

Cycloplegic Refractions in Healthy Children Aged 1 Through 48 Months

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Objectives: To provide a description of refractive errors in healthy, term-born children, aged 1 through 48 months, and to test the hypotheses that spherical equivalent becomes significantly less hyperopic and less variable with increasing age.

Methods: Following a prospective, cross-sectional design, cycloplegic retinoscopy was used to measure the refractive error in both eyes of 514 healthy, term-born children in 12 age groups. Three hundred were aged 12 months or younger. Spherical equivalent and cylindrical power and axis were analyzed as a function of age. Prediction limits for spherical equivalent were calculated.

Results: Spherical equivalents of right and left eyes did

not differ at any age. Hyperopia declined significantly with increasing age. The variability in spherical equivalent also decreased significantly with age. Cylindrical error of 1 diopter or more was found in 25% of the children; the proportion with astigmatism was highest in infancy and then waned. Myopia and anisometropia were rare, occurring in 3% and 1% of the sample, respectively.

Conclusions: Significant declines in hyperopia and variability of spherical equivalent appear to be features of emmetropization. The normal prediction limits provide guidelines against which data from individual patients can be compared.

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IT HAS BEEN long and widely recognized that infants, on average, are hyperopic, and that the hyperopia gradually decreases during infancy and early childhood.

These changes in normal refractive error are presumed to reflect finely regulated eye growth,¹ controlled at least in part by the retina.^{2,3} The involved processes, known collectively as emmetropization, are accompanied by a high prevalence of astigmatism in infants.⁴⁻⁶ Despite numerous studies of refractive development, the new millennium has been entered without sufficient specification of refractive development in healthy infants and young children to support quantitative comparison with populations with disease, or to diagnose abnormal refraction in an individual youngster. This is because previous studies have sampled only a few ages during infancy when the change in hyperopia is thought to be rapid,⁷ because the children studied were drawn from clinical populations,^{8,9} or both. On occasion, the refractive errors were measured using nonstandard procedures.^{10,11}

Herein we report the results of cycloplegic retinoscopy in 514 normal sub-

jects. The data permit specification of normal refractive characteristics, including the limits of normal spherical equivalent for each of 12 age groups ranging from 1 through 48 months.

RESULTS

Figure 1 shows the spherical equivalents (n=514), along with the mean spherical equivalent and the 95% and 99% prediction limits for each age group. Myopia and anisometropia were rare in this sample. Myopia was found in 14 (3%) of 514. Four (1%) of 514 had anisometropia. There was a significant decline in hyperopia with age ($F_{11,502}=7.96$; $P\leq.01$). Distributions of spherical equivalent appeared broader at younger ages (**Figure 2**). Indeed, the SD of spherical equivalent (**Table**) was significantly larger at 1 month than at 48 months ($F_{31,32}=3.55$; $P<.01$).

Astigmatism was found in 126 (25%) of 514. High cylindrical errors were uncommon. Only 14 (3%) of 514 had 2 D or more of cylinder. The 2.5-, 4-, 6-, and 9-month age groups had the highest prevalence of astigmatism (**Figure 3**). The percentage of subjects with astigmatism was

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SUBJECTS AND METHODS

Refractive errors were measured in 514 healthy subjects, aged 1, 1.5, 2.5, 4, 6, 9, 12, 18, 24, 30, 36, and 48 months. Three hundred of the subjects were aged 12 months or younger. Age at refraction varied from the nominal age by no more than 10 days in the first year, and 14 days thereafter. The median number of subjects per age group was 43 (range, 32-52). These subjects had been recruited to participate in a study of normal visual acuity.¹² About 85% were white. All subjects were born at term (gestational age, ≥ 37 weeks) with Apgar scores of at least 8, had an uncomplicated neonatal course, were free of medical problems, and, by parental report, were experiencing normal development. Of 545 subjects undergoing refraction, 31 were excluded because of an ophthalmic abnormality (cataract [$n=2$], disc anomaly [$n=1$], esotropia [$n=2$]) or incomplete cycloplegia ($n=26$) as judged by the retinoscopist at the time of measurement. The study was approved by the Children's Hospital Committee on Clinical Investigation, Boston, Mass. Written informed consent was obtained from each subject's parent.

