Effect of Pupil Size on Uncorrected Visual Acuity in Pseudophakic Eyes With Astigmatism

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ABSTRACT

PURPOSE: To study the effect of pupil size on the relationship between refractive astigmatism and uncorrected distance visual acuity (UDVA) and pseudoaccommodation in pseudophakic eyes.

METHODS: Thirty-six eyes from 36 patients who underwent phacoemulsification and intraocular lens (IOL) implantation were included. All eyes were divided into two groups based on the presence of postoperative with-the-rule astigmatism or against-the-rule astigmatism. Uncorrected and corrected distance visual acuity (CDVA), refractive astigmatism, subjective accommodation amplitude, and pupil sizes under photopic and mesopic conditions were measured 1 month postoperatively. The effects of pupil size on the relationship between refractive astigmatism and UDVA were investigated.

RESULTS: Against-the-rule astigmatism had a moderate but significant negative linear correlation with UDVA irrespective of the pupil size ($R^2=0.60, P<.01$). A moderate but significant negative linear correlation was found when the pupil diameter exceeded 2.9 mm in eyes with with-the-rule astigmatism ($R^2=0.46, P=.04$). Refractive astigmatism was not significantly correlated with pseudoaccommodation regardless of the pupil diameter in either group.

CONCLUSIONS: The results of the current study suggest that pupil size may have an impact on postoperative UDVA in eyes having against-the-rule astigmatism and in eyes with a large pupil diameter and with-the-rule astigmatism. [J Refract Surg. 2012;xx(x):xxx-xxx.]

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A significant number of patients undergoing cataract surgery have preexisting corneal astigmatism.1-3 Astigmatism induces image distortion4,5; thus, surgical correction of preexisting astigmatism during cataract surgery is beneficial to achieve better postoperative uncorrected distance visual acuity (UDVA). Several surgical options are available to correct preexisting astigmatism, including excimer laser refractive procedures after cataract surgery, astigmatic keratotomy using limbal relaxing incisions (LRIs) during or after cataract surgery, and implantation of toric intraocular lenses (IOLs). Toric IOLs have become the most common and reliable astigmatic correction method at the time of cataract surgery.6-9 Recent studies have shown that a larger percentage of patients who receive toric IOLs achieve good UDVA independent of spectacle correction compared with conventional IOLs without intraoperative refractive correction.9,10 This has resulted in lesser need to enhance vision with spectacles, contact lenses, or corneal refractive surgeries, such as LASIK and LRIs. Toric IOLs provide an additional 10 to 20 quality-adjusted life years compared with conventional IOLs with and without intraoperative refractive correction.11 Another study also reported that toric IOL implantation is useful even in eyes with a small amount of astigmatism.12 However, considering that the first-year cost of toric IOLs is higher than that of conventional IOLs, it is important to determine the degree of residual astigmatism that actually affects UDVA after cataract surgery.

Many studies have been published on the relationship between postoperative refractive astigmatism and UDVA after...
cataract surgery, although most have focused primarily on the relationship between astigmatism and pseudo-accommodation. Visual function, including UDVA and pseudoaccommodation, is affected by multiple factors, including refraction, astigmatism, pupil size, and corneal multifocality.

In the current study, we investigated the impact of astigmatic axis and pupil size on the relationship between postoperative refractive astigmatism and UDVA and pseudoaccommodation.

**PATIENTS AND METHODS**

The current study included 36 consecutive eyes from 36 patients who underwent cataract extraction and IOL implantation at Keio University Hospital. Patients with a senile cataract and postoperative visual acuity of 20/25 or better were eligible for the study.

Exclusion criteria included postoperative spherical equivalent refraction exceeding ±0.50 diopter (D), previous or coexisting ocular pathology, and intra- or postoperative complications. Patients with astigmatism other than with-the-rule astigmatism and against-the-rule astigmatism were considered to have oblique astigmatism and were excluded from this study. In addition, patients with refractive astigmatism >1.50 D were excluded from the assessment of pseudoaccommodation.

All patients provided written informed consent. The study adhered to the tenets of the Declaration of Helsinki. The institutional review board of Keio University School of Medicine approved the study.

**VISUAL ACUITY MEASUREMENTS**

Uncorrected and corrected distance visual acuity (CDVA) were measured preoperatively and 1 month postoperatively using Landolt acuity charts. logMAR visual acuity scores were used for all analysis in this study.

**REFRACTIVE ASTIGMATISM MEASUREMENTS**

Refractive astigmatism was measured using the ARK-730A (NIDEK Co Ltd, Aichi, Japan). Ten consecutive measurements were taken from each patient and the mean of the measurements was recorded as the refractive astigmatism.

