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 noncomparative 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=.886). The mean AULCSF with glare improved significantly after surgery (P=.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=.0294). The preoperative refraction 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. [*J Refract Surg.* 2009;25:25-32.]

Refractive corneal surgery for myopia using the excimer laser has shown good results[1-3] and has become the most common procedure used to correct myopia.[4] However, in these procedures, the correctable power is limited by the patient's corneal thickness. In addition, the visual function degrades as the attempted corrective power increases[5] because higher order aberrations increase with the corrected power.[6-8] Recently, improved ablation profiles using wavefront-guided technology have enabled correction without great increases in higher order aberrations, theoretically improving retinal image quality and consequently ameliorating postoperative visual function.[9-10] However, increases of higher order aberrations still occur, especially in cases of high myopia correction.[10-12]

Phakic intraocular lens (PIOL) implantation has been reported to have good results,[13-20] especially in the correction of high myopia in patients who are not candidates for refractive corneal surgery using an excimer laser. Surgical correction of myopia with Artisan PIOLs (Ophtec BV, Groningen, The Netherlands; Verysyse, AMO, Santa Ana, Calif) has been reported to cause less postoperative higher order aberrations,[21] better visual function,[22] and higher patient satisfaction[22] compared with correction by LASIK; however, the factors affecting the postoperative visual function in eyes with PIOLs have not been reported.

In the current study, we investigated the factors affecting the postoperative visual function in eyes with PIOLs to correct high myopia.

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The authors have no financial or proprietary interest in the materials presented herein.

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Received: July 23, 2007

Accepted: January 16, 2008

Posted online: May 30, 2008

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 of ⩾3.0 mm; endothelial cell count of ⩾2000 cells/mm^2; 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 enclavated 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

TABLE 1

Clinical Data Before and After Implantation of Artisan PIOLs in 60 Eyes of 36 Patients

Parameter	Preoperative	Postoperative	*P* Value*
Spherical equivalent refraction (D)	−12.40±2.30	−0.17±0.67	
UCVA (logMAR)	1.31±0.21	−0.051±0.17	
BSCVA (logMAR)	−0.11±0.072	−0.18±0.083	.0002
HOAs (μm)			
Total RMS	11.9±2.7	1.34±0.76	
Total HOA-RMS	0.21±0.16	0.33±0.26	.017
Coma-like aberration (S3)	0.14±0.16	0.27±0.17	.01
Spherical-like aberration (S4)	0.096±0.083	0.22±0.17	.01
AULCSF without glare	1.35±0.19	1.35±0.23	.886
AULCSF with glare	1.21±0.23	1.33±0.32	.018

PIOL = phakic intraocular lens, UCVA = uncorrected visual acuity, BSCVA = best spectacle-corrected visual acuity, logMAR = logarithm of the minimum angle resolution, HOA = higher order aberrations, RMS = root-mean-square, AULCSF = area under the log contrast sensitivity function
Safety index: 1.18; efficacy index: 0.91
**Paired t test.*

