REFRACTIVE PROFILE OF NAVAJO CHILDREN

W.C. MAPLES, O.D.
J.W. ATCHLEY, O.D.
JAMES HUGHES, O.D.

Abstract

The Navajo Indians of the southwestern United States have recently been reported to have shown a dramatic increase in with-the-rule astigmatic refractive error. In an attempt to better understand the progress of this condition, a retrospective cross-sectional study of visual examinations performed on young Navajos at the Shiprock, New Mexico, IHS Optometry Clinic was conducted. A total of 1,106 patients of both sexes from the age of 6 to 20 years were included. The study shows that among the youngest patients, large amounts of corneal and refractive with-the-rule astigmatism are present. Both refractive and corneal astigmatism decrease with age. A decrease in refractive astigmatism was noted before 10 years of age. Corneal toricity also shows a decrease in the steepness of the vertical meridian with age. A hyperopic mean spherical refraction was found in younger Navajos which changed to myopia at 9 years of age for girls and 10 years for boys. There also was a corresponding increase in the prevalence of myopia at these ages. Possible etiologies of these refractive conditions are discussed in relationship to the data presented in this paper.

Key Words

Native Americans, Navajos, Indians, refractive error, myopia, corneal astigmatism, refractive astigmatism, with-the-rule astigmatism, epidemiology

A major mission of the profession of optometry is to assess and treat refractive errors. Refractive errors fall into three broad groups—hyperopia, myopia and astigmatism. Myopia is generally considered to be the most prevalent refractive error among children, but hyperopia and astigmatism are also significant conditions in all age groups.

Optometrists report that many Native Americans exhibit unique refractive error profiles. Myopia has been noted in some populations,[1-6] but a high prevalence and amount of with-the-rule astigmatism is the most commonly reported feature of Native American populations.[1-11] The high prevalence of myopia may have an artifactual component when spherical equivalents are used in populations where simple myopic astigmatism or mixed astigmatism are common.

Although with-the-rule astigmatism is the most prevalent refractive characteristic of American Indians, it does not appear to be uniformly exhibited among the different American Indian tribes. Genetic and biological, as well as geographic and cultural, factors appear to impact upon the eventual refractive status of Native Americans.[1-21]

The mean amount and high prevalence of with-the-rule astigmatism in Navajo populations is puzzling since early studies of American Indians show neither a high mean amount or a high prevalence of astigmatism.[10,22] A 1906 study of the cycloplegic refraction of Indians did not show large mean amounts of astigmatism.[22] Navajos born after 1935 had a rate of high astigmatism almost 10 times greater than those born before this date.[10]

Astigmatism is certainly a common refractive condition in a general non-Indian clinical population, but not at the high mean amount and prevalance as the Navajo nor with the overwhelmingly with-the-rule axis bias as is found in the Navajo tribe.[23] Clinically significant astigmatism is not very common in the general population. A random sample of non-Indian school-aged children revealed clinically significant astigmatism only about 6% of the time.[19]

The question then arises as to what might be causing this recent increase in with-the-rule astigmatism. A number of etiologies have been put forward. Genetics,[14] lid tension,[21] and eye scan patterns[24-26] have been suggested as possible causes. Recent longitudinal studies of infants and the course of development of the refractive state of the eye have described early developmental changes in refraction.[27-29]

The Caucasian infant begins life with against-the-rule astigmatism,[27,28] while orientals exhibit with-the-rule astigmatism.[29] In the course of emmetropization this astigmatic component is largely lost by school age. Very little, however, is known about the course of astigmatism in the Navajo.

Many Native Americans have their eye and vision care provided by the Indian Health Service (IHS), a division of the United States Public Health Service. The high prevalence of refractive errors in Native Americans places an unusual demand

upon the manpower and financial resources of this federal agency. If causes of these conditions could be discovered, then strategies might be designed to decrease their incidence and severity. This, in turn, would reduce the need for visual care in this group.

Our study of the clinical records of the Navajo population at Shiprock, New Mexico, was undertaken to analyze variables which may be contributing to this high prevalence of refractive errors and to describe clinical characteristics of this condition. The Shiprock Clinic was chosen because of its availability, its high percentage of pure-blood Navajos and the fact that this clinic had been included in a previously reported epidemiological study.[11]

Methods

A retrospective study was undertaken at the Shiprock, New Mexico, IHS clinical facility, which serves primarily members of the Navajo tribe. A total of 2,000 examination records of younger patients were evaluated. The records often included data from multiple examinations of the same individual; therefore, we chose to take a random sample of only one refraction per patient. This reduced the total examinations reported in this paper to 1,106.

