Corneal Topography of Neonates and Infants

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Objective: To evaluate corneal curvature by direct topographic analysis during the first 6 months of life.

Methods: We evaluated corneal topography in 200 infants using a specialized handheld topographic instrument at a mean of 1.6 days after birth, and in some again at 3 and 6 months in the newborn nursery and ophthalmology clinic of a public hospital.

Results: At birth, the mean central corneal power measured 48.5 diopters (D) (95% confidence interval [CI], 48.2-48.8 D; range, 41.4-56.0 D) and astigmatism measured 6.0 D (95% CI, 5.6-6.3 D), usually “with the rule” (80%) with a mean axis of 95°. The mean astigmatism on the semimeridian map at 3 mm was 6.4 D (95% CI, 6.0-6.8 D); and at 5 mm, 5.9 D (95% CI, 5.4-6.3 D). At birth, neonates delivered vaginally had a greater frequency of with-the-rule astigmatism than those delivered by cesarean section (P = .02). By 6 months, the mean central corneal power and astigmatism decreased to 43.0 (95% CI, 41.3-43.1) D and 2.3 (95% CI, 1.4-3.2) D, respectively (P < .005 for each).

Conclusions: Newborns have steep, high, astigmatic (generally with-the-rule) corneas at birth that flatten significantly by the age of 6 months. The method of delivery can affect the astigmatic axis at birth.

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The shape of the corneal surface in infants has been quite steep in several studies. Clinicians have appreciated this steepness when donor corneas from infants were transplanted onto adult recipients, resulting in keratometry measurements averaging 57.7 diopters (D).1 Few studies have attempted to directly measure corneal curvature in neonates and infants. Most had a small sample size and used techniques to determine the refractive error and then secondarily implied the contribution of the cornea. Others have used keratometers. Keratometers, however, assume a spherocylindrical corneal shape and are limited to monitoring the corneal curvature based on 4 points. Placido disc–based videokeratography, as used in this study, has provided reliable data about the anterior corneal surface, approaching the spherocylindrical ideal.2,3 To our knowledge, this study is the first to evaluate corneal curvature by direct topographic analysis in neonates and infants, as determined by a search on the PubMed Web site of the National Library of Medicine and in our literature review.

Methods: The Human Subjects Committee of the Harbor-UCLA Medical Center approved the protocol. Written informed consent was obtained from each mother before her child was studied. The infants were securely wrapped in a swaddling cloth. The eyelids were separated with 2 cotton-tipped applicators and were always elevated off the ocular surface. Great care was taken to apply the applicators only to the upper and lower rims of the orbit. No pressure was applied directly on the eye.

The topography of each cornea was then studied with a specialized topographic instrument (Vista Handheld Corneal Topographer; EyeSys Premier, Irvine, Calif), a Placido disc–based system. Before each use, the instrument was calibrated according to the manufacturer’s instructions. A study was accepted only if at least 3 complete Placido rings were visible, centered, and properly focused on the recorded image. If these criteria were not met, the study was repeated until the criteria were satisfied. The data were directly downloaded to a portable computer and analyzed with software for the topographic instrument.

Data for each eye of each infant, where available, were used in all statistical analyses, summarized with means and frequencies over all eyes. Confidence intervals (CIs) and statistical comparisons that incorporate the correlation between the 2 eyes of an individual were...
**RESULTS**

Of the 200 neonates studied, 95 were female. All newborns who met the criteria and whose parent consented were consecutively recruited for the study from March 7, 1999, through June 6, 2000. The racial proportion was as follows: 74% Latino American, 12% African American, 8% white, and 5% other (percentages do not total 100 because of rounding). The mean±SD birth weight was 3318±543 g (range, 1890-5030 g). At examination, the mean±SD postnatal age was 1.6±1.2 days (range, 0-8 days), and the mean±SD postconceptional age was 39.3±1.7 weeks (range, 29.9-42.7 weeks). Repeat examinations were conducted on a mean±SD of 3.0±0.5 and 6.0±0.5 postnatal months.

For the neonates, the mean central corneal power was 48.5 (range, 41.4-56.0) D. The mean keratometric astigmatism was 6.0 (range, 0.2-16.4) D. The mean astigmatism on the semimeridian map at 3 mm was 6.4 (range, 0.01-22.5) D; and at 5 mm, 5.9 (range, 1.1-18.3) D.

The mean axis of the astigmatism in the neonates was 95.0°. Most of the astigmatic axes (80%) were with the rule (within 20° of 90°), while 19% were at an oblique axis and less than 1% were “against the rule” (within 20° of 180°).