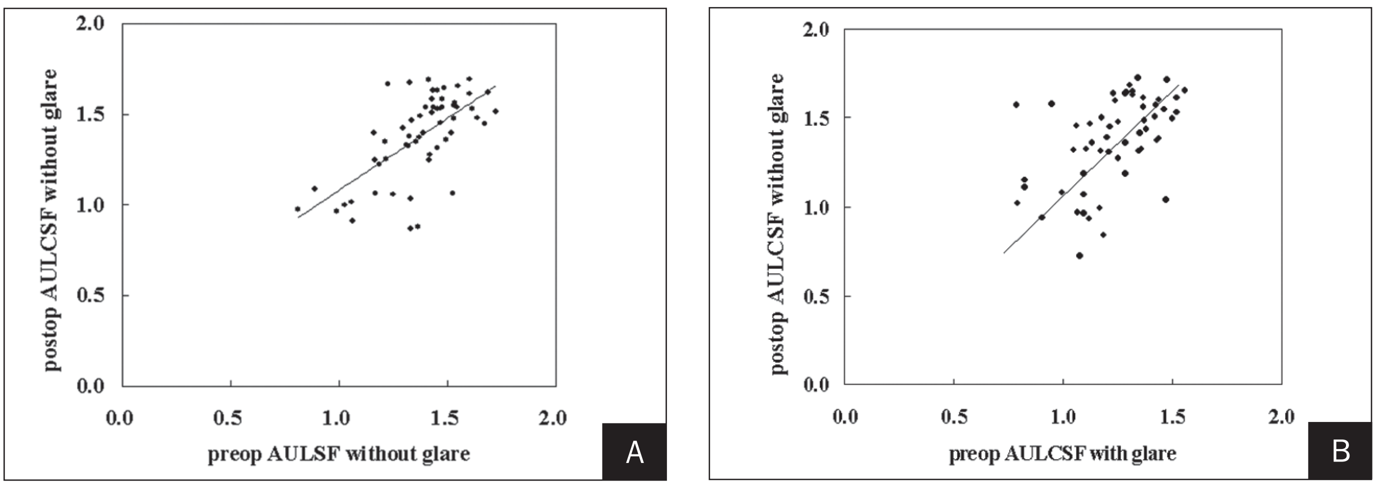

Figure 1. Correlation between the pre- and postoperative area under the log contrast sensitivity function (AULCSF) **A)** without glare and **B)** with glare (Pearson's correlation coefficient (a) r=0.77, $P<.0001$, (b) r=0.658, $P<.0001$).

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:

$$\text{Postoperative AULCSF (without glare)} = (-0.101\times\text{axial length}) + (-0.008\times\text{age}) + 4.56 \quad (R^2=0.261)$$

$$\text{Postoperative AULCSF (with glare)} = (-0.127\times\text{axial length}) + (-0.012\times\text{age}) + 5.31 \quad (R^2=0.368)$$

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

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

Variables	Partial Regression Coefficient	Standardized Partial Regression Coefficient	*P* Value
AULCSF without glare			
Axial length (mm)	−0.101	0.579	.0002
Age (y)	−0.008	−0.227	.0063
Constant Adjusted R^2=0.261	4.56		
AULCSF with glare			
Axial length (mm)	−0.127	0.53	<.0001
Age (y)	−0.012	−0.237	.0294
Constant Adjusted R^2=0.368	5.31		