The eyes were divided into two groups to determine notable trends based on the presence of with-the-rule astigmatism, in which the axis of the flat meridian is between 0 and 30° or between 150° and 180°, and against-the-rule astigmatism, in which the axis of the flat meridian is between 60° and 120°.

**PUPIL DIAMETER MEASUREMENTS**

Three pupil diameter measurements were taken in each eye and the mean of the measurements was recorded as the pupil diameter of that eye. Pupil diameter in the iris plane was measured using the FP-10000 handheld infrared digital pupillometer (TMI Co, Saitama, Japan) under photopic and mesopic conditions (150 and 0.35 cd/m², respectively).

**PSEUDOACCOMMODATION**

Pseudoaccommodation was evaluated with an accommodometer (D’ACOMO; WOC, Kyoto, Japan), with a constant stimulus speed during binocular viewing using polarizing filters. A spherical lens of 2.00 or 3.00 D was added to the full distance correction, and the patient was required to read a cross-shaped target that corresponded in size to 0.0 logMAR at a distance of 30 cm. The chart was slowly brought closer, until the patient reported blurring of the image. The target was then moved back until it became clear. The distance in diopters at which blurring and refocusing occurred was recorded as the near point of pseudoaccommodation. The amount of pseudoaccommodation was calculated from the far and near points.

**SURGICAL TECHNIQUES**

Two experienced surgeons (T.Y., K.N.) performed all surgeries following the same surgical techniques. After topical application or a sub-Tenon injection of lidocaine 2% to induce anesthesia, a 2.20- or 2.75-mm corneoscleral incision was created at 12 o’clock.

Sodium hyaluronate 1% (Opegan Hi; Santen, Tokyo, Japan) was used to reform and stabilize the anterior chamber and protect the endothelial cells and was removed completely at the end of the procedure. A 5.0- to 5.5-mm continuous curvilinear capsulorrhexis was created with a 27-gauge needle, and the nucleus was removed during standard phacoemulsification using the Infinity (Alcon Surgical, Ft Worth, Texas) or CV-24000 (NIDEK Co Ltd) phacoemulsification unit. The IOLs were injected into the capsular bag using an injector system.

Patients were implanted with one of the following aspheric IOLs: the AcrySof IQ SN60WF (Alcon Laboratories Inc, Ft Worth, Texas) or PY60AD (HOYA, Tokyo, Japan). The spherical aberrations of the Alcon SN60WF and HOYA PY60AD IOLs are −0.20 μm and −0.18 μm, respectively, for 6-mm pupil diameter. These aspheric IOLs have the same philosophy, in which the postoperative target spherical aberration is slightly positive as in young healthy eyes.

Postoperative medications included levofloxacin (Cravit, Santen) and betamethasone sodium phosphate 0.01% (Sanbetazon, Santen) three times daily for 1 month. Patients instilled diclofenac sodium 0.1% (Diclod; Wakamoto, Tokyo, Japan) three times daily for 3 months.
STATISTICAL ANALYSIS

Results were expressed as mean±standard deviation. P<.05 was considered significant. A paired t test was used to compare the differences between pre- and postoperative manifest refraction, refractive astigmatism, UDVA, and CDVA. An unpaired t test was used to compare the photopic and mesopic pupil diameter, manifest refraction, refractive astigmatism, UDVA, and CDVA between eyes with with-the-rule astigmatism and against-the-rule astigmatism. Spearman rank correlation coefficient was used to determine the relationship between astigmatism and UDVA and pseudoaccommodation. StatView version 5.0 analysis was used for all statistical comparisons (SAS Institute Inc, Cary, North Carolina).

RESULTS

Thirty-six eyes from 36 patients were included in this study. Mean patient age was 68.5±8.2 years (range: 49 to 83 years). Mean axial length was 24.4±2.0 mm (range: 22.0 to 29.3 mm). The Table shows the pre- and postoperative manifest refraction, refractive astigmatism, UDVA, and CDVA.

Table A (available as supplemental material in the PDF version of this article) shows the patient profiles of the two groups classified according to the astigmatic axes. No significant differences were noted between groups in relation to age, pupil diameter, manifest refraction, refractive astigmatism, UDVA, or CDVA. Refractive astigmatism had a moderate but statistically significant negative linear correlation with UDVA in patients with against-the-rule astigmatism irrespective of pupil size (R²=0.60, P<.01) (Fig 1). No significant correlation was noted between UDVA and with-the-rule astigmatism (R²=0.17, P=.15).