Data gathered on each individual included demographic information of birth date, sex, date of examination and symptoms. The optometric data included visual acuities with and without habitual correction (both at far and near distances), results of keratometry, distance retinoscopy, far and near cover tests, observed ocular pathology and the final prescription.

For the purposes of this paper, hyperopia is defined as a spherical measurement of >+0.75 and myopia as > -0.25 D regardless of the cylindrical component. It was felt that if the spherical equivalent was considered, high cylindrical findings could distort the spherical component changes by increasing the average minus spherical equivalent power. Emmetropia was defined as a spherical measurement of less than +1.00 D or less than -0.50 D. Astigmatism was defined as cylindrical measurement (both for corneal and refractive) of >0.25 D. We did not consider examinations where the majority of the information was not available, as in the case for patients presenting for acute care.

Results

A total of 1,106 examination records were evaluated. Females exceeded males 55.7% (616) to 44.3% (490) in this sample. Latest census data from the Shiprock Service Unit shows that females exceed males in the total clinical population 52.1% to 47.9%. The mean age of this sample was 10.7 years (males 10.7, females, 10.7) with a range of from 6 to 20 years. Table 1 depicts the demographic distribution of this sample by sex and age. We do not report statistics on subjects aged 18-20 due to lack of adequate number of subjects in each age level.

A total of 956 Navajos revealed some type of refractive error. The spherical component of the two eyes were not statistically different (right eye -0.62 D, left eye -0.54 D, $t = -1.042$, $p > 0.05$). Only right eye data will be presented in table form to collapse the data and make it more readable. Where significant differences between the two eyes were found, both eyes will be reported in the text.

The mean spherical and astigmatic refractive errors of the right eye of male and female Navajos is shown in Table 2. Total mean spherical refractive error was significantly different between sexes. Female right eye mean myopia (-0.71 D) was more than males (-0.51 D) ($t = 1.99$, $p < 0.05$). Left eye means, although following the same trend (females -0.59 D, males -0.48 D), did not show significantly different gender differences ($t = 0.94$, $p > 0.05$).

Table 2 also shows the mean corneal toricity by sex. Females manifested significantly more corneal toricity than did the males ($t = -2.10$, $p < 0.05$). The mean corneal toricity of the right eye of females was -1.62 D, compared to -1.46 D for males. The left eye showed a similar significant difference (female 1.82 D, male 1.58 D; $t = -3.15$, $p < 0.01$). By calculating the difference in pooled means of corneal toricity of both sexes, comparing the two eyes to one another, the mean of the right eye (1.55 D) was found to be significantly less than the mean of the left eye (1.72; $t = -6.71$, $p < 0.01$).

Table 3 contains the overall prevalence of refractive errors in this total sample. Myopia (> -0.25 D) was found in 47.5% of males and 54.8% of females. In these myopes, with-the-rule astigmatism (> 0.25 D) was found at a rate of 56.2% in males and 65.7% in females. Hyperopia (>+0.75 D) was not as prevalent, being found in only 13.7% of the boys and 9.9% of girls. Astigmatism was very prevalent in conjunction with hyperopia. Males with hyperopia exhibited astigmatism at a rate of 95.6% with hyperopia while the females' rate was 91.9%. The prevalence of astigmatism as the only refractive component (sphere reading <+1.00 D or <-.25 D) was found in 23.9% of boys and 22.7% in girls. There were 150 (13.6%) individuals who were emmetropic.