Each subject underwent a complete eye examination, including cycloplegic retinoscopy. Retinoscopy was performed by two of us (B.D.M. and A.B.F.) in dim room light with a streak retinoscope, at least 30 minutes after instillation of 1% cyclopentolate hydrochloride using punctal occlusion. Scheduling limitations resulted in 1 examiner (B.D.M.) conducting more (52%) eye examinations. Interexaminer reliability was evaluated in a subgroup of 43 subjects randomly selected from the sample. Each refractionist was masked as to the other's results.

For each eye of the 514 subjects, spherical equivalent and power and axis of cylinder were recorded. Astigmatism was defined as 1.0 diopter (D) or more of cylinder. Axis of cylinder was categorized as with the rule (minus cylinder axis at $180^\circ \pm 15^\circ$), against the rule (minus cylinder axis at $90^\circ \pm 15^\circ$), or oblique (all else). Myopia was defined as spherical equivalent of at least -0.5 D. Anisometropia was defined as a difference of at least 1.0 D between eyes in spherical equivalent or cylinder. The mean spherical equivalent and the mean cylinder did not differ significantly between right and left eyes at any age. Therefore, data from the subject's right eye were used to summarize the results.

Preliminary analyses indicated that the spherical equivalents at each age did not differ significantly from a normal distribution (Lilliefors test).¹³ The 95% and 99% prediction limits were calculated for each age group.¹⁴ Components of refraction were analyzed for significant variation with age. The intraclass correlation coefficient and t tests were used to analyze interexaminer differences.¹⁵ Statistical significance was accepted for tests with P values of no greater than .01 (2-tailed).

not uniform across age groups ($\chi^2_{11}=77$; $P<.01$). Against-the-rule astigmatism was more common (71 [56%]) than with-the-rule (37 [29%]) or oblique (18 [14%]) astig-

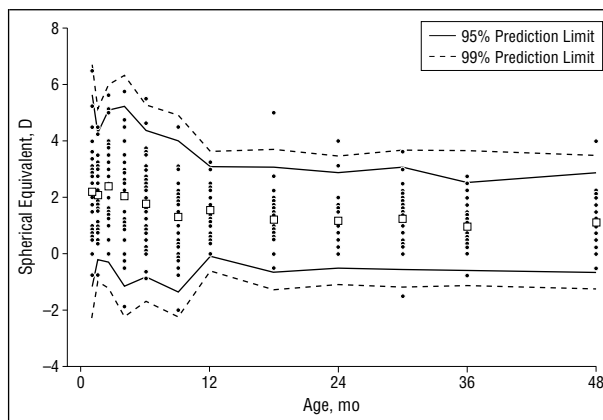


Figure 1. Spherical equivalent of the right eye in 514 subjects in 12 age groups. For each group, the mean spherical equivalent (open squares) and prediction limits connected by line segments are shown. D indicates diopters.

matism. In all those with oblique astigmatism, the axes of right and left eyes were mirror images.

For the 43 subjects undergoing refraction by both examiners, the correlation between spherical equivalents was high (intraclass correlation coefficient, 0.757). However, 1 examiner (B.D.M.) found significantly more hyperopia (mean difference, 0.6 D) (within-subject t test, $t_{42}=5.67$; $P\leq.01$). For the whole sample, the mean spherical equivalent in the several age groups was 0.3 to 1.0 D (median, 0.5 D) more hyperopic for the subjects examined by B.D.M. This small but consistent discrepancy, which suggests procedural differences between examiners, is within the range of reported interexaminer variations and is similar to the intraexaminer test-retest differences for cycloplegic retinoscopy in cooperative adults.¹⁶⁻¹⁸ The power of cylinder does not differ significantly between examiners in the subset of 43 subjects or in the whole sample.

