Prevalence of Corneal Astigmatism in Tohono O’odham Native American Children 6 Months to 8 Years of Age

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PURPOSE. To describe the prevalence of corneal astigmatism in infants and young children who are members of a Native American tribe with a high prevalence of refractive astigmatism.

METHODS. The prevalence of corneal astigmatism was assessed by obtaining infant keratometer (IK4) measurements from 1235 Tohono O’odham children, aged 6 months to 8 years.

RESULTS. The prevalence of corneal astigmatism >2.00 D was lower in the 1- to <2-year-old age group when compared with all other age groups, except the 6- to <7-year-old group. The magnitude of mean corneal astigmatism was significantly lower in the 1- to <2-year age group than in the 5- to <6, 6- to <7, and 7- to <8-year age groups. Corneal astigmatism was with-the-rule (WTR) in 91.4% of astigmatic children (≥1.00 D).

CONCLUSIONS. The prevalence and mean amount of corneal astigmatism were higher than reported in non-Native American populations. Mean astigmatism increased from 1.43 D in 1-year-olds to nearly 2.00 D by school age. (Invest Ophthalmol Vis Sci. 2011;52:4350–4355) DOI:10.1167/iovs.10-6061.

A high prevalence of astigmatism has been documented among preschool- and school-age members of several Native American tribes (Kershner RM, et al. IOVS 1984;25:ARVO Abstract 70).¹,¹¹ including the Tohono O’odham of southern Arizona.⁹⁻¹¹ Other studies have documented that the astigmatism is primarily corneal (Kershner RM, et al. IOVS 1984;25:ARVO Abstract 217).⁹⁻¹⁰ However, no information has been published concerning the prevalence of corneal astigmatism in Native American children younger than 5 years nor are data available concerning any change in prevalence between infancy and school age.

The purpose of the present study was to examine the prevalence of corneal astigmatism in infants and young children who are members of the Tohono O’odham Nation, a Native American tribe with a high prevalence of astigmatism (Kershner RM, et al. IOVS 1984;25:ARVO Abstract 217)⁹⁻¹⁰ that is primarily with-the-rule (WTR)⁹⁻¹⁰ and corneal in origin (Kershner RM, et al. IOVS 1984;25:ARVO Abstract 217).¹⁰

METHODS

Subjects

The subjects were children who were recruited between September 2005 and December 2008, at 6 months through 7 years of age, into a study of refractive error development. The children were recruited from the Women, Infants, and Children (WIC) clinics, the Head Start program, the community, and kindergarten and first grade classrooms on the Tohono O’odham reservation in southern Arizona. Data from the first study encounter for each child (ages 6 months through 7 years) were included in the analyses (n = 1502).

This research complied with the Declaration of Helsinki and was approved by the Tohono O’odham Nation and by the Institutional Review Board of the University of Arizona. Parents provided written informed consent before testing.

 Infant Keratometer

The IK4 infant keratometer consists of a single-ring (200-mm-diameter) keratometer with 12 infrared light-emitting diodes (LEDs) attached to a custom telecentric telephoto lens designed for use with a camcorder (Sony TRV-460 Digital8; Sony Electronics, Inc., San Diego, CA). The LEDs pose an insignificant hazard to the eye.¹² The instrument incorporates infrared imaging to minimize ambient illumination artifacts and to improve the attractiveness of the central fixation target for the child. A telecentric design was used to minimize magnification variation for images within the depth of field and to improve the accuracy of corneal curvature measurements. Two appropriately spaced, infrared-coated, achromatic lenses, one of +50-mm focal length and one of -50-mm focal length, were used for the telephoto system, along with prototyping hardware from Edmund Industrial Optics (Barrington, NJ). The lenses add 70 mm to the length of the camcorder and serve to mount the ring keratoscope. Calibration constants specific to the keratometer and the imaging lens were determined and were verified periodically throughout the study interval, through measurement of a reference surface. The working distance of the IK4 is approximately 11.5 cm from the child’s eye. Studies have shown good agreement between IK and Retinomax K+ (Nikon, Tokyo, Japan) keratometry measurements of young children (Miller JM, et al. IOVS 2005;46:ARVO E-Abstract 5625; Clifford-Donaldson CE, et al. IOVS 2007;48:ARVO E-Abstract 997).