Table 1
Navajo Sample by Age and Sex (N = 1,106)

AGE	SEX MALE	SEX FEMALE
6	38	46
7	69	56
8	45	56
9	53	65
10	80	66
11	55	83
12	50	77
13	46	60
14	40	42
15	19	29
16	18	11
17	18	15
18	5	7
19	2	3
20	3	0
TOTAL	490	616

Table 2
Mean Spherical and Astigmatic Refractive Components of a Clinical Sample Of Navajos (N = 1,106) (Right Eye)

Refractive Component	Male	Female
Mean Spherical	-0.51 (1.72)	-0.71 (1.58)
Mean Refractive Cylinder	1.10 (1.30)	1.13 (1.37)
Mean Corneal Cylinder	1.46 (1.16)	1.62 (1.17)

( ) Indicates Standard Deviation

Table 3
Prevalence in Percentages of the Refractive Components of a Clinical Sample of Navajos (Right Eye)

Total Percentage	Male	Female
Myopia	47.5	54.8
	(65.2)	(65.7)
Hyperopia	13.7	9.9
	(95.6)	(91.9)
Astigmatism	23.9	22.7

() Percentage of Indicated Refractive Condition with Astigmatic Component

Table 4 presents the total sample mean spherical and astigmatic components for the right eye by age and sex. An analysis of variance revealed that with age the mean refractive error becomes more myopic ($F = 5.739$, $p < 0.01$). Nine years of age marks the first time a myopic mean refractive error is recorded in girls. Boys lag by one year in first showing a myopic mean in this clinical sample. This trend tends to increase rapidly in both sexes until about age 12 years. After 12 years of age, the increase continues but is not as linear. The right eye spherical mean by age is plotted for boys and girls in Figure 1.

Table 5 shows the prevalence of refractive error by age and gender. Emmetropia and hyperopia percentages decrease as myopia increases with age. This trend begins with both sexes between 7 and 8 years. The trend shows another large increase in myopia for girls between age 8 and 9 years from 32.1% to 49.2%. There is a large increase in the myopia in boys between the ages of 9 and 10 years. The prevalence of myopia in boys jumps dramatically from 28.2% at age 9 years to 60.0% at age 10 years. Boys begin to show myopia at the same age as girls but the large increase in prevalance appears to lag behind girls by approximately one year. The prevalence of myopia with or without a cylindrical component (males and females combined) was found to be 14.3% in 6-year-old children ($N = 84$), 70.9% at age 12 years ($N = 127$) and 82.6% at age 17 years ($N = 23$). Figure 2 shows this increase in prevalence of myopia between the sexes in this clinical sample at the different ages.

Refractive astigmatism of any amount (0.25 D or more) was found in 82.5% of the total sample and ignores the spherical component. The axis of the astigmatism was found to be overwhelmingly with-the-rule (30 from 180). Against-the-rule astigmatism (30 from 90) represented about 4% of all the astigmatism found, while oblique astigmatism (neither with-the-rule nor against-the-rule) represented only about 1% of the group, leaving 95% of those showing refractive astigmatism having with-the-rule type.

Pooled mean refractive astigmatism was not found to be significantly different between the two eyes or sexes. Refractive astigmatism decreases significantly ($F = 4.377$, $p < 0.01$) through age 10, at which time there is no significant change in the refractive astigmatic component (Table 4 and Figure 1). The variations seen in the mean spherical component among the older subjects is not significant since the sample size decreased in the older age groups. Unilateral refractive astigmatism was present in 15.7% of those with refractive astigmatism. No differences in the occurrence of unilateral astigmatism between the right and left eyes was found.

Corneal astigmatism was present in 99.5% of the patients for whom keratometry data were available (1,068). This represented 95% of the total sample. Of those not having keratometer readings (58), there was a balance between girls and boys (33 and 25, respectively).

