Calibration of the Hirschberg Test in Human Infants

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Purpose. The Hirschberg ratio has been defined as the ratio of the change in angular position of the line of sight to the change in location of the first Purkinje image relative to the pupil center. This study was designed to determine empirically whether the adult value of the Hirschberg ratio (approximately 22 prism diopters/mm) is a suitable value to use for all ages. Because many structures in the eye are growing during the 1st year, it is possible that there could be some change in the Hirschberg ratio during this period.

Methods. A photographic technique was used to calculate the Hirschberg ratio for 323 infants between the ages of 27 and 365 days and for ten adult subjects. The study also measured angle λ, the angle between the line of sight and the pupillary axis, in these populations.

Results. The Hirschberg ratio did not change with age during infancy and was similar for adults and infants both in value and in variance. Angle λ, however, declined rapidly, from an extrapolated value of about 8.4° at birth to near 5° at 5 months, a change that is assumed to reflect axial growth of the eye.

Conclusions. The results suggest that the same average Hirschberg ratio can be used to estimate angle of strabismus across age. The change in angle λ is important to consider when evaluating angle of deviation from measures using the Hirschberg test. Invest Ophthalmol Vis Sci. 1994;35:538–543.

One of the earliest techniques to be used for measuring ocular alignment of the eyes was the Hirschberg test.[1] In this simple procedure, a small light source is directed toward one or both eyes; as the eye rotates, the reflection of this light (first Purkinje image) is seen to change position on the eye, relative to some fixed landmark in the eye (typically the center of the pupil). This observation has been used for more than 100 years to assess strabismus in children and young infants because it requires minimal cooperation from the subject. Measurement of the distance between the first Purkinje image and, for instance, the pupil center can be used to estimate changes in alignment of the eye over a range of visual angles of about 20°.[2] By convention, the Hirschberg ratio reflects the change in angular rotation of the eye away from primary position that corresponds to a 1 mm change in the position of the first Purkinje image and is expressed in prism diopters (PD) per millimeter or degrees per millimeter.[2,3] Vergence position can be calculated by adding the first Purkinje image displacements in each eye and multiplying the total by the average Hirschberg ratio.[4] Calibration of the Hirschberg test in adults, from measurements of known ocular alignment of the eye, has shown that the test is reliable, allowing a reasonable estimate of ocular alignment without recalibration for each adult subject.[2] There has, however, been some disagreement as to whether this Hirschberg ratio is also appropriate for infants.

Figure 1 shows the measurements that are used to calculate the Hirschberg ratio. To calculate the change in angular position of the eye (the numerator of this ratio), the ocular alignment of each eye can be controlled by having subjects look at targets placed at different distances from them. To calculate the change in position of the first Purkinje image (the denominator [$PI_p - P_p$]), one needs to establish two points of reference on a plane within the eye: for instance, the center of the entrance pupil (P) and the center of corneal curvature. Because it is not possible to measure the center of corneal curvature directly, one can measure the position of the first Purkinje image instead, ie, the

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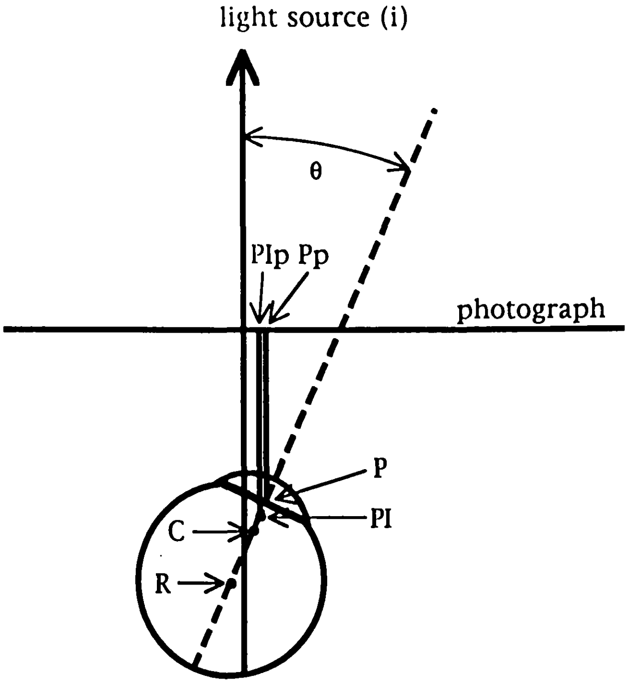

