Factors Affecting Contrast Sensitivity With the Artisan Phakic Intraocular Lens for High Myopia

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ABSTRACT

PURPOSE: To evaluate the factors affecting postoperative visual function in eyes with Artisan phakic intraocular lenses (PIOLs).

METHODS: This study examined a retrospective non-comparative case series. Phakic IOLs were implanted in 60 eyes of 36 patients with high myopia. Contrast sensitivity for spatial frequencies of 1.1, 1.7, 2.6, 4.2, 6.6, and 10.4 cycles per degree with and without glare and wavefront aberrations were measured before and 3 months after surgery. The area under the log contrast sensitivity function (AULCSF) was calculated from the contrast sensitivity. Stepwise regression analysis was used to assess the factors that affected the postoperative AULCSF.

RESULTS: No significant difference was noted between the preoperative AULCSF without glare and the postoperative AULCSF without glare \((P=0.886)\). The mean AULCSF with glare improved significantly after surgery \((P=0.018)\). The variables affecting the postoperative AULCSF without glare were axial length (partial regression coefficient \(B=-0.101, P=.0002\)) and age \((B=-0.008, P=.0063)\). The variables affecting the postoperative AULCSF with glare were axial length \((B=-0.127, P<.0001)\) and age \((B=-0.012, P=0.0294)\). The preoperative refractive error showed multicollinearity with the axial length, and coma-like aberration and spherical aberration showed multicollinearity with age.

CONCLUSIONS: Contrast sensitivity without glare was the same before and after surgery and contrast sensitivity with glare improved after surgery. Longer axial length and older age predispose patients to degradation of the postoperative visual function in eyes with Artisan PIOLs.
PATIENTS AND METHODS

Sixty eyes of 36 patients (16 men, 20 women) who underwent implantation of Artisan PIOLs (Ophtec BV) for high myopia at Minamiaoyama Eye Clinic were included in this study. Patient age ranged from 22 to 57 years (mean: 36.5±7.9 years) and preoperative spherical equivalent refraction was −6.75 to −23.75 diopters (D) (mean: −12.52±3.10 D). The preoperative pupil diameter in a dim room was 6.4±0.82 mm measured by ARK10000 (NIDEK, Aichi, Japan). The inclusion criteria were minimum age of 20 years; anterior chamber depth 3.0 mm; endothelial cell count of ≥2000 cells/mm²; and best spectacle-corrected visual acuity (BSCVA) of 20/20 or better. Patients were excluded if they had keratoconus examined by videokeratography; a history of uveitis, diabetic retinopathy, or glaucoma; or pathological myopic macular degeneration. Signed informed consent describing the risk and benefits of the procedure was obtained from each patient before surgery.

The logarithm of minimum angle of resolution (logMAR) uncorrected visual acuity (UCVA), BSCVA, contrast sensitivity function, and ocular wavefront aberrations were evaluated before and 3 months after implantation of Artisan PIOLs.

Contrast sensitivity was measured at six spatial frequencies of 1.1, 1.7, 2.6, 4.2, 6.6, and 10.4 cycles per degree (cpd) with and without glare under photopic conditions using CGT1000 (Takagi Seiko Co, Nagano, Japan) with best-corrected lenses. The area under the log contrast sensitivity function (AULCSF) was calculated from the data. The AULCSF was determined according to the method of Applegate et al.23 The log of the contrast sensitivity was plotted as a function of the log spatial frequency and the third-order polynomials were fit to the data. The fitted function was integrated between 0.041 (corresponding to 1.1 cpd) and 1.02 (10.4 cpd), and the resultant value was defined as the AULCSF.23

The wavefront aberration was measured by ARK10000 with natural pupillary dilation in a dim room without instillation of cycloplegic agents. The coefficients of Zernike polynomials were determined up to the sixth order for 4-mm pupil diameter from the wavefront data. The pupil diameters during measurements were >4 mm in all patients. The root-mean-square (RMS) of the total higher order aberrations from the third- to sixth-order Zernike coefficients was calculated. The RMS of the third-order coefficients was used to represent coma-like aberrations (S3) and the RMS of the fourth-order coefficients was used to denote spherical-like aberration (S4). The axial length was measured using A-scan ultrasound (US1800, NIDEK). Endothelial cell count was measured by noncontact specular microscopy, SP-9000 (Konan, Hyogo, Japan).