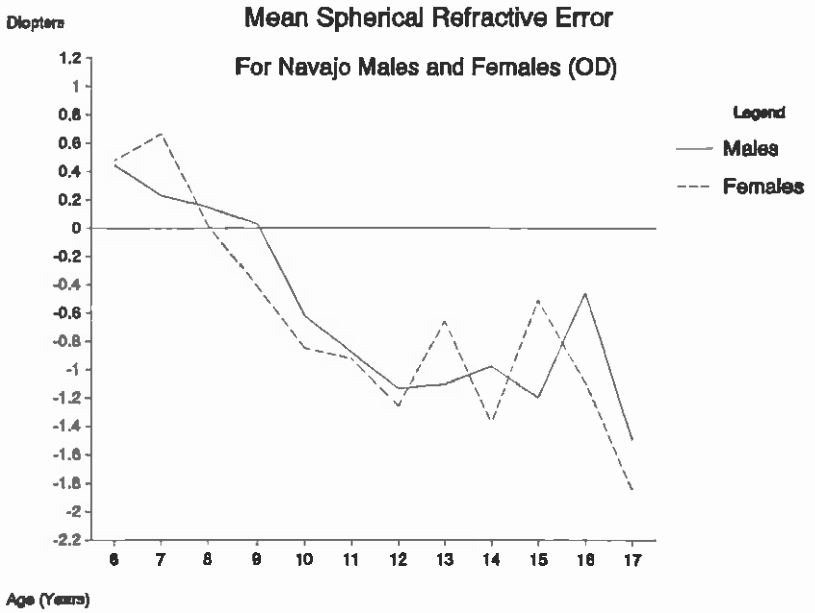

Figure 1.

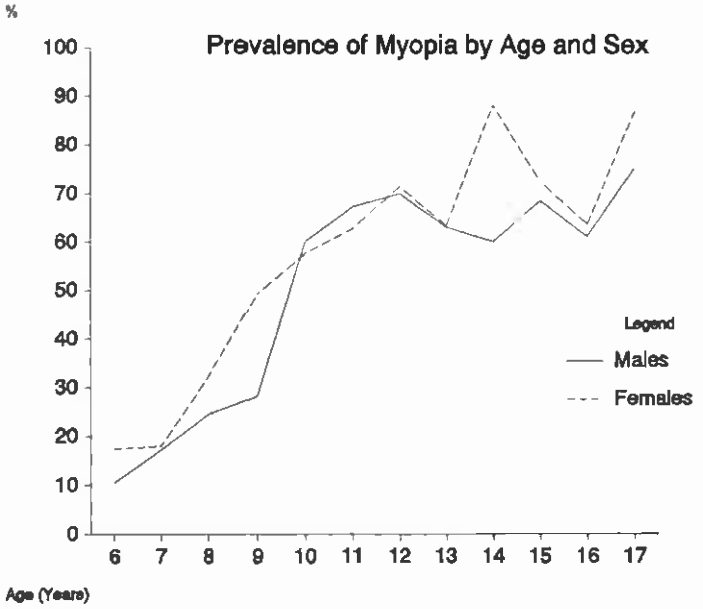

Figure 2.

Table 4
Right Eye Mean Refractive Values by Age and Sex

Age	Male Sphere	Female Sphere	Male Cylinder	Female Sphere
6	+0.45	+0.48	1.51	1.76
7	+0.23	+0.67	1.28	1.78
8	+0.15	+0.02	1.45	1.32
9	+0.03	-0.41	1.42	1.29
10	-0.62	-0.85	0.71	0.85
11	-0.88	-0.93	0.91	0.76
12	-1.14	-1.26	0.67	0.98
13	-1.11	-0.66	1.20	1.20
14	-0.98	-1.38	0.98	0.73
15	-1.20	-0.51	0.96	0.90
16	-0.46	-1.09	0.53	1.11
17	-1.50	-1.85	1.44	1.05

Table 5
Right Eye Prevalence of Spherical Refractive Error Percentage by Age and Sex

Age	Male (Emmetropia)	Female (Emmetropia)	Male (Hyperopia)	Female (Hyperopia)	Male (Myopia)	Female (Myopia)
6	57.9	58.7	31.6	23.9	10.5	17.4
7	63.8	55.4	19.0	26.8	17.2	17.9
8	46.7	51.8	28.9	16.1	24.4	32.1
9	50.9	38.5	20.8	12.3	28.2	49.2
10	24.0	39.4	16.0	3.0	60.0	57.6
11	29.1	31.3	3.6	6.0	67.3	62.7
12	22.0	22.1	8.0	6.5	70.0	71.4
13	30.4	28.3	6.5	8.3	63.0	63.3
14	37.5	11.9	2.5	0.0	60.0	88.1
15	31.6	24.1	0.0	3.4	68.4	72.4
16	27.8	36.4	11.1	0.0	61.1	63.6
17	25.0	13.3	0.0	0.0	75.0	86.7

Table 6
Right Eye Mean Keratometric Findings by Age

Age	Vertical Power	Horizontal Power
6	43.43	41.43
7	43.79	41.76
8	43.60	41.94
9	43.62	41.93
10	43.17	41.80
11	43.26	41.97
12	43.04	41.85
13	43.32	41.89
14	43.05	41.88
15	43.29	42.04
16	43.28	41.77
17	43.94	42.12

