in

those with 1.00 D or greater anisometropia (1.42 D [\pm 1.18]) in both the total sample and the subgroups (Table 5). An independent samples *t* test analysis of data showed clear significance ($P = .0001$).

When age-related evolution of astigmatism was considered, it was always greater in patients with 1.00 D or greater anisometropia than in the total sample or in patients with less than 1.00 D anisometropia (Table 6 and Fig. 6). High statistical significance was shown with one-way analysis of variance ($P = .000$).

The authors also considered astigmatism and anisometropia in the spherical equivalent range -9.00 to +9.00 D and found significantly increased values, with more hyperopic and more myopic refractions (Table 7 and Fig. 7). There was no significant statistical difference between the total sample and the subgroups.

There was no significant difference regarding sex.

DISCUSSION

First, the authors considered the distribution curves of the sample. The percentage patient distribution with regard to both the total sample and various subgroups appears to be normal, because the

Table 4
Percentage of Patients With 1 Diopter or Greater Astigmatism (With-the-Rule and Against-the-Rule Types) in the Total Sample and Subgroups

Group	Astigmatism (≥ 1.00 D)	With-the-Rule Type	Against-the-Rule Type
Total	39.25%	31.16%	8.10%
Orthophoria	37.26%	30.30%	6.96%
Strabismus	40.85%	32.71%	8.14%
exotropia	33.24%	25.96%	7.28%
esotropia	43.89%	34.71%	9.18%

D = diopter.

Table 5
Mean and Standard Deviation of Astigmatism Related to Anisometropia in the Total Sample and Subgroups

Group	Anisometropia < 1.00 D	Anisometropia ≥ 1.00 D
Total	0.83 \pm 0.92 D	1.39 \pm 1.13 D
Orthophoria	0.81 \pm 0.92 D	1.38 \pm 1.11 D
Strabismus	0.85 \pm 0.92 D	1.42 \pm 1.18 D
exotropia	0.64 \pm 0.87 D	1.42 \pm 1.17 D
esotropia	1.45 \pm 1.17 D	1.40 \pm 1.18 D

D = diopters.

mean and median curves are almost superimposable, showing a clear Gaussian trend. Furthermore, a statistically significant percentage of subjects, more than 68%, showed a spherical equivalent ± 1 SD from the mean, whereas more than 95% of patients showed a spherical equivalent ± 2 SD from the mean. The high percentage of patients in the strabismus group (37.89%) is probably attributable either to the fact that the orthoptic outpatient clinic is a second-level institution (in which patients who are seen usually have just undergone ophthalmologic examination), or because this group also included patients with heterophoria AQ4 (over 4 prism diopters for esophoria and over 8 prism diopters for exophoria), increasing the number of subjects who can be defined as having strabismus.

In patients with esodeviation, the age-related trend in the spherical equivalent differs in a statistically significant way from that of the other groups. More precisely, it shows higher initial hypermetropia, with a tendency to increase in the first years of life (as some authors have pointed out), whereas in later years, a lower myopic shift can be detected. This

Table 6
Age-related Variations (diopters) in Mean Astigmatism in the Total Sample and in Patients With Less Than 1 Diopter Anisometropia Versus 1 Diopter or Greater Anisometropia

Age (Y)	Anisometropia < 1.00 D	Anisometropia ≥ 1.00 D	Total
1	0.51	0.90	0.56
2	0.44	0.93	0.49
3	0.64	1.14	0.71
4	0.79	1.27	0.85
5	0.97	1.50	1.04
6	1.03	1.50	1.09
7	0.95	1.52	1.02
8	0.93	1.40	0.98
9	0.89	1.54	0.95
10	0.94	1.41	1.00
11	0.83	1.38	0.91
12	0.96	1.45	1.04
14	0.85	1.52	0.98
16	0.88	1.53	1.06
18	0.86	1.48	1.00
> 18	0.97	1.47	1.07

D = diopters.

type of refractive evolution with regard to patient age and type of strabismus suggests that hypermetropic refraction is significant in esodeviation,^{20,21} and even if it is decreasing, it persists over the years. In contrast, in patients with exodeviation, the age-related refractive trend is absolutely superimposable with that of patients with orthophoria, confirming its minimal influence on the pathogenesis and evo-