Surgical Procedures

Laser iridotomy was performed at the 1 or 11 o’clock position on the peripheral iris 2 weeks before surgery. Pupils were constricted by instillation of 1% pilocarpine before surgery, and a corneoscleral tunnel of 5.0 or 6.0 mm was made at the 12-o’clock position under topical and subconjunctival anesthesia. The anterior chamber was filled with a high-viscosity viscoelastic material (Viscot; Alcon Laboratories Inc, Ft Worth, Tex). The PIOL was introduced into the anterior chamber, rotated inside the eye, fixed with the iris, and encased in the claw of the PIOL. The viscoelastic material was removed and the wound was closed with 10-0 nylon sutures. All surgeries were performed by two experienced surgeon (K.T., H.A.) using the corneoscleral incision.

Artisan PIOLs with an optical zone of 6 mm (model 204) were implanted in 54 eyes and Artisan PIOLs with an optical zone of 5 mm (model 206) were implanted in 6 eyes. The lens power was determined for emmetropia according to the power calculation using the Van Der Heijde formula.

Data Analysis

Statistical analysis of the higher order aberrations and the AULCSF was performed by a paired Student t test for comparison of the pre- and postoperative means. A P value <.05 was considered statistically significant. Stepwise regression analysis was performed to investigate the relation between the postoperative AULCSF and age, sex, preoperative refraction, preoperative keratometric power (the average of the steepest and flattest meridians, ARK1000), axial length, and postoperative S3 and S4. All statistical analyses were performed with StatView (SAS Institute Inc, Cary, NC) computer software.

RESULTS

The pre- and postoperative clinical data are shown in Table 1. No severe complications developed during or after surgery in any eyes. Mean spherical equivalent refraction 3 months after surgery was −0.17±0.67 D (range: −1.75 to +1.50 D), and 53 (88.3%) of 60 eyes were within 1.00 D of the intended correction 3 months postoperatively. The mean BSCVA improved significantly 3 months after surgery (P=.0002). The safety index (postoperative BSCVA/preoperative BSCVA) and efficacy index (postoperative UCVA/preoperative BSCVA) were 1.18 and 0.91, respectively. The means of the total higher order aberrations, S3, and S4 significantly increased 3 months after surgery (P=.017, P=.01, and P=.01, respectively). No significant difference was noted between the preoperative AULCSF without glare...
and the postoperative AULCSF without glare ($P=.886$). The mean AULCSF with glare improved significantly postoperatively ($P=.018$). The postoperative AULCSF without glare was significantly correlated with the preoperative AULCSF without glare, and the postoperative AULCSF with glare was significantly correlated with the preoperative AULCSF with glare (Fig 1).

The results of stepwise regression analysis are shown in Table 2. The variables relevant to the postoperative AULCSF with or without glare were axial length and age. The preoperative refraction showed multicollinearity with the axial length. Postoperative S3 and S4 showed multicollinearity with age. Therefore, these parameters were not entered into the regression model.

The multiple regression equations were as follows:

Postoperative AULCSF (without glare) =

\[ (-0.101 \times \text{axial length}) + (-0.008 \times \text{age}) + 4.56 \]  
\( R^2=0.261 \)

Postoperative AULCSF (with glare) =

\[ (-0.127 \times \text{axial length}) + (-0.012 \times \text{age}) + 5.31 \]  
\( R^2=0.368 \)

Standardized partial regression coefficients were assessed to discern the magnitude of the effect of each variable. The axial length was the most relevant variable followed by age (Table 2). The postoperative AULCSF
was negatively correlated with axial length (Fig 2) and age (Fig 3). A positive correlation was observed between postoperative S3 and age and between the postoperative S4 and age (Fig 4). The changes in S3 (ΔS3) and S4 (ΔS4) before and after surgery were correlated with age (Fig 5), but there was no significant correlation between the axial length and ΔS3 or between the axial length and ΔS4 (Fig 6).

**DISCUSSION**

Our results showed that patient age and axial length significantly affected the postoperative AULCSF, which is one of the indices of visual function, in eyes with Artisan PIOLs both with and without glare.