Procedures

Video keratographic images were obtained with the IK4 for each child’s right eye (RE). The older children were asked to remain still and to fixate on the center green light in the display; the younger children sat on a parent’s lap, and the parent and tester directed their attention toward the IK4. The tester looked through the monitor of the IK4’s camcorder and aligned the reflected images of the circle of 12 infrared LEDs around the perimeter of the child’s pupil. The tester moved the...
instrument forward or backward, so that the reflected ring of lights was in sharp focus. Short videos, approximately 15 to 30 seconds in length, were recorded.

Data Analysis

Custom image analysis software was written to score the IK4 image data. The software automatically scans captured video, analyzing each frame for corneal curvature, pupil size, alignment, and image motion. Calibration constants for the software were established by imaging two lenses with radii of curvature that cover the anticipated range expected for children. The lenses were plano-convex and had radii of 6.19 and 8.25 mm, (parts 45-693 and 45-694, respectively; Edmund Optics). Petroleum jelly was smeared on the flat side of the lenses to disrupt Purkinje reflections on their surfaces. For each frame, the software locates the position of the 12 LEDs reflected from the cornea. Each of the LED spots is analyzed to determine the quality of the frame. Elongated spots suggest image motion during acquisition, whereas large-diameter spots indicate that the keratometer is not properly focused for a given frame. Frames falling into these preceding categories are discarded, and the remaining images are reviewed manually for quality. For images judged to be stable and in focus, the positions of the LED spots are fitted by computer to an ellipse and scaled by a calibrated magnification factor (Edmund Optics). The keratometry and orientation values were transformed into J0 and J45 components, and the median J0 and median J45 were determined.

Results

Prevalence and Axis of Corneal Astigmatism

Subjects. Data from 267 of the 1502 children were excluded from the analysis: 28 because of ocular abnormalities other than high refractive error and 238 because scorable IK4 images were not obtained. Of the latter 121 were excluded because the child did not cooperate during the measurement or because the video quality was too poor to score (e.g., off center, or out of focus), 107 due to technical/experimenter error (e.g., the tester failed to initiate recording before measurement), and 10 because the instrument was not functioning on the test day). In addition, the measurement from one child was an extreme outlier (~13 D) and was therefore excluded. Failure to obtain scorable IK4 images (n = 238) varied significantly across age (χ² 3 = 107.19, P < 0.001), and occurred in 85 (23.5%) of 361 6-month to <1-year-olds, 75 (28.5%) of 263 1- to <2-year-olds, 54 (21.0%) of 258 2- to <3-year-olds, 19 (11.2%) of 170 3- to <4-year-olds, 15 (6.9%) of 217 4- to <5-year-olds, 3 (2.6%) of 115 5- to <6-year-olds, 5 (3.4%) of 149 6- to <7-year-olds, and 2 (3.1%) of 65 7- to <8-year-olds. After Bonferroni correction for multiple comparisons, the measurement success rate was significantly better in each of the oldest four age groups (ranging from 4 to <8 years) than in any of the youngest three age groups (ranging from 6 months to <3 years), and the success rate was significantly better in the 3- to <4-year-old age group than in the 6-month to <1-year-old and 1- to <2-year-old groups. The mean age of the final sample of 1235 children was 3.35 years (SD 2.19; range, 0.50–7.97 years).

Prevalence of Corneal Astigmatism. Table 1 shows the prevalence of corneal astigmatism in terms of cylinder magnitude (clinical notation) as a function of age group. The prevalence of astigmatism ≥1.00 D did not differ significantly across age group. Table 1 also shows prevalence of corneal astigmatism by sex. There was no significant relation between sex and prevalence of corneal astigmatism.

Figure 1 shows the prevalence of corneal astigmatism >2.00 D in each age group. Also shown in Figure 1 is the
prevalence of refractive astigmatism $>2.00$ D from previously published data on this sample. The $X^2$ analysis indicated a significant difference across age in prevalence of corneal astigmatism $>2.00$ D ($X^2 = 21.51$, $P < 0.001$), and pairwise $X^2$ analyses showed a significant difference between prevalence of astigmatism $>2.00$ D in the 1- to <2-year age group when compared with all other age groups except the 6- to <7-year-old group ($P < 0.05$ before Bonferroni correction, with only the comparisons of the 1- to <2-year age group compared with each of the five older age groups ranging from 2 to 2 years to 6 to <7 years and significantly less prevalent in the 1- to <2-year age group than in the 4 to <5 and 5- to <6-year age groups before correction for multiple comparisons. After Bonferroni correction for multiple comparisons, only the <1-year versus 3- to <4-year and the <1-year versus 4- to <5-year comparisons remained significant.