Neonates delivered vaginally had the same \(P=.49\) mean central corneal power (48.5 D; 95% CI, 48.2-48.9 D) as those delivered by cesarean section (48.5 D; 95% CI, 47.7-48.9 D). The astigmatism was also the same \(P=.49\): 6.0 (95% CI, 5.6-6.4) D and 6.0 (95% CI, 5.0-6.4) D, respectively. By 3 months, the difference for central corneal power was 44.5 (95% CI, 43.4-44.6) D and 44.1 (95% CI, 42.7-45.3) D, respectively, and the astigmatism was 3.6 (95% CI, 2.6-4.5) D and 2.9 (95% CI, 1.6-3.9) D, respectively; these values were also not statistically different \(P>.30\).

However, the type of delivery was related to the astigmatic axis. At birth, neonates delivered vaginally had a greater frequency of with-the-rule astigmatism (83%) than those delivered by cesarean section (72%) \(P=.02\). By 3 months, the frequencies were similar (86% and 73%, respectively) to those at birth, but nonsignificant \(P=.37\) because of the reduced number of infants observed at this point. There are insufficient data for comparison at 6 months.

The follow-up data for the 3- and 6-month examinations are given in the Table. Figure 1 and Figure 2 show examples of differential maps from birth to the ages of 3 and 6 months, respectively. The decreases in central power and astigmatism from birth to the 3- and 6-month measurements were statistically significant \(P<.005\). From 3 to 6 months, the reductions in central power and astigmatism were not significant \(P=.93\) and \(P=.14\), respectively. Frequencies of type of astigmatism are almost identical at birth and at 3 months. An observed reduction in frequency of with-the-rule astigmatism at 6 months is nonsignificant \(P>.10\).

For all comparisons at all ages studied, there were no statistically significant differences whether the infants were stratified by sex or race \(P>.05\) for all.

<table>
<thead>
<tr>
<th>Variable</th>
<th>At Birth*</th>
<th>At 3 mo</th>
<th>At 6 mo</th>
</tr>
</thead>
<tbody>
<tr>
<td>Central power</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. of infants/eyes</td>
<td>193/385</td>
<td>22/40</td>
<td>8/14</td>
</tr>
<tr>
<td>Mean (95% CI), D</td>
<td>48.5 (48.2-48.8)</td>
<td>44.0 (43.1-45.0)</td>
<td>43.0 (41.3-43.1)</td>
</tr>
<tr>
<td>Central astigmatism</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. of infants/eyes</td>
<td>190/364</td>
<td>22/39</td>
<td>8/14</td>
</tr>
<tr>
<td>Mean (95% CI), D</td>
<td>6.0 (5.6-6.3)</td>
<td>3.3 (2.5-4.0)</td>
<td>2.3 (1.4-3.2)</td>
</tr>
<tr>
<td>Astigmatism (semimeridian)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>At 3 mm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. of infants/eyes</td>
<td>190/361</td>
<td>22/38</td>
<td>8/14</td>
</tr>
<tr>
<td>Mean (95% CI), D</td>
<td>6.4 (6.0-6.8)</td>
<td>3.8 (2.9-4.6)</td>
<td>2.7 (1.4-3.7)</td>
</tr>
<tr>
<td>At 5 mm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. of infants/eyes</td>
<td>110/144</td>
<td>14/22</td>
<td>8/14</td>
</tr>
<tr>
<td>Mean (95% CI), D</td>
<td>5.9 (5.4-6.3)</td>
<td>3.5 (2.7-4.3)</td>
<td>2.7 (1.3-3.7)</td>
</tr>
<tr>
<td>Type of astigmatism†</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>With the rule (90° ± 20°)</td>
<td>293 (80)</td>
<td>31 (79)</td>
<td>7 (50)</td>
</tr>
<tr>
<td>Against the rule (180° ± 20°)</td>
<td>1 (&lt;1)</td>
<td>1 (3)</td>
<td>1 (7)</td>
</tr>
<tr>
<td>Oblique (between with the rule and against the rule)</td>
<td>70 (19)</td>
<td>7 (18)</td>
<td>6 (43)</td>
</tr>
</tbody>
</table>

Abbreviations: CI, confidence interval; D, diopters.

*The mean ± SD postnatal age was 1.6 ± 1.2 days.