FIGURE 1. The measurement of the distance of the center of corneal curvature from the center of the pupil. Measurements were made from photographs of the eyes taken while the subject fixated targets set at different distances. The distance between the photographic image of the first Purkinje image and the photographic image of the center of the pupil was measured. This is directly proportional to the angular rotation of the eye for angles less than ±25° to 30°.[3] i, light source; τ, angle of rotation of the eye (prism diopters); C, center of corneal curvature; R, center of rotation of the eye; PI, first Purkinje image; P, center of the entrance pupil; PI_p, photographic image of PI; P_p, photographic image of P.

position of the virtual image (C) formed by reflection of a distant light source "i" from the anterior surface of the cornea. The denominator of the Hirschberg ratio can be derived from the distance between the position of the first Purkinje image and the center of the entrance pupil ($PI_p - P_p$).[2,5] This measure is correlated with both corneal curvature and the anterior chamber depth (which is related to the anterior–posterior position of the anatomical lens with respect to the center of the cornea).[6] The steeper the cornea the smaller the change in the position of the first Purkinje image for a given ocular rotation; thus, a steep cornea reduces the value of the denominator and increases the Hirschberg ratio all other things being equal. The relationship between the Hirschberg ratio and corneal curvature has also been measured empirically. Eskridge et al[7] found that people with steeper corneas had higher Hirschberg ratios (correlation coefficient = 0.78).

There is both theoretical and empirical evidence to support the use of a Hirschberg ratio of 21 to 22 PD/mm (12.3°/mm to 13.0°/mm) for adult subjects.[5–10]

However, the studies that have used infant subjects are in conflict about what conversion factor should be used in the Hirschberg test. Inagaki showed that infants of less than 2 months of age have steeper radii of curvature of the cornea,[11] and this has been used to suggest that infants would have a higher Hirschberg ratio than adults.[7] Because corneal curvature decreases with age, one might expect to find a developmental change in the Hirschberg ratio if this structural change was the only contributing factor. However, growth in structures in addition to the cornea might affect the Hirschberg ratio. One theoretical study used measurements of corneal curvature and anterior chamber depth to calculate the expected Hirschberg ratio in children from birth to 5 years of age.[12] These authors concluded that the Hirschberg ratio should *not* change over this time period and predicted a value of 19.5 PD/mm for this age range. This value is lower than that most frequently used for average adult subjects, perhaps because the measures of corneal curvature were from one population of infants and anterior chamber depth measures from another. To date, there are no empirical data on calibration of the Hirschberg ratio in young infants, data that could resolve this issue.

It is known that the line of sight of the eye (the line connecting the center of the entrance pupil to the fixation target) is not identical to the pupillary axis (the line connecting the center of the pupil and optical center of the cornea). The angle between these axes is known as angle lambda (λ).[11–14] Slater and Findlay[15] have shown that angle λ is larger in newborn infants than in adults (an average of 8.3° versus 5°), probably as a result of an increase in the eye's axial length between infancy and adulthood (although this study did not measure directly angle λ beyond the newborn period).

In this study, we have attempted directly to measure the value of the Hirschberg ratio and angle λ for young infants. We used a photographic technique (paraxial photorefraction) to measure the angle of rotation for each eye at several target distances in a large sample of infants less than 1 year of age.[4] These empirical data were then used to determine whether there was any change in the Hirschberg ratio and angle λ during the 1st year of life.