**DISCUSSION**

The results of the present study provide the first data on the prevalence and amount of corneal astigmatism in Native American infants and very young children who are members of a tribe with a high prevalence of refractive astigmatism. The prevalence of corneal astigmatism $>2.00$ D (78.3%) was extremely high across all age groups and did not vary with age. When high astigmatism was defined as $>2.00$ D, there was evidence of a decrease in prevalence in 1- to <2-year-olds compared with all but one of the other age groups. This finding mirrors our previous finding on the prevalence of refractive astigmatism in these children, which also showed a lower prevalence in the 1- to <2-year-olds, as illustrated in Figure 1. The apparent increase in prevalence of corneal astigmatism in the oldest age group was not observed in the refractive astigmatism.
Corneal Astigmatism in Native American Children

The mean amount of corneal astigmatism and the mean amount of corneal astigmatism on the vertical–horizontal meridian \( (J_0) \) were lower in infants and toddlers than in older subjects in our sample, with the mean amount of astigmatism ranging from 1.43 D (SD 0.74) at age 1 to <2 years to 1.98 D (SD 1.19) at age 7 to <8 years (Table 2). As is the case with refractive astigmatism in this population, \( J_1 \) axis of corneal astigmatism was overwhelmingly WTR, although less so in the youngest age groups.

Data from the present study confirm and extend to younger ages the results of previous studies that have shown a high prevalence of corneal astigmatism among children who are members of Native American tribes in which there is a high prevalence of refractive astigmatism (Table 4). The average power of corneal astigmatism in the Tohono O’odham infants (1.62 D) was well above the values of 0.8 to 1.0 D previously reported for white infants (Table 5). In addition, torticity (vertical–horizontal) in the Tohono O’odham infants and preschoolers was greater than was observed in a sample of white infants and preschoolers, was greater in the Tohono O’odham school-age children than in African American, Hispanic, Asian, and white school-age children, and was similar to previous findings in Tohono O’odham school-age children of the same age (Table 6). Although some previous studies of Caucasian and Native American children have reported a higher prevalence and higher amounts of corneal astigmatism in girls than in boys, we found no evidence of a difference in prevalence or in amount of astigmatism, either across all ages or within individual age groups, although the boys had a greater oblique-axis component \( (J_{45}) \) than did the girls.

The present study has several strengths: (1) a large sample size, with prevalence analyses based on data from 1235 children; (6 months to 7 years of age). (2) a high proportion of children in whom scorable IK4 images could be obtained (84.1%; 1264/1502), (3) the use of a community-based rather than a clinic-based sample; and (4) use of the same instrument to obtain measurements of corneal astigmatism across the entire age range tested. There are also several limitations in the present study. The first is that the portion of the sample comprising children aged 4 years and younger may not be representative of the population as a whole, since there are family income requirements for both the WIC and Head Start programs. In contrast, the older children in the sample are likely to be representative, since approximately 85% of kindergarten and first grade children on the reservation participated. A second limitation of the prevalence data is that we were unable to obtain scorable IK4 images on a greater percentage...
### Table 5. Mean Amount of Corneal Astigmatism across Studies