COMMENT

The mean spherical equivalents analyzed herein and those reported in other studies^{7-9,18} are plotted in **Figure 4**. There are no conspicuous discrepancies between the results for healthy children and those with presumptively normal eyes. Compared with previous studies,^{7,9} we sampled more ages during the first year, when the rate of change appears to be rapid.⁷ Emmetropia had yet to be reached at 4 years of age (Figures 1 and 4). A reasonable ($r^2=0.90$), empirical summary of the course of emmetropization is provided by a simple exponential function (smooth curve; Figure 4), implying that the overall effect of the many biological processes involved in the control of refractive development is to decrease spherical equivalent at a constantly declining rate. Besides gradually decreasing hyperopia, we find another feature of normal development is the significant decrease in variability of the spherical equivalent (Figure 2 and Table). Furthermore, as development proceeds, there is a significant variation in cylindrical power (Figure 3) that in healthy infants is determined mainly at the cornea.¹⁹

Two applications of these data are envisioned. One pertains to analyses of data from groups of patients, such as those with retinal disorders of early onset. In **Figure 5**,

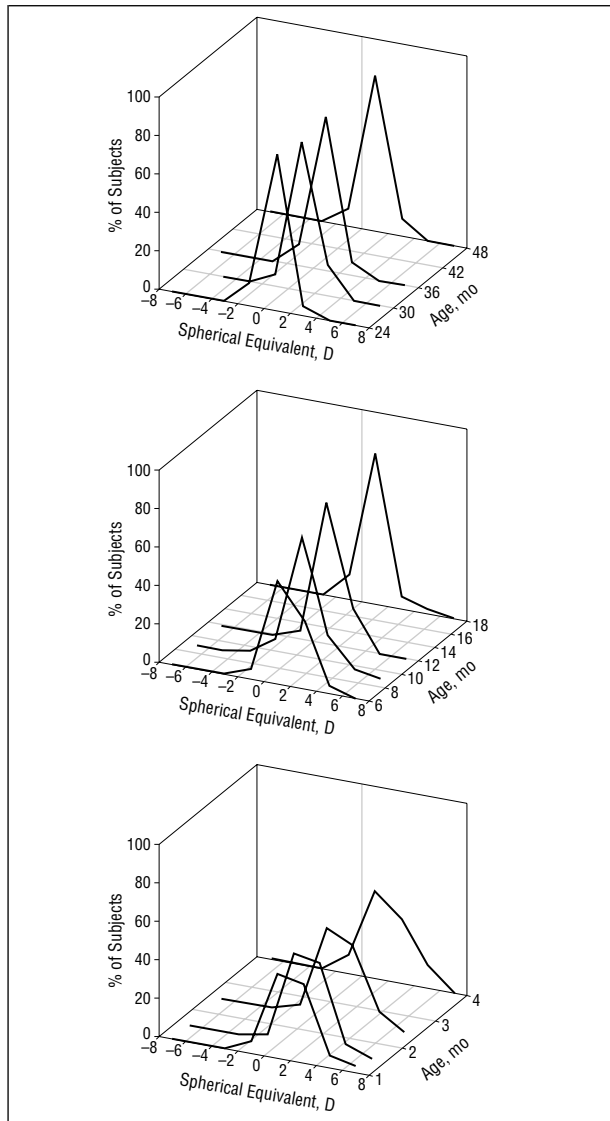


Figure 2. Distributions of spherical equivalent for the 12 groups. Data are plotted in 2-diopter (D) bins; the midpoint of each bin is indicated.

Spherical Equivalent (Diopters) and Prediction Limits*					
Age, mo (No. of Patients)	Spherical Equivalent, Mean (SD), D	95% Prediction Limits, D		99% Prediction Limits, D	
		Upper	Lower	Upper	Lower
1 (32)	2.20 (1.60)	5.51	-1.12	6.66	-2.27
1.5 (40)	2.08 (1.12)	4.36	-0.20	5.13	-0.98
2.5 (46)	2.44 (1.32)	5.13	-0.26	6.05	-1.17
4 (43)	2.03 (1.56)	5.21	-1.16	6.28	-2.23
6 (52)	1.79 (1.27)	4.39	-0.81	5.27	-1.69
9 (45)	1.32 (1.13)	3.63	-0.99	4.41	-1.77
12 (42)	1.57 (0.78)	3.16	-0.01	3.69	-0.55
18 (47)	1.23 (0.91)	3.09	-0.64	3.72	-1.27
24 (40)	1.19 (0.83)	2.89	-0.50	3.47	-1.08
30 (51)	1.25 (0.89)	3.07	-0.57	3.68	-1.19
36 (43)	1.00 (0.76)	2.56	-0.56	3.09	-1.09
48 (33)	1.13 (0.85)	2.89	-0.62	3.50	-1.23

*D indicates diopters.