METHODS

The study included 280 normal infants from 60 days to 1 year of age (range 60 to 365 days, mean ± standard error of the mean [SEM] 128 ± 4 days) and 43 normal infants younger than 60 days (range 27 to 59 days, mean ± SEM 46 ± 1 days). Informed consent was obtained from the parents of all infant subjects after the technique had been explained to them in full. Approval was received from Brooklyn College, City University of New York committee on the rights and welfare of human subjects, and the research followed the tenets of the World Medical Association Declaration of Helsinki. Infants younger than 2 months were treated separately because they may have a different Hirschberg ratio because of their steeper corneas.[11] Infants of this age also show different behavior than older infants on some tests of accommodation and refractive error.[4,16-19] The younger infants are less likely to relax their accommodation fully for more distant targets; as a result, it is difficult to estimate refractive error using a photorefractive technique without cycloplegia at these ages. A group of ten uninstructed adult subjects were also tested for comparison. Because we were unable to instruct our infant subjects, we compared them with adults who have also received no information concerning the nature of the test or what was required of them.

Paraxial photorefraction was performed in a dimly lit room to ensure that the pupils were large and that the only target that could be seen by the infant was the one to which they were required to attend. Infant and adult subjects were introduced to the lower lighting conditions at least 3 minutes before the test was performed. The test involved looking at targets placed at five distances (25, 33, 50, 100, and 200 cm), presented in an order that alternated near and far targets, beginning with an intermediate distance. The targets were small, plastic dolls that could play music and that were internally lit with small flashing lights; the farthest targets were bigger to give a rough size scaling. The targets were placed in the midline just below the infant's line of sight. Testing was binocular in all instances. A flash photograph was taken, using a camera placed 4.5m from the subject, during illumination of each target when the subject was seen to be attending. Because the flash was centered on the head, it was slightly off-axis for each eye; this caused a decentering of the first Purkinje image of less than 0.5° toward the nasal side in adult subjects. The effect of the decentering was even less in infants. A fast film was used in conjunction with a filtered flash to limit the amount of light reaching the infant's eye.[20-22]

In order to score the data, each photograph was displayed on a TV monitor using an apparatus that produced a constant and highly magnified image of one or both eyes. Measurements of interpupillary distance, horizontal pupil diameter, and the distance from the center of the first Purkinje image of the flash to the center of the pupil (calculated as half the horizontal pupil diameter) were made.

Two measures of eye position across a series of target distances were required in order to calculate the Hirschberg ratio. The numerator was determined on the basis of the infant's interpupillary distance and the distance to the target (Fig. 2). The denominator was determined by the change in position of the first Purkinje image relative to the center of the pupil.

Each of these measures depends on the assumption that the infant is visually attentive to each target and is converged at the plane of the target. To eliminate infants who might not have been attending at each target distance, we adopted a conservative criterion for including subjects; the data for each infant was plotted and only infants who changed accommodation and convergence in the appropriate direction for each change in target distance were included in this analysis. Although little is known about the interactions between accommodation and vergence in in-