The results of multiple regression showed that the axial length was the most relevant variable, and it had a significant negative correlation with the postoperative AULCSF (see Fig 2). The preoperative refraction (the attempted correction) had a significant negative correlation with the axial length (P<.0001) and showed multicollinearity with the axial length.

Regarding the influence of axial length on visual function, Kora et al24 reported visual acuity after cataract surgery in patients with high myopia decreases as the axial length increases. Visual function has also been reported to deteriorate in high myopia in normal eyes.25,26 Jaworski et al26 investigated the retinal integrity in high myopia using spatial psychophysical tasks and concluded that highly myopic eyes have either a reduced number of receptors, reduced sensitivity, or both, or reduced sensitivity of the postreceptoral processes. Those investigators also reported that the presence of normal contrast sensitivity at low spatial frequencies indicates dysfunction at a postreceptoral level in eyes with high myopia.26

In the current results, the axial length and preoperative refraction had a significant negative correlation

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### TABLE 2

**Results of Stepwise Regression Analysis to Select Variables Relevant to Postoperative Area Under the Log Contrast Sensitivity Function (AULCSF) With and Without Glare**

<table>
<thead>
<tr>
<th>Variables</th>
<th>Partial Regression Coefficient</th>
<th>Standardized Partial Regression Coefficient</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>AULCSF without glare</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Axial length (mm)</td>
<td>-0.101</td>
<td>0.579</td>
<td>.0002</td>
</tr>
<tr>
<td>Age (y)</td>
<td>-0.008</td>
<td>-0.227</td>
<td>.0063</td>
</tr>
<tr>
<td>Constant Adjusted R²=0.261</td>
<td>4.56</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AULCSF with glare</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Axial length (mm)</td>
<td>-0.127</td>
<td>0.53</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Age (y)</td>
<td>-0.012</td>
<td>-0.237</td>
<td>.0294</td>
</tr>
<tr>
<td>Constant Adjusted R²=0.368</td>
<td>5.31</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 2. Correlation between the axial length and area under the log contrast sensitivity function (AULCSF) A) without glare and B) with glare (Pearson’s correlation coefficient (a) r = -0.408, P = .0011, (b) r = -0.453, P = .0002).
with the postoperative AULCSF in eyes with Artisan PIOLs, which supports previous reports on the relationship between axial length and visual function. Considering those previous reports, the decrease in the AULCSF with axial length in our data might result from dysfunction at a postreceptoral level in eyes with a long axial length.

Regarding age, our study showed a significant negative correlation between age and the postoperative AULCSF (see Fig 3), and the postoperative AULCSFs were low, especially in three eyes of patients in the sixth decade of life (see Fig 3).

Some studies have reported the relationship between age and visual function in normal eyes. Generally, the degradation in contrast sensitivity with age is reported to be primarily caused by a change in optical function with age and a decline in the neurosensory elements of vision with age. Marcos reported that higher order aberrations increase with age mainly because of changes in the spherical aberration of the crystalline lens. Amano et al measured the ocular and corneal higher order aberrations in 75 normal eyes and reported that ocular coma increases with age mainly because of increases in corneal coma, and the ocular spherical aberration increases with age mainly because of the increase in the spherical aberrations in the internal optics.

In the current results, postoperative S3 and S4 showed multicollinearity with age and were significantly positively correlated with age (see Fig 4). Although these parameters were not entered into the regression model because of the multicollinearity, degradation of retinal images due to increased higher order aberrations with age was assumed to be a reason for loss of postoperative AULCSF in older patients.

Regarding the effect of aging on the neurosensory elements of vision, previous reports have suggested that the neurosensory function degrades with aging. Elliott et al compared contrast sensitivity thresholds in young patients with those in older patients and reported a significant reduction in contrast sensitivity in the older group predominantly due to the neural loss...
within the visual pathways with increasing age rather than optical changes due to aging. Previous reports suggested that the decreased AULCSF with age in our data might be affected not only by the optical change due to aging but also by the change in neurosensory function with age. Whatever the reason, our data indicated that the postoperative visual function in eyes with Artisan PIOLs is expected to degrade with age.