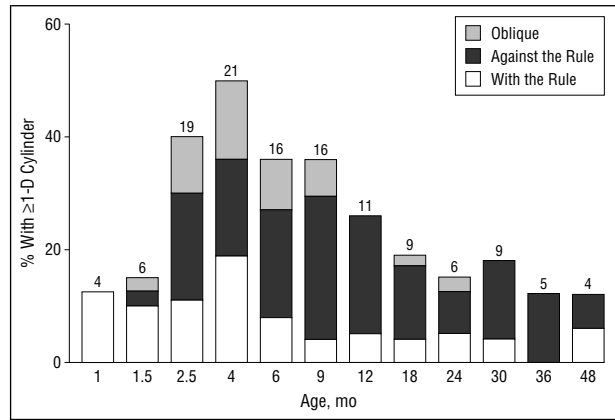


Figure 3. Percentage of subjects with astigmatism in each age group. The number of subjects with astigmatism in each age group is shown above the bar. The axis of astigmatism is as indicated. D indicates diopter.

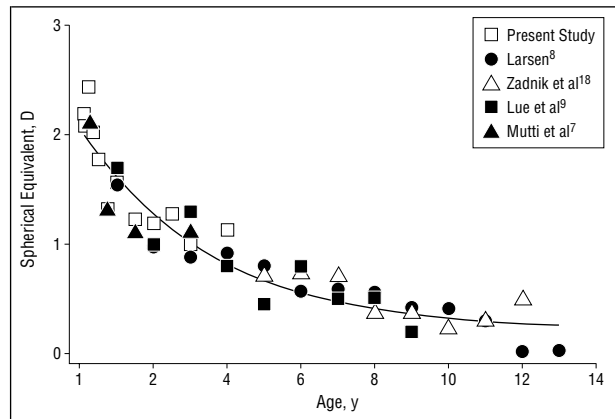


Figure 4. Mean spherical equivalents plotted in Figure 1 and those reported in Mutti et al.,⁷ Larsen,⁸ Lue et al.,⁹ and Zadnik et al.¹⁸ The smooth curve is a simple exponential function (time constant, 3.6 years) fit to all of the plotted points. D indicates diopters.

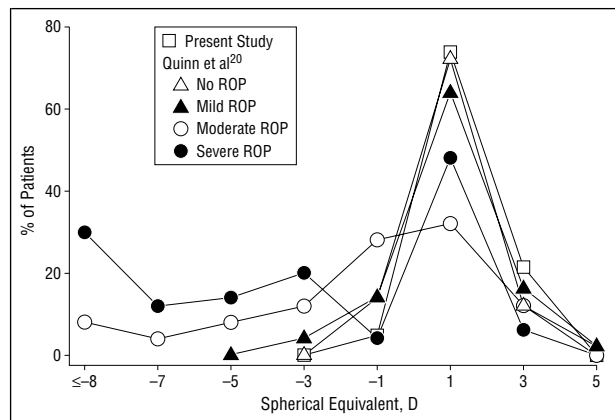


Figure 5. Distributions of spherical equivalent at 12 months of age plotted in Figure 2 and the Cryotherapy for Retinopathy of Prematurity study (data from Figure 1 in Quinn et al.²⁰). The midpoint of each 2-diopter (D) bin, -7 to 5 D, is indicated. Myopia of at least 8 D is indicated by no greater than -8 D. ROP indicates retinopathy of prematurity.

the distribution of spherical equivalent in our healthy 12-month age group is compared with distributions from the Cryotherapy for Retinopathy of Prematurity study.²⁰ At 12 months postterm, the former preterm infants who had

o retinopathy of prematurity have a distribution indistinguishable from that of the healthy, term-born 12-month-old infants. On the other hand, those with mild retinopathy of prematurity²⁰ show some increase in the frequency of mild myopia, and those with moderate and severe retinopathy of prematurity have distributions clearly skewed to myopic spherical equivalents.