To study the effect of pupil diameter on the relationship between astigmatism and UDVA, the correlation between astigmatism and UDVA was reanalyzed after dividing eyes having with-the-rule astigmatism into two groups as eyes with small and large pupils. The limits of the small and large pupil diameters were determined by searching the pupil diameters in 0.1-mm steps. Table B (available as supplemental material in the PDF version of this article) shows the correlation between UDVA and refractive with-the-rule astigmatism.
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Tism based on the pupil diameters. A moderate but significant negative correlation was found between UDVA and refractive astigmatism when the photopic pupil diameter was >2.9 mm ($R^2=0.46, P=.04$) (Fig 2).

In patients with with-the-rule refractive astigmatism $<1.50$ D ($n=10$), pseudoaccommodation and refractive astigmatism did not correlate significantly ($P=.57$). Similarly, pseudoaccommodation and against-the-rule refractive astigmatism did not correlate significantly regardless of the pupil diameter and axis of astigmatism ($P=.35, n=13$).

**DISCUSSION**

The direction of the astigmatic axis is thought to be an important factor that affects UDVA in daily life. Because vertical and horizontal lines predominate in test letters and in most environmental objects, vision is thought to be poorest when the ocular astigmatism is oblique. In the current study, Landolt rings with a horizontal or vertical gap were used to measure UDVA in eyes with with-the-rule or against-the-rule astigmatism. Thus, the direction of the astigmatic axis was assumed not to have affected the UDVA considerably. Nonetheless, the results showed that higher amounts of against-the-rule astigmatism were associated with a greater decrease in UDVA compared to with-the-rule astigmatism. A possible reason for the greater effect of against-the-rule astigmatism on the UDVA might be a constant or temporal pinhole effect in the vertical direction due to a narrow palpebral fissure width with aging and blinking. Further studies clarifying these issues should be performed.

Pupil size is another factor that could affect visual function in eyes with refractive error, because the amount of the aberrations, not only higher order aberrations but also lower order aberrations, are correlated with pupil diameter. Kamiya et al$^{26}$ reported that not only the amount of astigmatism but also pupil diameter might play an important role in determining UDVA in normal young phakic eyes. In an optical system with aberrations, including normal and pseudophakic eyes, optical quality decreases as the pupil size increases. We found that the UDVA was moderately negatively correlated in eyes with against-the-rule astigmatism irrespective of the pupil size, and that UDVA was moderately negatively correlated in eyes with with-the-rule astigmatism only when the pupils were large. These results also suggested that astigmatism should be corrected when the astigmatism is against-the-rule and when the pupil size exceeds 2.9 mm in with-the-rule astigmatism under photopic conditions. Nakamura et al$^{27}$ reported that photopic and scotopic pupil sizes decreased with age until 60 years and then stabilized. Yamaguchi et al$^{28}$ reported that the mean mesopic pupil size without a cycloplegic agent was 3.60 mm in pseudophakic eyes even in patients aged $>$60 years and $>$2.9 mm in most eyes. In our cases, the mean mesopic pupil sizes were 4.03±0.97 mm and 4.12±0.78 mm for with-the-rule astigmatism and against-the-rule astigmatism, respectively, and the pupil size under mesopic conditions was $>$2.9 mm in 92% of all eyes. Considering the pupil size under mesopic conditions, most cataract cases with corneal astigmatism might be candidates for surgical correction of astigmatism.

In the current study, only patients with refractive astigmatism $<1.50$ D underwent assessment of pseudoaccommodation, because pseudoaccommodation is thought to play a role only in lower astigmatism up to 1.50 D. It also has been reported that the direction of the astigmatic axis might affect pseudoaccommodation in pseudophakic eyes. Many studies have reviewed the axes and reported that myopic astigmatism, especially myopic against-the-rule astigmatism, is advantageous for pseudoaccommodation in pseudophakic eyes, although some reports found that with-the-rule astigmatism is more advantageous than against-the-rule astigmatism. Trindade et al$^{17}$ reported that patients with up to 1.50 D of against-the-rule myopic astigmatism after cataract surgery have better near reading vision compared to patients with with-the-rule astigmatism, because the horizontal lines are sharper for distance vision and the vertical lines are sharper for near vision in myopic against-the-rule astigmatism, and the average test letter is recognized more readily when the vertical components are clear and the horizontal components are blurred. Nanavaty et al$^{22}$ also reported that against-the-rule astigmatism plays a significant role in good uncorrected distance and near visual acuity after monofocal IOL implantation based on Sturm’s conoid principle. Therefore, those investigators considered that simple myopic against-the-rule astigmatism provides better UDVA than simple myopic with-the-rule astigmatism. However, pseudoaccommodation and refractive astigmatism were not correlated significantly regardless of the pupil diameter and axis of astigmatism in cases of with-the-rule and against-the-rule astigmatism. Kamiya et al$^{29}$ also demonstrated that corneal and refractive astigmatism do not significantly contribute to apparent accommodation in IOL-implanted eyes although the axis of astigmatism was not taken into consideration in this study.