Spherical Equivalent Range	Mean Astigmatism	Mean Anisometropia
-9	1.79	3.58
-7	1.72	2.73
-5	1.47	1.88
-3	1.12	1.22
-2	0.91	0.67
-1	0.76	0.58
0	0.58	0.29
1	0.84	0.22
2	0.58	0.19
3	0.91	0.32
5	1.27	0.54
7	1.54	0.87
9	1.53	1.55

lution of exodeviation. The high variance of mean values (high SD) confirms that the refractive component is important, but is not the sole cause of strabismus. In fact, either myopic or hyperopic high refractive values can be found in every considered subgroup, in both strabismus and orthophoria. The significance of hypermetropic refraction in the genesis of convergent strabismus is further supported by evidence that the distribution peak of patients with esotropia is clearly shifted toward higher hypermetropic values (approximately +5.00 D) than those found in other subgroups (approximately +2.00 D). It is also confirmed by the high prevalence (approximately 70%) of greater than +2.00 D hyperopic refraction in patients with esodeviation, compared with a lower percentage (approximately 30%) in those with orthophoria or exodeviation.

Even if the refractive correction of each subject could not be extrapolated from the database, it is possible to determine that both esotropia and high anisometropia always had adequate optical correction. Hypermetropic total correction can affect the emmetropization process, but it cannot be considered the sole cause.^{14,23,38} The lower myopic shift in patients with esodeviation can also be related to greater initial hypermetropia.^{9,15} Even the altered accommodative convergence/accommodation ratio

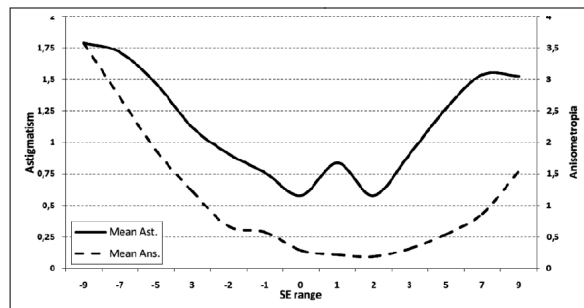


Figure 7. Mean astigmatism and mean anisometropia in the total sample related to a ± 9 D spherical equivalent (Se) range. Ast = astigmatism; Ans = anisometropia.

and the presence of amblyopia may be possible causes of the altered emmetropization process.²² The evolution of age-related refraction was not considered in each subject, because a long study period would be needed (almost 10 to 12 years). In this sample, for each subject, the authors considered refractive data obtained at a single examination. Visual acuity was not considered because it was not possible to study its evolution. It would be interesting to study the age-related refractive evolution in each patient with regard to motility, sensorial status, and changes in visual acuity.

As described in the literature, the age-related evolution of astigmatism^{33,39-41} showed an increase in the first 5 to 6 years of life, followed by stabilization of the mean value. The prevalence of with-the-rule astigmatism was also confirmed.⁹ It would be interesting to study the incidence of oblique astigmatism in refractive evolution and amblyopia, but this type of astigmatism could not be identified with the available database. It would be possible to determine the refractive power of horizontal and vertical meridians and establish the type of astigmatism (with the rule or against the rule). To permit evaluation of the incidence of oblique astigmatism, the database would have to be modified to include the axis of astigmatism as a separate value. However, this may not be an easy task.

Another interesting consideration is the behavior of astigmatism related to anisometropia. Its statistically significant higher incidence in 1.00 D or greater anisometropia means that astigmatism is an essential component of anisometropia and consequent amblyopia,^{34,42} even if the association with large refractive errors is more significant. The large percentage of subjects with 1.00 D or greater astigmatism and anisometropia can be explained by the type of patients seen at the authors' clinic. These pa-

tients are normally referred by other ophthalmologists for specific problems, so they can easily show anomalies of motility or refraction.

These findings confirm the need for correct cycloplegia for a reliable evaluation of refractive errors, by autorefractometer or retinoscopy, particularly in patients with strabismus.^{24,43}

Further data analysis will be necessary, particularly subdividing patients with esodeviation into accommodative and not accommodative types, to confirm the refractive error and its age-related trend.