The other application of these data pertains to diagnosis in the individual child. Data from the 514 healthy children provide a definition of the limits of normal spherical equivalent in infants and young children. The results from an individual child can be specified as within, or outside, these limits (Table). The broad prediction interval during infancy may bear consideration when planning screening programs that depend on refraction. Given the broad prediction intervals during infancy (Figure 1), screening refractions at 12 months of age or older may be more efficient. Nevertheless, detection of high cylindrical errors and anisometropia can contribute to the diagnosis of amblyogenic factors in infancy.²¹

In conclusion, our data further define the characteristics of refractive errors in the healthy, developing eye, and so specify limits of normal refractive error at 1 through 48 months of age.

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REFERENCES

1. Raviola E, Wiesel TN. Neural control of eye growth and experimental myopia in primates. In: Block G, Widdows K, eds. *Ciba Foundation Symposium*. New York, NY: John Wiley & Sons Inc; 1990:22-44.

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. Wallman J. Retinal control of eye growth and refraction. *Prog Retin Eye Res*. 1992; 12:133-153.
4. Atkinson J, Braddick O, French J. Infant astigmatism: its disappearance with age. *Vision Res*. 1980;20:891-893.
5. Fulton AB, Dobson V, Salem D, et al. Cycloplegic refractions in infants and young children. *Am J Ophthalmol*. 1980;90:239-247.
6. Mohindra I, Held R, Gwiazda J, Brill S. Astigmatism in infants. *Science*. 1978; 202:329-330.
7. Mutti DO, Frane SL, Friedman NE, et al. Ocular component changes during emmetropization in infancy [ARVO abstract]. *Invest Ophthalmol Vis Sci*. 2000;41: S300. Abstract 1580.
8. Larsen J. The sagittal growth of the eye, I: ultrasonic measurement of the depth of the anterior chamber from birth to puberty. *Acta Ophthalmol Scand*. 1971; 49:239-262.
9. Lue C-L, Hansen RM, Reisner DS, et al. The course of myopia in children with mild retinopathy of prematurity. *Vision Res*. 1995;35:1329-1335.
10. Atkinson J, Braddick O, Durden K, Watson PG, Atkinson S. Screening for refractive development in 6-9 month old infants by photorefractometry. *Br J Ophthalmol*. 1984;68:105-112.
11. Mohindra I. Refraction in humans from birth to five years. *Doc Ophthalmol*. 1981; 28:19-27.
12. Mayer DL, Beiser AS, Warner AF, et al. Monocular acuity norms for the Teller acuity cards between ages 1 month and 4 years. *Invest Ophthalmol Vis Sci*. 1995; 36:671-685.
13. Norusis MJ. *SPSS 6.1: Base System User's Guide*. Chicago, Ill: SPSS Inc; 1994: 91-93.
14. Whitmore GA. Prediction limits for a univariate normal observation. *Am Statistician*. 1986;40:141-143.
15. Fleiss JL. *The Design and Analysis of Clinical Experiments*. New York, NY: John Wiley & Sons Inc; 1986:1-29.
16. Hyams L, Safir A, Philpot J. Studies in refraction, II: bias and accuracy of retinoscopy. *Arch Ophthalmol*. 1971;85:33-41.
17. Safir A, Hyams L, Philpot J, Jagerman LS. Studies in refraction, I: the precision of retinoscopy. *Arch Ophthalmol*. 1970;84:49-61.
18. Zadnik K, Mutti DO, Friedman NE, Adams AJ. Initial cross-sectional results from the Orinda Longitudinal Study of Myopia. *Optom Vis Sci*. 1993;70:750-758.
19. Howland HC, Sayles N. Photokeratometric and photorefractive measurements of astigmatism in infants and young children. *Vision Res*. 1985;25:73-81.
20. Quinn GE, Dobson V, Kivlin J, et al. Prevalence of myopia between 3 months and 5½ years in preterm infants with and without retinopathy of prematurity: Cryotherapy for Retinopathy of Prematurity Cooperative Group. *Ophthalmology*. 1998;105:1292-1300.
21. Abrahamsson M, Fabian G, Sjostrand J. Changes in astigmatism between the ages of 1 and 4 years: a longitudinal study. *Br J Ophthalmol*. 1988;92:145-149.