We believe that the aspheric optics of the IOLs did not greatly influence the results in the current study, because the influence of higher order aberrations, including spherical aberration is generally thought to be smaller than that of lower order aberrations including astigmatism. In addition, the mean photopic pupil di-
ameter was <3 mm in the current study, so that the difference in spherical aberration was assumed not to have a great influence with such a pupil diameter. Further investigation is warranted to confirm this.

It should be noted that visual acuity was measured only under photopic conditions in the current study. Further studies should be performed to determine whether the pupil size affects the correlation between the astigmatism and UDVA under mesopic conditions. Another issue is that we investigated only the effects of with-the-rule astigmatism and against-the-rule astigmatism on UDVA and did not determine the effect of oblique astigmatism. Future studies also need to be conducted regarding these issues.

Considering our results, against-the-rule astigmatism might degrade UDVA after monofocal aspheric IOL implantation irrespective of pupil size, and the correlation between UDVA and astigmatism might be affected by pupil size when the astigmatism is with-the-rule.

AUTHOR CONTRIBUTIONS
Study concept and design (K.N.); data collection (T.Y.); analysis and interpretation of data (K.W., K.N., M.D., H.T., K.T.); drafting of the manuscript (K.W.); critical revision of the manuscript (K.N., M.D., T.Y., H.T., K.T.); supervision (K.T.)

REFERENCES
### TABLE A

<table>
<thead>
<tr>
<th></th>
<th>With-the-Rule Astigmatism (n=19)</th>
<th>Against-the-Rule Astigmatism (n=17)</th>
<th>P Value*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (y)</td>
<td>68.3±9.6 (49 to 83)</td>
<td>68.8±6.8 (59 to 80)</td>
<td>.84</td>
</tr>
<tr>
<td>Photopic pupil diameter (mm)</td>
<td>2.74±0.56 (1.78 to 3.57)</td>
<td>2.75±0.60 (1.92 to 4.29)</td>
<td>.95</td>
</tr>
<tr>
<td>Mesopic pupil diameter (mm)</td>
<td>4.03±0.97 (2.30 to 5.96)</td>
<td>4.12±0.78 (2.75 to 5.81)</td>
<td>.75</td>
</tr>
<tr>
<td>Manifest refraction (SE) (D)</td>
<td>−0.06±0.33 (−0.50 to 0.50)</td>
<td>−0.19±0.25 (−0.50 to 0.38)</td>
<td>.19</td>
</tr>
<tr>
<td>Refractive astigmatism (D)</td>
<td>−1.25±0.65 (−2.50 to −0.50)</td>
<td>−1.09±0.68 (−3.00 to −0.50)</td>
<td>.47</td>
</tr>
<tr>
<td>UDVA logMAR (Snellen)</td>
<td>0.09±0.19 (−0.08 to 0.70) (20/23)</td>
<td>0.07±0.15 (−0.18 to 0.30) (20/22)</td>
<td>.79</td>
</tr>
<tr>
<td>CDVA logMAR (Snellen)</td>
<td>−0.09±0.09 (−0.30 to 0.10) (20/16)</td>
<td>−0.08±0.07 (−0.20 to 0.05) (20/17)</td>
<td>.61</td>
</tr>
</tbody>
</table>

*UDVA = uncorrected distance visual acuity, CDVA = corrected distance visual acuity

*Unpaired t-test.

### TABLE B

**Correlations Between logMAR UDVA and Refractive Astigmatism When Considering the Photopic Pupil Diameter in Patients With With-the-Rule Astigmatism**

<table>
<thead>
<tr>
<th>Pupil Diameter (mm)</th>
<th>No. of Eyes</th>
<th>R²</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;2.4</td>
<td>14</td>
<td>0.15</td>
<td>.31</td>
</tr>
<tr>
<td>&gt;2.5</td>
<td>12</td>
<td>0.33</td>
<td>.08</td>
</tr>
<tr>
<td>&gt;2.6</td>
<td>10</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>&gt;2.7</td>
<td>10</td>
<td>0.38</td>
<td>.05</td>
</tr>
<tr>
<td>&gt;2.8</td>
<td>9</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>&gt;2.9</td>
<td>9</td>
<td>0.46</td>
<td>.04*</td>
</tr>
</tbody>
</table>

N/A = not applicable due to absence of cases with a pupil diameter either between 2.6 and 2.7 mm or between 2.8 and 2.9 mm.

*Statistically significant (Spearman rank correlation coefficient).