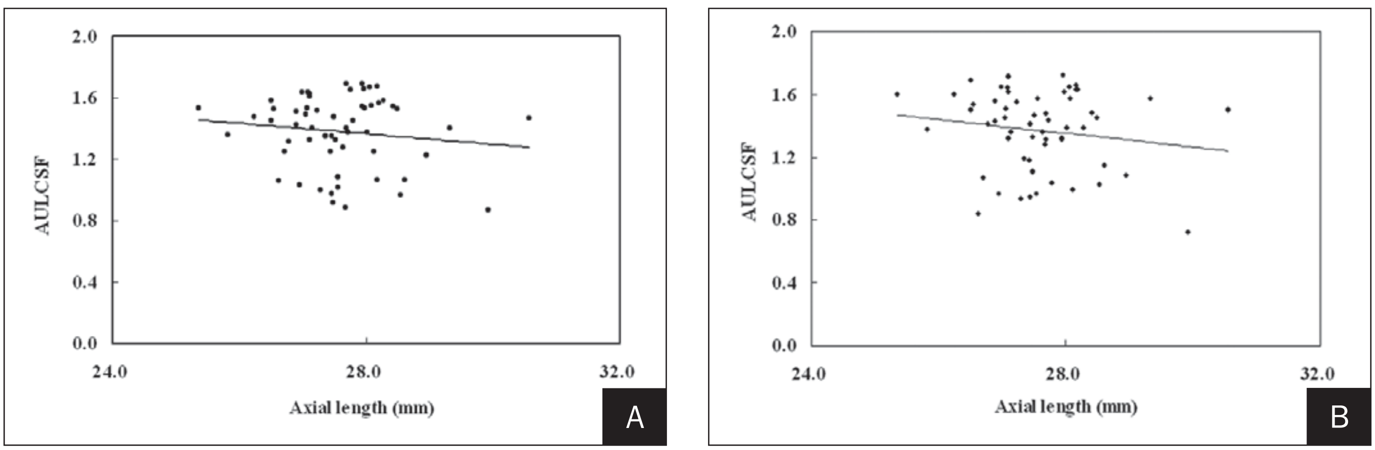

Figure 2. Correlation between the axial length and area under the log contrast sensitivity function (AULCSF) **A)** without glare and **B)** with glare (Pearson's correlation coefficient (a) r=−0.408, *P*=.0011, (b) r=−0.453, *P*=.0002).

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 al[24] 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 al[26] 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

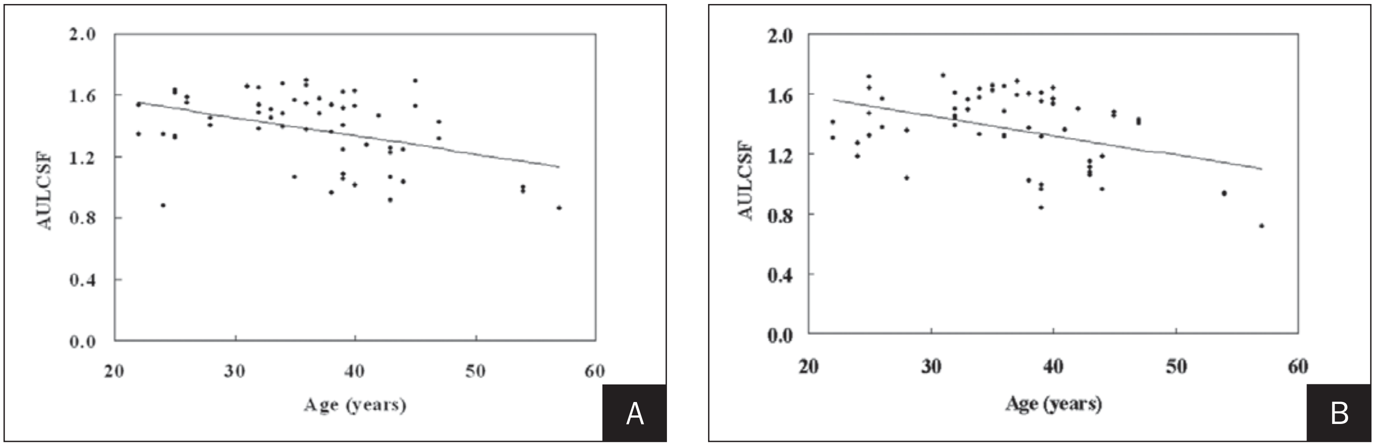

Figure 3. Correlation between age and the area under log contrast sensitivity function (AULCSF) **A)** without glare and **B)** with glare (Pearson's correlation coefficient (a) r=−0.466, *P*=.0057, (b) r=−0.492, *P*=.0031).