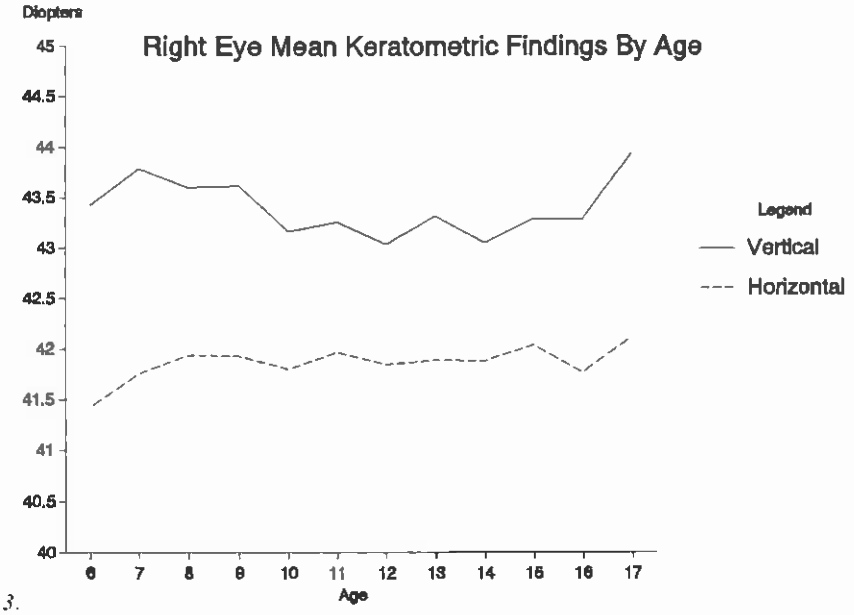

Figure 3.

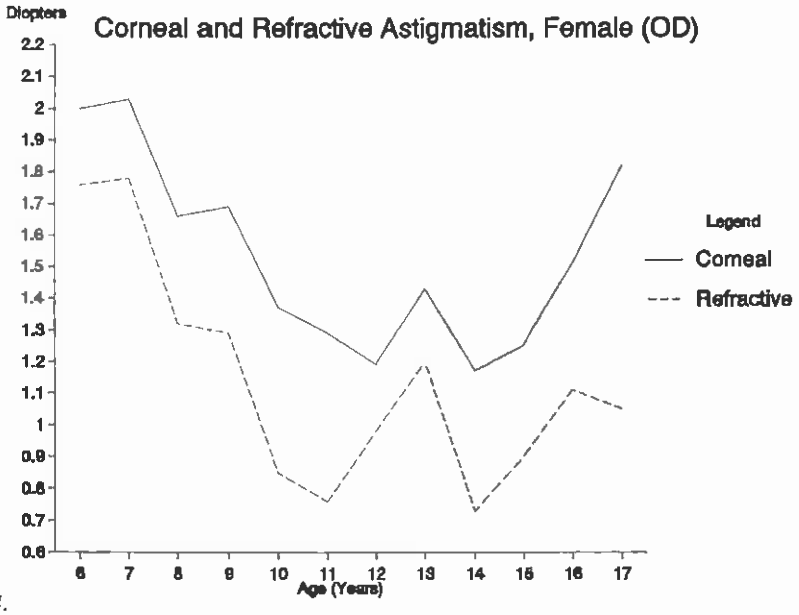

Figure 4.

An analysis of variance by age was performed on both the horizontal and vertical keratometric readings. A statistically significant difference with age was noted for the mean measurement of the vertical meridian but not for the horizontal meridian mean (OD Horizontal: $F = 0.886$, $p > 0.05$; OD Vertical: $F = 2.997$, $p < 0.01$) (see Table 6). Even though analysis of vertical corneal measurements by age show that substantial changes take place, this variation was of a more random fashion. An age where this change decreased could not be statistically determined. Figure 3 depicts this trend visually and one can see the flattening trend levels in the vertical meridian around age 10.