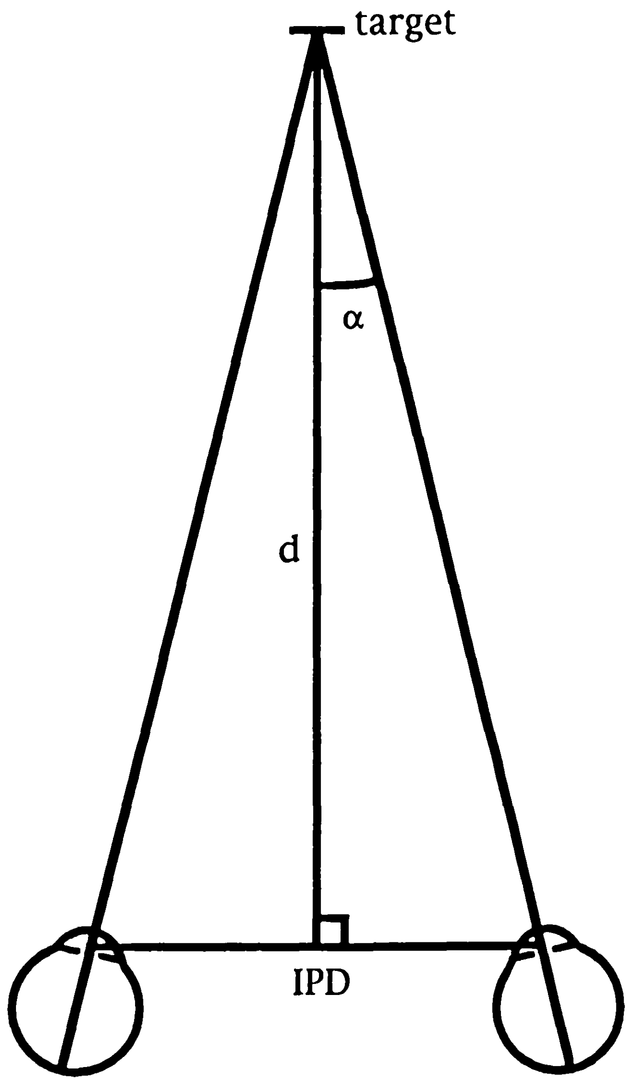

FIGURE 2. The calculation of the vergence position of the eyes. α, half the angle of convergence (degrees); IPD, interpupillary distance (meters); d, distance from subject to target (meters). The vergence position was calculated for a series of five target distances for each individual.

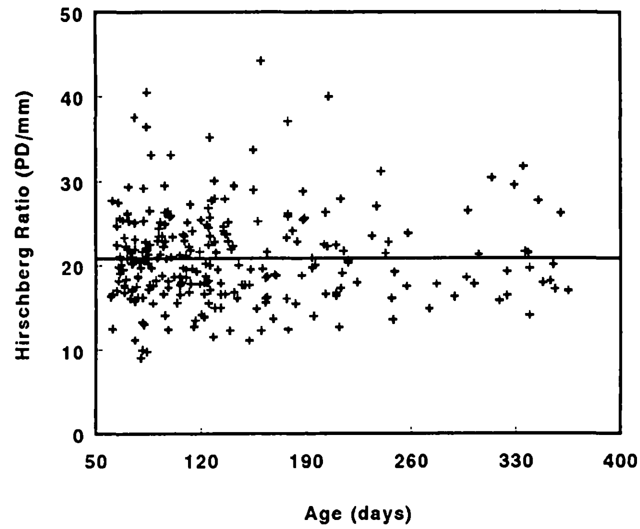

FIGURE 3. Plot of the individual Hirschberg ratios of 280 infants older than 60 days, by age. The line through the points is the linear regression. This line has a slope that is not different from zero (slope = 0.0001, R = 0.015), demonstrating the constancy of the Hirschberg ratio with age.

fancy, our previous analyses have shown that some infants who fail consistently to increase their accommodation with decreasing target distance will often still converge appropriately, so our data selection was perhaps stricter than needed.[4] The infants we evaluated were deliberately selected to be converging and accommodating to the targets placed at different distances. At the same time, inspection of results from a larger sample of data on infants who did not accommodate well suggested that refractive status did not influence the observed Hirschberg ratio.

Although the relationship between the first Purkinje image displacement and the center of the pupil is described by a sine function, theoretical and empirical measures on adults have shown that this measure is linear over a wide range of visual angles (approximately 25° to 30°).[2,3,5] Beyond this range, there is no longer a linear relationship between the position of the first Purkinje image and the angular position of the eye, because the cornea is not spherical but flattens toward its edge.[3] The convergence angle was, therefore, plotted against the displacement of the first Purkinje image within this range, and a bivariate linear regression was used to determine the slope of this response (the Hirschberg ratio). The results for each individual were plotted against age to give an indication of the systematic changes in the Hirschberg ratio that could be attributed to age effects.

This study also allowed estimation of angle λ from the position of the eyes when focussed at optical infinity. When the eye is fixating a distant target, the first Purkinje image is displaced an average of 5° temporally from the center of the pupil, giving a positive value for angle λ and the appearance of a slight divergence of the eyes.[23,24] The distance between the center of the pupil and the first Purkinje image of a distant light source was used to give a value for angle λ. The measurement was made by extrapolating the slope of the function describing changes in convergence angle with target demand back to 0 D demand. The vergence angle at optical infinity is twice angle λ (the sum of angle λ in each eye) for a target on the midline.