Some reports on optical and visual function in eyes with PIOLs have been published. Lombardo et al studied the pre- and postoperative photopic and mesopic contrast sensitivities in 49 eyes of 30 patients with myopia and myopia with astigmatism who underwent implantation of Artisan PIOLs. The authors reported that compared with preoperative measurements, the postoperative contrast sensitivity increased under photopic conditions and decreased slightly under mesopic conditions. Malecaze et al compared the refractive performance and safety of LASIK with that of Artisan PIOL in 25 patients with myopia ranging from −8.00 to −12.00 D, and reported no significant differences in contrast sensitivity between the two methods at all four spatial frequencies (3, 6, 12, and 18 cpd) at 1-year follow-up, although the contrast sensitivity values were slightly modified in the LASIK-treated eyes and improved in the Artisan-treated eyes.

The current results showed no significant difference in the AULCSF under photopic conditions, which supports the previous reports and suggests that the PIOL, in contrast to LASIK, corrects high myopia without degrading postoperative visual function.

In eyes with an Artisan PIOL, as described previously, postoperative S3 and S4 were excluded from the multiple regression analyses because of multicollinearity with age. However, postoperative higher order aberrations are an important factor affecting visual function in normal and postoperative eyes after refractive surgery. In excimer laser corneal refractive surgeries, postoperative higher order aberrations increase with the amount of the refractive correction and postoperative visual function decreases with increases in higher order aberrations. Degradation of visual

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**Figure 5.** A significant correlation was found between age and A) $\Delta S_3$ and B) $\Delta S_4$ (Pearson’s correlation coefficient (a) $r=0.420$, $P=.018$, (b) $r=0.486$, $P=.0036$).

**Figure 6.** No significant correlation was found between the axial length and A) $\Delta S_3$ and B) $\Delta S_4$ (Pearson’s correlation coefficient (a) $r=−0.188$, $P=.299$, (b) $r=−0.132$, $P=.468$).
function is a major problem associated with excimer laser corneal surgery, although the visual function improved when wavefront-guided methods were introduced.39

Only a few reports have been published on postoperative higher order aberrations in eyes with PIOLs. Brunette et al39 measured the wavefront aberrations in four eyes and analyzed the higher order aberrations for each combination of order (third to seventh) and pupil size (3, 4, and 5 mm). The investigators reported that the mean postoperative RMS values were lower than the mean preoperative RMS values.39 Buhren et al40 reported that higher order aberrations increased slightly after implantation of the Artisan PIOL and that induction of Z3, –3 and Z4,0 especially contribute to increased higher order aberrations. The authors also reported that trefoil (Z3, –3) was induced as a result of the incision, whereas the increase of spherical aberration is due to the implant.40 To our knowledge, the report by Tehrani and Dick41 includes the most cases on higher order aberrations after PIOL implantation; over 12-month follow-up, the third- and fourth-order higher order aberrations did not increase after foldable iris-claw PIOL implantation in 41 myopic eyes.

Our study, which comprised 60 eyes implanted with Artisan PIOLs, included the most cases among the previous studies. In our results, the higher order aberrations, both S3 and S4, increased significantly after implantation of Artisan PIOLs. Factors that may affect the postoperative third- and fourth-order aberrations are patient age, which is related to the preoperative higher order aberrations and to accommodation; surgically induced aberrations such as coma and astigmatism produced by corneoscleral incision; PIOL decentration; or spherical aberration in a PIOL itself. In our results, patient age and the increases in S3 and S4 (ΔS3, ΔS4) had significant positive correlations (see Fig 5). However, no significant correlations existed between the amount of refractive correction (preoperative spherical equivalent) and ΔS3 or ΔS4 (see Fig 6). The loss of accommodation with aging might be attributed partially to the fact that ΔS3 and ΔS4 were positively correlated with age because the aberrations were measured without cycloplegia in the current study. The effect of accommodation on the higher order aberrations in eyes with PIOLs should be investigated further by measuring aberrations under cycloplegia.

In conclusion, the postoperative visual function in eyes with Artisan PIOLs is affected primarily by patient age and axial length. In general, PIOL decentration and corneoscleral incision induce higher order aberrations that degrade postoperative visual function. However, in this study, surgically induced aberrations showed multicollinearity with age and did not independently affect postoperative visual function. The results in this study suggested that implantation of Artisan PIOL does not affect or degrade the postoperative visual function, but younger patients, especially younger than 50 years, were more likely to attain better postoperative visual function. Long-term observation is needed to evaluate the effect of aging on visual function after implantation of Artisan PIOL in young patients.

REFERENCES