†Data are given as number (percentage) of eyes at each point. Percentages may not total 100 because of rounding. Data were available for 364 eyes at birth, 39 eyes at 3 months, and 14 eyes at 6 months.
The validation studies on the adult eyes found no significant differences among the instruments ($P > .70$). For steepest and flattest meridians compared with a different instrument (IOLMaster), the topographic system used (Vista) demonstrated a mean difference of 0.13 D flatter and 0.03 D steeper. The numbers for the comparison with the second instrument (ARK-760A) were 0.1 D steeper and 0.2 D steeper.

**COMMENT**

**SPHERICAL VALUES**

There have been few studies that directly measured corneal curvature in newborns. In 1976, Ehlers and colleagues\(^8\) reported the mean±SD corneal curvature in 19 mature newborns to be 7.1±0.07 mm using a keratometer. By using an ophthalmometer on neonates, Gordon and Donzis\(^9\) found the mean±SD apical keratometry to decrease from 53.6±2.5 D in 11 eyes at 30 to 35 postconceptional weeks to 51.2±1.1 D in 10 eyes at 39 to 41 postconceptional weeks. In 11 infants younger than 1 year, they found the mean±SD keratometric value to further decrease to 45.2±1.3 D. There was no measurement of astigmatism. While these numbers are higher than our corresponding numbers of 48.5 D at birth and 43.0 D at 6 months, their measurements are within 1 SD of our findings. Interestingly, the nearly 6-D reduction they found from birth to 1 year is quite similar to the reduction from birth to 6 months reported in this study. In Japan, Inagaki\(^10\) performed automated keratometry on 11 mature neonates and found a mean±SD keratometry reading of 47.0±1.2 D. The curvature decreased to a mean±SD of 44.1±1.7 D by the age of 3 months in the 8 infants he
followed up. These numbers are close to the results of this investigation. A 2004 study, which used a keratometer, reported higher values than those found in this study—58.6 D horizontally and 54.0 D vertically when averaging both eyes.11

The use of infantile corneas for keratoplasty to adult recipients has been reported. Koenig and associates1 believed that the large value of 57.7 D following such a keratoplasty might reflect a steepening effect induced by suturing the relatively elastic infantile cornea to an adult recipient. Wood and Nissenkorn12 attributed the myopia found in their adult recipients of infant corneas to corneal steepness, with an average keratometry reading in the adults of 46.5/50.9 D.

**ASTIGMATIC CYLINDER VALUES**

In a 2004 study, Friling and associates,11 using keratometry, reported 6 D of cylinder in their 32 infants whose postconceptual age was younger than 32 weeks and 3.3 D for the 30 infants whose postconceptual age was older than 36 weeks.

The nature and amount of astigmatism reported in neonates and infants are controversial. By using near retinoscopy without cycloplegia, Mohindra and colleagues13 found that, of 17 newborns younger than 1 week, about 20% had astigmatism of 2 D or more. The same 20% proportion was still present at the age of 6 months. In a later report, astigmatism of at least 1 D in 55% of infants younger than 5 months was found, with 10% displaying a cylinder exceeding 3 D.14

By using photorefractive techniques, Howland and associates15 studied 15 neonates younger than 10 days, and reported that 50% had astigmatism, with 25% exceeding 1 D. At the age of 6 months, the proportion was also parallel. With similar methods, Atkinson and coworkers16 found that almost all of their 20 infants at the age of 3 months had at least 1 D of astigmatism and that the quantity was reduced to adult levels by the age of 18 months. Weale17 calculated that the with-the-rule astigmatism should measure 3.5 D in white and 5.8 D in Japanese neonates.

We measured a greater mean astigmatism at birth (5.6 D) and 3 months (3.3 D) than these previous studies. This could be attributed to the strong possibility that the direct topographical analysis used in this study is more accurate than the other methods attempted. To ensure that the handheld system we used was as accurate as other instruments, we compared it with 2 other devices and found the measurements nearly identical among the 3. It is also possible that we measured the neonates closer to birth (mean, 1.6 days, with some as early as a few hours after birth) than the other studies. Thus, we would more likely appreciate the direct effects of the birth process, which may have compressed the eye and produced a larger astigmatism than reported in previous studies. By the age of 6 months, our findings (2.3 D) are more similar to previously reported values.

Most cesarean section deliveries were begun after the neonate’s head was already engaged in the birth canal. This would explain our finding that a vaginal delivery caused a similar amount of astigmatism as a cesarean delivery.