RESULTS

Figure 3 shows a scatter plot for the Hirschberg ratio of the 280 older infants by age. The solid line through the points is the linear regression of Hirschberg ratio against age in days. This line was found to have a slope not significantly different from 0 $PD \cdot mm^{-1} \cdot day^{-1}$; that is, there was no change in Hirschberg ratio with age. The average Hirschberg ratio for infants was found to be 20.92 PD/mm (12.25°/mm), with an SEM of 0.32 PD/mm (0.19°/mm).

Figure 4 shows a scatter plot for the Hirschberg ratio against age for the 43 younger infants. The solid line is the linear regression of Hirschberg ratio against age. The slope of this line also did not differ significantly from 0 $PD \cdot mm^{-1} \cdot day^{-1}$, showing no change in Hirschberg ratio and age. The mean Hirschberg ratio in this group was 20.49 PD/mm (12.0°/mm; SEM = 0.81 PD/mm or 0.47°/mm). This value is close to that found for older infants in this study. A Student's t test comparing the two age groups showed no significant difference in the value of the Hirschberg ratio (t = 1.34, df = 58.16, P = 0.18).

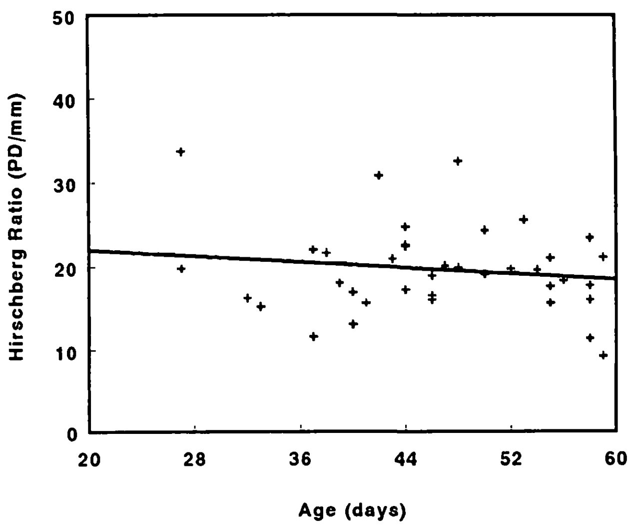

FIGURE 4. Plot of the individual Hirschberg ratios of 43 infants younger than 60 days, by age. The line through the points is the linear regression. This line has a slope not different from zero (slope = −0.089, R = 0.16), demonstrating the constancy of the Hirschberg ratio with age.

TABLE 1. Variance Across Age for the Hirschberg Ratio (PD/mm)

Age (days)	36	45	67	80	95	111	136	165	210	300
Mean	20.3	19.3	21.5	20.1	22.2	19.4	21.4	21.5	21.1	20.8
SD	5.4	4.7	4.1	6.4	4.7	5.3	5.2	7.3	5.6	4.9
SEM	1.2	1.0	0.8	0.9	0.9	0.6	0.8	1.3	1.1	1.0
N	20	23	32	53	30	36	41	33	29	27

The mean Hirschberg ratio for a group of ten uninstructed adults tested in the same manner as the infants was found to be 20.22 ± 1.24 PD/mm (11.8 ± 0.73°/mm). There were no significant differences between the groups (adults versus younger infants: $t = 0.02$, $df = 21.63$, $P = 0.98$; adults versus older infants: $t = 1.11$, $df = 11.08$, $P = 0.29$). The values for all age groups are similar to previously reported values. The similarity of the infant and adult values also provides some internal consistency in support of our criteria for including infants who we believed to be appropriately converging on the targets.

Although this data demonstrates that the average Hirschberg ratio is constant across infancy, it should be noted that individual infants do not have identical values. Table 1 shows the mean, standard deviation and standard error of the mean for infants grouped by age. The data suggest that at each age range there is the possibility of some measurement error involved in using an average Hirschberg ratio. However, this error is the same for all ages of infants tested and is probably less than error found in clinical measures of the Hirschberg test. The average standard error for the groups in this study is ±5.37 PD/mm.