<table>
<thead>
<tr>
<th>Study</th>
<th>Ethnicity</th>
<th>Technique</th>
<th>Boys vs. Girls</th>
<th>0.5 to &lt;1</th>
<th>1 to &lt;2</th>
<th>2 to &lt;3</th>
<th>3 to &lt;4</th>
<th>4 to &lt;5</th>
<th>5 to &lt;6</th>
<th>6 to &lt;7</th>
<th>7 to &lt;8</th>
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</thead>
<tbody>
<tr>
<td>Howland and Sayles(5,0)</td>
<td>White</td>
<td>Photokeratometer</td>
<td>Not stated</td>
<td>~1.00(^*(4,4))</td>
<td>~0.50 (7,5)</td>
<td>~0.75 (26)</td>
<td>&lt;0.50 (18)</td>
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<tr>
<td>Huynh et al.(2,5)</td>
<td>Asian and Caucasian</td>
<td>IOL master</td>
<td>Higher in girls</td>
<td>—</td>
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<td>1.08 (190)</td>
<td>0.82 (1712)</td>
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<tr>
<td>Lai et al.(2,6)†</td>
<td>Taiwanese</td>
<td>KR8100</td>
<td>Not stated</td>
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<td>2.35 (≈100)</td>
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<td>Heard et al.(5)‡</td>
<td>Native American</td>
<td>B&amp;L Keratometer</td>
<td>Not stated</td>
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<td>1.56 (33)</td>
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<tr>
<td>Lyle et al.(2,9)</td>
<td>Saskatchewan Indians</td>
<td>B&amp;L Keratometer</td>
<td>Higher in girls</td>
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<td>—</td>
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<td>—</td>
<td>0.87 (48)</td>
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<tr>
<td>Present study§</td>
<td>Native American</td>
<td>IK4</td>
<td>No difference</td>
<td>1.62 (269)</td>
<td>1.43 (183)</td>
<td>1.66 (125)</td>
<td>1.67 (149)</td>
<td>1.75 (197)</td>
<td>1.82 (108)</td>
<td>1.82 (143)</td>
<td>1.98 (61)</td>
</tr>
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Data are expressed in diopters. Sample size indicated in parentheses. Manufacturers are listed in Table 4.

* 0 to 1 year.
† > 1.50 D.
‡ Ages not given; grades K through 3.
§ ≥2.00 D.

### Table 6. Corneal Toricity Means

<table>
<thead>
<tr>
<th>Study</th>
<th>Ethnicity</th>
<th>Technique</th>
<th>Age (y)</th>
<th>0.5 to &lt;1</th>
<th>1 to &lt;2</th>
<th>2 to &lt;3</th>
<th>3 to &lt;4</th>
<th>4 to &lt;5</th>
<th>5 to &lt;6</th>
<th>6 to &lt;7</th>
<th>7 to &lt;8</th>
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<tr>
<td>Mutti et al.(3,1)</td>
<td>White</td>
<td>Handheld custom</td>
<td>0.5 to &lt;1</td>
<td>~0.75D (243)</td>
<td>~0.75D (257)</td>
<td>~0.75D (220)</td>
<td>0.99, 0.83 (118,107)</td>
<td>0.93, 0.87 (64,66)</td>
<td>1.02, 0.94 (141,152)</td>
<td>1.03, 1.15 (45,48)</td>
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<td></td>
<td>African American</td>
<td>keratometer</td>
<td>1 to &lt;2</td>
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<td>Asian</td>
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<td></td>
<td>Hispanic</td>
<td>Alcon auto-keratometer</td>
<td>3 to &lt;4</td>
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<tr>
<td>Present Study</td>
<td>Native American</td>
<td>IK4</td>
<td>0.5 to &lt;1</td>
<td>1.37 (269)</td>
<td>1.24 (183)</td>
<td>1.57 (125)</td>
<td>1.64 (149)</td>
<td>1.74 (197)</td>
<td>1.80 (108)</td>
<td>1.76 (143)</td>
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Data are vertical-horizontal corneal power in diopters. Positive values represent with-the-rule astigmatism, and negative values represent against-the-rule astigmatism. Sample sizes provided in parenthesis. Autokeratometer; Alcon, Fort Worth, TX.

* Data provided are for girls, boys.
of children in the younger age groups. We do not know whether inclusion of data from children of higher income families or from children who were uncooperative during testing would have significantly influenced the prevalence values obtained for the youngest age groups.

In conclusion, the results showed a higher prevalence and higher mean amounts of corneal astigmatism in young members of a Native American tribe with a high prevalence of refractive astigmatism than has been reported among non-Native American populations. The results also revealed an increase in mean corneal astigmatism of approximately 0.50 D between infancy and early school age, against which there are no comparative data from Caucasian or Asian populations. Finally, corneal astigmatism data mirrored the findings in a previous study in which we observed a decrease in prevalence of refractive astigmatism during the second year of life and an increase thereafter. Longitudinal data from this population will allow us to better evaluate and understand the patterns of change in astigmatism observed in individual infants and children.

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References