Figure 4 graphically depicts the mean corneal and refractive astigmatism present in both eyes and sexes as a function of age. There is a statistically significant relationship between refractive and corneal astigmatism. The Pearson r correlation coefficients for corneal and refractive astigmatism in the right and left eye are 0.78 D and 0.84 D respectively. These values are statistically significant at the p 0.01 level, meaning that as corneal astigmatism decreases with age, so does refractive astigmatism.

High amounts of corneal and refractive astigmatism (>1.75 D) were found in 27.4% of the subjects. Three diopters or more of corneal or refractive astigmatism was present in 16.9% of the sample.

Discussion

Myopia (spherical component) and with-the-rule astigmatism (cylindrical component) are the primary refractive conditions exhibited by this clinical study of young Navajos. This agrees with most reports on refractive errors of American Indians. The notable exception is screening data by Wick and Crane;[7] they found a more hyperopic mean among Sioux children in grades one through five than in a group of Caucasians.

Up to about 12 years of age, myopia in our and other studies increases with age.[3,5,6] The prevalence of myopia in our sample was undoubtedly inflated because we studied a clinical sample. We found that when the two eyes were compared to one another, there was not a statistically

significant spherical difference. The notable difference was in the corneal astigmatism between eyes, the left eye being more cylindrical. When the data was separated by sex, differences in spherical refractive error were found. Adler-Grinberg[3] did not find a difference between either eye or sex; however, we found there to be significantly more mean myopia in girls than in boys (right eye female = -0.71 D, male -0.51 D). Girls show the myopia approximately one year earlier than boys. Boys tend to catch up by age 12 years. After this age the trend toward myopia becomes less linear. It has been noted that the prevalence of myopia occurs earlier in girls than in boys.[22]

Refractive astigmatism is certainly high in Navajo youth. This agrees with the great majorities of studies.[1-21] The axis of astigmatism was overwhelmingly with-the-rule. This also agrees with other studies. Wick and Crane[7] found that 2% of their sample of Sioux had against-the-rule, while our study found 4% of this type. Other investigators[10] have not documented any against-the-rule. Garber and Hughes[11] reported that older Navajos (born earlier than 1935) had less with-the-rule astigmatism than younger members of the tribe.

Refractive astigmatism varied substantially with age, with a trend towards less astigmatism with increased age. This trend was also noted by Hamilton.[2] There was high correlation between refractive astigmatism and corneal astigmatism. In our Navajo children, the vertical meridian mean is much steeper than the horizontal and becomes flatter with age, while the horizontal meridian does not change with age. This also is in agreement with others.[5] Lyle et al.,[8] however, reported a small increase in corneal astigmatism with age among unselected Saskatchewan Indians. Hamilton[2] previously suggested that only the vertical meridian was flattening as the individual became more myopic and older. Our data substantiates this finding.

Keratometric readings were reported on screenings conducted on Native Americans. The mean corneal toricity for all ages was reported by Heard[5] to be 2.21 D, while Lyle[8] found an overall average of 1.39 D, and Wick and Crane's[7] mean corneal astigmatic value was 1.51 D. The mean corneal toricity in our study (right eye) was 1.55 D.

Refractive astigmatism has been reported as 1.07 D.[7] Refractive astigmatism is reported to be from 0.25 to 0.75 D less than corneal astigmatism.[5] Our study found a mean refractive astigmatism in the same eye of 1.11 D, 0.44 less than the measured corneal toricity. Therefore, both the corneal and refractive astigmatism found in this study compare closely to these other studies.

Sexual differences in astigmatism have been reported. Wick and Crane[7] found statistically significant differences in astigmatism between boys and girls, with girls being more astigmatic (1.63 D girls vs. 1.39 D boys). They also found a similar difference in the retinoscopic astigmatism measurement (1.20 D girls, 0.90 D boys). Lyle et al.[8] also reported that girls had more corneal astigmatism than boys. We found that both mean corneal and mean refractive astigmatism were greater in females than in males (see Table 2), but only the difference in corneal astigmatism was statistically significant ($p < 0.05$).

The prevalence of high refractive astigmatism (> 1.75 D) has been reported variously as 26.1%[10] of Navajo children and 12.8%[9] for three diopters or more. Our findings are similar to those of these earlier studies. We discovered 27.4% of our sample had 2.00 D or more of refractive astigmatism and 16.9% had 3.00 D or more.