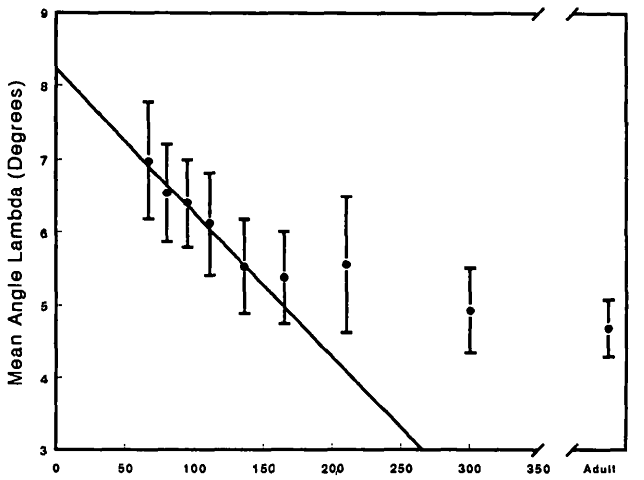

FIGURE 5. Plot of average angle λ for eight age groups of infants and the adults. A linear regression calculated over the first six age groups extrapolates back to an angle λ of 8.24° for newborns, a value that compares favorably with previous estimates.[15]

Figure 5 plots the mean angle λ against age group, for all the infants and the ten adults. It can be seen that, unlike the Hirschberg ratio results, the adult values are significantly smaller than those of the infants. This graph shows that angle λ changes rapidly and linearly over the first 150 days and then begins to level off. A linear regression on the early part of the curve (150 days or less) gave an intercept value for the newborn angle λ of 8.24°.

DISCUSSION

Previous studies of the Hirschberg ratio have produced conflicting information on whether the ratio changes with age during early childhood. In this study, 323 infants from 27 to 365 days old were studied to determine whether there was a developmental trend in this ratio. The results showed that the Hirschberg ratio did not alter with age, staying constant at an average value of 20.8 ± 0.30 PD/mm (12.2 ± 1.8°/mm), which is similar to both the adult values found in this study (20.22 ± 1.24 PD/mm or 11.8 ± 0.73°/mm) and previously reported adult values (21 to 22 PD/mm or 12.3°/mm to 13.0°/mm).[2,8] Theoretically, the value of the Hirschberg ratio changes as a result of growth of anterior chamber depth and corneal curvature of the eye.[5] Because the infant eye is still growing during the 1st year of life, our finding of a constant Hirschberg ratio from infancy to adulthood confirms that the developmental changes in the optics of the infant eye must work in a compensatory fashion.[12]

A clear developmental trend was found for changes in angle λ; this was found to decrease from 6.98° in infants younger than 2 months to 4.69° in the uninstructed adult sample. The extrapolated value of 8.4° in newborns agrees well with the value of 8.2° measured by Slater and Findlay[15] for newborns. The adult values also compare favorably with previously reported values for angle λ.[23,24] The changes in angle λ with age are not a result of a migration of the fovea toward the pupillary axis; in fact, the linear distance between the fovea and the retinal intersection of the pupillary axis remains constant at all ages. Rather, angle λ decreases because an increase in the axial length of the eye results in a reduction of the angular separation between the fovea and the retinal intersection of the pupillary axis.[25]

The results of this study are of direct relevance to clinicians and scientists wishing to measure visual angle in infants. The empirical results reported here suggest that a Hirschberg ratio of about 21 PD/mm (12.3°/mm) should be used to convert from first Purkinje image displacement to visual angle for all infants regardless of age or refractive error.

Because angle λ is found to decrease with each, this suggests that care should be taken to estimate correctly the difference between the visual and the pupillary axes when estimating where an infant is looking. The change in angle λ with age reported here demonstrates that it is necessary to take into account the age of the infant when evaluating whether an infant is orthotropic or not; younger infants will appear considerably more exotropic than older ones when the infant is aligned properly, gauging alignment by the position of the first Purkinje images in the pupil.

These results provide the first empirical data on measurement of the Hirschberg ratio and angle λ in a large sample of infants of different ages. This provides useful calibration data for estimating visual angle in infants, a notoriously difficult population in which to measure strabismus.

Key Words

Hirschberg test; infant; angle lambda; convergence angle; strabismus

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