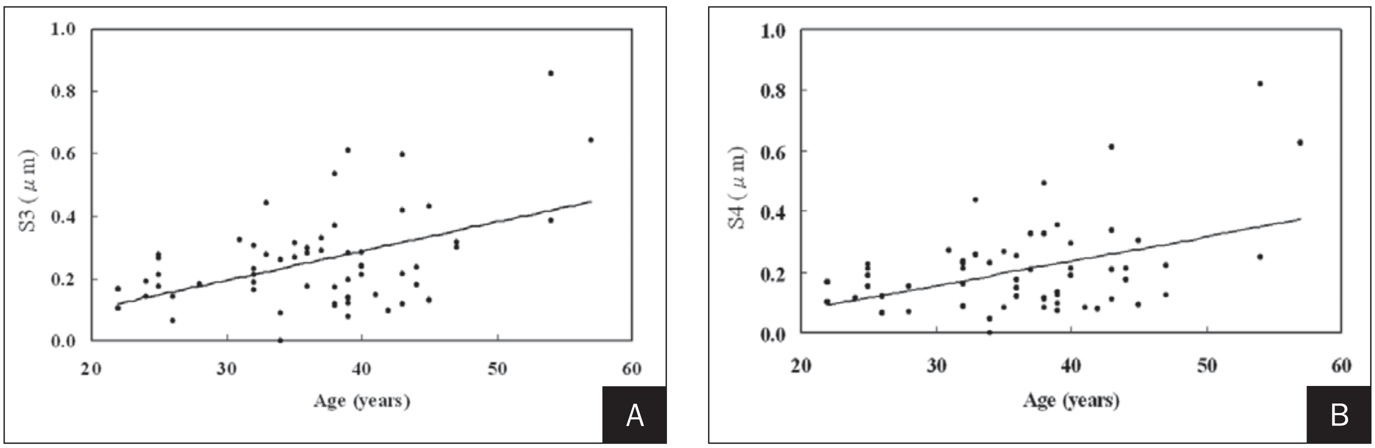

Figure 4. A significant correlation was found between age and **A)** S3 and **B)** S4 (Pearson's correlation coefficient (a) r=−0.474, *P*=.0001, (b) r=−0.427, *P*=.0006).

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.[27-31] Generally, the degradation in contrast sensitivity with age is reported to be primarily caused by a change in optical function with age[27-29] and a decline in the neurosensory elements of vision with age.[30,31] Marcos[27] reported that higher order aberrations increase with age mainly because of changes in the spherical aberration of the crystalline lens. Amano et al[28] 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.[30,31] Elliott et al[30] 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

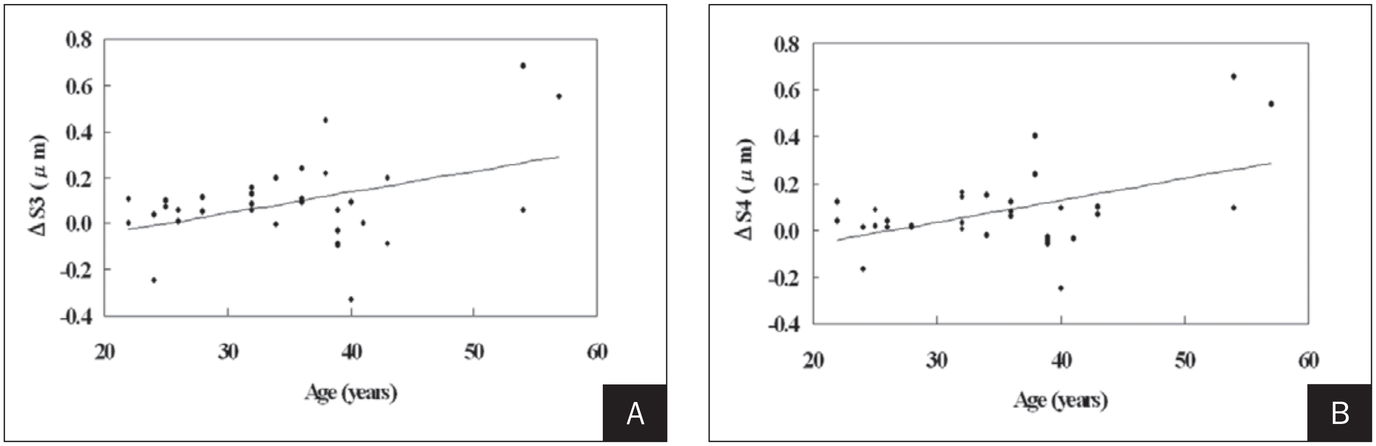

Figure 5. A significant correlation was found between age and **A)** ΔS3 and **B)** ΔS4 (Pearson's correlation coefficient (a) r=0.420, *P*=.018, (b) r=0.486, *P*=.0036).