The prevalence of unilateral refractive astigmatism has been reported to be as high as 17.5%.[10] We found a similar percentage (15.7%). Garber[10] further reported that in 70% of those exhibiting unilateral astigmatism, the condition was found in the left eye. Our study does not confirm this finding. We found that unilateral astigmatism was equally distributed between the two eyes.

Conclusions

Our results support the conclusion that myopia in Navajo children between the ages of 6 and 18 years increases in both amount and prevalence. This trend is present in both sexes, but begins somewhat earlier in girls than boys. Girls also exhibit more mean myopia than boys.

Research reported here also supports the conclusion that Navajo children have significantly greater amounts of corneal and refractive astigmatism than is expected in a non-Indian population.[5,7,8,17,19,22-24] The great preponderance of this astigmatism is with-the-rule and it decreases significantly with age. Refractive astigmatism appears to level off after the age of 10. Corneal toricity shows this same trend but is distributed more evenly throughout the ages represented here. Decreases in astigmatism appear to be related to the flattening of the vertical corneal meridian with age. Unilateral astigmatism is equally distributed between the two eyes.

Girls exhibit more corneal toricity than do boys. Refractive astigmatism does not vary between eyes but corneal toricity does, with the left eye having the larger toroidal component. The same sample is now being investigated to evaluate if these refractive and physical changes take place longitudinally within the same patient and within identified family groups.

Although causative relations cannot be drawn from this study, it does indicate that the Navajo child presents at first grade with a high prevalence and mean amount of with-the-rule astigmatism. It is unlikely that this is caused by genetics since the older Navajos do not appear to show this condition in nearly the same prevalence or mean amount.[10] It is also unlikely that this condition is caused by lid tension since lid tension and "squinting" of the eyes have been taking place for hundreds of years with this population. Further, it has been shown that the Native Americans with the least lid spring constant measures (indirect measure of lid tension) measured more, not less, corneal astigmatism.[21] Equally unlikely is the scan path model. These children show high amounts of with-the-rule astigmatism before being introduced to sustained nearpoint or eye scanning situations.[24-26]

The more likely scenario is that the Navajo, being of oriental descent, are born with the with-the-rule astigmatism,[29] but that something, possibly the nutrition of the mother or child, interferes with the normal emmetropization process.

Our next planned research is to keratometrically screen a large number of Navajo preschool children. Since refractive astigmatism correlates closely with corneal astigmatism in this population, this will be an objective method of documenting the changes in astigmatism in the preschool Navajo. We will compare keratometric findings by age and by sex to ascertain if there are corneal developmental changes taking place. We will compare these changes to those which have been

reported by others, both in caucasian and oriental populations.[27-29]

Acknowledgments

Support for this project was received from the Faculty Research Committee, Northeastern State University, Tahlequah, OK 74464.

The opinions expressed in this paper are those of the authors and do not necessarily reflect the views of the IHS.