REFERENCES

1. Slataper FJ. Age norms of refraction and vision. *Arch Ophthalmol*. 1950;43:466-481.
2. Troilo D, Wallman J. The regulation of eye growth and refractive state: an experimental study of emmetropization. *Vision Res*. 1991;31:1237-1250.
3. Troilo D. Neonatal eye growth and emmetropisation: a literature review. *Eye*. 1992;6(Pt 2):154-160.
4. Zadnik K. The Glenn A. Fry Award Lecture (1995): myopia development in childhood. *Optom Vis Sci*. 1997;74:603-608.
5. Ayed T, Sokkah M, Charfi O, El Matri L. Epidemiologic study of refractive errors in schoolchildren in socioeconomically deprived regions in Tunisia. *J Fr Ophthalmol*. 2002;25:712-717.
6. Holmström GE, Larsson EK. Development of spherical equivalent refraction in prematurely born children during the first 10 years of life: a population-based study. *Arch Ophthalmol*. 2005;123:1404-1411.
7. Smith EL III. Spectacle lenses and emmetropization: the role of optical defocus in regulating ocular development. *Optom Vis Sci*. 1998;75:388-398.
8. Hung GK, Ciuffreda KJ. Model of human refractive error development. *Curr Eye Res*. 1999;19:41-52.
9. Ehrlich DL, Braddick OJ, Atkinson J, et al. Infant emmetropization: longitudinal changes in refraction components from nine to twenty months of age. *Optom Vis Sci*. 1997;74:822-843.
10. Pennie FC, Wood IC, Olsen C, White S, Charman WN. A longitudinal study of the biometric and refractive changes in full-term infants during the first year of life. *Vision Res*. 2001;41:2799-2810.
11. Mayer DL, Hansen RM, Moore BD, Kim S, Fulton AB. Cycloplegic refractions in healthy children aged 1 through 48 months. *Arch Ophthalmol*. 2001;119:1625-1628.
12. He M, Zeng J, Liu Y, Xu J, Pokharel GP, Ellwein LB. Refractive error and visual impairment in urban children in southern China. *Invest Ophthalmol Vis Sci*. 2004;45:793-799.
13. Mutti DO, Mitchell GL, Jones LA, et al. Axial growth and changes in lenticular and corneal power during emmetropization in infants. *Invest Ophthalmol Vis Sci*. 2005;46:3074-3080.
14. Ong E, Grice K, Held R, Thorn F, Gwiazda J. Effects of spectacle intervention on the progression of myopia in children. *Optom Vis Sci*. 1999;76:363-369.
15. Atkinson J, Anker S, Bobier W, et al. Normal emmetropization in infants with spectacle correction for hyperopia. *Invest Ophthalmol Vis Sci*. 2000;41:3726-3731.
16. Clegg M, Woodhouse JM, Stewart RE, et al. Development of refractive error and strabismus in children with Down syndrome. *Invest Ophthalmol Vis Sci*. 2003;44:1023-1030.
17. Lepard CW. Comparative changes in the error of refraction between fixing and amblyopic eyes during growth and development. *Am J Ophthalmol*. 1975;80:485-490.
18. Ingram RM, Traynar MJ, Walker C, Wilson JM. Screening for refractive errors at age 1 year: a pilot study. *Br J Ophthalmol*. 1979;63:243-250.
19. Ingram RM, Gill LE, Lambert TW. Emmetropisation in normal and strabismic children and the associated changes of anisometropia. *Strabismus*. 2003;11:71-84.
20. Ingram RM, Walker C, Wilson JM, Arnold PE, Dally S. Prediction of amblyopia and squint by means of refraction at age 1 year. *Br J Ophthalmol*. 1986;70:12-15.
21. Abrahamson M, Fabian G, Sjöstrand J. Refraction changes in children developing convergent or divergent strabismus. *Br J Ophthalmol*. 1992;76:723-727.
22. Gwiazda J, Thorn F. Development of refraction and strabismus. *Curr Opin Ophthalmol*. 1999;10:293-299.