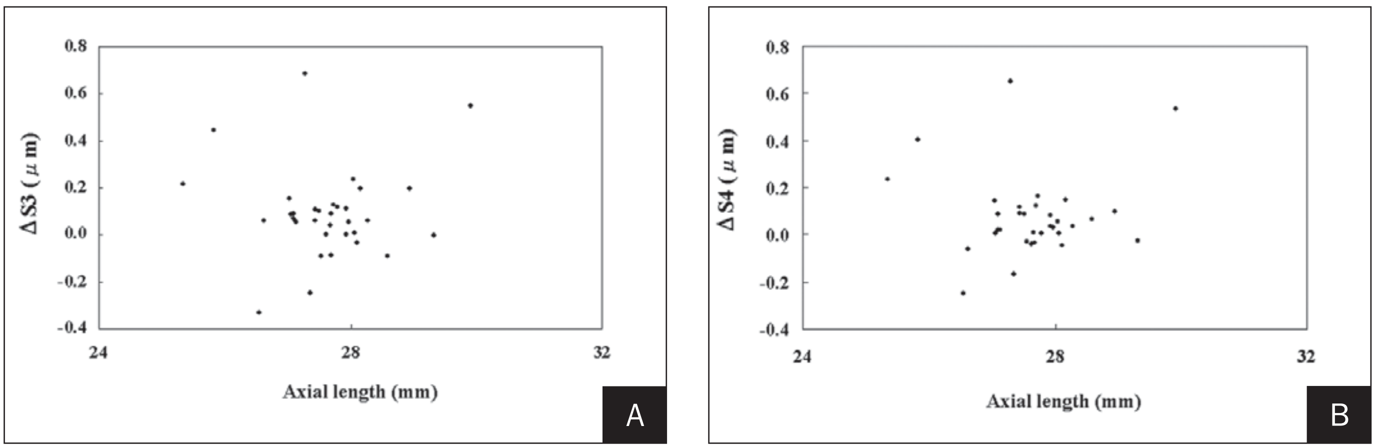

Figure 6. No significant correlation was found between the axial length and **A)** ΔS3 and **B)** ΔS4 (Pearson's correlation coefficient (a) r=−0.188, *P*=.299, (b) r=−0.132, *P*=.468).

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.[32,33] Lombardo et al[32] 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.[32] Malecaze et al[33] 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,[9,34-36] and postoperative visual function decreases with increases in higher order aberrations.[9,10,37,38] Degradation of visual 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 al[39] 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 al[40] 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 Dick[41] 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