**AXIS OF ASTIGMATISM**

Previous reports of the axis of astigmatism in newborns and infants are even more contradictory. By using near retinoscopy without cycloplegia, Gwiazda and coworkers14 examined 440 infants younger than 5 months. They found that the astigmatism of at least 1 D that was present in 235 infants was with the rule in 45% of the cases and against the rule in 45%. This study was somewhat contradicted by a subsequent investigation by Thorn and colleagues.18 Also using near retinoscopy without cycloplegia, Thorn et al reported that 51% of 45 white infants (aged 3½-11.8 months) had with-the-rule astigmatism and only 13% had against-the-rule astigmatism. They also reported that 59% of 22 Chinese infants (aged 3½-12 months) had against-the-rule astigmatism.

There are potential problems with studies using near retinoscopy. Wesson and colleagues19 found significant differences between near retinoscopy and cycloplegic refraction for sphere and cylinder power, especially in infants. Maino and coworkers20 found near retinoscopy and cycloplegic retinoscopy to agree (within 0.5 D) in only 27% of 311 children between the ages of 18 and 48 months. Saunders11 indicated several potential sources for error using this technique, including not neutralizing the meridians simultaneously when cycloplegia is not used and performing retinoscopy off axis, especially in the highly curved infant cornea. She also was concerned about the large disparity in the angle between the visual and optical axes (angle α) in newborns (8°-10°) compared with adults (4°-5°). This angle α effect might influence not only retinoscopy but also techniques using cameras for photorefraction. Indeed, using isotropic and orthogonal photorefractive techniques, Howland and Sayles22 reported an against-the-rule astigmatism rate of about 50% in 76 astigmatic infants younger than 1 year (mean age, 6 months).

In a recent study, Mayer and colleagues23 reported that all their 1-month-old infants with greater than 1 D of cylinder demonstrated a with-the-rule axis. By the age of 6 months, the proportion had decreased to about a third. Weale17 postulated that the with-the-rule astigmatism and corneal ellipticity found in newborns are attributable to the oblate form of the fetal eye, supported by the observation that the young cornea yields less to stress than does the sclera.

Our findings of with-the-rule astigmatism in about 80% of infants at birth and at the age of 3 months show a greater preponderance of with-the-rule astigmatism than previous studies. Possible explanations for this discrepancy might include the increased accuracy implicit in this study by using direct corneal topography instead of somewhat subjective retinoscopy or photographic techniques. Our observation of the with-the-rule frequency decreasing to 50% by the age of 6 months, while the oblique and against-the-rule groups were increasing (which is, however, based on only 8 infants) is consistent with the general trend over life to shift from with-the-rule to against-the-rule astigmatism.24

The type of delivery was related to the astigmatic axis. At birth, with-the-rule astigmatism was more frequent in neonates delivered vaginally (83%) than in those de-
livered by cesarean section (72%) (P = .02). Because ce-
sarean sections were generally begun shortly after the head
was engaged in the birth canal, the angle of compres-
sion on the eye may have been different than following
a complete vaginal delivery. A similar difference accord-
ing to type of delivery was observed at 3 months, but is
not statistically significant because fewer infants were
observed at this point.

This study does have limitations. To open the eye-
lids, we used cotton-tipped applicators. To minimize the
possibility that pressure was exerted on the globe, we ap-
plied direct pressure only to the orbital rims and actu-
ally generally elevated the eyelids off of the ocular sur-
face. We chose this method because previous studies
found problems using an eyelid speculum. Masci23 dem-
onstrated that use of a speculum reduced the cylinder in
with-the-rule subjects by a mean ±SD of 0.7 ±0.2 D, and
increased the cylinder in against-the-rule subjects by a
mean ±SD of 0.2 ±0.2 D. Wilson and colleagues26 found
that, for eyes with toricity greater than 0.6 D with the
mean ± SD of 0.2 ±0.2 D. Wilson and colleagues26 found
increased the cylinder in against-the-rule subjects by a
mean ± SD of 0.7 ±0.2 D, and demonstrated that use of a speculum reduced the cylinder in
children are under anesthesia. For children younger than 4
years, the measured cylinder had an average difference
of 1.7 D when comparing 2 different types of eyelid specula
(P < .001). Recently, the use of an eyelid speculum in
children was shown to increase the intraocular pressure an-
average of 4 mm Hg.28 To avoid the artifact induced by
using a speculum, we decided to use a manual tech-
nique. It is possible that despite our efforts, some pres-
sure may have contacted the globe in some infants. We
also lost several infants for the 3- and 6-month fol-
low-up examinations. These were healthy infants with
little reason to return for the examination, despite our
efforts to contact all of them.

In conclusion, corneal topography determinations in
neonates reveal steep, high, astigmatic (generally, with-
the-rule) measurements at birth that flatten signifi-
cantly by the age of 6 months. The method of delivery
affects the astigmatic axis at birth, but not the amount of
astigmatic cylinder.

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