23. Lowery RS, Hutchinson A, Lambert SR. Emmetropization in accommodative esotropia: an update and review. *Compr Ophthalmol Update*. 2006;7:145-149.
24. Ingram RM. Refraction as a basis for screening children for squint and amblyopia. *Br J Ophthalmol*. 1977;61:8-15.
25. Ingram RM, Barr A. Changes in refraction between the ages of 1 and 3 1/2 years. *Br J Ophthalmol*. 1979;63:339-342.
26. Cook RC, Glasscock RE. Refractive and ocular findings in the newborn. *Am J Ophthalmol*. 1951;34:1407-1413.
27. Ingram RM. Refraction of 1-year-old children after atropine cycloplegia. *Br J Ophthalmol*. 1979;63:343-347.
28. O'Neal MR, Connon TR. Refractive error change at the United States Air Force Academy: class of 1985. *Am J Optom Physiol Opt*. 1987;64:344-354.
29. Zhao J, Mao J, Luo R, Li F, Munoz SR, Ellwein LB. The progression of refractive error in school-age children: Shunyi district, China. *Am J Ophthalmol*. 2002;134:735-743.
30. Kuo A, Sinatra RB, Donahue SP. Distribution of refractive error in healthy infants. *J AAPOS*. 2003;7:174-177.
31. Cheng D, Schmid KL, Woo GC. Myopia prevalence in Chinese-Canadian children in an optometric practice. *Optom Vis Sci*. 2007;84:21-32.
32. Hendricks TJ, De Brabander J, van Der Horst FG, Hendrikse F, Knottnerus JA. Relationship between habitual refractive errors and headache complaints in schoolchildren. *Optom Vis Sci*. 2007;84:137-143.
33. Ehrlich DL, Atkinson J, Braddick O, Bobier W, Durden K. Reduction of infant myopia: a longitudinal cycloplegic study. *Vision Res*. 1995;35:1313-1324.
34. Huynh SC, Wang XY, Ip J, et al. Prevalence and associations of anisometropia and aniso-astigmatism in a population based sample of 6 year old children. *Br J Ophthalmol*. 2006;90:597-601.
35. Atkinson J, Braddick O, Nardini M, Anker S. Infant hyperopia: detection, distribution, changes and correlates: outcomes from the Cambridge infant screening programs. *Optom Vis Sci*. 2007;84:84-96.
36. Miller JM, Harvey EM, Dobson V. Visual acuity screening versus noncycloplegic autorefraction screening for astigmatism in Native American preschool children. *J AAPOS*. 1999;3:160-165.
37. Vision in Preschoolers Study Group. Ohio State University, College of Optometry, Columbus, USA: does assessing eye alignment along with refractive error or visual acuity increase sensitivity for detection of strabismus in preschool vision screening? *Invest Ophthalmol Vis Sci*. 2007;48:3115-3125.
38. McLean RC, Wallman J. Severe astigmatic blur does not interfere with spectacle lens compensation. *Invest Ophthalmol Vis Sci*. 2003;44:449-457.
39. Mutti DO, Mitchell GL, Jones LA, et al. Refractive astigmatism and the toricity of ocular components in human infants. *Optom Vis Sci*. 2004;81:753-761.
40. Huynh SC, Kifley A, Rose KA, Morgan I, Heller GZ, Mitchell P. Astigmatism and its components in 6-year-old children. *Invest Ophthalmol Vis Sci*. 2006;47:55-64.
41. Huynh SC, Kifley A, Rose KA, Morgan IG, Mitchell P. Astigmatism in 12-year-old Australian children: comparisons with a 6-year-old population. *Invest Ophthalmol Vis Sci*. 2007;48:73-82.
42. Dobson V, Miller JM, Harvey EM, Mohan KM. Amblyopia in astigmatic preschool children. *Vision Res*. 2003;43:1081-1090.
43. Fotadar R, Rohtchina E, Morgan I, Wang JJ, Mitchell P, Rose KA. Necessity of cycloplegia for assessing refractive error in 12-year-old children: a population-based study. *Am J Ophthalmol*. 2007;144:307-309.