1. O'Doherty M, O'Keeffe M, Kelleher C. Five year follow up of laser in situ keratomileusis for all levels of myopia. *Br J Ophthalmol.* 2006;90:20-23.
2. Sekundo W, Bonicke K, Mattausch P, Wiegand W. Six-year follow-up of laser in situ keratomileusis for moderate and extreme myopia using a first-generation excimer laser and microkeratome. *J Cataract Refract Surg.* 2003;29:1152-1158.
3. Perez-Santonja JJ, Bellot J, Claramonte P, Ismail MM, Alió JL. Laser in situ keratomileusis to correct high myopia. *J Cataract Refract Surg.* 1997;23:372-385.
4. Duffey RJ, Leaming D. US trends in refractive surgery: 2004 ISRS/AAO Survey. *J Refract Surg.* 2005;21:742-748.
5. Bailey MD, Olson MD, Bullimore MA, Jones L, Maloney RK. The effect of LASIK on best-corrected high-and low-contrast visual acuity. *Optom Vis Sci.* 2004;81:362-368.
6. Oshika T, Klyce SD, Applegate RA, Howland HC, El Danasoury MA. Comparison of corneal wavefront aberrations after photorefractive keratectomy and laser in situ keratomileusis. *Am J Ophthalmol.* 1999;127:1-7.
7. Moreno-Barriuso E, Lloves JM, Marcos S, Navarro R, Llorente L, Barbero S. Ocular aberrations before and after myopic corneal refractive surgery: LASIK-induced changes measured with laser ray tracing. *Invest Ophthalmol Vis Sci.* 2001;42:1396-1403.
8. Marcos S, Barbero S, Llorente L, Merayo-Lloves J. Optical response to LASIK surgery for myopia from total and corneal aberration measurements. *Invest Ophthalmol Vis Sci.* 2001;42:3349-3356.
9. Lee HK, Choe CM, Ma KT, Kim EK. Measurement of contrast sensitivity and glare under mesopic and photopic conditions following wavefront-guided and conventional LASIK surgery. *J Refract Surg.* 2006;22:647-655.
10. Alió JL, Montés-Micó R. Wavefront-guided versus standard LASIK enhancement for residual refractive errors. *Ophthalmology.* 2006;113:191-197.
11. Kim TI, Yang SJ, Tchah H. Bilateral comparison of wavefront-guided versus conventional laser in situ keratomileusis with Bausch and Lomb Zyoptix. *J Refract Surg.* 2004;20:432-438.
12. Sakimoto T, Rosenblatt MI, Azar DT. Laser eye surgery for refractive errors. *Lancet.* 2006;367:1432-1447.
13. Alió JL. Advances in phakic intraocular lenses: indications, efficacy, safety, and new designs. *Curr Opin Ophthalmol.* 2004;15:350-357.
14. Chang DH, Davis EA. Phakic intraocular lenses. *Curr Opin Ophthalmol.* 2006;17:99-104.
15. Sanders DR, Vukich JA. Comparison of implantable contact lens and laser assisted in situ keratomileusis for moderate to high myopia. *Cornea.* 2003;22:324-331.
16. Sanders DR, Doney K, Poco M. United States Food and Drug Administration clinical trial of the Implantable Collamer Lens (ICL) for moderate to high myopia: three-year follow-up. *Ophthalmology.* 2004;111:1683-1692.

17. Bloomenstein MR, Dulaney DD, Barnet RW, Perkins SA. Posterior chamber phakic intraocular lens for moderate myopia and hyperopia. *Optometry*. 2002;73:435-446.

18. Uusitalo RJ, Aine E, Sen NH, Laatikainen L. Implantable contact lens for high myopia. *J Cataract Refract Surg.* 2002;28:29-36.

19. Asano-Kato N, Toda I, Hori-Komai Y, Sakai C, Fukumoto T, Arai H, Dogru M, Takano Y, Tsubota K. Experience with the Artisan phakic intraocular lens in Asian eyes. *J Cataract Refract Surg.* 2005;31:910-915.

20. Sarver EJ, Sanders DR, Vukich JA. Image quality in myopic eyes corrected with laser in situ keratomileusis and phakic intraocular lens. *J Refract Surg.* 2003;19:397-404.

21. Nio YK, Jansonius NM, Geraghty E, Norrby S, Koojiman AC. Effect of intraocular lens implantation on visual acuity, contrast sensitivity, and depth of focus. *J Cataract Refract Surg.* 2003;29:2073-2081.

22. Tahzib NG, Bootsma SJ, Eggink FA, Nuijts RM. Functional outcome and patient satisfaction after Artisan phakic intraocular lens implantation for the correction of myopia. *Am J Ophthalmol*. 2006;142:31-39.

23. Applegate RA, Howland HC, Sharp RP, Cottingham AJ, Yee RW. Corneal aberrations and visual performance after radial keratotomy. *J Refract Surg.* 1998;14:397-407.