References

1. Hamilton JE. Vision anomalies of school children. Am J Optom Physiol Opt, 1974; 51: 482-86.
2. Hamilton JE. Vision anomalies of Indian school children: the Lame Deer Study. J Am Optom Assoc, 1976; 47: 479-87.
3. Adler-Grinberg D. Need for eye and vision care in an under-served population: refractive errors and other ocular anomalies in the Sioux. Am J Optom Physiol Opt, 1986; 63: 553-58.
4. Maples WC, Atchley J, Ashby W, Ficklin T. An epidemiological study of the ocular and visual profiles of Oklahoma Cherokees and Minnesota Chippewas. J Am Optom Assoc, 1990; 61: 784-88.
5. Heard T, Reber N, Levi D, Allen D. The refractive status of Zuni Indian children. Am J Optom Physiol Opt, 1976; 53: 120-23.
6. Abraham JE, Volovick JB. Preliminary Navajo optometric study. J Am Optom Assoc, 1972; 43: 1257-60.
7. Wick B, Crane S. A vision profile of American Indian children. Am J Optom Physiol Opt, 1976; 53: 34-40.
8. Lyle WM, Grosvenor T, Dean KC. Corneal astigmatism in American children. Am J Optom Physiol Opt, 1972; 49: 517-24.
9. Mohindra I, Nagaraj S. Astigmatism in Zuni and Navajo Indians. Am J Optom Physiol Opt, 1977; 54: 121-24.
10. Garber JM. High corneal astigmatism in Navajo school children and its effect on classroom performance. J Am Optom Assoc, 1981; 52: 583-86.
11. Garber JM, Hughes J. High corneal astigmatism in the adult Navajo population. J Am Optom Assoc, 1983; 54: 815-18.
12. Bezan DJ. The prevalence of anisometropia in a Native American population. In: Goss DA, Edmondson LL, eds. Eye and vision conditions in the American Indian. Yukon, OK: Pueblo Publishing, 1990: 117-31.
13. Cook DT. Results from vision screenings of Northeastern Oklahoma school children: refractive errors. In Goss DA, Edmondson LL, eds. Eye and vision conditions in the American Indian. Yukon, OK: Pueblo Publishing, 1990: 101-16.
14. Wixson RJ. The relative effect of hereditary and environment upon the refractive errors of identical twins, fraternal twins and like sex siblings. Am J Optom Arch Am Acad Optom, 1958; 35: 346-51.
15. Hofstetter HW, Rife DC. Miscellaneous optometric data on twins. Am J Optom Arch Am Acad Optom, 91953; 30: 139.
16. Luneburg RJ. Practice among American Indians, study of clinical findings, Part 1. Opt J Rev Optom, 1975; 112(8): 40-46.
17. Anderson MR, Burt RR. Refractive errors in a Native American clinical population. Student Research Thesis: Northeastern State University College of Optometry, 1983.
18. Maples WC, Ficklin T. Visual profile of preschool Native Americans. In Goss DA, Edmondson LL, eds. Eye and vision conditions in the American Indian. Yukon, OK: Pueblo Publishing, 1990.
19. Goss DA. Astigmatism in American Indians: prevalence, descriptive analysis, and management issues. In: Goss DA, Edmondson LL, eds. Eye and vision conditions in the American Indian. Yukon, OK: Pueblo Publishing, 1990: 61-76.
20. Goss DA. Meridional analysis of with-the-rule astigmatism in Oklahoma Indians. Am J Optom and PHysiol Opt, 1989; 66: 281-87.
21. Wilson G, Goss DA, Vaughan WA, Roddy KC. Corneal toricity, lid tension, intraocular pressure, and ocular rigidity in North American Indians. In: Goss DA, Edmondson LL, eds. Eye and vision conditions in the American Indian. Yukon, OK: Pueblo Publishing, 1990: 77-84.
22. Jones CP. A study of 100 refraction cases in Indians fresh from the plains. J Am Med Assoc, 1906; 51(4): 308-12.
23. Borish IM. Clinical refraction, 3rd Ed. Chicago, IL: Professional Press, 1970.
24. Forrest EB. A new model of functional astigmatism. J Am Optom Assoc, 1981; 52: 889-97.
25. Forrest EB. Astigmatism as a function of visual scan, head scan, and head posture. Am J Optom Physio Opt, 1980; 57: 884-60.
26. Forrest EB. Eye scan therapy for astigmatism. J Am Optom Assoc, 1984; 55: 894-901.
27. Gwiazda J, Scheiman M. Mohindra L, Held R. Astigmatism in children: changes in axis and amount from birth to 6 years. Invest Ophthal Vis Sci, 1984l 25: 88-92.
28. Mohindra I, Held R, Gwiazda J, Brill S. Astigmatism in infants. Sci, 1978; 202: 329-31.
29. Thorn F, Held R, Fang LL. Orthogonal astigmatic axes in Chinese and Caucasian infants. Invest Ophthal Vis Sci, 1987; 28: 191-94.
30. Young FA, Beattie RJ, Newby FJ, Swindal MT. The Pullman Study—a visual survey of Pullman school children, Part II. Am J Optom Arch Am Acad Optom, 1954; 31: 192-203.
31. Langer MA. Changes in ocular refraction from ages 5-16. Master's Thesis, Indiana University, Bloomington, 1966.
32. Hirsch MJ. The changes in refraction between the ages of 5 and 14—theoretical and practical considerations. Am J Optom Arch Am Acad Optom, 1952; 29: 445-59.

Corresponding author:
W.C. Maples, O.D.
Northeastern State University
College of Optometry
Tahlequah, OK 74464

Date accepted for publication:
November 11, 1995