24. Kora Y, Nishimura E, Kitazato T, Inatomi M, Koide R, Yaguchi S, Ozawa T. Analysis of preoperative factors predictive of visual acuity in axial myopia. *J Cataract Refract Surg.* 1998;24:834-839.

25. Liou SW, Chiu CJ. Myopia and contrast sensitivity function. *Curr Eye Res*. 2001;22:81-84.

26. Jaworski A, Gentle A, Zele AJ, Vingrys AJ, McBrien NA. Altered visual sensitivity in axial high myopia: a local postreceptoral phenomenon? *Invest Ophthalmol Vis Sci*. 2006;47:3695-3702.

27. Marcos S. Are changes in ocular aberrations with age a significant problem for refractive surgery? *J Refract Surg.* 2002;18:S572-S578.

28. Amano S, Amano Y, Yamagami S, Miyai T, Miyata K, Samejima T, Oshika T. Age-related changes in corneal and ocular higher-order wavefront aberrations. *Am J Ophthalmol*. 2004;137:988-992.

29. Fujikado T, Kuroda T, Ninomiya S, Maeda N, Tano Y, Oshika T, Hirohara Y, Mihashi T. Age-related changes in ocular and corneal aberrations. *Am J Ophthalmol*. 2004;138:143-146.

30. Elliott D, Whitaker D, MacVeigh D. Neural contribution to spatiotemporal contrast sensitivity decline in healthy ageing eyes. *Vision Res*. 1990;30:541-547.

31. Jay JL, Mammo RB, Allan D. Effect of age on visual acuity after cataract extraction. *Br J Ophthalmol*. 1987;71:112-115.

32. Lombardo AJ, Hardten DR, McCulloch AG, Demarchi JL, Davis EA, Lindstrom RL. Changes in contrast sensitivity after Artisan lens implantation for high myopia. *Ophthalmology*. 2005;112:278-285.

33. Malecaze FJ, Hulin H, Bierer P, Fournié P, Grandjean H, Thalamus C, Guell JL. A randomized paired eye comparison of two techniques for treating moderately high myopia: LASIK and artisan phakic lens. *Ophthalmology*. 2002;109:1622-1630.

34. Marcos S. Aberrations and visual performance following standard laser vision correction. *J Refract Surg.* 2001;17:S596-S601.

35. Tumbocon JA, Suresh P, Slomovic A, Rootman DS. The effect of laser in situ keratomileusis on low contrast vision. *J Refract Surg*. 2004;20:S689-S692.

36. Ricci F, Scuderi G, Missiroli F, Regine F, Cerulli A. Low contrast visual acuity in pseudophakic patients implanted with an anterior surface modified prolate intraocular lens. *Acta Ophthalmol Scand*. 2004;82:718-722.

37. Kaiserman I, Hazarbassanov R, Varssano D, Grinbaum A. Contrast sensitivity after wave front-guided LASIK. *Ophthalmology*. 2004;111:454-457.

38. Kremer I, Bahar I, Hirsh A, Levinger S. Clinical outcome of wavefront-guided laser in situ keratomileusis in eyes with moderate to high myopia with thin corneas. *J Cataract Refract Surg*. 2005;31:1366-1371.

39. Brunette I, Bueno JM, Harissi-Dagher M, Parent M, Podtetenev M, Hamam H. Optical quality of the eye with the Artisan phakic lens for the correction of high myopia. *Optom Vis Sci*. 2003;80:167-174.

40. Buhren J, Kasper T, Terzi E, Kohnen T. Higher order aberrations after implantation of an iris claw PIOL (Ophtec Artisan) in the phakic eye [German]. *Ophthalmologe*. 2004;101:1194-1201.

41. Tehrani M, Dick HB. Changes in higher-order aberrations after implantation of a foldable iris-claw lens in myopic phakic eyes. *J Cataract Refract Surg*. 2006;32:250-254.